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Unique Characteristics of Camel Body Systems: Adaptation to Harsh Conditions, Productive and Reproductive Performances: A Review

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Abstract

Dromedaries have been evolved a remarkable array of adaptations that enable them to live in harsh desert environments. These adaptations are evident in their body systems, which are specifically designed to conserve water, regulate temperature and withstand extreme conditions. The unique characteristics of camel body systems were described to withstand extreme environmental conditions. Furthermore, growth and reproductive performances in addition to milk and urine secretion and unique characters under harsh condition were presented. Therefore, the articles concerning unique characteristics of camel body systems resulting in adaptation to harsh condition in addition to growth, reproduction, milk and urine secretion were used for writing the manuscript and they were collected from google scholar, ScienceDirect, PubMed databases. The results indicated that camel body systems have unique features indicated in anatomical, physiological and behavioral adaptation that enable them to survive in harsh environmental conditions. The camel's respiratory system has several adaptations including long and convoluted nasal passages, a large lung surface area and low respiration rate to conserve water. Lifespan of camel RBCs lasts 90-150 days and they are oval-shaped with special plasma membrane characters resulted in high tolerance to osmotic stress and efficient oxygen transport. Camels' forestomach have unique pouch-like structures contributed to conserve water. It is worth noting that there are no seminal vesicles in Camelidae family and the ejaculated semen is viscous. She-camels are seasonal breeding animals with induced ovulation and diffused placenta. Growth and reproductive performances in addition to milk and concentrated urine secretion occur during these extreme harsh conditions. Intensive management system resulted in significant improvement in both productive and reproductive performances. It could be concluded that dromedaries is well-adapted to withstand extreme conditions in addition to their abilities to produce and reproduce.

Key words: Adaption, Camel, Meat, Milk, Production, Reproduction, Systems.

The global population is expected to increase to almost 10.0 billion by 2100 due to longer lifespans and lower death rates. This growth poses a challenge to food and water security, which can only be addressed through efficient and sustainable agriculture. To meet the growing demand for human food, livestock and crop production must be intensified and expanded (Mohammed and Alshaibani *et al.,* 2024a,b; Mohammed *et al.,* 2024a). Camels are well-suited to survive in harsh environments and can produce milk, meat and births, making them valuable livestock for arid regions (Kakar *et al.,* 2008; Mohammed and Mahmoud 2011; Djenane and Aider 2024) (Fig 1.). Applying assisted reproductive techniques in camels resulted in increased reproductive and productive performances, improved genetic traits in addition to diseases control (Mohammed 2014a,b, 2018; Al Zeidi *et al.,* 2022a,b; Al Aljubran *et al.,* 2023; Mohammed *et al.,* 2024a-f).

Camels have evolved a remarkable array of adaptations that enable them to survive in harsh desert environments. These adaptations are evident in their body systems, which are specifically designed to conserve water, regulate temperature and withstand extreme environmental conditions (Tibary and El Allali 2020). The characteristics of hump, rumen, kidney and blood cells were adapted to conserve water (Kandeel *et al.,* 2022). In addition, the coat, sweating and respiration and behavioral adaptations were adapted to regulate temperature (Samara, 2019). Furthermore, sensory adaptations of eyes, nostrils and feet were evolved to shield them from sand and dust and to search for food in the desert environment (Fesseha and Desta, 2020).

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Collectively, these adaptations in body systems, combined with their strong physical endurance, make camel breeds remarkable creatures that can survive and breed in the harsh challenging environments as desert (Fig 2). Therefore, this review aims to collect and discuss the specific features of camel body systems that enable them to thrive in harsh environments, leading to their growth, reproduction and milk production.

The study were approved by the research committee of King Faisal University [KFU-REC-2024-OCT-KFU242590]. The majority of articles in the last ten years concerning unique characteristics of body systems, their contribution to harsh conditions, growth, reproduction, milk and urine secretion and unique characters were collected form Google Scholar, ScienceDirect and PubMed databases. In addition, forty percent of references were selected in the last five years. Therefore, our targets were to highlight key aspects of unique characters of body systems related to adaptation to harsh environmental conditions and their contributions in productive and reproductive performances.

Camel's unique reproductive traits

Camels are seasonal breeds mating during the cooler months to give births during optimal conditions for offspring survival (Al-Bulushi *et al.,* 2019). The functions of the female and male reproductive systems are production of oocytes and spermatozoa, respectively, over puberty and sexual maturity followed by insemination during the breeding season. Both males and females exhibit oestrous and rutting behavior during the breeding season (Padalino *et al.,* 2015). Male sexual maturity occurs 3-4 years of age (Skidmore 2005). It is worth noting that there are no seminal vesicles in camel male reproductive system (Abdullahi Mahmud *et al.,* 2016). Reproductive activity of males continues until the age of 20 years, which may vary due to

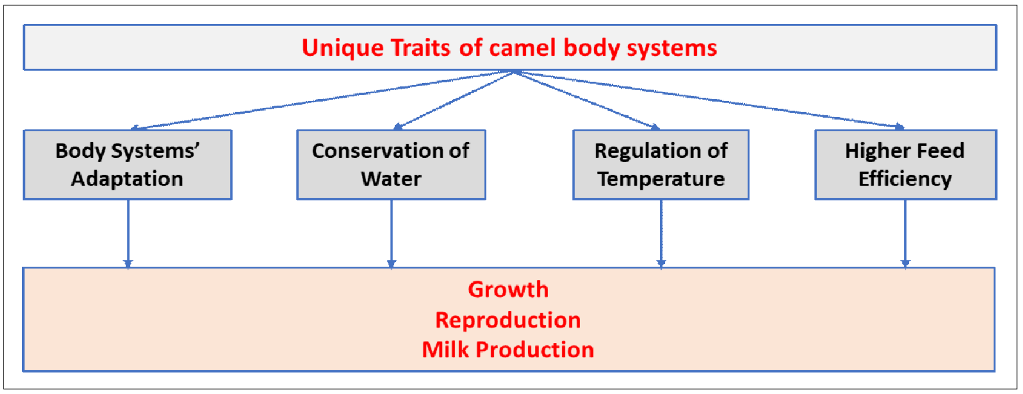


Fig 1: Unique characteristics of camel body systems to withstand extreme conditions in addition to growth, reproduction and milk production.

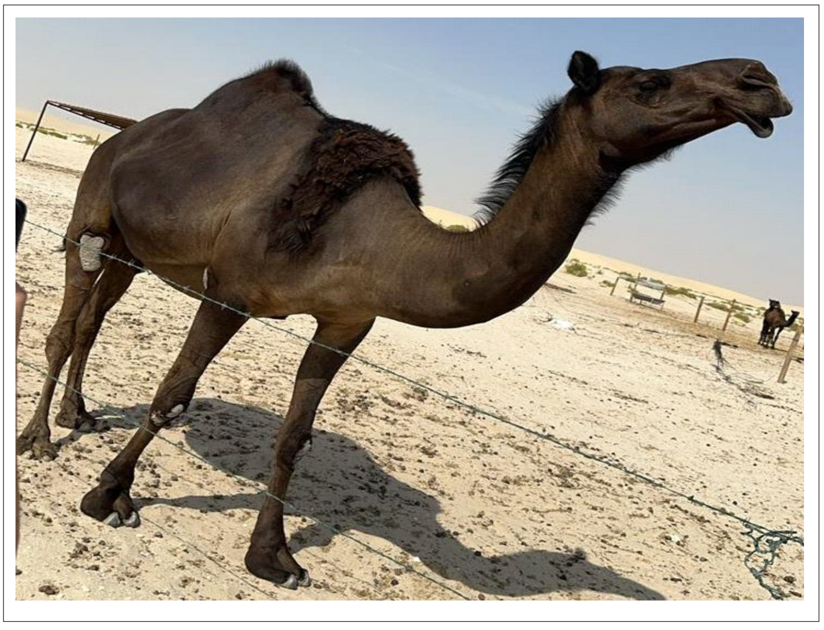
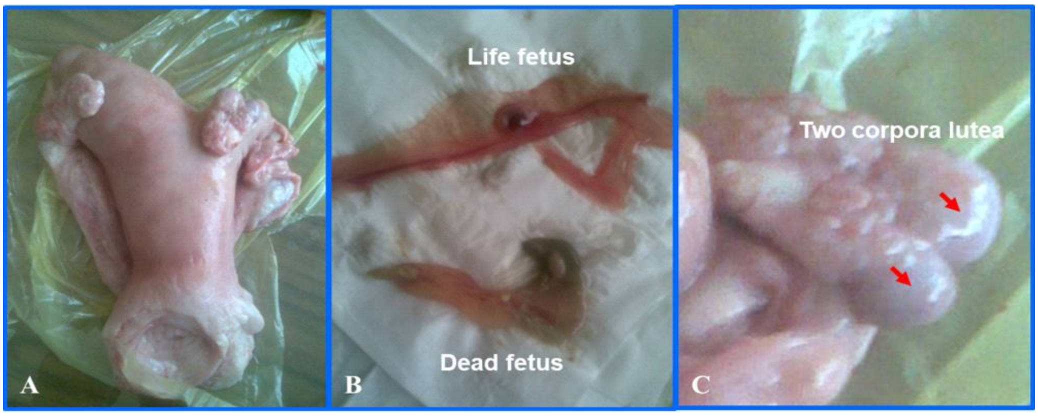


Fig 2: Mejham she-camel breed in extreme desert environment.

breeds, genetics, nutrition and climatic changes (Gherissi *et al.,* 2020). A male camel can inseminate 20-50 she-camels during the breeding season in good environmental condition (Yakubu *et al.,* 2022). Testicular weight and dimensions were increased with age until 10-15 years of age and decreased thereafter (Ismail 1982). Testicular weight and sperm count in the epididymis were reached their peak during the breeding season (Zeidan *et al.,* 2001 Samatar *et al.,* 2022). In addition androgen secretion increased in blood and urine in addition to the increase of poll gland secretion (El-Khaldi and Homeida 2020).

Puberty in Arabian she-camels occurs at two years of age and different factors as nutrition, season and breeds determine the age of sexual maturity (Gherissi *et al.,* 2020). Full reproductive capacity of she-camels was reached at 3-6 years and they might be bred until 30 years of age (Belina *et al.,* 2021).She-camels are seasonal breeding animals with induced ovulation. Ovulation occurred in most she-camels within 36-48 hours following copulation (El Allali *et al.,* 2017). The camel's uterus has a longer left horn and a shorter right horn, connected by a relatively long uterine body (Monaco *et al.,* 2024). This unique structure is believed to be an adaptation to the camel's reproductive strategy, with embryos typically implanting in the left uterine horn (Fig 3A). Camel twins are very rare (0.1-0.4%) might be due to the unique reproductive biology of camels. When twin pregnancies do occur, they often don't last long, as one pregnancy usually becomes dominant, leading to the loss of the other (Fig 3B). The placenta in camels is diffuse and therefore twin pregnancy cannot continue due to the lack of space in the placenta for two feti. However, there have been documented in recent years cases of successful twin births.

The camel germinal vesicle oocyte maturation *in vitro* lasts 44-48 hours (Fig 4). The oocyte maturation is the



(A) pregnant left uterine horn, (B) live and dead twin camel feti, (C) right ovaries with two corpora lutea.

Fig 3: Camel reproductive system traits.

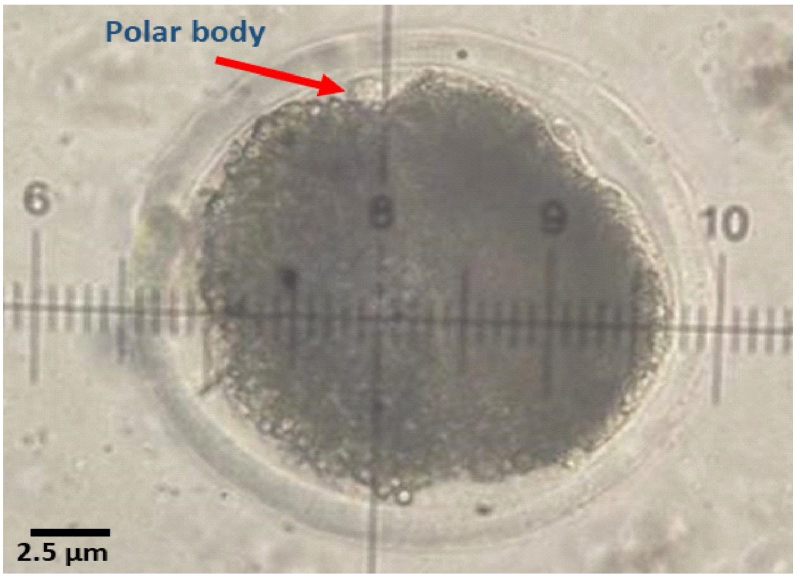


Fig 4: Camel's *in vitro* matured oocyte.

most important step for further embryo development (Mohammed *et al.,* 2008, 2010, 2019, 2024a-f). This longer time of camel oocyte maturation *in vitro* compromised the developmental competence of the resulting embryos when compared to 24h time maturation of bovine, ovine and caprine oocytes (Mohammed *et al.,* 2005; Mohammed and Mahmoud 2011; Mohammed and Alshaibani 2024b).

Poll glands

Poll glands are a unique feature of male camels located on the back of the neck, behind the ears and secrete a yellowish, offensive-smelling substance, especially during the breeding season. These glands are presented even in the newborn but they only become active over puberty. The poll glands can be easily distinguished from the surrounding skin because they are darker in appearance, slightly raised and covered with short and sparse hairs. The poll glands resemble histologically endocrine glands. The activity of the poll glands is linked to the reproductive activity of the male camel. When the level of testosterone level is high, the poll gland secretion is abundant. The secretion is dark brown and has a pungent odor to attract females (Dai *et al.,* 2024). These glands show maximum activity during the breeding season, when testicular activity is also at its peak, while the lowest activity has been recorded during the hot summer months. The poll glands are classified as compound tubulo-alveolar glands. Each gland consists of lobules and alveoli separated by a dense connective tissue (Ebada *et al.,* 2012). A number of septa extended from the connective tissue into the glandular parenchyma and divided it into lobules of varying sizes.

The poll glands are inactive before puberty and outside the breeding season and consist mainly of scattered groups of lobules and alveoli with connective tissue. The amount of connective tissue decreases when these glands become active during the breeding season (Ibrahim *et al.,* 2020).

Camel’s oestrous cycle

Female camels are seasonally polyestrous, exhibiting cyclical estrous cycles that are incomplete compared to ungulates. The average duration of these cycles has been documented as 28 days in Sudan, 24.2 days in Egypt and 11-30 days in Saudi Arabia. This variability in cycle length is attributed to factors such as cyclic ovarian activity and the presence or absence of copulatory stimuli. Additionally, age significantly impacts follicular development, with 6-10-year-old females exhibiting the highest number of ovarian follicles (Ashour *et al.,* 2017).

The ovarian activity in camels encompasses three stages: follicular growth, maturation and atresia (Ghallab *et al.,* 2024). The follicular growth phase extendsfor approximately 10.5 ± 0.5 days, during which follicles grow at a rate of 1 mm/day. Subsequently, the growth rate accelerates to 1.8 mm/day until the follicles attain their maximum size, ranging from 10 to 25 mm. The follicles persist at this maximum size for 2-3 days before entering the atresia stage, which lasts around 11.9 ± 0.8 days (Mohammed and Alshaibani 2024b). A positive correlation exists between follicular size and plasma 17-α estradiol concentration. In the absence of ovulation, mature follicles can continue to grow to sizes between 25 and 75 mm. Approximately one-third of anovulatory follicles undergo hemorrhagic and partial luteinization, leading to divergent perspectives on female management for superovulation. Anovulatory follicles typically regress within 8-45 days and may not consistently inhibit the development of a new follicular wave (Anouassi and Tibary 2013).

Characteristics of semen during breeding and non-breeding seasons

The volume and characteristics of semen varied according to the collection method, semen collection frequency, age and breeding or non-breeding season (Al-Bulushi *et al.,* 2018). The ejaculated semen volume of dromedary camels range from 2.0-10.0 ml as there is great variation between males after a copulation time of 11-36 minutes (Mansour 2023). The ejaculated semen volume was found to be 7.82, 8.12 and 7.94 ml at ages 2.50–5.0,>5.0–10.0 and >10.0–20.0 years, respectively (Zeidan, 1999; Zeidan *et al.,* 2001; Sarhan *et al.,* 2024). The ejaculated semen volume ranged from 5.3 ml in the reproductive season to 3.5 ml in the sexually inactive period (Rai *et al.,* 1997). The ejaculated semen volume collected by camel semen collection kit (CSCK) showed lower volume, gross activity, sperm concentration, total sperm motility and percentage of live sperm cells compared to electrical stimulation and artificial vagina (Mansour 2023). The percentage of motile sperm also varied according to the age of the animal and the reproductive season (Elsharnoby *et al.,* 2021). The pH of camel semen is alkaline with a range of 7.20-8.80 with an average of 7.80 (Zeidan *et al.,* 2001). The pH was insignificantly different in both non-rutting and rutting seasons at different ages (Sarhan *et al.,* 2024). The highest pH value was recorded at 5.0-10.0 years of age versus the lowest pH value recorded at 2.5-5.0 years of age.

Male and female sexual behaviors

Male camels are easily controlled, but during sexual activity “rutting” they become aggressive towards other males and humans. Male camels display many physiological and behavioral characteristics of masculinity during sexual activity or rutting (Padalino *et al.,* 2015). In mixed herds, a dominant male camel becomes dominant due to his size or high fighting ability, while subdued males quickly exit rut or show a decrease in sexual activity (Marai *et al.,* 2009; Fatnassi *et al.,* 2021). At the peak of sexual activity, male camels exhibit a range of behavioral and physical signs. The behavioral signs include increased aggression, vocalizations, tail flapping, urine spraying and mounting behavior. The physical signs include increased testosterone levels, poll gland activity and changes in body condition. She-camel sexual behavior includes 0actual heat period, which lasts about 3-4 days and is characterized by frequent urination, swollen vulva with small amounts of mucus, tail movement up and down in rapid succession, searching for the male and standing next to male (Padalino *et al.,* 2016).

Unique features of digestive system and nutritional efficiency

Camels are pseudo-ruminant herbivores that are able to utilize high-fiber forages. The ability of camels to survive and produce under the harsh desert conditions is thought to be due to their specific feeding habits, unique digestive system and other adaptive traits (Hinsu *et al.,* 2021). The digestive tract is a muscular tube that extends from the mouth to the anus and may be up to 60 meters long. The amount of saliva secretion varies between 30 liters per day in camels. The parotid gland is the largest salivary gland in camels, producing 12-21 liters of saliva per day depending on the type of feeding. Amyloytic activity of the parotid gland has been confirmed (Almansour *et al.,* 2024). The mandibular glands are less than half the size of the parotid gland. The gland produces a rapid secretion during feeding and a slow secretion during rumination.

The esophagus in camels is a long muscular tube with a large capacity that transports food from the pharynx to the stomach. The esophagus length in camels can range from 165 to 215 cm due to the length of the neck (Thanvi and Joshi 2019). The esophageal wall consists of four distinct layers: the mucosa, the submucosa, the muscularis and the outer layer (adventitia or serosa). The mucosa consists of keratinized, stratified squamous cells along the length of the esophagus. The keratinized cells consist of about 7-10 layers of cells (Hussein *et al.,* 2016).

The forestomach in camelids is dilations and modifications of the esophagus. The camel's forestomach is more than one meter long with different functions. It includes three main compartments: the rumen, the reticulum and the abomasum. These organs are designed to host a specific type of microorganisms that breaks down plant material into short-chain fatty acids and others (Hinsu *et al.,* 2021). Furthermore, camel forestomach have unique pouch-like structures (Gelberg 2017).These specialized structures contribute to the camel's ability to efficiently digest tough plant material and conserve water in harsh desert conditions.

Camels, like ruminants, ferment their feed in their forestomach using microbes. This process breaks down carbohydrates into short-chain fatty acids (acetic, propionic and butyric acids) and proteins into amino acids. The resulted amino acids are then used to create microbial protein, which is further digested to amino acids. The resulting nutrients, including amino acids and fatty acids, are absorbed and reached the liver for further metabolism. The resulting nutrients of digestion can vary depending on the season, camel species and consumed feed intake (Gharechahi *et al.,* 2022; Kandeel *et al.,* 2022).

Efficiency of nitrogen consumption in camels

It has been known that camels are remarkably efficient in utilizing nitrogen from their diets. This efficiency is due to several factors including efficient microbial digestion, selective absorption, water conservation and efficient protein synthesis. The efficiency of nitrogen utilization is averaging H"25% in ruminants and camels. Camels exhibit higher digestion capacities compared to sheep when fed on low-protein diets (Khattab *et al.,* 2023), which is crucial for their survival in nutrient-scarce habitats.

Camels fed on low-protein diets conserve nitrogen by recycling urea in their forestomach and reducing urine nitrogen (Homeida and AL-Shami 2009). Camels excrete in the urine about 40% of blood urea filtered in the glomeruli when they fed a balanced nitrogen diet (H" 33 g nitrogen/ day; 206 g crude protein/day) compared to 1-2% of excreted blood urea when they fed a low nitrogen diet (H" 15 g nitrogen/ day; 94 g crude protein/day). Additionally, it was found that giving a blood urea injection to camels fed a low nitrogen diet did not increase urinary nitrogen excretion and the nitrogen injected was retained in the body. Furthermore, Homeida and AL-Shami (2009) found that the rate of urea excretion increased with increasing nitrogen intake. Plasma urea concentration increased linearly with increasing dietary protein intake. The effect of water restriction and complete water deprivation on nitrogen balance and urea cycling was also studied in camels, sheep and desert goats fed a low-quality desert grass containing 3.2% crude protein (Mousa *et al.,* 1983). All animals lost weight during both water restriction and total water deprivation. Although camels showed a decrease in dry matter intake (0.75 g/kg) and a decrease in apparent dry matter digestibility, the animals showed less weight loss (% of initial weight) and an increased urea recycling rate. The rate of increase in urea recycling in camels with low nitrogen intake resulted in a negative nitrogen balance accompanied by a decrease in urine and dung nitrogen (mg/kg0.75) compared to sheep. The results of several studies (Mousa *et al.,* 1983; Homeida and AL-Shami 2009) supported that camels fed low nitrogen diets were more efficient than ruminant species in recycling urea and decomposing it in the foregut. This partly explains the continued survival and production of camels under very harsh desert conditions compared to other ruminant species.

Milk secretion

Camel milk production varies depending on factors such as breed, age and environmental conditions (Mohammed and Alshaibani 2024a). However, she-camel can produce 2-10 liters of milk per day. Some Arabian camels can produce even higher milk yields, up to 20 liters per day. The lactation stage typically lasts 6-12 months. Camel milk has several unique nutritional properties that make it a valuable food source (Mohammed and Alshaibani 2024a). Camel milk contains high protein content, low fat and lactose contents, rich in vitamins and minerals **and** unique immunoglobulins. Camel milk contains unique immunoglobulins that can boost the immune system and protect against various infections. Due to its unique nutritional profile and potential health benefits, camel milk has gained popularity in recent years (Ganzorig *et al.,* 2020; Liu *et al.,* 2023) and its production and consumption are on the rise in many parts of the world (El-Hanafy *et al.,* 2023; El Alia *et al.,* 2023).

Body growth and meat production

The birth weight of one-humped camels ranges from 30-40 kg and the weight at one year of age is about 150-180 kg, while the weight of the mature body is 500-600 kg on average, which is reached at the age of 6-7 years (Bene *et al.,* 2020). The Arabian camel is a good source of meat, especially in areas where the climate adversely affects the performance of other meat-producing animals. The average birth weight of camels varies widely between regions, breeds and within the same breed. Camels are limited to moderate growth rates (500 g/day). Camels, however, produce meat mostly under traditional extensive systems at levels of malnutrition and most are slaughtered at an advanced age after work, racing or milk production. Camels yield carcasses weighing 124 to 400 kg with a dressing percentage of 55% to 70%. Camel carcasses contain approximately 57% muscle, 26% bone and 17% fat with the front halves (from skull to rib 13) being significantly heavier than the hind halves. The red, lean camel meat contains about 78% water, 19% protein, 3% fat and 1.2% ash with a small amount of intermuscular fat, which makes it a healthy food for humans (Kadim *et al.,* 2008). The color of camel meat has been described as ranging from raspberry red to dark brown and camel fat is white. Camel meat is similar in taste and texture to cattle meat. The amino acid and mineral contents of camel meat are often higher than cattle meat, probably due to the lower levels of intramuscular fat (Baba *et al.,* 2021). Camel carcasses can provide a significant amount of meat for human consumption with certain parts of the carcass such as the hump and liver being a favourite delicacy in Middle Eastern markets (Kadim *et al.,* 2014). Although camel meat marketing systems are not well organized, there is evidence of a high demand for fresh camel meat and camel meat for use in blended meat products even among non-camel-keeping communities. Camel meat can be an inexpensive option to meet the growing meat needs in developing countries, especially for low-income populations (Saparov and Annageldiyev 2005).

Unique features of blood profiles

Camel blood profiles exhibit several unique features that reflect their remarkable adaptations to harsh desert environments. Camel red blood cells are oval-shaped, unlike the circular shape found in most mammals, to allow them to pass through narrow capillaries more easily, improving oxygen delivery, especially during dehydration. Camels have a higher concentration of red blood cells (3.80 x l06 to 12.6 X l06 RBCs/µL) compared to many other mammals. This increased oxygen-carrying capacity is crucial for their survival in low-oxygen environments and during periods of physical exertion. The lifespan of camel RBCs can vary depending on environmental conditions and the camel's hydration status and it generally ranges from 90 to 150 days (Pesen *et al.,* 2023).Camel hemoglobin has a higher affinity for oxygen than human hemoglobin, allowing for efficient oxygen uptake, even in low-oxygen conditions. Hemoglobin value was 10.61 – 15.29 g/dL, packed cell volume was 19.93 – 32.51 % and white blood cells was 7.35 – 18.36 X103/µL (Martín-Barrasa *et al.,* 2023). Camels have the ability to regulate their blood volume to conserve water during dehydration. They can significantly reduce blood volume without compromising vital functions. Camels have specialized mechanisms to maintain electrolyte balance, particularly sodium and potassium, which are essential for various physiological processes. These unique blood features contribute to the camel's remarkable ability to survive and thrive in harsh desert environments.

Unique features of urine traits

Camel urine has several unique features that distinguish it from other animals including high concentration of urea and uric acid, alkalinity and presence of unique metabolites (Fig 5). Our unpublished work on camel urine indicated differences in urine total protein recorded by refractometer device due to management systems (Mohammed *et al.,* unpublished). These unique features of camel urine have led to its use in traditional medicine for centuries (Mohammed and Alshaibani 2025).Camel urine has been shown to possess various health benefits, including antibacterial, antifungal and antiviral properties. It has also been found to be effective in protecting the liver and gastrointestinal tract, as well as in fighting cancer cells *in vitro* (Salamt *et al.,* 2021; Tharwat *et al.,* 2023).The unique

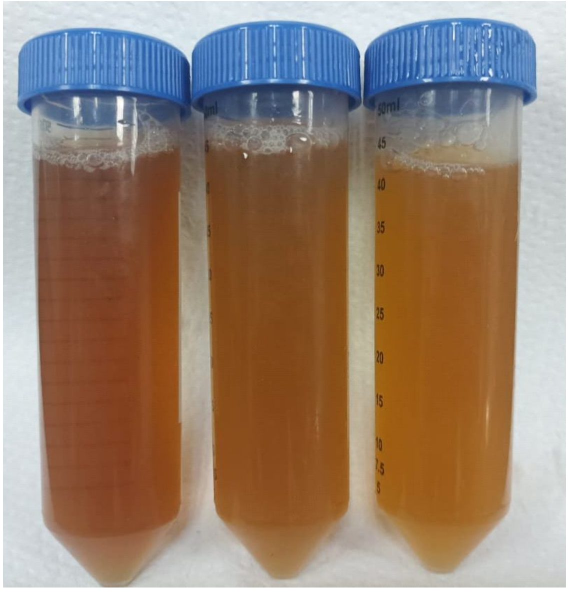


Fig 5: Variations in physical characters of camel urine over species and management systems.

compounds present in camel urine, such as metabolites, hormones. The unique compounds present in camel urine, such as metabolites, hormones, corticosteroids and urea, contribute to its therapeutic effects. These compounds can help kill bacteria, viruses and fungi and promote recovery from various ailments (Sumia *et al.,* 2016; Amina *et al.,* 2024a,b). This suggests that camel urine and its compo-snents have a broad spectrum of activity against a wide range of pathogenic microorganisms and diseases (Khedr and Khorshid 2016; Ali *et al.,* 2019).

CONCLUSION

Dromedaries have been evolved a remarkable array of adaptations that enable them to live in harsh desert environments. These adaptations are evident in their body systems, which are specifically designed to conserve water, regulate temperature and withstand extreme conditions. Furthermore, dromedaries bred under extensive harsh conditions can produce births, meat and milk. Further researches are still needed to fully understand the physiological and ecological implications of camel body systems in addition to the potential health benefits of camel products to human body.

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Disclaimers

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Informed consent

Not applicable

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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