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## In This issue



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Journal of Camel Practice and Research (JCPR) publishes only research and clinical manuscripts related to the Camelids (Old and New World camelids), hence published contents are consistent with the title and scope of the journal. Review articles on emerging research are invited and published. JCPR also publishes the news related to the New or Old World Camelids, specially those related to new products, conferences, books, trainings or workshops etc.

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**Courtesy:** Dr. A.K. Kataria-a coloured painting prepared by him

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EDITORIAL

# BIOMARKER BASED DIAGNOSIS- A BOON TO CAMEL MEDICINE

Research on biomarker-based diagnosis is becoming increasingly important for more accurate and efficient disease detection and monitoring of camel diseases. A wide range of biomarkers including cardiac, bone, inflammation, transport, stress, and pulmonary, which are used to reach towards a concrete disease diagnosis in camels. Myocardial damage in camels is assessed through cardiac biomarkers (cTnI and CK-MB), specially with cTnI showing higher specificity and sensitivity for myocardial injury. Serum amyloid A (SAA) and haptoglobin (Hp) are acute-phase proteins (APPs) that increase in response to infection and inflammation found in camel diseases, and other non-inflammatory stressors like physical stress or parturition. Increased levels of bone metabolism biomarkers, i.e. pyridinoline (PYD) in blood or urine are associated with bone resorption, indicating potential bone diseases in camels. Stress biomarkers are used to assess stress levels in camels, including those related to transport, racing or disease. Pulmonary biomarkers may also play important role in diagnosing pulmonary diseases in racing and other camels. Biomarker-based diagnosis is a cost effective and reliable tool to make disease detection more accessible, especially in remote areas or resource-limited settings. Machine learning algorithms can analyse biomarker data to identify patterns and improve diagnostic accuracy. Proteomics is emerging as a powerful tool for biomarker discovery in camel medicine, allowing the identification of disease-related proteins in biological fluids. Biomarkers ensure early disease detection, thus facilitate a timely and targeted treatment, leading to better clinical prognosis. It is opined that biomarkers contribute remarkably to camel welfare by allowing for proactive management and treatment of diseases. As the industry of camel products like milk and meat is growing fast, the biomarker-based diagnosis helps ensuring product safety and quality. The use of biomarkers in camel medicine not only helps in disease management but also helps to improve the camel health and productivity of camel related industries. Appropriate use of biomarker kits may improve the clinical outcomes in the field conditions also.

The current issue has good focus on the research of Bactrian camels. It involves research done by Chinese scientists on Bactrian camel whey protein powder which alleviates acute heat stress-induced kidney injury and apoptosis, decoding the cross-cultural symbolism of “Han Dynasty Nanyang Picture Stone Bactrian Camel” in the design of Chinese characters-implications for Chinese poster design, Bactrian camel milk and ancient Bactrian camel-shaped cultural relics. The dromedary research involves a study on Rift valley fever - a neglected pathogenic virus, effect of aluminium hydroxide as a conjugate to FSH for use in super-stimulation, endoscopic diagnosis and management of cases of oesophageal obstruction, structured camel milk therapy alongside an individualised botanical support protocol to facilitate immune modulation in a child diagnosed with pans/pandas co-morbid with lyme disease and autism, camel pastoralism, impact of refrigeration on the shelf life, biochemical and hygienic quality of raw dromedary camel milk. The series on “My Journey to Camel Science” has been participated with cherished notes by the Surong Hasi, Christina Adams and Tarun Kumar Gahlot.

I am happy to note that Journal of Camel Practice and Research is still a popular scientific periodical and authors engaged in camel research from various countries are publishing their research in this journal. I owe my sincere thanks to them.

Best wishes

(Dr. Tarun Kumar Gahlot)
Editor

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# RIFT VALLEY FEVER - A NEGLECTED PATHOGENIC VIRUS OF CAMELIDAE

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## ABSTRACT

New World camels and dromedary camels can contract Rift Valley Fever with severe consequences. RVF has not been documented in Bactrian camels. RVF outbreaks are regularly observed after heavy rains in many different African countries and has also entered Saudi Arabia affecting human beings and livestock in 2000. RVF epidemics regularly cause serious economic hardship to animal owners due to loss in production and fatalities. The virus causes abortion storms in dromedary camels at all stages of pregnancy and systemic disease in young stock has been reported. RVF virus has been isolated during the RVF outbreak in Mauritania in 2010. Inactivated and live-attenuated vaccines are available, but have not been scientifically evaluated for use in camelids.

**Key words:** Epidemiology, prevention, Rift Valley Fever, treatment

Many pathogenic livestock viruses do not disease the *Camelidae* family. They are robust animals and show a high resilience to many diseases. Dromedary camels are resistant to Foot-and-mouth Disease (FMD), Peste des Petits Ruminants (PPR), Blue Tongue (BT), West Nile Fever (WNF) and Wesselbron disease. However, in recent years it had become obvious that New World Camels (NWCs) and Old World Camels (OWCs) can contract Rift valley fever (RVF).

Rift Valley fever (RVF) is an arthropod-borne viral disease of animals including humans, but mostly found in ruminants. Infection in humans is primarily a result of contact with material from infected carcasses (Hoogstraal *et al*, 1979). In addition to human health hazards, RVF epidemics regularly cause serious economic damage to animal owners through loss in production and fatalities, exacerbated by the 100% abortion rate at all stages of pregnancy. Strikingly, all of the RVF epizootics described to date have followed unusually severe rainy seasons, probably indicating a very large insect population as a vector prerequisite (Heubschle, 1983). RVF does not occur in very arid areas. In NWCs, the RVF virus (RVFV) causes not only abortions, but also systemic disease, whereas, in dromedaries, abortion at any stage of gestation is the predominant clinical sign in addition to haemorrhagic fever and pneumonia. RVF is an acute to peracute zoonotic disease of domestic ruminants predominantly in Africa. Floodwater-breeding mosquitoes of the *Aedes* genus, and less importantly biting flies, are considered to be epidemic vectors.

## Aeitology

The Rift Valley virus (RVFV) is a member of the *Phlebovirus* genus of the family *Bunyaviridae*. The *Bunyaviruses* are spherical, are 80-120µm in diameter and have a host-cell-derived lipid bilayer envelope through which virus-coded glycoprotein spikes project. No significant antigenic differences have been detected between RVF isolates, but differences in virulence have been demonstrated. RVFV is a single-serotype vector-borne RNA virus. The non-structural protein NSs is a multifunctional protein that enables RVFV to evade the host's antiviral response. This protein is unique among the *Bunyaviruses*, as it forms a filamentous structure in the nucleus, but the virus replicates in the cytoplasm. Altogether, it appears that NSs has multiple functions to counteract the host cell interferon defence mechanism (Pepin *et al*, 2010).

## Human implication

Rift Valley fever in humans appears as an influenza-like syndrome in 95% of infections, and the disease can be confused with malaria. This mild form may last for a week. However, during RVF outbreaks in Egypt and Mauritania, severe disease also developed in some patients showing the ocular, the meningo-encephalitic and the haemorrhagic forms. The last-mentioned form is certainly the most

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severe form, as it always leads to the death of the patient. Prevention of the disease depends on the implementation of an early warning system based on the epidemiological monitoring of animals. Human vaccines exist, but are not commercially available and are administered only to people at high risk.

**Epidemiology**

For more than 90 years, RVF epidemics have occurred at prolonged intervals in eastern and southern Africa. It has been accepted that the virus is endemic in indigenous forests, where it circulates in mosquitoes and vertebrates, spreading to livestock-rearing areas when heavy rains favour the breeding of mosquito vectors. The *Phlebovirus* is transmitted by mosquitoes from 23 species belonging to the *Anopheles, Culex, Aedes and Mansonia genera*. RVF in ruminants is mainly inapparent in non-pregnant adult animals, but in outbreak situations, it is responsible for many abortions and high neonatal mortality, particularly in European breeds and NWC crias. The virus was first isolated in 1931 in livestock on a farm located in the Rift Valley of Kenya. The virus is now endemic in much of sub-Saharan Africa, with epidemics occurring also in West Africa (Saluzzo *et al,* 1987). It has also spread into Egypt, Sudan, Kenya and Mauritania and clearly has the potential to spread elsewhere with climate change and ever increasing unpredictable flooding in different parts of the world. In South Africa, RVF occurs at regular intervals: the first known outbreak was reported in the 1950s, a major outbreak in 1974–1976 and small localised outbreaks in 1981 and 1999. In 2008, RVF reoccurred, and isolated outbreaks were reported in 2009, followed by an extensive epidemic in 2010 affecting most parts of South Africa. In 2000, the disease for the first time affected humans and livestock outside Africa, when it was diagnosed in the southern parts of Saudia Arabia and Yemen (Khan *et al,* 2002; Shoemaker *et al,* 2002). The globalisation of trade and altered weather patterns are a concern for the future spread of RVF, as the causative agent, the RVFV, is capable of utilising a wide range of mosquito vectors. In the last outbreak in Mauritania, at the end of September to the beginning of October 2010, unprecedented rainfall created large ponds of water in the oases of the Saharan region of Adrar, northern Mauritania. Such rain had not been observed for decades, and the locals refer to 1956 (locally known as the 'year of the fever') to describe the recent similar events.

This climatic event lead to unusually profuse growth of vegetation, attracting shepherds and pastoralists from remote areas, including the south and south-east regions of the country. It also favoured the multiplication in high densities of several species of mosquito, mainly from the genera *Culex* and *Anopheles (Culex quinquefaciatus, Anopheles pharoensis, Anopheles protoriensis, Culex poicilipes, Anopheles gambiae, Aedes vexans, Culex antenatus, Anopheles rufipes, Mansonia uniformis, Anopheles ziemani)*, including competent vectors for major arboviruses.

A few weeks after this period of rain, severe outbreaks of malaria and RVF were reported in several oases ('Graret') of the Adrar region. Interestingly, the first probably reportable case in livestock was a dromedary camel that became sick during the last week of October 2010 in the Aoujeft area (Ould Al Mamy *et al,* 2011). Dromedaries in the area exhibited an RVF immunoglobulin M (IgM) seroprevalence of 33% and suffered from two clinical forms: a peracute form with sudden death within 24 hours and an acute form with fever, ataxia, blood-tinged nasal discharge, blindness, haemorrhages of the gum and central nervous system signs. Abortions also occurred. The virus was isolated from four dromedaries. It seems that dromedaries play a major role in the epidemiology of RVF outbreaks.

Epidemiological studies of RVF have always been performed during episootics or immediately afterwards. This was the case for epidemics in Sudan, Kenya and Egypt. Several studies also included the local dromedary populations. Scott *et al* (1963) reported outbreaks of RVF in cattle, following severe rainfall in Kenya, parallel to a drastic increase in abortions in dromedaries. Antibodies to RVF were found in 45% of the dromedaries examined during this outbreak. The authors stated that the RVFV was responsible for the increased rate of abortions; however, no virological studies were performed to substantiate this supposition. Meegan *et al* (1979) also observed an increased abortion rate in dromedaries during an RVF epizootic in Egypt. In this case, the epidemic was supposedly carried by Sudanese dromedaries to Egypt (Abd El-Rahim *et al,* 1999; Hoogstraal *et al,* 1979), as severe epidemics were raging in northern Sudan at the time (Eisa *et al,* 1977). During this period, Hoogstraal *et al* (1979) registered 31 RVF reactors in dromedaries. Other than the increased abortion rate during outbreaks of RVF, no other clinical signs have been observed so far in camels (Davies *et al,* 1985). Aly (1979) found antibodies with the Haemagglutination inhibition (HI) test in 15.6% of dromedaries in Egypt, and Walker (1975) described abortions and deaths in young one-humped camels during RVF outbreaks. Peters and Meegan (1981), however, observed only a subclinical form of RVF. Olaleye *et al* (1996) examined 180 dromedaries with the haemagglutination inhibition test and the serum neutralisation test in Nigeria and detected 3.3% of cases to be positive. The authors stressed the involvement of camels in the transmission cycle of RVFV. Out of 1,119 serum samples from dairy camels in Dubai, four (0.35%) were positive in the RVF inhibition enzyme-linked immunosorbent assay (ELISA), which has, according to Paweska *et al* (2005), a 100% specificity and sensitivity for camelids. These four samples were from adult dairy dromedaries. None of the calves had seroconverted. The low incidence of RVF is not unexpected because the Arabian Peninsula experiences very little rainfall, unfavourable for the breeding of high numbers of mousquitoes. However, it should be kept in mind that camels which are imported from countries that regularly experience RVF outbreaks should be tested (Wernery *et al,* 2008).

Imam *et al* (1978) and Eisa (1984) were able to isolate the virus from a healthy, naturally infected dromedary. Experimental infections with the RVFV have failed to induce clinical signs in non-pregnant dromedaries (Davies *et al,* 1985). In spite of high RVF antibody titres, the same authors were not able to determine an increased rate of abortion in infected dromedaries.

Severe RVF epidemics have recently occurred in East Africa (Anonymous, 1998). Many domestic animals and humans were affected in vast areas of Kenya, southern Sudan and northern Tanzania in December 1997 and January 1998. It was claimed that the 1998 Kenyan outbreak most probably eliminated the entire camel calf population, as perhaps as many as 150,000 animals died (Mungere, 2000). During the Mauritanian outbreak in 1998, immunoglobulin G antibodies were detected in dromedaries, but no virus was isolated (Nabeth *et al,* 2001). It is of great relevance to carry out proper investigations to elucidate the role of RVF in dromedaries because of the zoonotic potential of this disease. Intensive investigations were conducted by Munyua *et al* (2005) during the 2006–2007 RVF outbreaks in Kenya in which thousands of cattle, sheep, goats and dromedaries were affected. Again, abortion was the main clinical sign in dromedaries, with a prevalence of up to 38%. However, no attempts were made to isolate the virus from aborted foetuses or placentas. Reports emerged in 2011 of many llamas and alpacas dying from RVF in 2010 and 2011 in South Africa. South Africa's NWCs are used to guard sheep from predators, such as jackals and leopards, and on some farms they are also reared for their wool, which has a cashmere quality. The disease broke out in the Western Cape Province in January 2010. Not all alpacas die when infected with the RVFV; some get flu-like clinical signs and recover quickly. In these outbreaks, the morbidity rate was 12.5% and the mortality rate 0.13%. Interestingly, although the farm on which the fatalities occurred is an alpaca enterprise comprising alpacas of all ages, only the yearling group was affected. The disease was also observed in young llamas. Rift Valley Fever outbreaks in South Africa occurred in 2009, 2010 and last in 2011. Although South Africa has an alpaca population of around 3000 only 22 animals succumbed to RVF in 2010 and 2011.

In 2024 and 2025, disease outbreaks were reported again in some parts of Ethiopia and Kenya after heavy rain in these areas. Several clinical signs observed in dromedary camels during these outbreaks were similar as described by Oud El Mamy *et al* (2011) with fever, staggering, ventral oedema, blood stinged nasal discharge, severe conjunctivitis, abortions, oedema of neck and head. Currently serological and viral testing is performed and will be reported later.

**Clinical signs**

During the most recent RVF outbreaks in East Africa, the WOAH (OIE) received many reports of high mortality in camels throughout the affected areas. Some descriptions of morbidity and mortality were highly suggestive of camelpox or parapox (*Ecthyma contagiosum*), with ballooning of the head and upper neck, swollen eyes and huge mucoid membrane sloughs in the mouth covering some ulcers.

However, the general disease pattern was that of fever and abortion, which were the predominant features, but early neonatal death and jaundice were also observed. As RVFV was not isolated from camels during these outbreaks, it is not clear whether the disease was caused by RVF. However, death and abortions in many dromedaries were observed in the Saudi Arabian RVF outbreak of 2000 and the 2006 outbreak in Kenya (WOAH, 2007), but no thorough investigations were carried out. The clinical signs of RVF in NWCs were described during the outbreak in South Africa. The disease had an abrupt onset and short course, lasting only between 4 and 6 h. The four affected alpaca crias were anorexic, severely depressed and pyrexic and showed signs of abdominal discomfort. They also developed respiratory distress, and, despite supportive therapy, they died. During necropsy, widespread petechiae and ecchymoses were seen in the buccal mucosa, subcutis, serosal surfaces, epi- and endocardium, liver, lungs and lymph nodes. Histologically, the liver showed coagulative to lytic necroses. In two animals, intranuclear inclusions were detected, and real-time polymerase chain reaction (PCR) and immunohistology staining confirmed RVF (Gers and Grewar, 2010).

In general, RVF affects a wide range of animal species, but the severity of clinical signs varies according to age, and, in sheep, peracute, acute, subacute and inapparent RVF forms have been described. In young bovine calves under ten days of age, the acute form, with hyperthermia, profuse fetid diarrhoea and depression combined with respiratory distress, is frequent. Death is very rapid (within 48 h), and the mortality rate may exceed 50%. Goats are generally considered to be more resistant to RVF than sheep, but kids may be affected and show the same clinical signs as lambs.

In adult dromedary camels, after a brief period of viremia, abortion seems to be the only visible sign of infection which can also be caused by brucellosis, camelpox and *Trypanosma evansi* infections. In younger dromedary camels, Oud El Mamy *et al* (2011) were the first who described the clinical features which were fever, ventral oedema, swollen head, staggering, severe conjunctivitis, blood tinged nasal discharge with haemorrhages of eyes and tongue. These lesions were also seen in the 2024, 2025 outbreaks in Kenya and Ethiopia (Cran, Pers. Communication 2025). Gross pathological lesions were icteric enlarged liver, petechiae on organ surfaces and free blood in abomasum and intestines which resemble alterations seen in entertoxaemias or haemorrhagic diathesis (HD, Wernery *et al,* 2014). RVF has not been documented in Bactrian camels, as RVF outbreaks have not been reported where Bactrians are reared.

## Diagnosis

Diagnostic techniques are well described in the WOAH (OIE) chapter "Rift Valley Fever" (OIE, 2018). The definitive diagnosis of RVF depends on virological and serological investigations, as other arthropod-borne virus diseases tend to occur under the same climatic conditions. This is especially true for Wesselsbron disease, which can also cause mortality in lambs, kids and calves and abortion in ewes. However, RVF is associated with higher mortality and abortion rates. Lesions in the livers of young animals also differ in RVF and Wesselsbron disease. Wesselbron disease have not been described in *Camelidae*. Hepatic changes are usually less extensive in RVF than in Wesselsbron disease. Specimens for laboratory confirmation should include heparinised blood, liver, spleen, kidney, lymph nodes and brain from aborted foetuses for virus isolation on Vero and BHK 21 cells or suckling and weaned mice. Antibodies to RVF can be demonstrated by the complement fixation test, agar gel immunodiffusion test, Haemagglutination inhibition test and ELISA. Results by Paweska *et al* (2005) showed that the inhibition ELISA is a highly accurate diagnostic tool for RVF disease surveillance and control programmes, and for monitoring the immune response after vaccination. It has the advantage of being independent of the species tested. This was confirmed by Martin-Folgar *et al* (2010), who tested dromedary sera with the competative ELISA after the 2006/2007 RVF outbreak in Kenya. Viral antigen can also be detected by immunofluorescence in impression smears of infected tissues. It is noted that the available IgM ELISA kits are not validated in camels.

## Treatment and prevention

Measures, such as the chemical control of vectors, movement of livestock to higher altitudes or the confinement of animals to mosquito-proof stables, are usually impractical or too late. Immunisation remains the only effective way to protect livestock. The main purpose of a RVF vaccine is to prevent the spread of the virus into species of economic interest like cattle, sheep, goats and camelids and limit the impact on animal and public health.

Although it has still not been determined decisively whether dromedaries actually develop RVF, Guillaud and Lancelot (1989) have concerned themselves with the production of a vaccine. The authors determined that the attenuated vaccine strain MVP-22 has yielded satisfactory results in the dromedary. Following a single subcutaneous vaccination, 18 of 22 dromedaries developed neutralising antibodies. A challenge infection with the RVFV was not performed.

Currently, there is no specific RVF vaccine designed for camelids. It is not known whether the sheep vaccine, which has been used in South Africa to protect alpacas from RVF, is effective or not, and this cannot be determined until proper vaccine trials have been conducted. In Dubai, two dromedaries were vaccinated with a live attenuated (Namibia: NSR 0580) and an inactivated (Namibia: NSR 0966) vaccine, both of which were from Onderstepoort and designed for cattle, sheep and goats. With a cattle dose, even after five injections, no antibodies were detected using the inhibition ELISA.

Further serological investigations with an inactivated RVF vaccine should be initiated, as the number of dromedary camels used in this immunisation was far too small. However, it is known that formalin inactivated RVF vaccines gave a short-lived immunity in cattle and require multiple administrations. Vaccination with classical live attenuated RVF vaccines has been associated with foetal malformations, still birth and foetal demise and should therefore be only used in non-preganant animals. However, in cattle they give a life-long immunity and may be tried in camels too. Two live attenuated vaccines are commercially available: Smithburn strain, which was isolated in Uganda, and clone 13 vaccine. Both vaccines are effective with one administration. Clone 13 vaccine is a natural RVFV isolate that contains a large (70%) deletion in its NSs gene. This vaccine appears to be a very good potential vaccine strain without any side-effects (Wichgers Schreur *et al,* 2023; Wichgers Schreur *et al,* 2025). However, a large experiment with pregnant ewes demonstrated that the clone 13 RVFV vaccine spread to the foetus, resulting in malformation and still births (Makoschey *et al,* 2016). Next generation live attenuated RVF vaccine are in the making and recombinant vaccines using either Capripox virus or vaccinia virus have been developed but not really used in proper field trials.

## Conclusion

It is now agreed that NWCs and OWCs cannot only contract a RVFV infections but also develop a disease. In adult dromedary camels the main clinical sign of RVF is abortion at any stage and young stock may develop a systemic disease. RVF outbreaks are regularly observed after heavy rains in many different African countries and climate change has the potential that RVF virus may enter countries outside Africa. Inactivated and live attenuated RVF vaccines are available and have not been scientifically evaluated for the use in *Camelidae*. Both have their advantages and disadvantages in ruminating animal species.

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# EXPLORING STRUCTURED CAMEL MILK THERAPY ALONGSIDE AN INDIVIDUALISED BOTANICAL SUPPORT PROTOCOL TO FACILITATE IMMUNE MODULATION IN A CHILD DIAGNOSED WITH PANS/PANDAS CO-MORBID WITH LYME DISEASE AND AUTISM

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## ABSTRACT

This article discusses the benefits seen with different types of camel milk administered in a 2 structured manner at predetermined intervals along with supportive herbal supplements in a child with PANS/PANDAS, Lyme Disease and Chronic Inflammatory Response Syndrome (CIRS) that may help improve intestinal barrier function, reduce inflammation, strengthen the microbiome and restrict bacterial invasion for optimal immune regulatory and neurological outcomes, i.e. PANS: Paediatric Autoimmune neuropsychiatric Syndromes and PANDAS: Paediatric Autoimmune neuropsychiatric syndrome associated with streptococcus.

**Key words:** Autism, autoimmune encephalopathy, camel milk, herbal support, immune modulation,leaky gut syndrome, Lyme Disease, molecular mimicry, nanobodies, PANS/PANDAS

Over the past two decades, paediatric neuroimmune and neuropsychiatric conditions have shown a marked increase in incidence and complexity, particularly in children showing sudden-onset symptoms such as obsessive-compulsive behaviour, severe anxiety, rage episodes, tics, or cognitive regression. These presentations are increasingly being recognised as Paediatric Acute-onset Neuropsychiatric Syndrome (PANS) and Paediatric Autoimmune Neuropsychiatric Disorders Associated with Streptococcal Infections (PANDAS) — disorders with autoimmune and infectious underpinnings that target the brain and nervous system leading to an autoimmune encephalopathy presentation. Despite growing awareness in clinical and research communities, many children remain misdiagnosed, often labeled with idiopathic autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), or psychiatric disorders, rather than appropriately evaluated for underlying infectious or inflammatory causes (Swedo and Leonard, 2012; Chang *et al,* 2015). The hypothesis that infections and immune dysfunction can drive neuropsychiatric syndromes is now supported by multiple studies showing elevated levels of pro-inflammatory cytokines, altered immunoglobulin levels and microglial activation in affected children (Morris and Berk, 2017; Hornig and Lipkin, 2016). In many of these children, a history of chronic infections—particularly tick-borne diseases such as Lyme borreliosis (*Borrelia burgdorferi*) and Bartonella species—has been documented. These pathogens have been associated with immune dysregulation, molecular mimicry and persistent inflammation that can trigger or exacerbate PANS flares (Coughlin and Yang, 2021; Bransfield, 2018). Further complicating the clinical picture is the increasing recognition of chronic inflammatory response syndrome (CIRS), a multi system illness triggered by biotoxins such as mold and microbial fragments, which often coexists with PANS/PANDAS in environmentally sensitive children (Shoemaker and Schaller, 2016). The bidirectional gut-brain axis, modulated by the enteric immune system and microbiota, plays a central role in both neurodevelopment and neuroinflammation. Children with PANS/PANDAS frequently exhibit food sensitivities, gastrointestinal symptoms and altered microbial profiles, which

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may further exacerbate behavioural and cognitive challenges through systemic cytokine release and increased blood-brain barrier permeability (De Theije and Koelink, 2014). As conventional treatment options such as antibiotics, corticosteroids and IVIG are not always sustainable or well-tolerated, there is a growing interest in integrative approaches that support immune regulation, reduce inflammation and enhance gut-brain homeostasis. Nutritional interventions, particularly those with immunomodulatory and 5 microbiome-balancing properties, are gaining traction in the functional medicine and paediatric neurology communities. Camel milk has emerged as one such promising adjunct. Rich in immunoglobulins, lysozyme, lactoferrin and small-chain bioactive peptides, camel milk has demonstrated antibacterial, anti-inflammatory, antioxidant and prebiotic effects in both animal and human studies (Al-Numair and Al-saif, 2020; Shabo and Yagli, 2005). Importantly, it lacks the allergenic β-lactoglobulin found in cow's milk, making it more tolerable for children with multiple food sensitivities. Emerging clinical data and case reports suggest that camel milk may improve immune tolerance, enhance intestinal barrier function and modulate neurological symptoms in children with neuroimmune conditions, including those with PANS/PANDAS and chronic Lyme disease. This article presents clinical observations from a case study of one child diagnosed with PANS/PANDAS co-morbid with Lyme disease and Autism, who received structured camel milk therapy alongside an individualised botanical support protocol. The objective of the case study was to highlight potential improvements in immune biomarkers, gastrointestinal function and behavioural outcomes while exploring the mechanisms through which camel milk may influence the gut-immune-brain axis.

## Clinical Case Study

### *Demographic and Medical Background*

The patient was a 5-year-old Caucasian male from the United States, born full-term via vaginal delivery with no complications during pregnancy or birth. Developmental milestones were achieved on schedule until the age of three, when a cluster of upper respiratory infections—alongside a suspected streptococcal pharyngitis episode—was followed by noticeable regression. The child gradually lost expressive language, became increasingly irritable and began demonstrating repetitive motor behaviours and restricted interests. At age four, he was formally diagnosed with Autism Spectrum Disorder (ASD) Level I and Attention-Deficit/Hyperactivity Disorder (ADHD). Despite intensive conventional therapies, including speech-language and occupational therapy, along with gluten- and casein-free dietary interventions, only minimal improvements were observed. At age five, the child was referred to an integrative medicine clinic due to severe neuropsychiatric flares marked by sudden rage episodes, obsessive-compulsive behaviours and self-injurious actions. Environmental and infectious exposure history revealed a prior tick bite during a family camping trip at age two and prolonged water damage with visible mold growth in the home from ages two through four. Multiple antibiotic courses were prescribed in early childhood to manage chronic otitis media and sinusitis.

### *Presenting Symptoms and Expanded Diagnosis*

***At the time of intake, the child presented with:***

- High anxiety and emotional lability
- Sensory hypersensitivity to light, sound and touch
- Aggressive outbursts and sleep dysregulation
- Severe gastrointestinal symptoms including bloating, gas, pain, constipation and food intolerances. The episodic nature and abrupt shifts in behavioural presentation raised clinical suspicion for Paediatric Acute-onset Neuropsychiatric Syndrome (PANS). A working diagnosis of PANS with comorbid ASD, ADHD and Chronic Inflammatory Response Syndrome (CIRS) was made based on symptomatology, history of mold and tick exposure and laboratory findings.

### *Laboratory Testing and Functional Biomarkers*

A comprehensive laboratory work-up was initiated to explore immune activation, microbial colonisation and detoxification pathways. Key findings included:

- CaMKII: Elevated to 161% of baseline (normal <130%), indicating autoimmune basal ganglia activation
- MARCoNS: Nasal culture positive for Multiple Antibiotic-Resistant Coagulase Negative Staphylococci, consistent with chronic sinus colonisation and immune dysregulation

***CIRS Panel:***

- TGF-β1: 19,500 pg/mL (elevated; normal <2,380 pg/mL)

- VEGF: 12 pg/mL (low; normal 31–86 pg/mL)
- MMP-9: 1,320 ng/mL (elevated; normal <332 ng/mL)
- SIgA: 2400 ug/g (elevated), indicating gastrointestinal immune hyperactivation

This constellation of abnormalities supported a multifactorial diagnosis involving PANS, CIRS and likely vector-borne and environmental triggers.

### *Nutritional Intervention with Camel Milk*

Given the severity of immune dysregulation, gut inflammation and food intolerances, a camel milk intervention was initiated, with informed consent from parents, using raw, frozen camel milk from a USDA-certified source (Camel Milk Association, USA), which conducts third-party pathogen testing. Camel milk was chosen for its low allergenicity, anti-inflammatory peptides and gut barrier-modulating properties. The child began with 1 teaspoon daily, titrated over four weeks to ¼ cup twice daily based on tolerance.

### *Adjunctive Integrative Interventions*

To support detoxification, immune regulation and microbial balance, the following therapies were implemented under clinical supervision:

- Low-dose herbal antimicrobials: Cryptolepis and Cat's Claw (herbal glycerite formulations, USDA organic) given two hours after camel milk consumption.
- Binders: Alternating activated charcoal and chlorella given two hours after camel milk consumption
- Nasal therapy: Customised MARCoNS-targeting sprays compounded at Hopkinton Drug Compounding Pharmacy (Massachusetts, USA)
- Methylation and mitochondrial support: Adenosyl-Hydroxy B12, folinic acid and phosphatidylcholine
- Neuroplasticity-based sensory Integration training: Daily limbic system, vagus nerve and bilateral hemispheric rebalancing exercises
- Notably, no corticosteroids, IVIG, or immunosuppressants were used during the first 90 days of intervention.

### *Clinical Improvements Over 90 Days*

By the end of the first month, parents reported the following changes:

#### *Sleep and Behaviour*

- Child fell asleep independently without prolonged agitation
- Nighttime awakenings reduced
- Rage episodes decreased from 3–5 per day to 1–2 per week

#### *Gastrointestinal Function:*

- Resolution of pain, gas, bloating and constipation
- Daily formed bowel movements without magnesium or laxatives

#### *Histamine and Food Tolerance:*

- Reintroduction of previously reactive foods (e.g., fermented items, strawberries, garlic, onions) without behavioural or dermatologic flares

#### *Cognition and Language:*

- Improved receptive communication and verbal expression
- Increased frustration tolerance and ability to follow multi-step instructions
- Engaged in short back-and-forth conversations by month three

### *Ongoing Supportive Therapies*

Throughout the intervention, the child continued:

- Weekly speech and occupational therapy sessions
- Daily neuroplasticity sensory integration retraining
- Environmental modifications including home mold remediation, HEPA filtration and dust and pollution control
- Continued methylation and mitochondrial repair protocols

### *Parental Observations and Clinical Interpretation*

The child's parents described the progress as "life-altering," observing that he appeared "more present in his body than ever before." They credited camel milk with being the single most impactful intervention, correlating with early improvements in gastrointestinal and emotional regulation.

From a clinical standpoint, camel milk may have facilitated immune modulation through reduced gut permeability, improved microbiota balance and downregulation of inflammatory cytokines. Follow-up labs at 90 days showed:

- TGF-β1: Decreased to 9,200 pg/mL
- MMP-9: Dropped to 670 ng/mL

These trends indicate a significant reduction in systemic inflammation and suggest that camel milk may offer therapeutic value in complex cases of

PANS/PANDAS with overlapping ASD, CIRS and Lyme triggers.

The tables below provide a summary of pre- and post-intervention findings, highlighting the clinical outcomes and changes observed following camel milk treatment in patients with neuroimmune conditions.

**A. Laboratory Biomarkers**

| Biomarker | Pre-Intervention | Post-Intervention | Interpretation |
|---|---|---|---|
| TGF-β1 | 19,500 pg/mL | 9,200 pg/mL | Reduced systemic inflammation |
| MMP-9 | 1,320 ng/mL | 670 ng/mL | Reduced vascular permeability and inflammation |
| CaMKII | 161% of baseline (normal <130%) | Not reassessed | Suggestive of autoimmune basal ganglia activation |
| sIgGA | 2400 ug/g (elevated) | Not reassessed | Gl immune hyperactivation |
| VEGF | 12 pg/mL (low; normal 31-86) | Not reassessed | Impaired capillary perfusion |
| MARCoNS | Positive nasal culture | Not reassessed; clinical improvement observed | Suggestive of biofilm-related colonisation |

**B. Clinical Outcomes**

| Domain | Pre-Intervention | Post-Intervention | Parent/Clinician Observation |
|---|---|---|---|
| Sleep | Agitation, multiple night awakenings | Falls asleep independently; fewer night wakings | Significant improvement |
| Rage Episodes | 3-5 daily | 1-2 per week | Dramatic reduction |
| Gastrointestinal | Bloating, gas, pain, constipation | Resolved; daily formed stools | No longer needs magnesium/ laxatives |
| Food Intolerance | Histamine-rich and reactive foods triggered symptoms | Previously reactive foods reintroduced safely | No adverse reactions |
| Language & Cognition | Regressive speech, poor comprehension | Back-and-forth conversations, better tolerance | Marked improvement |

## Discussion

Paediatric Acute-onset Neuropsychiatric Syndrome (PANS) represents a uniquely challenging clinical entity due to its unpredictable symptom flares, multifactorial triggers and involvement of immune, neurological, gastrointestinal and psychological domains. Conventional approaches—typically centered around antibiotics, steroids, psychotropic medications and behavioural therapies—often fall short of delivering sustained improvements. These modalities may target surface-level symptoms but fail to address the underlying terrain dysfunction, chronic infections, or environmental toxicants that perpetuate immune dysregulation. Paediatric Acute-onset Neuropsychiatric Syndrome (PANS) and Paediatric Autoimmune Neuropsychiatric Disorders Associated with Streptococcal Infections (PANDAS) are clinical entities characterised by the abrupt onset of obsessive-compulsive behaviours or severely restricted food intake, often accompanied by a constellation of neuropsychiatric symptoms such as anxiety, irritability, regression in academic or developmental milestones, urinary frequency and sleep disturbances leading to an autoimmune encephalopathy clinical presentation. The defining feature is a sudden and dramatic symptom onset, often within 24–48 hours, distinguishing these conditions from primary psychiatric or neurodevelopmental disorders (Swedo and Leonard, 2012).

In the presented case, the child had received standard therapies, including occupational and speech therapy, dietary changes and multiple courses of antibiotics, yet continued to suffer from severe neuropsychiatric symptoms and gastrointestinal distress. This is emblematic of many children with PANS/PANDAS, particularly those with co-morbid ASD, Lyme Disease or CIRS, where mono-therapies tend to be insufficient. The syndrome's complexity necessitates a layered, systems-biology approach that can intervene at multiple physiological checkpoints—immune regulation, detoxification, microbial balance and neurological stability.

Integrative care models incorporating nutritional therapeutics, herbal antimicrobials, targeted detoxification strategies and environmental remediation appear more suited for such multifactorial presentations. Camel milk has emerged as one such promising adjunct. Rich in immunoglobulins, lysozyme, lactoferrin and small-chain bioactive peptides, camel milk has demonstrated antibacterial, anti-inflammatory, antioxidant and prebiotic effects in both animal and human studies (Al-Numair and Al-Safi, 2020; Shabo and Yagli, 2005).

The therapeutic potential of camel milk in this population lies in its unique biochemical composition, which includes a blend of immunologically active proteins, peptides and micronutrients capable of exerting systemic effects. The child in the case study showed significant improvements in sleep, gastrointestinal function, histamine tolerance and language—many of which correspond to camel milk's known immunomodulatory and gut-healing actions.

Several bioactive peptides in camel milk, such as lactoferrin, immunoglobulins, lysozymes and alpha-lactalbumin exhibit anti-inflammatory and antimicrobial properties. Lactoferrin, for instance, binds free iron, starving pathogenic bacteria and inhibiting their proliferation while also modulating cytokine production. Lysozymes enhance the innate immune response by degrading bacterial cell walls, especially in Gram-positive organisms, which are frequently implicated in chronic sinusitis and MARCoNS colonisation. These peptides may also play a role in down regulating pro-inflammatory cytokines such as IL-6, TNF-α and IFN-γ—three of the most consistently elevated markers in PANS and other autoimmune neuropsychiatric conditions. The decline in TGF-β1 and MMP-9 seen in the patient's follow-up labs further suggests a reduction in systemic inflammation and vascular permeability, possibly attributable to camel milk's anti-inflammatory load. Beyond immunomodulation, camel milk appears to offer gut-specific benefits by enhancing mucosal immunity and repairing intestinal barrier function. This is critical in PANS and CIRS, where leaky gut contributes to immune hyperactivation through the translocation of endotoxins like LPS into the systemic circulation. Camel milk upregulates tight junction proteins (e.g., claudin, occludin) and stimulates mucosal IgA production, thus helping to restore gut integrity and microbial tolerance. Moreover, camel milk may exert regulatory effects on mast cells, which are often overactivated in children with histamine intolerance, mold sensitivity, or MCAS (mast cell activation syndrome). By providing natural antioxidants (e.g., vitamins C, E, glutathione enzymes), camel milk helps stabilise mast cells, lower ROS burden and reduce neuroinflammation—all of which may have contributed to the improved behavioural and histamine tolerance observed in the case study. Though not yet validated in large-scale trials, anecdotal reports and emerging practitioner feedback suggest that camel milk may support detoxification pathways, possibly by enhancing glutathione activity or binding toxins via lactoferrin. Another unexplored but plausible mechanism is the potential role of camel milk in mycotoxin clearance. Given the child's history of mold exposure and subsequent symptom reduction, this warrants further exploration.

Camel milk contains a rich blend of biologically active compounds, including immunoglobulins, lysozyme, lactoferrin, alpha-lactalbumin and small molecular weight peptides—all of which exhibit strong antimicrobial and immunomodulatory properties as compared to cow milk (Al-Numair and Al-Safi, 2020). Importantly, these components remain largely bioavailable due to the unique nanostructure and absence of allergic casein proteins that commonly trigger reactions in children with food sensitivities. One of camel milk's key advantages lies in its high content of immunoglobulins, especially IgG and IgA, which can aid in mucosal immunity and help neutralise pathogenic antigens in the gastrointestinal tract. These antibodies are smaller and more heat-stable than those in bovine milk, allowing for greater bioavailability and potential penetration of mucosal barriers (Shabo and Yagli, 2005).

Lactoferrin, another critical protein in camel milk, exerts broad-spectrum antimicrobial effects by sequestering iron (thereby inhibiting microbial growth), breaking down bacterial membranes and modulating cytokine expression (Conesa and Garcia, 2010). Additionally, lysozymes in camel milk can degrade the peptidoglycan walls of bacteria, especially Gram-positive organisms, enhancing the body's innate immune response. Notably, camel milk lacks beta-casein A1, the pro-inflammatory variant found in most cow's milk. A1 casein produces beta-casomorphin-7 (BCM-7), a peptide linked to gastrointestinal inflammation, opioid-like behavioural symptoms and immune dysregulation in susceptible children. The absence of A1 casein in camel milk renders it safer and more tolerable for children with autism, ADHD and PANS-like presentations, many of whom suffer from cow's milk intolerance (Cozzi and Ricci, 2020).

Camel milk has demonstrated potent immunomodulatory capabilities in both *in vitro* and in vivo models. Several studies indicate that camel milk can suppress the expression of pro-inflammatory cytokines such as interleukin-6 (IL-6), tumour necrosis factor-alpha (TNF-α) and interferon-gamma (IFN-γ), all of which are known to be elevated in children with PANS and related neuroinflammatory conditions (Salami and Moosavi-Movahedi, 2011). By modulating the Th1/Th2 balance and promoting the development of regulatory T cells (Tregs), camel milk may help dampen excessive immune responses triggered by infections or autoimmunity. Moreover, camel milk appears to enhance intestinal barrier integrity by upregulating tight junction proteins such as claudin and occludin, reducing the leakage of endotoxins like lipopolysaccharide (LPS) into systemic circulation. This action directly supports the repair of leaky gut, a key driver of systemic inflammation and behavioural dysregulation in complex PANS (Fasano, 2012). Another important attribute is camel milk's ability to counteract oxidative stress. Children with PANS/PANDAS and CIRS often show elevated reactive oxygen species (ROS) and impaired antioxidant capacity. Camel milk contains vitamins C and E, glutathione peroxidase and zinc—nutrients that neutralise ROS and promote mitochondrial function in immune cells. In experimental studies, camel milk has been shown to reduce lipid peroxidation and elevate superoxide dismutase (SOD) and catalase activity, thereby restoring redox balance (Korish and Arafah, 2013). Emerging anecdotal evidence and clinical speculation also suggest that camel milk may play a role in biofilm interference and the suppression of difficult-to-eradicate microbial colonies such as MARCoNS (Multiple Antibiotic-Resistant Coagulase-Negative Staphylococci). Though direct studies are limited, the combined action of lactoferrin and lysozyme may disrupt biofilm formation, particularly in the nasopharyngeal and sinus cavities where MARCoNS is often detected. This hypothesis aligns with observed clinical improvements in children with persistent sinusitis and neurological flares following therapeutic usage of structured camel milk protocols.

One of the most promising and yet underexplored features of camel milk is its ability to act as a prebiotic—supporting the growth of beneficial bacteria such as Lactobacillus and Bifidobacteria. By creating a more favorable intestinal environment, camel milk can help correct the dysbiosis commonly seen in PANS and post-infectious neuroinflammation. Camel milk also exerts trophic effects on gut-associated lymphoid tissue (GALT), which houses a substantial portion of the body's immune cells. Through its bioactive peptides and immunoglobulins, camel milk supports the crosstalk between enteric immune cells and gut microbiota, enhancing oral tolerance and reducing hypersensitivity reactions to food and environmental antigens (Yagil and Etzion, 2014). Perhaps most critically, camel milk may assist in restoring the Treg/Th17 balance—a key immune axis disrupted in autoimmune and neuroinflammatory conditions. Th17 cells promote inflammation and tissue damage, while Tregs suppress inappropriate immune responses. An imbalance in this axis has been implicated in both autoimmunity and persistent microbial infections. Camel milk's anti-inflammatory proteins and antioxidant content may help shift the immune response toward regulation rather than activation (Abdel Gader and Alhaider, 2016).

Taken together, camel milk offers a novel, safe and multifaceted intervention for children with complex neuroimmune disorders. Its combined effects on immune modulation, microbiome rebalancing, antioxidant support and gut repair make it a compelling adjunct in integrative protocols for PANS/PANDAS with Lyme and CIRS comorbidity.

### *Limitations of Current Evidence*

While the clinical response in this case is compelling, it is important to acknowledge the limitations in current evidence surrounding camel milk for neuroimmune disorders. To date, no randomised controlled trials (RCTs) have evaluated camel milk in populations specifically diagnosed with PANS, PANDAS, Lyme Disease, or CIRS. Most published studies focus on its impact in autism or diabetes and extrapolation of results to complex immune conditions must be done cautiously. Additionally, the heterogeneity within the PANS/PANDAS population complicates the ability to generalise the findings. Symptom profiles vary widely—from rage and OCD to tics, anorexia and enuresis—depending on the primary triggers (e.g., strep, mold, tick-borne pathogens), genetic predispositions and environmental exposures. A single therapeutic agent is unlikely to offer uniform benefits across such a diverse clinical landscape. Another confounding factor is the individual variability in microbiome composition. Since camel milk may exert prebiotic or microbial-balancing effects, the baseline diversity and dysbiosis level in each child may influence their responsiveness. Children with severe fungal overgrowth or poor commensal resilience might respond differently compared to those with intact or partially functional microbiota. Moreover, the case report included additional interventions such as herbal antimicrobials, binders and environmental remediation, all of which likely contributed to the observed improvements. It is difficult to isolate the effects of camel milk alone in such a complex, integrative protocol.

### *Ethics Approval and Case Documentation*

This case study was conducted under informed parental consent in accordance with the ethical principles of the United States for individual case reports. A full case record sheet was maintained throughout the clinical observation period.

### *Conflict of Interest Statement*

The authors declare no conflict of interest related to the subject matter, materials, or methods used in this study.

## Conclusion

This case study highlights the potential role of camel milk as a therapeutic intervention in a child with PANS/PANDAS, complicated by chronic infections such as Lyme disease and environmental biotoxin exposure consistent with Chronic Inflammatory Response Syndrome (CIRS) and ASD. These overlapping conditions—though often overlooked in mainstream diagnostic frameworks—can represent complex neuroimmune presentations marked by immune dysregulation, gut barrier dysfunction, microbial imbalance and neuroinflammation.

In this case, meaningful symptom resolution was observed following an integrative treatment approach that included camel milk. Improvements were noted in gastrointestinal function, behaviour, emotional regulation and sleep, along with reductions in key inflammatory markers. Camel milk, with its array of bioactive compounds—including immunoglobulins, anti-inflammatory peptides, lactoferrin and prebiotic oligosaccharides—may have contributed to gut barrier restoration, microbial balance and immune modulation.

Although further studies are needed, the clinical outcomes in this case suggest that camel milk, when used as part of a personalised, multisystemic protocol, may offer support for children with immune-mediated neuropsychiatric symptoms. This observation warrants cautious consideration for further investigation.

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# EFFECT OF ALUMINIUM HYDROXIDE AS A CONJUGATE TO FSH FOR USE IN SUPER-STIMULATION OF OVARIAN FOLLICLES IN DROMEDARY CAMEL (*Camelus dromedarius*)

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## ABSTRACT

This study was conducted to develop a simple protocol for super-stimulation of ovarian follicles in dromedary camels using a single subcutaneous injection of commercial FSH product diluted in slow-release diluent, aluminium hydroxide and the feasibility of storing it after dilution at room and refrigeration (4°C) temperatures. In Experiment 1, a total of 50 donors were used, which were divided in 5 groups. The first group was prepared as per our standard protocol with a single injection of 2500 IU eCG and 400 mg FSH (Foltropin-V) in decreasing doses twice daily for 4 days (Control). The second group donors were administered 2500 IU eCG and a single subcutaneous injection of FSH (400 mg) dissolved in 10 mL of aluminium hydroxide. The third group of donors received half the dose of FSH (200 mg) dissolved in aluminium hydroxide in addition to eCG. Groups four and five were administered FSH like group 2 and 3 without eCG. In Experiment 2, FSH diluted in aluminium hydroxide was stored for 14 days at room (Group 2) or refrigeration (Group 3) temperature before administering (200 mg each) subcutaneously to donors as a single injection, in addition to an initial injection of 2000 IU of eCG. Our results show that FSH diluted in slow-release aluminium hydroxide could be used for super stimulation of ovarian follicles in dromedary camels and gives similar results to that of the control group. We have been able to reduce the dose of FSH and its frequency of administration without affecting the quantity of super-stimulation and embryo production. Storing the FSH diluted in Aluminium hydroxide at room or refrigerator temperatures maintains its efficacy up to 14 days and produces similar results to the control group for super-stimulation and embryo production.

**Key words:** Aluminium hydroxide, dromedary camel, FSH, superovulation

Dromedary camels are fundamental livestock resource providing milk, meat, and draught power in dry regions of Asia and Africa in addition to camel racing, which is a highly sought after and well-organised multimillion-dollar sport in Middle East. Also, camel festivals, including camel beauty contests, and a massive demand for camel milk, leading to establishment of highly mechanised camel dairy farms in different countries, has led to an interest in camel breeding and research, including using multiple ovulation and embryo transfer (MOET) (Wani, 2021). Different ovarian superovulation protocols that are used in other ruminant species have been applied in camels as well, which include use of eCG, (Tinson *et al,* 2001), FSH of porcine (McKinnon *et al,* 1994) or sheep origin (Anouassi and Tibary, 2013), or combination of eCG and FSH (Skidmore and Billah, 2005). The super-stimulation treatment usually starts on Day 4 after induced ovulation of a dominant follicle by an exogenous administration of GnRH (Nikjou *et al,* 2008) or even after two days following injection of GnRH (Ararooti *et al,* 2017; 2018).

The eCG is a complicated glycoprotein having long half-life (40 h) with both LH and FSH activity that represents an advantage because a single dose will induce super stimulation of the ovaries. However, the eCG injection leads to development of 2 variable follicle generations, premature follicle luteinisation, failure of ovulation and big anovulatory follicle development (Anouassi and Tibary, 2013). In contrast to eCG, the half-life of pituitary derived FSH is 5 h and needs frequent injections for inducing super-Stimulation. Two times per day injection of FSH has been found to be more efficient than one time each day, making it labour intensive. In addition, it causes stress to the animal, resulting in a reduced super stimulation

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response (Vyas *et al,* 2004). After subcutaneous injection of follitropin-V diluted in aluminium hydroxide, the concentration of FSH increases gradually in the blood and reaches its peak at 8-12 hours and is still detectable after 96 hours (Kimura, 2016). Keeping in view the above facts that either FSH or eCG or a combination of both has its own problems, the present study was designed to develop a simple protocol for super-stimulation of ovarian follicles in dromedary camels, using a single subcutaneous injection of commercial FSH diluted in a drawback problems slow release diluent aluminium hydroxide.

## Materials and Methods

All procedures performed were reviewed and approved by Animal Ethic Committee, in accordance with the regulations of the Ministry of Climate Change and Environment, the government of United Arab Emirates (Permit Number 550353).

### *Animals*

This study was conducted from October 2021 to March 2023. All experiments were performed on the animals maintained at reproductive biotechnology centre Dubai, UAE. Only camels with healthy reproductive tract as examined by ultrasonography with good body condition score (BCC) were selected. Each animal was provided mixed dried hay, water and lick blocks of mineralised salt *ad lib*. In addition, they were provided with 2 kilograms of formulated camel feed every day. Twenty bulls (9 to 15 years in age), with normal fertility were used for natural breeding.

### *Pre-treatment procedures*

All donors were subjected to a protocol for the follicular synchronisation. Briefly, they were injected with GnRH ((100µg, FERTILIN, VETEQUINOL, France) on day-22 and day-12 and intramuscular injections of PGF2α (500µg, BIOESRRUVET VETEQUINO, France) on the day-15 and day-5. A dominant follicle (diameter of 11-17 mm) was expected to be present on either of the ovaries on day 0. All the animals were scanned on day 0 to detect the position and size of dominant follicle (DF) and were treated with GnRH to induce ovulation and synchronise emergence of new follicular wave (Fig 1, A). All donors were examined after 48 hrs to verify the ovulation and only ovulated animal was used in this study for super stimulation.

### *Experimental design*

Experiment 1 was carried out to develop a simple, cost and labour affective protocol for super stimulation of ovarian follicles in dromedary camels. The donor camels (n = 50) aged 8-16 years were used in this experiment. They were randomly divided into five groups with 10 animals in each group. Group 1 of animals received 2500 IU eCG and 400 mg FSH (Folltropin-V) dissolved in saline (20 ml), two times a day intramuscularly (i.m.) for four days in decreasing dose (traditional regimen). Group 2 received 2500 IU eCG and a single injection of 400 mg FSH (Folltropin V), S/C, dissolved in 10 ml aluminium hydroxide (Imject alum, Thermofisher scientific). Group 3 received 2500 eCG and a single injection of FSH 200 mg dissolved in Aluminium hydroxide s/c. Groups 4 and 5 received only 400 and 200 mg FSH diluted in 10 ml inject as a single injection subcutaneously (s/c) without any eCG, respectively.

Experiment 2 was aimed to study the effect of storing diluted FSH in aluminium hydroxide on its efficacy. Thirty donors were divided into 3 groups of 10 animals each. Group 1 was injected with FSH 400 mg in traditional regimen, similar to that of experiment 1 to act as control. Group 2 and 3 received a reduced dose of FSH 200 mg diluted in aluminium hydroxide stored at room and refrigeration temperature for 14 days as s/c injections, respectively. All animals in all the 3 groups also received 2500 IU eCG at the day of starting treatment.

### *Embryo collection and grading*

All donors were scanned to record the number of follicles before mating and number of ovulations 48 h after mating (Fig 1, B). Collection of embryos was performed 8 days after mating in all experiments. The donors were secured in stand-up position in a suitable place and sedated by intravenous injection of 60 mg xylazine. Faeces were removed from rectum and the perineum was cleaned with mild disinfectant. Then the two-way Foley catheter with stylet was guided through the vagina with a sterile hand, then manually the cervix was opened and the catheter was entered. Then the catheter was entered into the internal os of the cervix and the catheter cuff was inflated with 20 to 30 mL of air. Both horns were flushed same time by trans-cervical uterine lavage repeatedly. A total of 500-1000 mL of the flushing medium was used for flushing of every animal. The collected media was filtrated using EmCon filter until 20 to 30 mL of medium remained which was poured into sterile Petri dish and examined under stereomicroscope for embryos and unfertilised ova. Embryos were graded from I-IV depending on the size, macroscopic morphology and stage of development (Manjunatha *et al*, 2019). All transferable embryos (Fig 1, C) were transferred to left uterine horn of synchronised recipients.

### *Statistical analysis*

One-way analysis of variance (ANOVA) was used to compare groups. First, the normal distribution of data and homoscedasticity (ANOVA assumptions) were checked using Shapiro-Wilk and Levene's tests, respectively. Then, multiple comparisons between groups was conducted by Bonferroni post-hoc test. Data are represented in the form of bar graphs as (mean ± SD). Groups without shared letters indicate a significant difference between them (p-value < 0.05). All statistical analysis and graphs were performed using RStudiov1.3.1093 (RStudio Team, 2020) and R programming language v4.0.3 (R Core Team, 2020).

## Results

The response of ovaries and embryo production in experiment 1 were summarised in Table 1. The proportion of mature follicles and the ovulations were similar (P> 0.05) in donors of first three treatment groups (Groups 2, 3 and 4), however, the donors in Group 5, which received a single s/c injection of 200 mg of FSH dissolved in aluminium hydroxide developed lower number of follicles and also had lower ovulated follicles when compared to other three groups and the control group (P< 0.05). The number of transferrable embryos was similar in group 2 and 4 (8.2±3.88; 8.3±2.44) and were not different (P > 0.05) from the control group (8.1±2.47), however, donors in group 3 and 5 produced lower number (P < 0.05) of transferrable embryos (4.9±2.47; 5.5±2.92) when compared to the other two treatment groups and control group.

We did not find any difference in the super-ovulatory response and embryo production among donors treated with FSH stored at room temperature (Group 2) or refrigeration (Group 3) when compared to control group as summarised in Table 2.

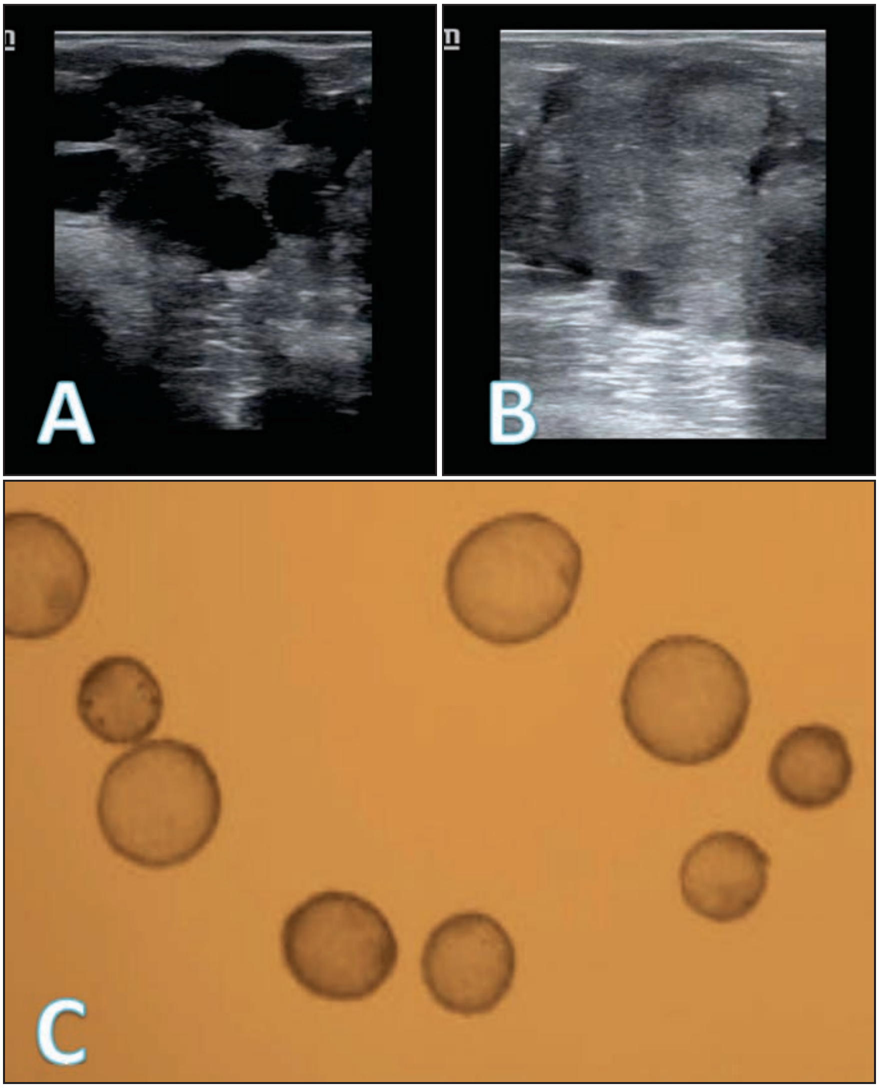


**Fig 1.** Representative pictures of A, multiple follicles as observed on the ovary after super-stimulation; B, Ovulated follicles on the same ovary as observed after breeding and C, Embryos flushed on D8 after breeding for transfer to synchronised recipients.

## Discussion

To the best of our knowledge, this is the first study to investigate the effect of aluminium hydroxide, as a diluent for FSH, for its slow release after s/c administration, to induce ovarian super stimulation in dromedary camels. Regardless of the type of gonadotrophin product, its preparation or the protocols used for ovarian super-stimulation in camels, considerable variation have been reported in the super-ovulatory response in this species, which still remains one of the biggest challenges in application of embryo technology at farm level in dromedary camele (Anouassi and Tibary, 2013). Our results are encouraging and

**Table 1.** The effect of aluminium hydroxide, as a diluent to FSH, on ovarian super-stimulation and embryos production in dromedary camel (*Camelus dromedarius*) (Data expressed as mean ± SD).

| Parameter | G1 | G2 | G3 | G4 | G5 |
|---|---|---|---|---|---|
| Ovulatory follicles | 21.1 ± 4.9[a] | 22.7± 6.4[a] | 19.1 ± 6.6[a] | 17.7±3.7[a] | 11.8±4.0[b] |
| Ovulations | 19.5±4.6[a] | 21.2±5.5[a] | 17.6±5.7[a] | 16±3.3[a] | 10.7±3.2[b] |
| Un-ovulated follicles | 1.6±0.9[a] | 1.5±1.08[a] | 1.5±1.1[a] | 1.7±1.3[a] | 1.1±1.1[a] |
| Total embryos | 9.5±2.7[a] | 9.5±4.1[a] | 7.7±3.8[a] | 10.1±2.7[a] | 6.3±3.2[a] |
| Transferable embryos | 8.1±2.4[a] | 8.2±3.8[a] | 4.9±2.4[b] | 8.3±2.4[a] | 5.5±2.9[ab] |
| Non- transferable embryos | 1.3±0.8[ab] | 1.3±1.1[ab] | 2.8±1.4[a] | 1.3±1.1[ab] | 1.2±1.3[b] |
| Unfertilised ova | 1.5±1.4[a] | 2.1±3.6[a] | 0.7±1.5[a] | 0.3±0.6[a] | 0.5±1.5[a] |

Rows with different superscripts ae significantly different (P<0.05).

G1: Group 1, donors which received a traditional super stimulation protocol of 2500 IU of eCG and 400 mg of FSH is divided doses for 4 days

G2: Group 2, donors which received 2500 IU eCG as a single injection and 400 mg FSH (Folltropin V), dissolved in 10 ml of aluminium hydroxide (Imject alum) as a single subcutaneous injection.

G3: Group 3, donors received 2500 IU eCG as a single injection and 200 mg FSH (Folltropin V), dissolved in 10 ml of aluminium hydroxide (Imject alum) as a single subcutaneous injection.

G4: Group 4 donors received only as a single injection of 400 mg FSH (Folltropin V), dissolved in 10 ml of aluminium hydroxide (Imject alum) as a single subcutaneous injection.

G5: Group 5 donors received a single injection of 200 mg FSH (Folltropin V), dissolved in 10 ml of aluminium hydroxide (Imject alum) as a single subcutaneous injection.

**Table 2.** The effect of storing FSH, diluted in aluminium hydroxide, at room or refrigeration temperature on ovarian super-stimulation and embryos production in dromedary camel (*Camelus dromedarius*) (Data expressed as mean ± SD).

| Parameter | G1 | G2 | G3 |
|---|---|---|---|
| Ovulatory follicles | 21.1 ± 4.9[a] | 18.8± 3.4[a] | 19.5± 3.9[a] |
| Ovulations | 19.5±4.6[a] | 17.2± 3.7[a] | 17.5± 3.9[a] |
| Unovulated follicles | 1.6±0.9[a] | 1.2± 0.8[a] | 2± 1.3[a] |
| Total embryos | 9.5±2.7[a] | 7.8±3.6[a] | 7.5±2.9[a] |
| Transferable embryos | 8.1 ± 2.4[a] | 7 ± 3.9[a] | 7.1 ± 3.1[a] |
| Non- transferable embryos | 1.4 ± 0.9[a] | 0.8 ± 1.0[b] | 0.4 ± 1.0[b] |
| Unfertilised ova | 1.5±1.4[a] | 0.7± 1.5[b] | 1.3± 1.2[a] |

Rows with different superscripts ae significantly different (P<0.05).

G1: Group 1, donors which received a traditional super stimulation protocol of 2500 IU of eCG and 400 mg of FSH is divided doses for 4 days

G2: Group 2, donors received a reduced dose of FSH (200 mg) diluted in aluminium hydroxide and stored at room temperature for 14 days as a single subcutaneous injections.

G3: Group 3, donors received a reduced dose of FSH 200 mg diluted in aluminium hydroxide stored at refrigeration temperature for 14 days as a single subcutaneous injections.

demonstrate that a single subcutaneous injection of FSH diluted in slow-release diluent aluminium hydroxide gives similar results to that of our traditional protocol (control group) where FSH is injected two times per day in a decreasing dose for five days (P > 0.05). Using FSH diluted in saline in a traditional protocol injected twices per day for five days sometimes leads to muscle induration at the site of injection and increases the possibility of errors especially when the treated animals show irritable temperament. Also, it increases the stress on the animals because of handling that sometimes decreases the ovulatory response (Skidmore and Billah, 2005). The cost of hormones and manpower needed to administer these hormones in donors for super stimulatory treatments are major obstacles in widespread use of embryo transfer technology in camels. Some studies have reported that using a combination of FSH and eCG may lead to development of more than one generation of follicles, pre-mature luteinisation of follicle, decreased ovarian response or ovulation failure and increased cost of treatment (Anouassi and Tibary, 2013). The results of the present study showed that a dose of FSH reduced to half of traditional dose administered as a single s/c injection avoids all the above-mentioned side effects without jeopardising the number of follicles and embryos obtained per flush. Results of the present study are similar to those reported by Manjunatha *et al* (2019), who used slow release preparation of FSH in divided doses for super stimulation in camels and found no difference in the ovarian response and ovulations when compared with traditional protocol.

The findings of this study are in agreement with earlier studies where it was found that using a combination of folltropin and equine chorionic gonadotropin increases ovulatory response and embryo production (Cooper *et al*, 1992; Nowshari and Ali, 2005). However, results are not consistent with these Ararooti *et al* (2018) who mentioned that FSH alone gives better results than combination of eCG and FSH.

In the current study, there were no significant (P > 0.05) difference in the super ovulatory response and embryo production among groups of donors receiving FSH diluted in aluminium hydroxide and stored at room temperature or 2-8°C for 14 days when compared to control group, who received FSH in traditional protocol. Further studies with a large sample size are planned to validate our findings.

## Conclusion

This study investigated the effect of aluminium hydroxide, as a diluent for FSH, for its slow release after its administration subcutaneously, for inducing ovarian super stimulation in dromedary camels. We have developed a simple and cost effective protocol for ovarian super-stimulation in camels. The protocol uses a single subcutaneous injection of 200 mg of FSH diluted in aluminium hydroxide which produces similar results of the traditional protocol (400 mg of FSH in divided doses for 4 days, two times a day) for super ovulation in dromedary camels. The approach is easy to implement, cost and labour-effective, user-friendly and importantly, reduces stress on donor animals.

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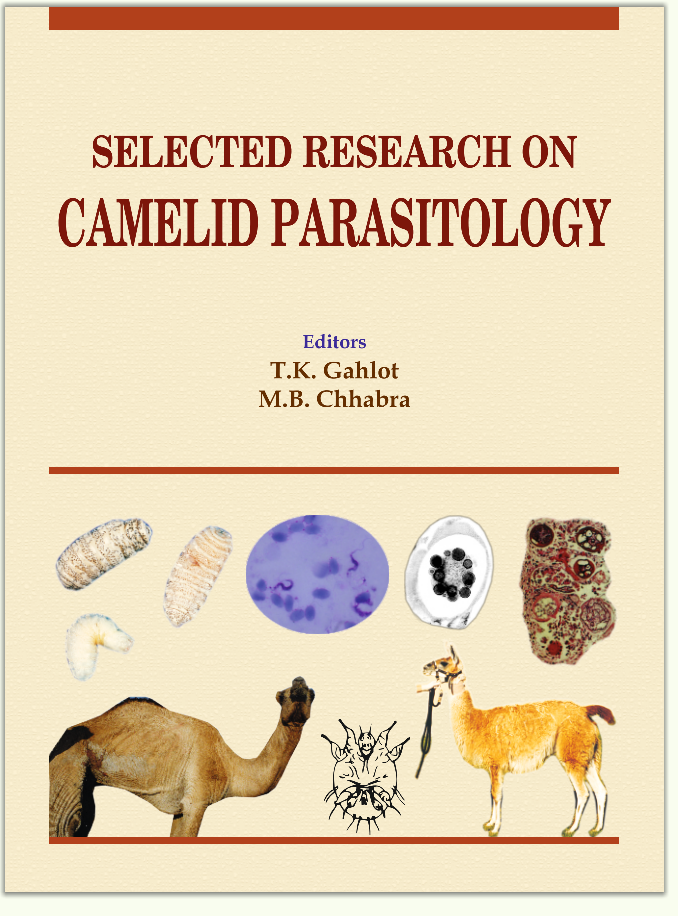


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# DECODING THE CROSS-CULTURAL SYMBOLISM OF “HAN DYNASTY NANYANG PICTURE STONE BACTRIAN CAMEL” IN THE DESIGN OF CHINESE CHARACTERS-IMPLICATIONS FOR CHINESE POSTER DESIGN RESEARCH

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## ABSTRACT

The present study explores the cross-cultural symbolism of the bactrian camel image in Chinese character design through a multidisciplinary approach that combines historical artefacts with artificial intelligence to generate design experiments. Utilising camel images from the Nanyang pictorial stones of the Han Dynasty (202 BC-220 AD) as the iconology baseline, Pannowsky’s three-layer iconolgy analysis was employed to decode the camel’s biomorphology and cultural encoding mechanism. As demonstrated in the relevant literature, there is a correlation between the biological characteristics of the camel, such as the S-shaped curve of the neck and the Z-shaped joints of the legs, and the strokes of Chinese characters (e.g., ” (”, “驼”). This correlation has been verified through AI fusion experiments, which have shown a similarity of 92% in the alignment of the neck curves. The proposed “structural metaphor” methodology reveals the possibility of integrating biomorphic forms of non-hieroglyphic Chinese characters (e.g., ”驼” camel) in accordance with the principles of calligraphic aesthetics, which reflects the transformation of the camel from a practical means of transport along the Silk Road to a cultural symbol. The study provides an innovative approach to negative space dynamics and biomechanical simulation in Chinese poster design, and advocates interdisciplinary collaboration to promote the narrative dimension and cultural carrying capacity of Chinese character design.

**Key words:** Chinese character design, chinese poster design, cross-cultural symbolism, han dynasty nanyang picture stone, image of the Bactrian camel, structural metaphor

### Bactrian camels in cultural and historical contexts

Bactrian camels are predominantly located in Central Asia (e.g., China, Mongolia, Kazakhstan, etc.) (Faye, 2020), and their size is adapted to arid environments, while their robust leg structure renders them suitable for long-distance trekking across deserts and grasslands (Meng and Xie, 1999). The utilisation of camels in the context of long-distance transportation and trade can be traced back to the Han Dynasty ($7^{th}$ century), coinciding with the inception of the Silk Road. The strategic deployment of these animals was attributed to their capacity to navigate the arduous terrain and variable climate that characterised the Central Asian geography, thereby facilitating continuous trade operations. This assertion is corroborated by Ge (2018), who asserts that camels were instrumental in supporting large-scale trade operations. The Tang Dynasty’s inclusive and open governance strategy resulted in increased demand for trade, thereby highlighting the distinctiveness of camels in terms of their trade and transport requirements. The prevalence and diversity of camel motifs in Han and Tang cultural artefacts (Guo, 2017) serve as a testament to the profound admiration and respect for the camel spirit. The camel is not merely a mere symbol; it is a representation of the intrepid pioneering spirit that characterised the Silk Road.

Bactrian camels symbolise endurance in Mongolian and Central Asian cultures, and their dairy products and furs were once important commodities in the Silk Road trade (Nagy *et al,* 2022). Bactrian camels racing and panniering in the Gobi region still retain traces of historical trade routes (Otgonsuren *et al,* 2022). Since the $7^{th}$ century BC, the Steppe Silk Road has played an important role in China’s foreign economic and cultural exchanges as one of the main transport routes through the Han and Tang dynasties

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to the Yuan and Ming dynasties. For example, the "travelling Mongolian merchants" (Liu, 2015) owned 1, 500 commercial camels under the trade name "Dashengkui 大盛魁". The camel, through the economic flow of the road, the mainland's agricultural products, industrial products and livestock products from the Mongolian steppe began a frequent two-way flow. This is the economic significance of camels.

The centrality of the camel in the Silk Road economy, in the absence of any Chinese character representation, constitutes a cultural paradox.

Despite the pivotal function of the camel in the Silk Road Economic Belt, there is an absence of "etymological evolution" and "word formation and expansion". A comparison of the character for horse, which is also a transport animal, reveals that horse was already a pictograph in the earliest Chinese character system, the oracle bone inscriptions (Fig 1), and was used independently and in a stable form at an early stage, with a clear evolutionary lineage, and a clear simplification process from pictographs to seal scripts and regular scripts. The character camel "骆驼" did not function as an independent element in either oracle bone or jinwen; rather, it emerged in bronze inscriptions during the Shang and Zhou Dynasties as a synonym for "橐驼" (e.g., "Yi Zhou Shu" records that "橐驼" were imported from the Western Regions). It was not until the Western Jin Dynasty, when Zhang Hua inscribed it in the "Museum Records", that its name became "骆驼" , which was later simplified to "驼" (tuó).

With regard to the processes of word formation and expansion, the morpheme "驼" (camel) is analysed as consisting of "马" (horse) on the left for meaning (an animal of the family Equidae) and "它" (it) on the right for sound. The lexicon is characterised by a paucity of extension words, the majority of which pertain to camel itself (e.g."hump", "camel's bell"). There is an absence of rich derivation. In contrast, the radical "马" has been shown to possess a robust capacity for character formation, contributing to the development of a considerable number of Chinese characters (e.g. "骑", "驾", "驰"). As a radical, it has been used to form a large number of Chinese characters (e.g. "ride", "drive", "run fast", etc.), and has given rise to a rich vocabulary of words such as "horse", "horse power", "horse armour", etc., which encompasses both physical objects and abstract concepts as well as metaphors.

While the bactrian camel is indispensable in trade, it is semiotically marginal, reflecting differences in cultural application. The camel's historical role has been predominantly in the form of tribute, particularly in the Western Regions, or as livestock for northern ethnic minorities. Consequently, its application within the Central Plains culture is limited, with the majority of extant documentary records focusing on transport, tribute, or entertainment (e.g., the Xiongnu's "camel fights"). In contrast, the horse, as the first of the five animals, is used throughout farming, military, transport and other fields, with far-reaching cultural symbols, such as "马到成功 beginner's luck", "汗马功劳 sweat and horses" and other symbolism. This discrepancy may be attributed to the non-native status of the camel and the agricultural bias of the Chinese characters, which prioritised native animals such as the horse and the ox through the creation of hieroglyphic characters. Conversely, the acoustic character "camel" signifies a belated linguistic adaptation that, in contrast to other language families, lacks the visual immediacy of camel imagery embodied in the term "camel" in Arab or Persian cultures. The aforementioned factors give rise to a paradox: the economic importance of the camel, given its minimal representation in the Chinese character system. The paradox lies in the significant discrepancy between the camel's actual economic role and its representation in the writing system, forming the paradox of "high practical value and low symbolic representation". The historical and cultural roots of the paradox are rooted in non-native animals and the lag of writing. In consideration of the pertinent biological facts, the Bactrian camel (*Camelus ferus*) is believed to have originated in the desert regions of Central Asia. It was subsequently introduced to the Central Plains during the Han Dynasty (206 BCE – 220 CE) through the Silk Road, thus classifying it as an exotic species in China. In the context of the evolution of writing, the hieroglyphic system of Chinese characters, otherwise referred to as oracle bone script, emerged during the Shang and Zhou periods (1600BC-256BC). This development preceded the substantial dissemination of calligraphy.

**Research status**

In recent years, the study of Bactrian camel images in Han Dynasty art has gradually become a focal point for interdisciplinary research, with its cultural symbols and visual expressions providing unique semiotic resources for Chinese character design. As demonstrated in the relevant archaeological and art historical studies, the depiction of camels in Han Dynasty tomb art has been shown to carry multiple cultural connotations, thus establishing them as "exotic symbols" of the Silk Road (Wang, 2020). Ge (2018) further suggests that camels in the Han Dynasty were childish in shape and scarce in number, contrasting with the delicacy of images of celestial horses in the same period, implying that Bactrian camels had not yet become mainstream cultural symbols. A thorough iconographic analysis reveals a duality in Han Dynasty Bactrian camel art. Firstly, there is a realistic tendency, as demonstrated by Qi (2004). Secondly, and by contrast, there is a surreal reconstruction of the creature's features, as seen in the work of Guo (2017). However, extant studies have predominantly concentrated on the archaeological interpretation of the images themselves, and have yet to systematically explore the potential correlation between their morphological structure and the configuration of Chinese characters. In the domain of Chinese character design, there has been a preponderance of deconstruction and recreation of hieroglyphs (e.g., digital reconstruction of oracle bones, Chen, 2017). However, there remains a paucity of cross-cultural translation methodology for non-hieroglyphic characters. In recent years, AI generative design has attempted to explore the possibility of symbol transliteration through morphological mapping (Nourian *et al,* 2023), but there is a lack of validation of the structural suitability of Chinese characters' squares. The intersection study of Chinese characters and camels has not yet been incorporated into the theoretical framework of design science. Existing results have a split between the practical functions of camels and symbolic representations, and have not established a three-dimensional correlation framework between archaeological objects, written records, and artistic images, especially lacking interdisciplinary research on the camel's character-symbol system.

The present paper provides a case study, utilising Han Dynasty Nanyang Picture Stone as a prototype, employing the "驼"（camel) Han Jian glyph as a method, and "synthetic design" through an artificial intelligence platform, thereby providing a scientific analysis case to verify the correlation and applicability between Chinese characters and images.

The study hypothesises that the morphological analogy between Bactrian camel images and Chinese character structures in the Han Dynasty can provide a cross-cultural semiotic translation method for non-phantom Chinese character designs. The objective of this study was threefold: firstly, to interpret Bactrian camel images in Han Dynasty artefacts, to verify the feasibility of mapping biological features to Chinese character structures in AI-generated designs and to propose 'structural metaphors' inspirations applicable to Chinese poster design.

## Materials and Methods

It is imperative that a clear and explicit link is established between the artefacts and the design of experiments.

The following section will provide a concise overview of the history of the subject. The utilisation of Han Dynasty brick carvings (Fig 1) as a benchmark for camel Iconology is founded upon scientific and specific criteria.

The authority of historical time points. The Han Dynasty (202 BC-220 AD) represented a pivotal era in the history of the Silk Road, during which it was formally established and institutionalised. Following Zhang Qian's expedition to the Western Regions, the camel was documented as a formally recognised means of desert transportation in the "史记Shiji" and "the 汉书Book of Han", as well as other official historical records. As the earliest extant visual material from the Han Dynasty, the camel image of the brick carving documents is an archeological artefact of particular interest. The primitive nature of the image is notable insofar as it serves as a direct historical document, reflecting the level of knowledge of the camel at that time. To illustrate this point, one need only consider the evidence recorded during the Northwest Han Dynasty. It is clear that official positions such as "牧橐令丞"（Mùtuó Commandant and Assistant Commandant. 颜师古注. "牧橐，言牧养橐驼也。" 又引如淳曰："橐泉厩在橐泉宫下。"） formed a chain of "text-object" mutual evidence with the images of brick carvings.

The standardisation of modelling features is of paramount importance. The depiction of the camel in the brick carvings of the Han Dynasty has established a persistent visual archetype: the proportion of the hump is deemed harmonious, the limbs are considered elongated, and the neck is delineated in the shape of "S". This paradigm was subsequently adopted by subsequent camel figurines from the Northern and Southern Dynasties to the Tang Dynasty (a notable example being the Tang three-colour camel). Archaeological discoveries have demonstrated that Han dynasty camel images exhibit a high degree of compatibility with the skeletal measurements of extant Bactrian camels (shoulder height/length ratio of approximately 1:1.8), whereas artistic representations of camels from the Northern and Southern Dynasties onwards exhibit a gradual escalation in exaggeration (Wurihan, 2022). As posited by images from the Han Dynasty are thus deemed to possess a biomorphological benchmark value.

The primitiveness of cultural symbols. The Han Dynasty is widely regarded as a pivotal era in the transition of the camel from a utilitarian instrument to a cultural emblem. In the Han portraits, the Hu people are depicted as riding camels to the east, bearing goods from the western regions. This trade between the east and west played a pivotal role in the emergence of camel imagery in Han portraits. As demonstrated in the Book of Han - Luntai Edict, camels are depicted as transporting goods, thereby validating the depiction of "bactrian camel - hu man" in Han portraits. In comparison to the earlier sporadic records of the Warring States period or the later romanticised representations of the Tang dynasty, the Han images are devoid of the mythical imagery found in the Shanhaijing. However, they do not exceed the bounds of decorum, maintaining a balance between utility and symbolism. The camel assumed a cultural significance that was particularly pronounced during the Han Dynasty, as evidenced by its depiction in various media, including portraiture on stone and brick. These representations offer a more visual and realistic depiction of the camel than is found in historical records.

The concentration of archaeological materials. According to the findings of the scientific research conducted by the scholar Xin Lixiang, which have gained widespread acceptanceamong scholars specialising in Han portraiture, approximately 80-120 bactrian camel-themed portrait bricks/stones have been unearthed in China during the Han Dynasty. These artefacts are primarily concentrated in the nodes of the Silk Road, including the provinces of Shaanxi, Henan, and Gansu, thus forming a relatively extensive sample group. In contrast, only sporadic bone carvings and distorted forms (e.g., hooves depicted in the shape of horses) are found in pre-Qin period bactriancamel images. Consequently, the Han Dynasty material is deemed to meet the data requirements for image typology studies.

Therefore, utilising the Han Dynasty brick carvings as the experimental benchmark can circumvent the ambiguity of the early images and the exaggerated deformation of the later art, which serves as the "time anchor point" in the research of iconography. This material selection not only fulfils the staging requirements of archaeological typology, but also corresponds to the historical stage of the Silk Road's development. The scientific nature of this approach is rooted in the establishment of a triple verification system comprising "documentary records, physical remains and biological features".

The following discourse will deconstruct the semantic-visual divide by examining the etymology of the word "camel" (Fig 2). In Chinese, the word "骆驼" is a noun composed of the characters "骆luò" and "驼tuó". In the experiment, the single character "驼" was employed as the character object. The etymology of the Chinese character "驼" is a compound of the characters "马" and "它", which is the standard linguistic abbreviation of "骆驼". This is the standard linguistic abbreviation for "camel". In contrast to the pictographic animal characters that characterised earlier Chinese characters (e.g., "horse"), the construction of "camel" reflects a borrowed cultural concept. Lexical evidence confirms its semantic exclusivity:pre-modern texts use "camel" exclusively for camels, while modern compounds (e.g., "camel team") retain this specificity. From a cross-linguistic perspective, the absence of visual similarity between "驼" and camel is in stark contrast to the Arabic "جمل", a term that encompasses admiration for pastoralists, with camels being profoundly culturally internalised. It is evident that the disparity between the semantic and visual dimensions inherent in non-hieroglyphic Chinese characters gives rise to the ensuing outcomes:

1. The process of abstraction in relation to cultural heritage is of particular relevance in the context of Chinese characters. As these characters evolve, they gradually move away from figurative shapes and become more symbolic in nature. This evolution necessitates a systematic teaching approach within the educational system, aimed at facilitating the comprehension of their connotations. This approach is essential to prevent intuitive associations with these characters, which could hinder a comprehensive and nuanced understanding of their symbolic significance.

2. The pluralism of artistic expression is characterised by the separation of visual and semantic elements, thereby creating a creative space for the arts of calligraphy and seal carving. These disciplines are able to express meaning through formal beauty.

3. The following factors act as barriers to cross-cultural communication:The non-hieroglyphic nature of Chinese characters makes it difficult to convey core meanings directly through visuals. This requires additional understanding of the cultural logic behind the symbols for non-native speakers of Chinese. This dichotomy has had a profound impact on the unique

cultural depth of Chinese characters and has given rise to significant communication and cognitive challenges.

The following essay will present a photographic analysis of bactrian camel motifs in Nanyang Han pictographs, adopting a perspective similar to that of Panofsky.

The Nanyang Picture Stones constitute a significant element within the corpus of stone carving art of the Han Dynasty (206 BC to 220 AD) and provide substantial visual evidence of cultural exchange along the Silk Road. Among the rich array of motifs employed, while bactrian camel motifs are less prevalent than horse motifs, they offer a distinctive perspective on cross-cultural exchange. The Bactrian camel and Elephant Picture (Fig 1), unearthed in Nanyang, Henan Province, is the earliest Han portrait to depict bactrian camel in China. The bactrian camel and elephant are depicted in a left-facing posture, with the bactrian camel positioned on the left. The camel in question is identified as a Bactrian camel, distinguished by its elongated and slender limbs. The neck and back of the bactrian came are depicted in the shape of a "U", reminiscent of the ancient Chinese dragon. This study employs Erwin Panofsky's three-layered iconology approach (Panofsky, 1955) to analyse a representative image of a camel from a Nanyang pictorial stone, with a focus on the biomorphological adjustments of the camel, the textural rendering, and the semiotic potential of the synthesis of Chinese character design.

**Fig 1.** "Bactrian camel and Elephant picture" Han Dynasty Nanyang Picture Stone.

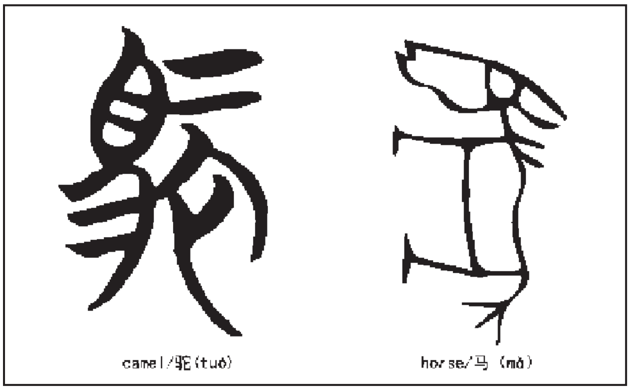


**Fig 2.** Comparison of the etymology of the Chinese characters "驼" (camel) and "马 (horse)".

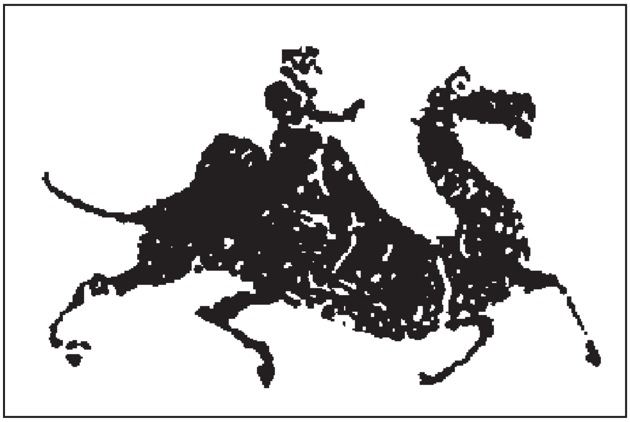

**Fig 3.** "Bactrian camel-rider motifs" in the Nanyang Picture Stones of the Han Dynasty.

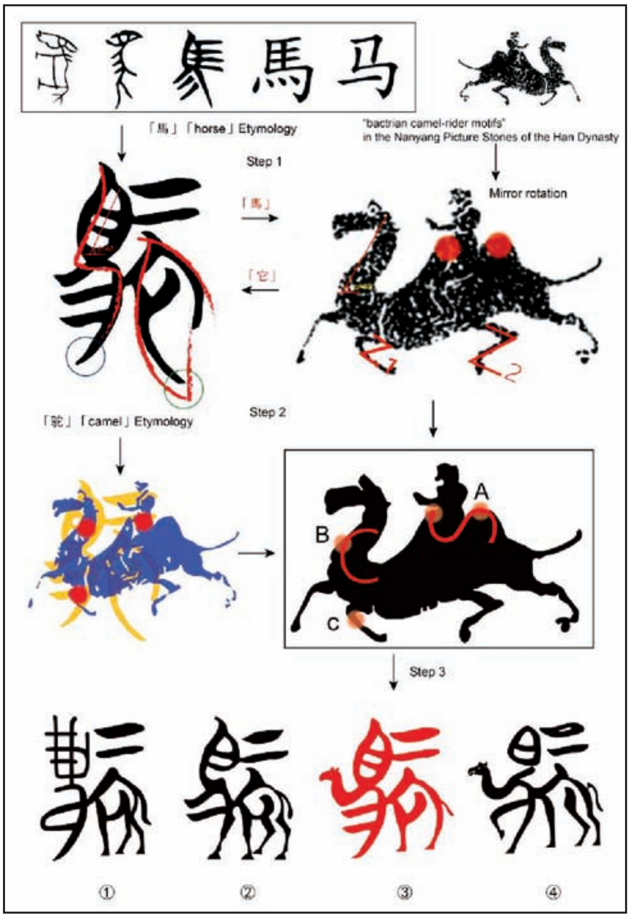


**Fig 4.** Artificial Intelligence generated "驼" + camel fusion experiment.

## Pre-iconographical Descriptions:formal analyses

The pictorial stone in question depicts a rider on a camel, with flat line carvings that are typical of the Eastern Han workshops (Xue, 2021). The image provides a stylised representation of key biomorphological features of the camel. While anatomically precise, the image features an exaggerated hump structure, reminiscent of the camel's bactrian hump, rendered as a triangular silhouette. This stylisation is likely intended to emphasise the functional role of the hump in fat storage. This is in marked contrast to the depiction of the dromedary camel in Persian art, which reflects the Han artists' awareness of the physiological characteristics of the bactrian camel. As observed in the leg proportions, the legs are of a considerable length and exhibit a slight curvature, thus capturing the camel's distinctive toe-walking posture. The broad feet have been modified to an oval shape, suggesting that they are adapted for desert travel. The abstract texture of the portrait is suggestive: parallel incised lines evoke the camel's hide, or alternatively, the texture of thick fur or harness straps.

**Iconographical Analysis: encoding culture**

The depiction of the camel in the image is consistent with Han dynasty trade imagery, where the duality of the rider and camel composition can be observed. For instance, the rider's frontal pose and raised arm (possibly holding the reins) is analogous to that of the leader of a Silk Road caravan (Wang and Zhu, 2024). This composition was standardised in Han art (Xie Changyi, 1989) and symbolises foreign trade. Furthermore, the absence of any load on the camel should not be overlooked; in contrast to the ceramic camels of the Tang dynasty, which were laden with goods, this relief does not depict any such load, most likely in order to emphasise the symbolic role of the camel as a cultural bridge (Guo, 2017).

**Iconological Interpretation: A Bridge between Semiotics and Chinese characters**

The stylised form of the camel is analogous to the structure of the Chinese character, suggesting an underlying connection between the two. The curve of the camel's hump bears resemblance to the "捺nà" stroke of the clerical script, thus suggesting a design metaphor for the character "驼" (骆驼). The concept of leg spacing can be considered as a form of character spacing adjustment. The distribution of the legs of the camel is analogous to the balanced negative space in the Seal Script composition, a principle that is also applicable to the layout of ideographs. This provides the basis for synthesising the visual nature of the camel with the textual nature of the Chinese characters. The Nanyang carvings serve to distil the camel into a symbol that is culturally legible through the medium of selective biomorphic emphasis (hump, legs) and textural abbreviations. These adaptations, grounded in the ideology of "drawing on analogies" in Chinese character formation, furnish a design vocabulary for incorporating camel features into Chinese characters, particularly in terms of structural metaphors (e.g., the hump as a radical modifier). It is recommended that future research endeavours involve the testing of these principles with AI-generated glyphs.

**Design Methods**

Structural Metaphors: The present study explores thelimitations of artificial intelligence-assisted experimentation and aesthetic coherence in the process of combining Han Dynasty brick camel silhouettes with Chinese character strokes.

Data source: The Chinese character '駝' in the 楚系汉简 'camel' in the Nanyang portrait bricks are examined.（Simplified Chinese character record of the Chu system (from the Han dynasty onwards).

Output: The design rules for biological symbols have been finalised. These rules stipulate that the hump should be represented by a stroke curvature, the legs by a stroke staccato, and the weight-bearing gesture by negative space between characters.

**Step 1: Key Line Extraction and Stroke Modulation**

Based on the evolution of the Chinese character "驼":the curved strokes of the "马" radical (e.g."㇉" apostrophe) and the curved structure of the "它" radical (e.g. "乚" vertical hook) are extracted and combined to form a non-hieroglyphic but dynamic character skeleton. Han Dynasty brick camel: the image was inverted according to the order of writing Chinese characters from left to right (visual observation habit); the double hump contour line (S-shaped continuous crest), the leg joint folding line (Z-shaped rigid line) and the C-shaped curve of the neck stretching forward were extracted by vector tracing.

Methods: Adoption of the stroke-biometric mapping method to transform the S-shaped outline of the hump into the '宝盖头'name of 'roof' radical in Chinese characters (Kangxi radical 40) in Chinese characters (Kangxi radical 40)' part of the "它" part on the right side of the character '驼'(宀), and at the same time, the Z1-shaped articulation line of the camel's leg is strengthened into the staccato lifting of the last stroke of the "马". At the same time, the Z(1)-shaped joint line of the camel's leg is strengthened to be the staccato lift of the last stroke of the "马" radical (blue circle), and the Z2-shaped joint line of the camel's leg is strengthened to be the curvature of the vertical hook of the last stroke of the "它" radical (green circle). This step should follow the principle of "form breaks and meaning is continuous" to maintain the consistency of biological features and calligraphic strokes.

**Step 2: Structural Stacking and Node Fusion**

***Operational Processes:***

Spatial alignment: superimpose the side-view profile of the camel in Fig 2 on the "camel" skeleton in Fig 1 and mark the three key fusion nodes (see process diagram Fig 4):

Node A (apex of the hump → turning point of the "它" part) Node B (curve of the neck → start of the apostrophe at the beginning of the "马" part) Node C (joints of the legs → transverse hook at the beginning of the "马" part)

***Parametric adjustment:***

At node A, a Bessel curve is fitted so that the curvature of the upper end of the "它" part is the same as the slope of the hump (radius of curvature R ≥ 5 mm);

Node B is constrained by a tangent line to ensure that the dynamic sense of the neck reaching forward is parallel to the direction of the skimming build-up;

Node C is rigidly deformed, transforming the support of the camel's legs into a heavy closing stroke at the end of the "马" radical.

**Step 3: Iterative AI Validation and Failure Analysis**

Positive case (AI Raw No. ③): fusion of typeface penmanship and camel dynamics

"The wave limb strokes in Han Dynasty inscriptions are essentially a record of movement trajectories, and are isomorphic with dynamic line drawings of animals. " (Qiu, 2015), based on this, the strokes in the case have coherence, the arc next to the "ear" at the top of the Chinese character simulates the C-shaped curve of the camel's neck stretching forward, and the turns of the stroke retain the sense of waves and turns of the Han Dynasty clerical script of the limbs of the limbs of the Chinese character, which matches with the dynamic rhythms of the camel's marching (data validation Table 1:92% similarity). The "匕" part of the lower part of the character "它", referring to the "Z" shape of the camel's leg, is transformed into a biological feature through AI parameterisation. The staccato strokes of the brush simulate the muscle tension of the camel when it is carrying weight (forming the muscle lines of the animal's legs), and the "white space" between the strokes also contrasts with the Chinese characters' flying white, reinforcing the visual metaphor of "camel trekking". The integration of cultural symbols across time and space is reflected in the fact that the AI training has enabled the character shapes to retain the Regular Script legalism while incorporating the collective imagery of a camel trekking with a heavy load.

**Table 1.** Data validation.

| Data Validation | | | |
|---|---|---|---|
| **Features** | **Camel biological** | **Chinese character conversion parameters** | **Similarity** |
| Neck curve angle | Angle $\alpha$ = 60° | "Ear" turning angle $\beta$ = 65° | 92% |

**Negative case (localised problem):**

The AI, due to over-reliance on StyleGAN (Karras *et al*, 2019), resulted in an anatomical error:the camel hump biometrics with the right part of the character "驼" with appeared incorrectly (the Bactrian camel imagery was visualised as a dromedary camel). Secondly, the broken strokes:the ambivalence of the camel hair texture and the regular script strokes is manifested by the failure of the original camel hair texture to show up in the Chinese character strokes, which are in regular script.

## Result

The capacity for camel biometric data to be mapped to Chinese character structure is a subject that has been the focus of interdisciplinary research. This research has verified the operationalisation of morphological isomorphism, which can be defined as the visual resonance of biological curves and calligraphic strokes. The visual fusion of camel and Chinese characters is realised through the cross-species empathy of dynamic line drawing. The camel's neck depicted in the Han Dynasty portrait bricks assumes an S-shaped curve, and its biological characteristics are analogous to the wave-like potential of the "press" brush in Chinese calligraphy. This observation serves to corroborate the theory proposed by Qiu Zhenzhong (Qiu, 2011) that "the essence of calligraphy brush potential is the solidification of the trajectory of movement". The experimental diagrams that were generated demonstrate that when the camel art form is matched with the Chinese character "驼", it is necessary to consider "biosimilarity (the degree of correspondence between the camel form and the Chinese character's strokes)", "legality of the brushstroke (whether the design conforms to the aesthetic norms of calligraphy)", and "legality of the brushstroke (whether the design conforms to the aesthetic norms of calligraphy)". In order to achieve visual harmony, it is necessary to consider two factors:firstly, whether the design complies with the aesthetic norms of calligraphy; and secondly, whether the symbol can be correctly interpreted by the target audience. The negative space between the camel's legs and torso becomes a visual metaphor, which is transformed into the relationship between the "horse" radical and the "it" radical in the Chinese character "驼", echoing Deng Shiru's theory of "counting white as black" (Deng, 2024). This relationship is then transformed into the relationship between the "horse" radical and the "it" radical in the character "camel", also echoing Deng Shiru's theory. This transformation reveals the topological equivalence of natural forms and abstract symbols.

Symbolic Translation: The Ascension from Utility to Cultural Imagery. The present study aims to verify the hypothesis that Chinese characters are aestheticised as functional symbols. The Han dynasty brick camel's load-carrying rope motif (utility function) evolved into a brushstroke texture in the AI-generated design (Fig 4), which is consistent with Gombrich's assertion that "ornamentation derives from utility" in his theory of the "sense of order" (Gombrich, 1979). The trade attributes of camel – such as the "camel caravan" and "camel bell" – are integrated into the Chinese character design through etymological symbiosis, forming a dual symbolic carrier of material and spiritual.

The reconstruction of cross-cultural symbols within a localised context. In contrast to the Arabic camel symbol (e. g., the pictorial nature of "جمل"), the Chinese character "驼" (camel) achieves "strangeness" of expression through the morpho-sound structure ("马"horse + "它"it), which confirms the theory of Zhao Yiheng's "markedness" (Zhao, 2023) - non-physicality rather strengthens the cultural identity. This finding serves to corroborate Zhao Yiheng's "markedness" theory (Zhao, 2023), which posits that the non-hieroglyphic nature of the Chinese character" 駝"serves to reinforce the cultural identity.

Methodological innovation:Structural Metaphor. The proposal is to utilise the biological characteristics of the camel, such as hump support and leg tension, to direct the allocation of stroke space in Chinese characters, as opposed to the conventional method of directly copying the shape. For instance, the tension of the arc delineating the right part of the character "驼" (camel) simulates the elastic deformation of the hump when it is loaded with weight, thus transcending the limitations of traditional pictograms found in the "Xu Shen's six-script". This paradigm shift transforms the camel from a mere "means of transport" to a "medium of cultural memory" through the three-layered mapping of biology-symbol-emotion "ecological symbol chain" (Ingold, 2011). This finding serves to corroborate the hypothesis.

## Discussion

The structural rhythms contained in the biological features of the Bactrian camel form a metaphorical correlation with the strokes of the Chinese characters, exploring the deep resonance between biomechanics and the aesthetics of writing, so that the Chinese characters can acquire a new visual vitality while retaining their cultural genes. The design strategy of transforming biological features into cultural metaphors sublimates the natural attributes of living creatures into the visual language of culture, so that Chinese poster design goes beyond the mere transmission of information and becomes a medium for carrying cultural memories. Whilst traditional pictographs depend on visual similarity for the purpose of conveying information, the design of non-physical Chinese characters requires the use of structural metaphors for the purpose of conveying meaning. Utilising the cross-cultural symbol of the Bactrian camel as a point of departure, this study elucidates the profound interconnection between design methodology and cultural investigation. The study demonstrates that the concept of 'morphological symbiosis' facilitates the interaction between biological features and the textual skeleton, thereby enabling the design of Chinese characters to achieve dual resonance:visual tension and cultural connotation. 'Structural metaphor' serves to transform biological attributes into cultural symbols, thereby constructing a multi-layered visual narrative system. The 'structural metaphor' is a theoretical framework that transforms biological properties into cultural symbols and constructs a multi-level visual narrative system.

This study proposes the establishment of an interdisciplinary collaborative platform with the objective of continuously expanding the possibilities of Chinese character design. This will be achieved through the two-way verification of design experiments and academic research. The ultimate aim is to rebuild the deep connection between human and nature, culture and symbols in the context of globalisation. This contemporary response to the spirit of the Silk Road constitutes a revolutionary contribution to the paradigm of visual culture research.

## Conflict of interest

Author declares no conflict of interest

## Subsidise

Not have

## Ethical Statement and Data Sources

The images of Nanyang Han portrait bricks used in this study are derived from published academic publications (cited), and their use strictly follows academic fair use.

The AI generation experiment relies on JiMeng AI Design Platform v3.2, which is based on the Stable Diffusion open source model branch.

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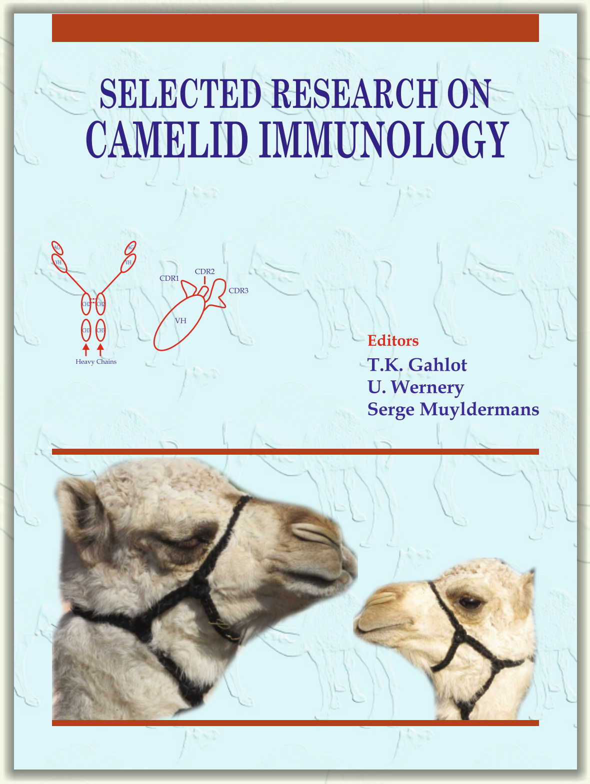
# SELECTED RESEARCH ON CAMELID IMMUNOLOGY

**(Hard Bound, 392 pages, few figs coloured, Edition 2016)**

In 1989 a group of biologists led by Raymond Hamers at the Free University Brussels investigated the immune system of dromedaries. This discovery was published in Nature in 1993. Based on their structure, these peculiar camelid antibodies have been named Heavy Chain Antibodies (HCAb), as they are composed of heavy chains only and are devoid of light chains. Sera of camelids contain both conventional heterotetrameric antibodies and unique functional heavy (H)-chain antibodies (HCAbs). The smaller size and monomeric single domain nature make these antibodies easier to transform into bacterial cells for bulk production, making them ideal for research purposes. Camelid scientists world over were greatly fascinated by a new field of research called "Camelid Immunology". Significant research has been done on camelid immunology in recent decade. In order to benefit future camelid immunology researchers, this book was planned in the series of "Selected Topics" by Camel Publishing House with a title- "Selected Research on Camelid Immunology" edited by T.K. Gahlot, U. Wernery and Serge Muyldermans. This book is a unique compilation of research papers based on "Camelid Immunology" and published in Journal of Camel Practice and Research between 1994-2015. Research on this subject was done in 93 laboratories or institutions of 30 countries involving about 248 scientists. In terms of number of published papers in JCPR on the immunology the following countries remain in order of merit (in parenthesis), i.e. Iran (1), India and UAE (2), China and Saudi Arabia (3), Sudan (4), Kenya and Belgium (5), USA (6), Germany (7) and so on. The book contains 11 sections and is spread in 384 pages. The diverse sections are named as overview of camel immune system; determinates of innate immunity, cells, organs and tissues of immune system; antibodies; immunomodulation; histocompatibility; seroprevalence, diagnosis and immunity against bacteria, viruses, parasites and combination of other infections; application of camel immunoglobulins and applications of immune mechanisms in physiological processes. The camelid immunology has to go a long way in its future research, therefore, this reference book may prove quite useful for those interested in this subject. Book can be seen on www.camelsandcamelids.com.

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# BACTRIAN CAMEL WHEY PROTEIN POWDER ALLEVIATES ACUTE HEAT STRESS-INDUCED KIDNEY INJURY AND APOPTOSIS IN RATS

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## ABSTRACT

This study was aimed to evaluate the protective effects of Bactrian camel whey protein (CWP) powder on acute heat stress (HS)-induced kidney injury and apoptosis in rats and to compare its efficacy with bovine whey protein (BWP). An acute heat stress rat model was constructed by randomly dividing SD rats into seven groups: control group, HS model group, CWP treatment group (low dose: 100 mg/kg, medium dose: 200 mg/kg and high dose: 400 mg/kg), BWP group (400 mg/kg) and N-acetylcysteine (NAC) positive control group. The key assessment parameters included core body temperature (Tc), serum urea nitrogen (BUN) and creatinine (S-cr) levels, histopathological changes in the kidneys, immunohistochemistry of NGAL expression and apoptosis assay using TUNEL assay. Exposure of rats to a temperature of 40°C ± 0.5°C and relative humidity of 60% ± 5% for 3 h induced heat stress and caused kidney injury and apoptosis, with the most severe damage occurring at 9 h of rewarming. Histopathological examination revealed glomerular congestion, inflammatory infiltrate and renal apoptosis.CWP treatment significantly reduced kidney injury markers and apoptosis rates, with the high dose (400 mg/kg) showing effect comparable to or superior to NAC and BWP. Immunohistochemical analysis showed that CWP effectively inhibited NGAL expression and promoted renal repair. CWP significantly mitigated acute HS-induced kidney injury in rats through its antioxidant and anti-apoptotic effects. Its efficacy exceeded that of BWP, highlighting its potential as a natural protective agent.

**Key words:** Acute heat stress, apoptosis, camel whey protein, kidney injury

In recent years, global warming has emerged as a critical issue that cannot be overlooked. As temperatures rise, heat stress, resulting from the exposure of organisms to high temperatures and humidity, has posed a significant threat to animal welfare. This has become a major impediment to livestock reproduction and productivity. Kidney damage is one of the common complications associated with heat stress (HS), often accompanied by apoptosis (Wang, 2019; Jing, 2024). Heat stress can be categorised into acute and chronic types, depending on the duration and frequency of exposure to elevated temperatures. Acute heat stress is typically characterised by rapid, short-term exposure to high temperatures, lasting for several hours. In contrast, chronic heat stress involves prolonged exposure over weeks or months, or exposure to cyclical temperature patterns (Yin, 2021). Both forms of heat stress have the potential to undermine the sustainability of the livestock industry.

Heat stress induces oxidative stress, which leads to the activation of highly reactive molecules such as reactive oxygen species (ROS) and reactive nitrogen species (RNS) in the organism (Yang *et al,* 2010). This results in an imbalance between the oxidative and antioxidant systems, contributing to tissue damage and metabolic disorders. Apoptosis plays a crucial role in tissue damage and oxidative stress can trigger apoptosis through multiple pathways, including the mitochondrial pathway, death receptor pathway and endoplasmic reticulum (ER) stress pathway (Destaw *et al,* 2023). Enhancing the body's antioxidant capacity is an effective strategy to mitigate tissue damage. However, long-term use of certain antioxidant drugs may lead to toxic side effects and antioxidants such as vitamin C are prone to oxidation, which complicates their prolonged use. Therefore, the identification of a natural antioxidant that can be used long-term without side effects, while maintaining efficacy and cost-effectiveness, is the central objective of this study.

Recent research on camel milk has confirmed its potential in significantly alleviating kidney damage in diabetic rats and inhibiting apoptosis (Adelakun

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*et al,* 2024). Camel whey protein contains bioactive peptides that scavenge free radicals, helping to prevent diseases associated with oxidative stress. Among these, lactoferrin is identified as the primary antioxidant component in camel whey protein, with its total antioxidant capacity comparable to that of vitamin C, making it a promising natural antioxidant (Zhang *et al,* 2005). Consequently, this study employed camel whey protein as an intervention in a rat model of acute heat stress, administering it to assess its effects on kidney injury and apoptosis induced by acute heat stress.

## Materials and Methods

### *Main reagents and instruments*

4% paraformaldehyde universal tissue fixative (Servicebio-G1101-500mL); Haematoxylin and Eosin (H&E) high-definition constant dyeing kit (Servicebio-G1076); Urease method detection kit for urea nitrogen (Nanjing Built Institute of Biological Engineering -C013-2-1); Creatinine sarcosine oxidase method detection kit (Nanjing Built Institute of Biological Engineering -C011-2-1); high-speed freezing centrifuge (Sigma, Germany); Artificial climate box (Jiangsu Jintan Liangyou Experimental Instrument Factory, China); Multifunctional Enzyme Labeler (Bio-Tex, USA, ELX800); EDTA(pH8.0) (Biofroxx-1340GR); Vitamin C (VC)/Ascorbic Acid (ASA) Assay Kit (Nanjing Built Institute of Biological Engineering -A009-1-1); NAC Antioxidant (Biyun Tian-S0077)

### *Ethics Statement and Animal Welfare*

The study was conducted using six-week-old Specific Pathogen Free (SPF) healthy SD rats, with equal representation of males and females, each weighing 220 ± 20 g. The rats were randomly housed in standard cages, provided with free access to food and water and kept in a controlled environment with a temperature of 25 ± 2°C and humidity of 50 ± 5%. A 12-hour light-dark cycle was maintained and the animals were allowed a 10-day acclimatisation period. The experiment was approved by the Scientific Research and Ethics Committee of Inner Mongolia Agricultural University (GB/T 35892-2018).

### *Collection and Preparation of Camel Whey Protein*

Fresh camel milk was aseptically collected from 20 healthy Bactrian camels in Alxa. The milk was then pooled in equal proportions, followed by centrifugation to remove the fat. The resulting skim milk was pasteurised and purified through acid precipitation of casein and ammonium sulfate. The protein fraction was dialysed overnight at 4°C using dialysis bags with a molecular weight cut-off of 3500. The dialysed camel whey was subsequently freeze-dried using a lyophiliser and stored at -20°C (Hao, 2020; Du, 2022).

### *Construction of Acute Heat Stress Model*

To investigate the effects of different rewarming durations on kidney injury in SD rats after heat stress (HS), 36 SD rats (18 male and 18 female) were randomly assigned to either the control group or the HS model group, which included subgroups with rewarming times of 0 h, 3 h, 6 h, 9 h and 12 h (n=6). After a 10-day acclimatisation period, the rats were exposed to HS by placing them in an artificial climatic chamber maintained at 40°C±0.5°C and 60%±5% relative humidity for 3 hours (Zhang, 2022; Geng *et al,* 2015). Following heat stress, the rats were transferred to a standard rearing environment to undergo rewarming. Rectal temperatures were recorded at 3-hour intervals and at each time point (0 h, 3 h, 6 h, 9 h and 12 h), rats were anaesthetised to collect blood for serum separation and to harvest kidneys for histological examination. The kidney tissues were fixed in 4% paraformaldehyde for H&E staining to evaluate renal damage associated with HS.

### *Assessment of Nephrotoxicity Markers (BUN, S-Cr)*

Serum samples were centrifuged at 3000 rpm for 10 minutes and analysed according to the manufacturer's instructions. The absorbance of serum creatinine (S-Cr) was measured at 546 nm and blood urea nitrogen (BUN) was measured at 640 nm.

### *Histopathological Analysis of Kidney Tissues*

Kidney tissue blocks were fixed in 4% paraformaldehyde overnight at room temperature. After fixation, the tissues were processed, embedded in paraffin and sectioned into 4 μm slices using a microtome. The sections were dewaxed, rehydrated, stained with haematoxylin and eosin (H&E) and mounted with neutral gum. Histological images were captured using a standard light microscope.

### *Experimental Design*

Six-week-old rats were acclimatised in the laboratory for 1 week and then randomly assigned to one of seven groups:

Control Group: Received saline via gavage at a dose of 1 mL/day for 10 days.

Model Group: Received saline via gavage at a dose of 1 mL/day for 10 days, followed by acute heat stress (temperature: 40 ± 0.5°C; humidity: 60 ± 5%; duration: 3 h).

CWP Groups: Divided into low, medium and high dose groups, receiving CWP at doses of 100, 200 and 400 mg/kg per day, respectively, for 10 days. Acute heat stress was then induced.

Bovine whey protein (BWP) Group: Received BWP at a dose of 400 mg/kg per day for 10 days, followed by acute heat stress.

NAC Positive Control Group: Received N acetylcysteine (NAC) at a dose of 100 mg/kg per day via intraperitoneal injection for 10 days, followed by acute heat stress.

Following 3 h of heat stress, the rats were returned to a room temperature environment for recovery. After 9 h of rewarming, they were anaesthetised and blood samples were collected from the heart. Kidney tissue was then harvested: a portion was fixed in 4% paraformaldehyde for pathological section analysis, while the remaining tissue was stored at −80°C for subsequent experiments.

### *Immunohistochemistry of Renal NGAL*

Kidney tissue sections underwent antigen retrieval using citric acid buffer (pH 6.0) and were incubated in 3% BSA at room temperature for 30 minutes. The sections were then incubated overnight at 4°C with a primary antibody against NGAL (1:100) in a humidified chamber. The following day, the sections were incubated with a horseradish peroxidase (HRP)-conjugated goat anti-rabbit secondary antibody (1:200) for 50 minutes at room temperature. Colour development was achieved using diaminobenzidine (DAB), after which the sections were mounted with a sealing gel. Results were visualised and interpreted under a light microscope.

### *TUNEL Detection of Apoptosis in Kidney Cells*

Kidney tissue sections underwent proteinase K treatment for antigen retrieval and cell nuclei were counterstained with DAPI. The sections were incubated in the dark at room temperature for 10 min, then mounted with an anti-fade mounting medium. Fluorescence microscopy was employed to visualise the sections and images were captured. DAPI was excited with a UV light (330–380 nm) and emitted a blue light (420 nm), while CY3 was excited with a green light (510–561 nm) and emitted a red light (590 nm).

### *Statistical Analysis*

Experimental data were analysed using SPSS 26.0 software, employing independent sample t-tests and one-way ANOVA. Data are expressed as mean ± SEM. The data visualisation was accomplished using GraphPad Prism 10.

## Result

### *Acute Heat Stress Model*

Core body temperature (Tc) is a critical index for assessing the onset of heat stress (HS) in animal organisms. Rectal Tc was measured immediately after exposure to HS and at 3 h, 6 h, 9 h and 12 h during the rewarming phase. The results showed that HS significantly elevated the rectal temperature in rats, with the mean body temperature rising from 37.81°C at baseline to 41.31°C after statistical analysis. As shown in Fig 1, the Tc at the end of HS was significantly higher compared to the control group. However, with the progression of rewarming, Tc gradually returned to baseline values and no longer differed significantly from the control group after 12 hours of rewarming.

When comparing the Tc values at different rewarming times to those at 0 h, no significant difference was found between the 0 h and 3 h groups, with an average hourly decrease of only 0.11°C. However, there was a significant difference in Tc between the 0 h and 6 h groups, with the 0 h group showing significantly lower Tc values after 9 h of rewarming. The Tc values of the 0 h group remained significantly higher than those of the control group throughout the experiment.

These findings indicate that exposure to a temperature of 40°C ± 0.5°C and a relative humidity of 60% ± 5% for 3 hours is sufficient to induce HS in rats, as evidenced by the significantly elevated Tc values.

### *Detection of Kidney Injury Indices in Rats Following Acute Heat Stress*

As illustrated in Fig 2, panel A shows the changes in blood urea nitrogen (BUN) concentration in rats. At 0 hours following the cessation of heat stress (HS), BUN levels remained relatively stable and did not differ significantly from the control group. However, after 3 hours of recovery, BUN concentration began to rise, with a highly significant increase compared to the control group. By 12 hours of rewarming, BUN levels had returned to baseline values, similar to those observed in the control group.

Panel B depicts the changes in serum creatinine (S-cr) concentration following HS. At 0 hours post-HS, there was no significant change in S-cr levels.

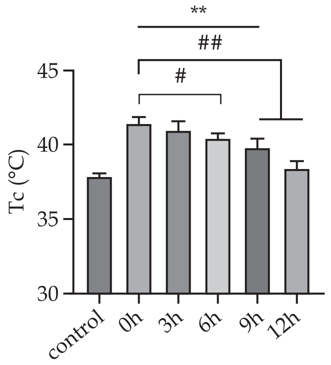


**Fig 1.** Effect of HS on Tc in rats. After HS, the temperature (Tc) of rectal nucleus was detected by electronic thermometer for animals. Data are expressed as mean ± SEM, "*" indicates a significant difference compared to the control group ($p < 0.05$) and "**" indicates a highly significant difference compared to the control group ($p < 0.01$);and "#" indicates a significant difference compared to the 0h group ($p < 0.05$); and "##" indicates a highly significant difference compared with the 0h group ($p < 0.01$).

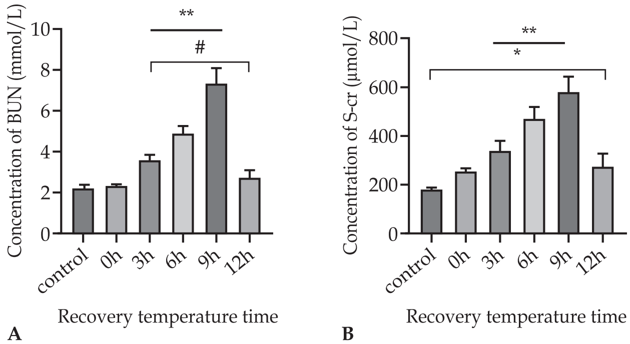


**Fig 2.** Effect of HS on BUN and S-cr, indicators of kidney injury in rats. A: Serum urea nitrogen (BUN) concentration in rats; B: Serum creatinine (S-cr) concentration in rats. The horizontal coordinates in the graphs indicate different rewarming times after HS. Data are expressed as mean ± SEM, "*" indicates a significant difference compared to the control group ($p < 0.05$) and "**" indicates a highly significant difference compared to the control group ($p < 0.01$);and "#" indicates a significant difference between the two groups ($p < 0.05$)

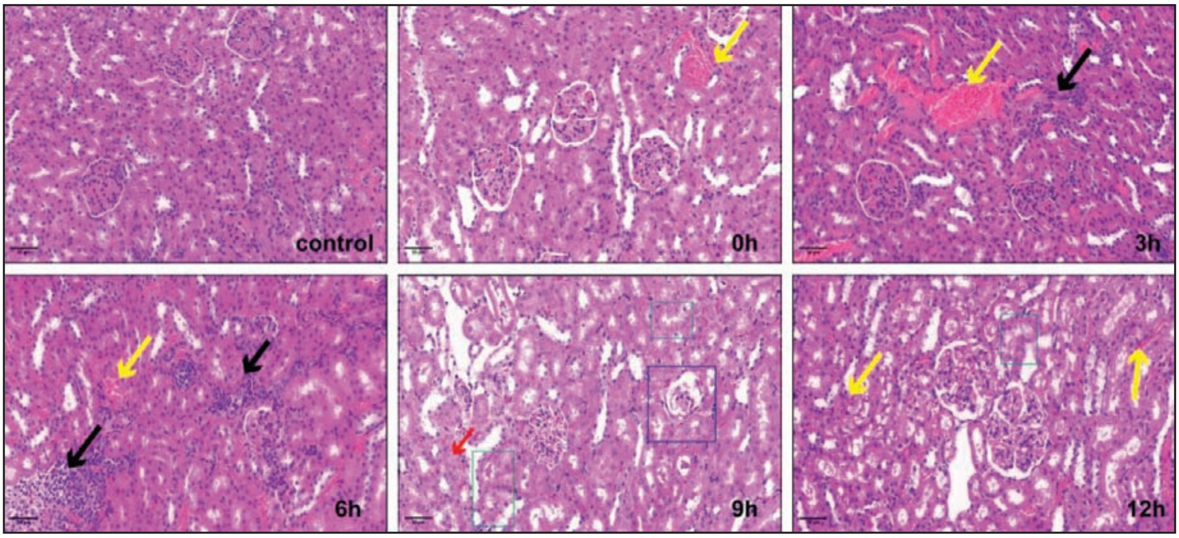


**Fig 3.** Histopathological changes in rat kidney at different rewarming times after HS (H&E, 200×, n=6). Rat kidneys were collected for HE staining and the intercepted field of view was 200× magnification image. The Fig is labelled with different experimental groups, i.e. different rewarming times after HS. The yellow arrows indicate renal haemorrhage, the black arrowheads point to inflammatory cell infiltration, the red arrowheads show cell nucleus fragmentation and lysis, the green box range shows granular degeneration and blistering degeneration and the blue box area shows glomerular thylakoid cells damage and loss of internal brush border structure.

After 3 hours of rewarming, S-cr concentrations rose rapidly, reaching their peak at 9 hours. The difference between the 3-hour and 9-hour time points was highly significant when compared to the control group. At 12 hours of rewarming, S-cr concentrations decreased significantly but remained notably higher than those in the control group.

The comparison of kidney injury indices further confirmed the significant increase in these biomarkers after HS, supporting the successful establishment of the acute heat stress rat model.

### *Histopathological Changes in Kidney Tissue of Rats After Acute Heat Stress*

The histopathological alterations in the kidney tissues of rats following acute heat stress (HS) are shown in Fig 3 In the control group, which was not subjected to HS, the glomerular and tubular structures of the kidneys were intact, with cells arranged neatly and exhibiting normal cellular morphology. In contrast, at 0 hours post-HS, the glomerular capillaries were dilated and congested, accompanied by interstitial capillary dilation. Several

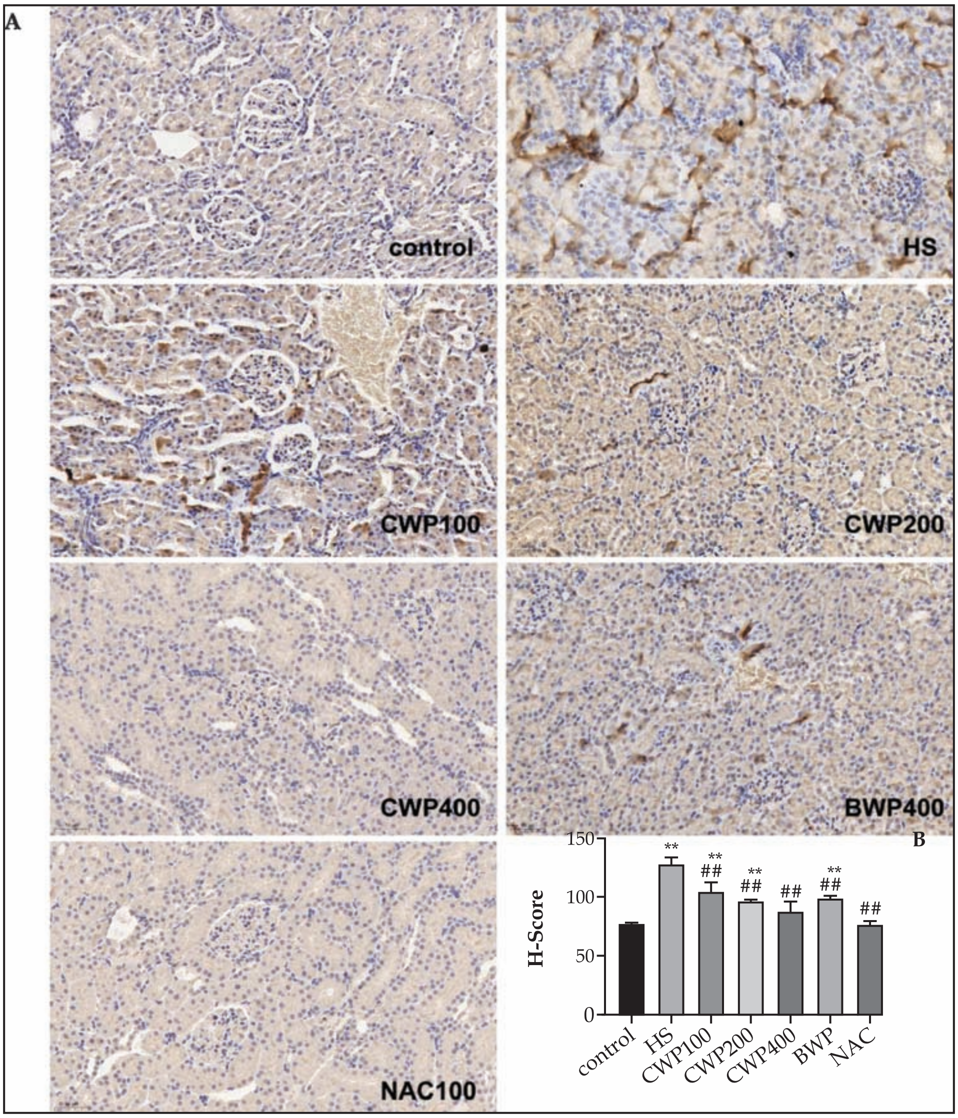


**Fig 4. A:** Immunohistochemical assay of CWP on kidney injury in acute heat stress rats (IHC, NGAL, 200×, n=6). **B:** Immunohistochemical scores. Immunohistochemical positivity scores were calculated after intelligent analysis according to Aipathwell software. Data were expressed as mean ± SEM values, "*" indicates significant difference compared to control group (P<0.05); "**" indicates highly significant difference compared to control group (P<0.01); "#" indicates a significant difference compared with the HS group (P<0.05) and "##" indicates a highly significant difference compared with the HS group (P<0.01).

areas showed distinct haemorrhagic lesions (indicated by yellow arrows).

At 3 hours of rewarming, interstitial haemorrhagic areas significantly increased, with a minor infiltration of inflammatory cells (black arrows). By 6 hours of rewarming, interstitial haemorrhages persisted, along with a substantial infiltration of inflammatory cells. At 9 hours of rewarming, structural damage to cellular tissues became evident. Notably, the renal tubular epithelial cells (highlighted by red arrows) exhibited nuclear fragmentation, lysis and granular as well as vacuolar degeneration. Urinary tubular patterns were also observed in the lumen of the renal tubules (green box) and severe damage to the glomerular capillary walls and associated cells led to cavity formation (blue box). At 12 hours of rewarming, haemorrhages remained in certain areas and vacuolar degeneration persisted in some regions.

These findings demonstrate that tissue damage did not occur immediately following HS but progressively manifested during the rewarming process. The results also confirm that exposure to a temperature of 40°C ± 0.5°C and relative humidity of 60% ± 5% for 3 hours induces kidney injury in rats, thereby establishing a successful model of acute heat stress-induced kidney injury.

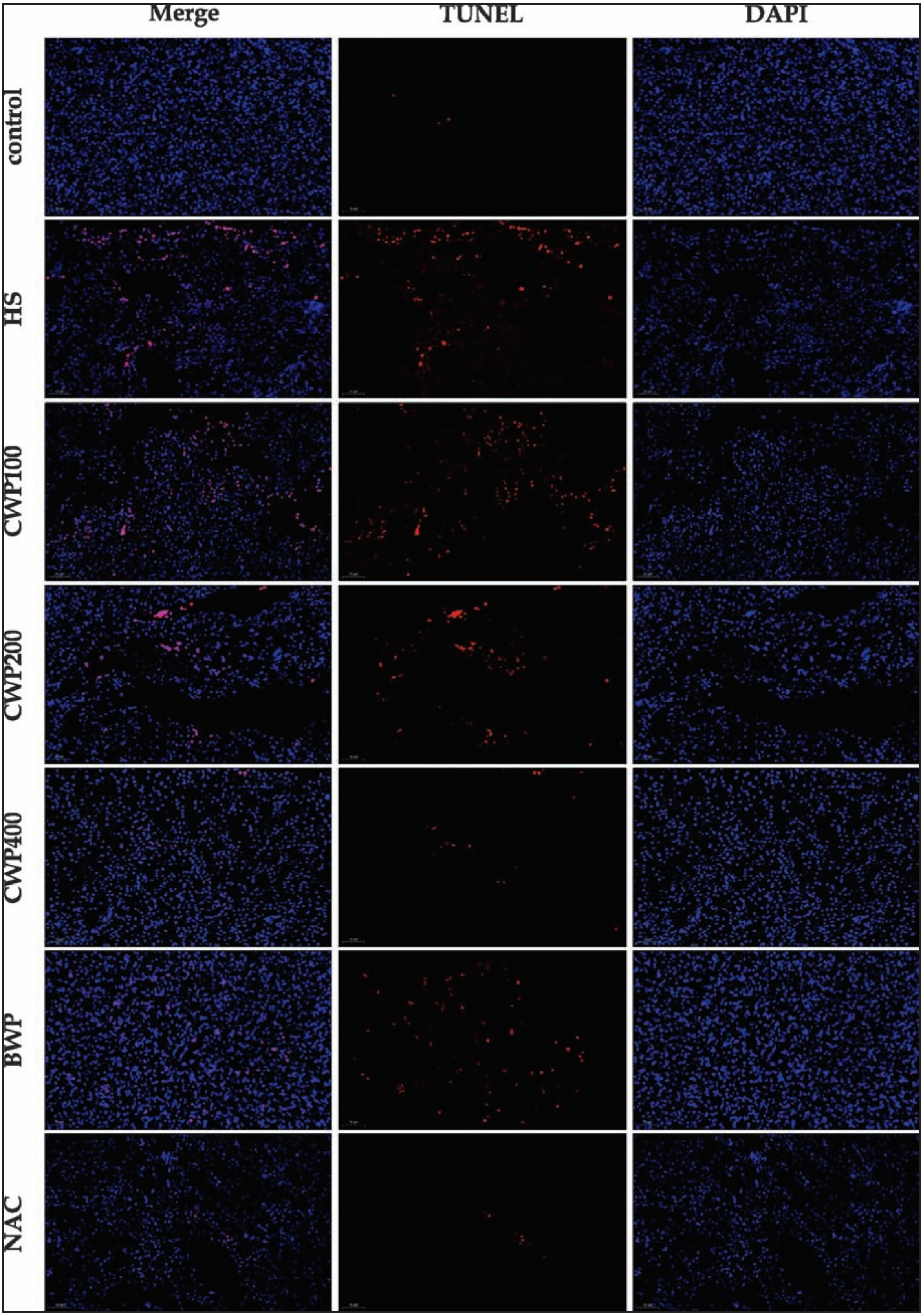


**Fig 5.** Apoptosis in rat kidney cells after acute heat stress (TUNEL, 200×, n=6). TUNEL assay was used to detect apoptosis in acute heat-stressed rat kidney cells under CWP intervention, 200× field of view, DAPI re-stained nuclei were blue under UV and CY3 fluorescein labelled positive apoptotic nuclei were red.

### *Detection of Kidney Injury in Acute Heat Stress Rats Using Immunohistochemical Methods*

As shown in Figs 4, the control group exhibited minimal positivity, with a yellowish colour and almost no positive staining, while the HS model group demonstrated significantly stronger positivity, appearing brownish in colour. These differences between the two groups were highly significant. In contrast, the degree of positivity in the low, medium and high-dose CWP groups gradually decreased and significant differences were observed between these groups and the HS model group. However, no significant difference was found between the high-dose CWP400 group and the control group, suggesting that CWP400 provides better kidney protection under acute heat stress than the HS model group. Interestingly, the BWP group showed localised areas of medium-positive brownish-yellow staining, as well as areas of strong positivity.

The positive cell ratio, defined as the number of positive cells relative to the total number of cells, reflects the extent of positive cell presence. The HS model and BWP groups exhibited relatively high values in this regard. In addition, positive cell density, calculated as the number of positive cells per unit area of tissue, was denser in the HS model group, indicating a more concentrated distribution of positive cells. Meanwhile, the average optical density (AOD), representing the cumulative optical density of the positive signal per unit area, demonstrated that while BWP had the lowest AOD, its positivity distribution was uneven, with areas of intense staining and others with weak positivity. This uneven distribution led to a lower average value.

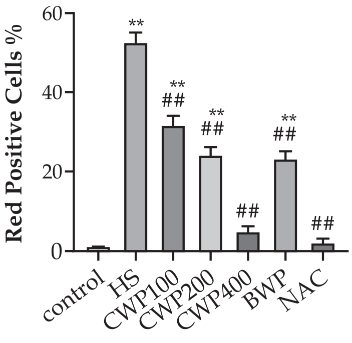


**Fig 6.** Apoptosis rate (Red Positive Cells %). Red light positive rate = total number of red light positive cells/total number of cells. Data are expressed as mean ± SEM values, "*" indicates significant difference compared with control group (P<0.05), "**" indicates highly significant difference compared with control group (P<0.01); "#" indicates a significant difference compared with the HS group (P<0.05) and "##" indicates a highly significant difference compared with the HS group (P<0.01).

Finally, histological scoring further corroborated these findings. The HS model group had the highest score, indicating the most intense positivity, followed by the CWP low, medium and high-dose groups. The BWP group showed positivity levels between the CWP low and medium doses, consistent with earlier conclusions. The NAC control group and the control group both exhibited the least positivity.

These results clearly indicate that as the CWP dose increases, kidney protection against injury improves significantly, outperforming BWP at equivalent doses.

### *Effect of CWP on Renal Cell Apoptosis in Acute Heat Stress Rats*

After 3 hours of acute heat stress, the number of apoptosis-positive cells in the kidneys of rats in the HS model group increased significantly, showing a marked difference compared to the control group (Fig 5, 6). The apoptosis rate was notably reduced in the CWP medium- dose group. Additionally, no significant difference was observed between the CWP400 high-dose group and the NAC group when compared to the control group, whereas the BWP group still exhibited a more severe apoptosis response. These results suggest that the high dose of CWP effectively prevents renal cell apoptosis under acute heat stress conditions.

## Discussion

Elevated body core temperature (Tc) is a hallmark of heat stress (HS), though there is no universally agreed-upon threshold Tc value for diagnosing HS. Several studies have indicated that apoptosis occurs when Tc exceeds 41.6°C for more than 45 minutes, while others report that tissue damage and apoptosis can be induced in rats by maintaining Tc at 41.5°C for 2 hours (Li *et al,* 2023). Notably, when Tc exceeds 40°C, central nervous system dysfunction and multi-organ damage, particularly to the liver and kidneys, are commonly observed (Fang *et al,* 2023). In this experiment, one rat died post-HS with a Tc of 41°C. No external trauma was observed, but foamy liquid was found in the nasal cavity, suggesting that individual susceptibility, possibly due to a weaker constitution, might have contributed to the fatal outcome.

Blood urea nitrogen (BUN) and serum creatinine (S-cr) are widely used markers for assessing renal function and monitoring kidney injury. BUN is the primary end product of protein metabolism, produced in the liver and excreted by the kidneys. Elevated BUN levels are indicative of renal dysfunction (Hang *et al,* 2024). The urease method is commonly employed to measure BUN, where urease hydrolyses BUN, releasing ammonia and carbon dioxide. The ammonia ions then form a blue substance in an alkaline medium, with the intensity of colour being directly proportional to BUN concentration (Lui *et al,* 2022). In our study, BUN levels began to rise 3 hours after HS and peaked at 9 hours post-rewarming, indicating a delayed onset of renal damage, consistent with the findings of Faten and coworkers (Faten *et al,* 2023).

S-cr, a byproduct of muscle metabolism, is normally filtered by the kidneys. Reduced glomerular filtration, as seen in renal impairment, leads to increased S-cr levels in the blood (Acharya *et al,* 2023). The sarcosine oxidase method for S-cr detection involves a series of enzymatic reactions, ultimately forming a purplish-red compound that can be quantified colourimetrically (Cevallos *et al,* 2024). Similar to BUN, S-cr levels in this study peaked 9 hours after rewarming, corresponding with the highest degree of kidney injury following HS.

To further assess kidney injury following acute heat stress, histopathological analysis was conducted on kidney tissues collected at different rewarming times. At 0 hours post-HS, only localised blood cells were observed and tissue structure remained largely intact, with no significant difference from the control group. However, by 3 hours post-HS, haemorrhaging, inflammatory infiltration, cellular blistering and nuclear fragmentation were evident, suggesting that the body initiated an inflammatory response to mitigate HS-induced damage, which progressively worsened over time (Jing *et al,* 2024). This finding supports the successful establishment of an acute heat stress-induced kidney injury model.

Immunohistochemical analysis revealed that the BWP group exhibited a more complex positive reaction compared to the CWP group. The BWP group showed moderate to strong brownish-yellow staining, indicating a weaker repair effect on kidney injury, particularly when compared to the CWP group. This could be attributed to the composition or bioavailability of BWP, suggesting it may not provide sufficient protection against acute heat stress-induced kidney injury (Szumilas *et al,* 2024).

In this study, CWP was shown to significantly alleviate HS-induced kidney injury in rats, improving renal function and inhibiting renal cell apoptosis. CWP, rich in lactoferrin, immunoglobulins and bioactive peptides, appears to enhance immune responses, counteract oxidative stress and reduce apoptosis (Gamal *et al,* 2017), thus demonstrating its potential as a natural bioactive agent in protecting against HS-induced kidney injury.

Despite these promising findings, several issues remain to be addressed. First, the precise mechanisms of CWP, particularly its effects on cellular signaling and gene expression, are not fully understood. Further molecular biological investigations are needed to elucidate these pathways. Second, optimal dosages and timing of CWP administration require further refinement, as different dosing regimens may yield varying therapeutic outcomes. Additionally, while CWP has shown efficacy in animal models, its safety and clinical applicability need to be rigorously evaluated in clinical trials.

In conclusion, CWP offers significant protective effects against acute heat stress-induced kidney injury and apoptosis in rats. Through its antioxidant and anti-apoptotic actions, CWP holds promise as a novel natural agent for mitigating heat stress-related kidney injury. Future studies are essential to explore the mechanisms of action, determine the optimal application and assess the clinical potential of CWP, providing valuable insights into the treatment of heat stress-associated diseases.

## Conclusion

An acute heat stress rat model was successfully established under conditions of 40°C ± 0.5°C ambient temperature and 60% ± 5% relative humidity for a duration of 3 hours. This model induced kidney injury, with the most pronounced damage observed at 9 hours post-rewarming. CWP demonstrated a significant protective effect in reducing kidney injury and apoptosis induced by acute heat stress in rats, with the effect being more pronounced at higher doses. At equivalent doses, BWP exhibited a less pronounced protective effect compared to CWP.

## Funding

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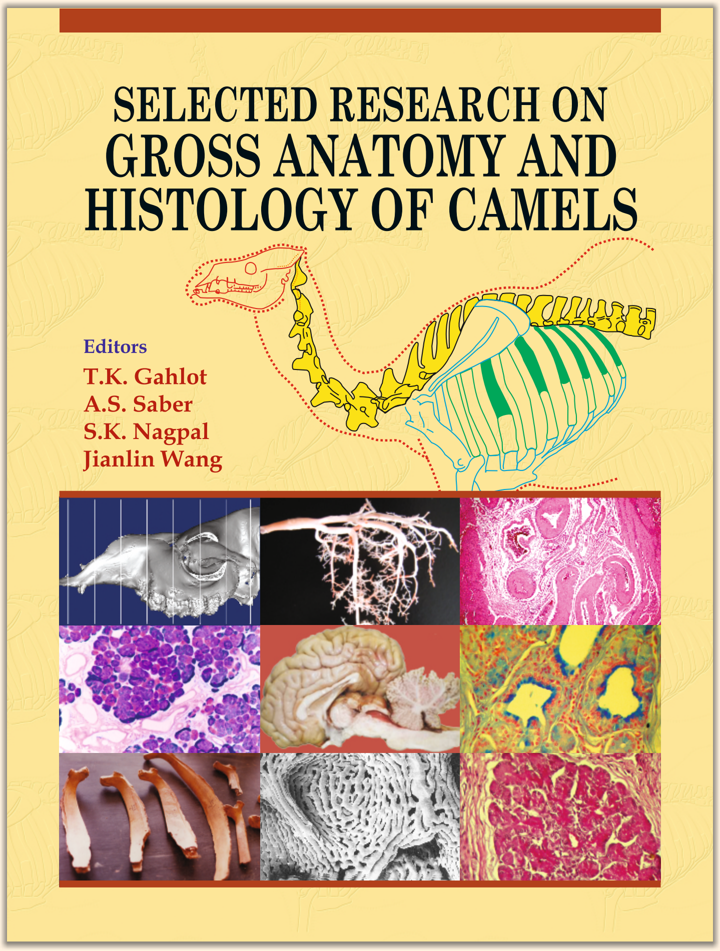


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# ENDOSCOPIC DIAGNOSIS AND MANAGEMENT OF CASES OF OESOPHAGEAL OBSTRUCTION IN DROMEDARY CAMELS

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## ABSTRACT

This study examined 18 dromedary camels suffering from different oesophageal disorders. These animals were either less than 6 months old (8 cases) or aged one year and above (10 cases). Each camel underwent special examination of the oesophagus and the associated clinical signs were noted. The sites of oesophageal obstruction were cervical (10 cases), thoracic inlet (2 cases), cervical and thoracic, both (2 cases) and thoracic (4 cases) regions. The causes of oesophageal obstruction were foreign bodies, feed straw or chronic oesophagitis. The obstructions were managed by repeated siphoning (4 cases), removal using crocodile forceps during endoscopy (8 cases), oesophagotomy (1 case which later died) and advancement of the obstructive mass into the rumen (2 cases). In present study, 15 camels recovered following various treatments. Two cases were euthanatised and one was slaughtered owing to their poor prognosis.

**Key words:** Dromedary camels, endoscopy, oesophageal obstruction

Oesophageal diseases are frequently reported in many livestock animals and they involve oesophageal obstructions(Sadan *et al,* 2023), oesophageal dilatation(Ahmadnejad *et al,* 2021), oesophagitis (Franz and Baumgartner, 2002), oesophageal stenosis or oesophageal rupture (Franz *et al,* 2024). Diseases affecting the oesophagus in camels can impact their productivity and might also influence their welfare. Recently, the application of endoscopy in camel medicine has significantly enhanced the clinical assessment of oesophageal diseases and it is considered as a rapid and non-invasive diagnostic technique (Shawaf *et al,* 2017). However, the diagnostic studies for gastrointestinal disorders in camels are under represented. Recently, ruminoscopy was used to visualise the interior of the rumen in clinically healthy camel calves, specially to evaluate the content, mucosal ruminal appearance and the ruminal motility (Almuhanna *et al,* 2025).

A retrospective study on choke of oesophagus in dromedary camels with use of stomach tube to locate the site of obstruction has been reported (Zabady and Shawaf, 2022). Ultrasonography was used to diagnose a case of benign oesophageal fibroid polyp in camels (Elmanakhly *et al,* 2020). Endoscopy is a popular diagnostic procedure for oesophageal and gastric diseases in horses (Franz *et al,* 2024). Endoscopy helps locating oesophageal obstruction throughout the entire length of the oesophagus. Intraluminal mucosal lesions can also be detected by endoscopy. Therefore, the current study was aimed to report some oesophageal disorders through the application of endoscopy in dromedary camels including the associated clinical signs and appropriate therapeutic interventions.

## Materials and Methods

A total number of 18 camels of mixed breeds (including Maghateer, Majaheem and Widdah) with age range of one month to 10 years, were included in this study. The present study had ethical approval from the university (KFU-REC 2025-FEB-ETHICS 3136). Each animal was assessed clinically immediately after admission to the Veterinary Teaching Hospital at King Faisal University. The clinical examination involved initial evaluation of the vital signs (heart rate, respiratory rate, mucous membrane appearance and the temperature) and the signalment of the examined camels were also reported. Each admitted case underwent a special examination for the oesophagus including clinical inspection for the presence of externally visible peristaltic movements over the ventral cervical area.

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Moreover, the ventral part of the entire cervical region was carefully palpated to identify regions with palpable obstructions. Subsequently, with the camel being positioned in sternal recumbency, each animal was sedated with 2% Seton* by intravenous route at a dose rate of 0.2 mg/kg (*Seton 2%; Laboratorios Calier, S.a.c./Barcelones, Barcenola, espana). In animals without externally detectable oesophageal obstruction, a stomach tube was passed to assess the patency of the oesophagus, especially in those camels where the obstruction was in the thoracic part of the oesophagus. Care was taken to avoid pushing the obstructive material further caudally. After that, oesophagus of each animal was examined using a portable video endoscopy (3.3 meter long and 12mm in external diameter). The endoscopy unit was powered with a source of LED light and had a irrigation system. It was provided with an instrument channel, 3.7mm in diameter, inside which a 4-meter foreign body forceps was inserted. The head of the examined animal was carefully secured and the endoscope was introduced into the oro-pharyngeal region. At this level, the tip of the insertion tube was allowed to touch the pharyngeal mucosa to stimulate the swallowing reflex which allows animal to swallow the endoscopy and then it was advanced caudally to allow a proper visualisation of the oesophageal lumen. In some camels, the procedure of oesophageal endoscopy was difficult due to excessive accumulation of saliva. It was overcome by lowering the position of the head and neck to a level below that of the thorax. A simultaneous manual massage at the ventral neck area helps passage of saliva towards distal part of the oesophagus.

The endoscopic visualisation of the oesophagus helped identifying the location and type of oesophageal obstruction and subsequent clinical approaches were decided accordingly. Oral removal of the obstruction was done using an 90cm long crocodile forceps in the obstructions in the upper cervical oesophageal area. Grasping and retrieval of the foreign body by a foreign body forceps was done. This forceps was passed through the instrument channel of the endoscopy. In few cases, the foreign body was pushed caudally towards the rumen via a large-bored stomach tube, particularly when the obstruction was located just cranial to the cardia. In cases of oesophageal impaction by the coarse fibrous feed repeated lavage with water followed by siphoning was employed. Cervical oesophagotomy was done in one animal where the obstruction was at thoracic inlet and it was firmly attached to the oesophageal mucosa. In two camels with extensive mucosal laceration, euthanasia was recommended and one animal was slaughtered due to poor prognosis.

## Results

The details of signalment for each animal, clinical signs, site and type of obstruction, procedure adopted to treat the obstruction and final outcome of the case are summarised in Table 1. The nature of vomiting associated with oesophageal obstruction is shown in Fig 1, while the nature of the oesophageal obstruction is illustrated in Fig 2. The process of foreign body removal through the endoscopic foreign body forceps is shown in Fig 3. Endoscopic visualisation of the oesophagus allowed identification of the nature of the obstructive materials, which involved obstruction by plastic bags, fabric materials such as piece of carpets or clothes, plastic ropes used for hay baling, bezoars-like structure, impaction by food materials, presence of extensive mucosal laceration or massive nodules formation.

Briefly, in young camel calves it was noted that the majority of the reported cases were oesophageal obstruction by environmental foreign body materials. In contrast, adult camels tended to develop obstruction by feed materials or became lodged with solid bezoar-like structure causing intraluminal oesophageal obstruction. In few adult animals, intraluminal chronic inflammatory lesions such as nodules formation or massive mucosal lacerations were seen.

## Discussion

In present study, the young camels aged 6 months and below (8 cases) were also affected which could be due to their open pasture grazing with environmentally polluted grounds. Camels with age of 1 year and above were also affected with oesophageal obstruction. The exact aetiology of such obstructions could not be ascertained. Endoscopic examination of the oesophagus along with documentation of the associated clinical presentation offers significant value in enhancing our understanding of commonly encountered oesophageal disorders. Our results indicated that the major clinical complaints in our cases were vomiting, excessive salivation and signs of anxiety. In some cases, visible peristaltic movement of the ventral aspect of the neck was also noted. Such clinical signs have been previously reported by handful of authors (Ahmed, 2011; Eljalii *et al,* 2014; Ramadan and Abdin-Bey, 1990; Ramadan *et al,* 1986; Sadan *et al,* 2023; Shawaf *et al,* 2017). However, our study also revealed atypical clinical theme in which the aforementioned common clinical signs were not seen despite having chronic and severe oesophageal lesions. For example, in cases number 12 and 18, the elevation of head and neck after swallowing without obvious vomiting was the only clinical sign noted and the endoscopic findings revealed the presence of nodular formations or massive ulceration. In camel literature, elevation of head and neck, also referred to as 'star-gazing', has been reported in cases of polioencephalomalacia (Meligy and El Nahas, 2020). Therefore, such findings should be differentiated carefully.

Our results showed that the majority of the oesophageal obstructions were caused by lodgement of plastic bags or clothing, this finding has been reported frequently and thought to be caused by the lack of environmental hygiene (Zabady and Shawaf, 2022). The ecological impacts of widespread plastic pollution and subsequent ingestion of anthropogenic waste, primarily plastic bags and ropes, by dromedary camels in the United Arab Emirates (UAE) and across the Arabian Peninsula has been reported (Wernery *et al,* 2021). Camels in the UAE have shown a regional mortality rate of 1% from ingesting plastic pollution (Erikson *et al,* 2021). Feed material impaction has also been documented in Saudi Arabia and it is usually dealt with by surgery (Sadan *et al,* 2023). However, the aetiology and risk factors associated with such occurrence has not been yet been investigated. The author postulates that oesophageal impaction by hay materials might be associated with the coarseness of the chewed fibres, greediness of the animal and possibly weakness of the oesophageal muscles. Nevertheless, further experimental studies are required to confirm or debunk such speculations. Lodgement of the oesophageal lumen with hard structures like bezoar was reported in a case report, which is thought to be formed initially in the rumen and become lodged in the oesophagus during the process of regurgitation (Zabady *et al,* 2022). The nodules formation in the oesophagus might reflect a process of chronic inflammation. Although the cause of such finding was not sought in this study, the morphological appearance of the lesions resembles those seen in a previous report documenting a fibroid polyps caused by a fungal infection (Elmanakhly *et al,* 2020).

Endoscopic retrieval of oesophageal foreign body using a forceps inserted through the endoscope has been frequently reported in dogs by many authors (Deroy *et al,* 2015; Gianella *et al,* 2009; Juvet *et al,* 2010; Michels *et al,* 1995). The procedure is simple and non-invasive and has a high success rate especially if the intervention was offered during the early course (Juvet *et al,* 2010). Furthermore, the advantage of using such technique is that it offers real-time visualisation of the foreign body and simultaneous manipulation of the endoscope with subsequent correct placement of the forceps, enabling proper grasping of the obstruction and eventually facilitates its removal (Mourya *et al,* 2018). In camels, the use of digestive endoscopy has only been applied to visualise and locate the oesophageal obstruction (Zabady *et al,* 2022; Zabady and Shawaf, 2022) and to remove the obstructive materials, with the aid of crocodile forceps, only if it is lodged in upper part of the cervical oesophagus (Shawaf *et al,* 2017). However, the ability to successfully intervene in such cases depends mainly on the location of the obstruction. For instance, the obstruction is removable only when it is accessible by

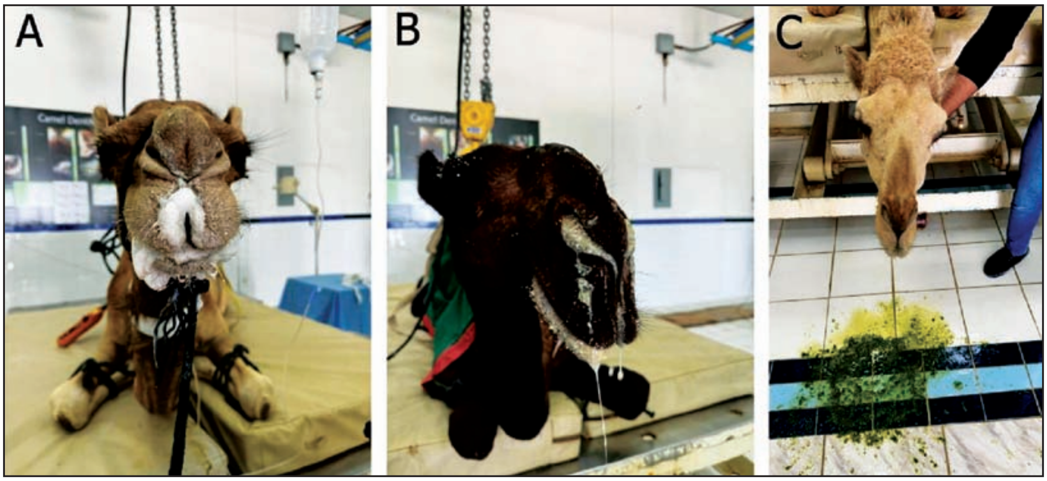


**Fig 1.** Types of vomited materials in camels with oesophageal obstructions. A- Frothy salivation in a camel with acute oesophageal obstruction. B- The vomiting is associated with regurgitation of milky fluid from the nostrils. C-Pasty olive/green vomitus in an animal with chronic oesophageal obstruction.

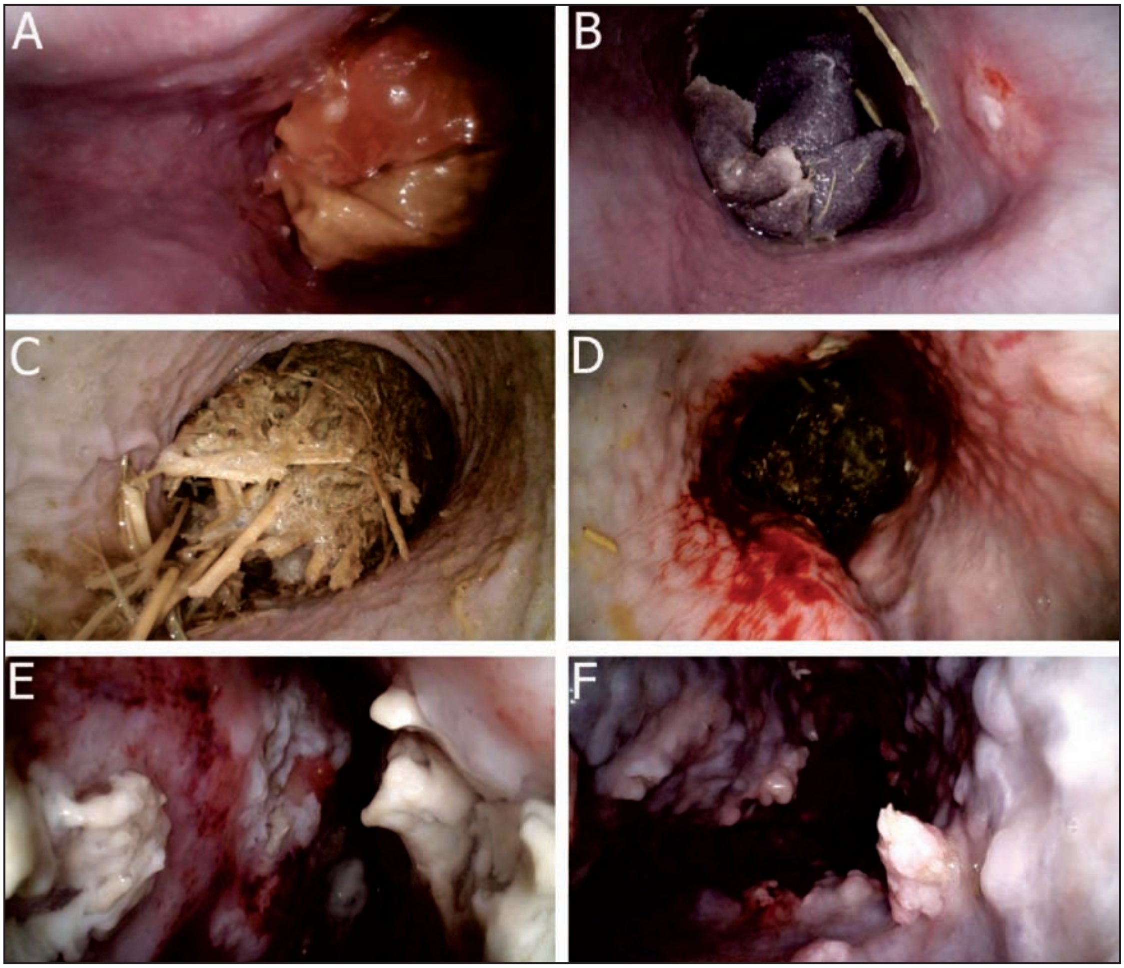


**Fig 2.** Examples of oesophagoscopic findings in camels with different types of oesophageal affections. A- Obstruction by a plastic bag materials. B- An obstruction by clothes. C- Cylindrical-shaped food materials causing impaction in the oesophagus. D-Obstruction by bezoar-like structure causing mucosal bleeding. E- Petechial haemorrhage is seen, some of which is covered with necrotic white material. F-Extensive nodules formation throughout the oesophageal lumen.

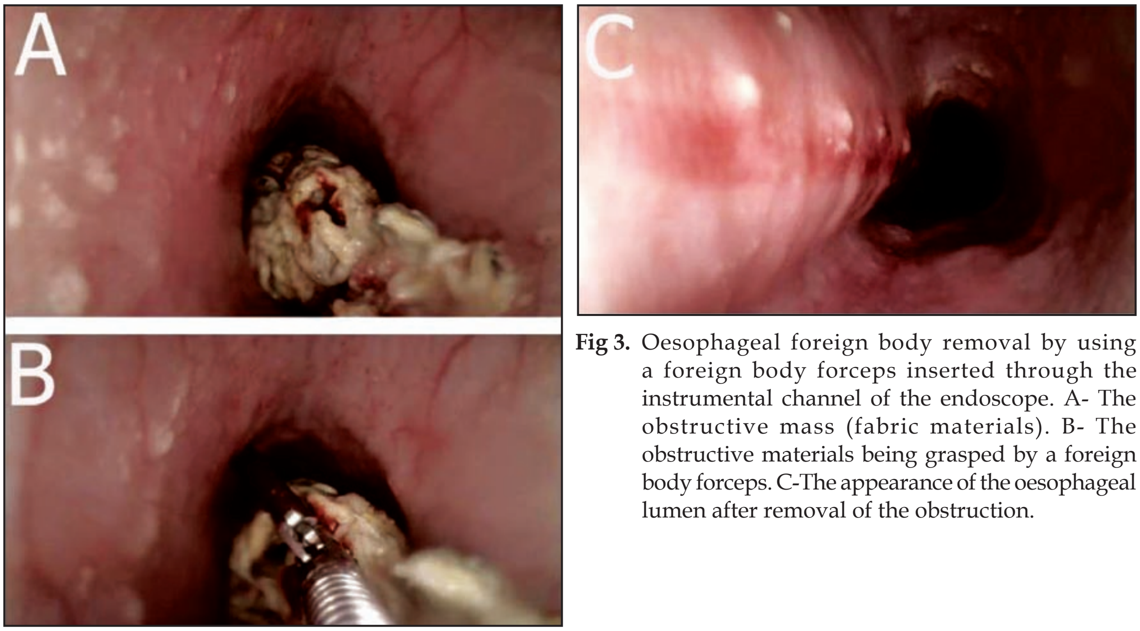


**Fig 3.** Oesophageal foreign body removal by using a foreign body forceps inserted through the instrumental channel of the endoscope. A- The obstructive mass (fabric materials). B- The obstructive materials being grasped by a foreign body forceps. C-The appearance of the oesophageal lumen after removal of the obstruction.

**Table 1.** The details of case signalment, clinical findings, endoscopic findings, site of affections, final diagnosis, therapeutic intervention and treatment outcomes.

| ID | Age | Sex | Clinical signs | Endoscopic findings | Site | Final diagnosis | Method of therapeutic intervention | Outcome |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 years | M | Drooling of solid food after mastication, occasional vomiting after eating and hind limb tremors | Impaction by food materials | Cervical | Oesophageal obstruction | Repeated siphoning with water | Recovered |
| 2 | 2 months | M | Sudden anxiety, excessive salivation repetitive head and neck movement | Lodgement by plastic bag | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 3 | 7 years | F | Sudden anxiety, frothy salivation and anorexia | Presence of bezoar-like structure | Thoracic inlet | Oesophageal obstruction | Oesophagotomy | Died |
| 4 | 1 month | M | Regurgitation of milk immediately after milk sucking, dullness | Obstruction by fabric materials | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 5 | 3 years | F | Chronic vomiting of freshly masticated food, clinically visible peristaltic movement of the oesophagus in the ventral neck area | impaction by food materials | Cervical | Oesophageal obstruction | Repeated siphoning with water | Recovered |
| 6 | 1 year | F | Chronic vomiting and progressive loss of body condition | Impacted food materials | Thoracic | Oesophageal obstruction | Repeated siphoning with water | Recovered |
| 7 | 7 years | F | Profuse frothy salivation developed suddenly | Oesophageal obstruction by bezoar-like structure | Thoracic inlet | Oesophageal obstruction | Slaughtering was recommended | Slaughtered |
| 8 | 1 year | F | Chronic vomiting and peristaltic movements | Impaction by food | Cervical | Oesophageal obstruction | Repeated siphoning with water | Recovered |
| 9 | 1 year | M | Vomiting of milky materials | Oesophageal obstruction by clothes | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 10 | 2 months | M | Vomiting after swallow | Oesophageal obstruction with fabric materials | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 11 | 3 months | M | Salivation and inappetance | Plastic ropes | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 12 | 10 years | F | Head elevation following swallowing | Extensive nodules formation occupying the entire oesophageal mucosa | Cervical and thoracic | Chronic oesophagitis | Euthanasia was recommended | |
| 13 | 2 months | M | Repeated head and neck elevation especially after swallowing for six months | Plastic bag materials obstruction in the thoracic part of the oesophagus | Thoracic | Oesophageal obstruction | Pushed to the rumen via stomach tube | Recovered |
| 14 | 1 month | F | Sudden anxiety and milk regurgitation after sucking | Obstruction by fabric materials | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 15 | 3 months | F | Frothy salivation, anorexia and vocalization | Oesohageal obstruction by ropes | Cervical | Oesophageal obstruction | Removed using crocodile forceps | Recovered |
| 16 | 6 months | M | Inappetence and vomiting | Oesophageal obstruction by a piece of carpet | Thoracic | Oesophageal obstruction | Removed with endoscopic foreign body forceps | Recovered |
| 17 | 1 year | M | Vomiting after swallow | Oesophageal obstruction by a plastic bag | Thoracic | Oesophageal obstruction | Pushed to the rumen via stomach tube | Recovered |
| 18 | 2 years | F | Chronic progressive loss of body conditions, inappetence, restlessness after swallowing and occasional vomiting | Diffuse petechial ulceration and presence of massive necrotic lesions | Cervical and thoracic | Chronic oesophagitis | Euthanasia was recommended | |

the crocodile forceps, which measures about 90 cm in length. On the other hand, the application of foreign body forceps passed through the instrumental channel of the endoscope has the capability of removing the obstruction even in most caudal parts of the oesophagus, in particular, in the thoracic part near the cardia, which was successfully applied in this study.

In conclusion, this study has reported an important oesophageal affections through endoscopic examination of the oesophageal lumen in camels with various oesophageal affections. The novel inflammatory lesions found in the oesophageal mucosa has not been reported previously in ante-mortem studies. Such findings highlights the importance of endoscopic utility in clinical examination of camel. Therefore, we recommend that endoscopic examination in camel practice should be done routinely in any case with non-specific symptoms as it can detect unexpected lesions.


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# EXPLORING THE NUTRITIONAL AND BIOCHEMICAL PROPERTIES OF BACTRIAN CAMEL MILK: INSIGHTS INTO FUNCTIONAL FOODS AND MEDICAL APPLICATIONS

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**ABSTRACT**

Bactrian camel (*Camelus bactrianus*) milk (BCM) has gained attention for its rich nutrients and unique biochemical properties. This review summarises its key nutritional components—proteins, fats, vitamins and minerals and its biochemical traits like antioxidant and immune-modulating effects. By examining current literature, we discuss its health benefits, disease prevention potential and role as a functional food. The review also highlights current research and suggests future studies to maximise its dietary and therapeutic benefits.

**Key words:** Bactrian camel milk, biochemical properties, functional foods, medical applications, nutritional components

Milk from the Bactrian camel (*Camelus bactrianus*) has attracted considerable scholarly attention due to its distinctive nutritional and biochemical characteristics. In contrast to conventional dairy products, Bactrian camel milk (BCM) is characterised by a higher protein content, reduced fat levels and a diverse array of vitamins and minerals, rendering it a promising alternative for various dietary requirements (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Huang *et al,* 2024). Research indicates that this milk contains essential amino acids and fatty acids vital for human health. Notably, the primary fatty acids present in BCM are palmitic, oleic and stearic acids, with a significant proportion of long-chain fatty acids that may confer health benefits, such as enhanced cardiovascular health and improved metabolic functions (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Huang *et al,* 2024; Pan *et al,* 2024). Additionally, the unique composition of BCM makes it suitable for individuals with lactose intolerance, as it contains lower lactose levels compared to cow's milk, thereby offering a viable option for those who experience discomfort with traditional dairy products (Pan *et al,* 2024; Du *et al,* 2025).

The biochemical attributes of BCM extend beyond its nutritional composition, exhibiting significant antioxidant properties that are crucial in mitigating oxidative stress and inflammation within the body. Empirical evidence suggests that the antioxidant capacity of BCM surpasses that of other types of milk, potentially contributing to its health-enhancing effects (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). This antioxidant activity is ascribed to various bioactive compounds present in the milk, which are instrumental in modulating immune responses and safeguarding cellular integrity. Furthermore, the presence of distinctive proteins, such as αs2-casein, highlights the potential of BCM as a functional food (Zhong *et al,* 2025; Du *et al,* 2025; Pauciullo *et al,* 2023). These proteins not only enhance the nutritional quality of the milk but also improve its applicability in food processing and product development.

In the realm of medical applications, has demonstrated potential across various therapeutic domains, notably including anti-inflammatory, antidiabetic and anticancer effects. Its bioactive constituents have been associated with the modulation of gut microbiota, a factor essential for maintaining overall health and preventing chronic diseases (Seyiti *et al,* 2024). The potential of BCM to function as a functional food in managing conditions such as diabetes and obesity is particularly significant, as it may aid in the regulation of blood

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glucose levels and lipid profiles. Furthermore, the milk's immunomodulatory properties may confer advantages in bolstering the body's defenses against infections and diseases (Iacobucci *et al,* 2019).

In summary, the investigation into the nutritional and biochemical properties of BCM highlights its considerable potential as both a functional food and a medical resource. The distinctive composition and associated health benefits of this milk underscore its value for dietary and therapeutic applications. Future research should aim to elucidate the mechanisms underlying its bioactive properties and explore its applications across diverse health contexts, thereby advancing its role in the fields of functional food science and medicine.

## Nutritional Composition of BCM

Bactrian camel milk is increasingly acknowledged for its distinctive nutritional composition, which offers significant benefits to populations residing in arid regions (Zhong *et al,* 2025; Huang *et al,* 2024). This milk is distinguished by its elevated levels of essential nutrients, including proteins, fats, vitamins and minerals. Research indicates that BCM is rich in a variety of bioactive compounds, enhancing its value as a dietary component (He *et al,* 2019; Zhong *et al,* 2025; Jiao *et al,* 2025). The nutritional composition of BCM can vary considerably due to factors such as geographical location, breed and feeding practices, all of which can impact its overall nutritional quality (He *et al,* 2019; Razuan *et al,* 2025).

The protein content of BCM is remarkably high, constituting approximately 3.5 to 4.0% of its overall composition. The primary proteins present are caseins and whey proteins, with caseins accounting for roughly 80% of the total protein content. The amino acid profile of BCM proteins is enriched with essential amino acids, which are vital for human health and development (Guo *et al,* 2023; Ma *et al,* 2025). Notably, BCM contains elevated levels of specific amino acids, such as lysine and methionine, compared to cow's milk, thereby enhancing its nutritional value (Zhong *et al,* 2025; Huang *et al,* 2024; Ma *et al,* 2025). These proteins also demonstrate functional properties, including emulsification and foaming, which are advantageous in food processing applications (Ma *et al,* 2025). Furthermore, BCM proteins have been linked to various health benefits, such as anti-inflammatory and antimicrobial properties, making them a subject of interest in the research of functional foods (Guo *et al,* 2023; Ma *et al,* 2025).

The fatty acid composition of BCM represents a significant element of its nutritional profile. Notably, it contains a higher proportion of unsaturated fatty acids, specifically monounsaturated and polyunsaturated fatty acids, in comparison to cow's milk. Prominent fatty acids in BCM include oleic acid, linoleic acid and palmitic acid (Chu *et al,* 2014). The presence of these fatty acids is linked to various health benefits, such as enhanced cardiovascular health and anti-inflammatory effects. Research suggests that the distinctive fatty acid profile of BCM may contribute to its potential therapeutic properties, particularly in the management of conditions such as diabetes and obesity (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). Additionally, the fatty acids in BCM are believed to facilitate the absorption of fat-soluble vitamins, thereby enhancing overall nutrient bioavailability (Chuluunbat *et al,* 2014; Zhan *et al,* 2023).

Bactrian camel milk is a substantial source of essential vitamins and minerals. It contains notable quantities of vitamins A, B, C, D and E, which are crucial for various physiological functions, including immune response, vision and skin health (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). The mineral profile is equally noteworthy, featuring elevated levels of calcium, magnesium, potassium and zinc, all of which are vital for bone health and metabolic processes (Zhong *et al,* 2025; Jiao *et al,* 2025). Research indicates that the mineral composition of BCM may vary according to the animal's diet and environmental conditions; however, it consistently serves as a valuable source of these nutrients (Huang *et al,* 2024). The bioavailability of minerals in BCM is enhanced by the presence of specific proteins that facilitate their absorption in the human body. This distinctive combination of vitamins and minerals renders BCM a nutritious option for augmenting dietary intake and promoting overall health (Razuan *et al,* 2025; Guo *et al,* 2023).

## Biochemical Characteristics of BCM

Empirical studies have demonstrated that BCM contains elevated levels of specific fatty acids, including palmitic acid, oleic acid and stearic acid, in comparison to other milk types, which may confer various health benefits (He *et al,* 2019; Pan *et al,* 2024). Additionally, the milk is characterised by a unique amino acid profile, with leucine, lysine and valine being predominant, which are essential for protein synthesis and overall health (Pan *et al,* 2024). There are certain differences in the specific nutritional composition between BCM and dromedary camel milk (DCM) (see Table 1 for details). This distinctive composition not only renders BCM an essential dietary resource for desert populations but also positions it as a functional food with potential therapeutic applications (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025).

The antioxidant properties of BCM are of significant academic interest due to their potential implications for health promotion and disease prevention (Zhong *et al,* 2025; Jiao *et al,* 2025; Du *et al,* 2025). Empirical studies have demonstrated that BCM possesses substantial antioxidant activity, which is primarily attributed to its rich composition of bioactive compounds, including vitamins, minerals and specific peptides (Jiao *et al,* 2025; Huang *et al,* 2024). Notably, the total antioxidant capacity (T-AOC) and the activity of antioxidant enzymes, such as superoxide dismutase (SOD) and catalase, have been observed to vary with the parity of lactating camels (Du *et al,* 2025). This variation suggests that the antioxidant profile of the BCM is subject to modulation by physiological factors (Jiao *et al,* 2025; Du *et al,* 2025). The underlying mechanisms of the antioxidant effects of BCM involve the scavenging of reactive oxygen species (ROS) and the modulation of redox signaling pathways, which are essential for cellular protection against oxidative stress (Jiao *et al,* 2025; Pan *et al,* 2024). This antioxidant activity not only underscores the health benefits of the BCM but also highlights its potential as a therapeutic agent in the management of conditions related to oxidative stress (Fig 1).

In addition to its antioxidant properties, BCM has been extensively studied for its immunomodulatory effects. Research suggests that components within BCM can enhance immune responses and modulate inflammation, positioning it as a promising candidate for therapeutic applications in autoimmune diseases and other inflammatory conditions (Jiao *et al,* 2025). For example, BCM has been demonstrated to influence immune cell activity, promoting a balanced immune response that may aid in the management of chronic inflammatory diseases (Huang *et al,* 2024). The immunomodulatory effects are believed to be mediated by various bioactive molecules present in the BCM, such as immunoglobulins and lactoferrin, which can enhance the body's defense mechanisms against pathogens and mitigate the severity of inflammatory responses (Chuluunbat *et al,* 2014). Additionally, it enhances the efficacy of chemotherapeutic agents, such as cisplatin, in a synergistic manner. Anti-cancer mechanism is to mediate the proliferation and apoptosis of cancer cells by relying on JNK signaling pathway, MAPK signaling pathway and NFkB signaling pathway, thereby playing an anti-cancer role (Jiao *et al,* 2025; Du *et al,* 2025) (Fig 2). This aspect of BCM highlights its potential as a functional food that not only provides nutritional benefits but also supports immune health.

In addition to its antioxidant and immunomodulatory characteristics, BCM demonstrates significant antimicrobial activity, thereby enhancing its functional profile. Research has shown that BCM inherently possesses antibacterial properties, largely due to the presence of specific proteins and peptides that inhibit the proliferation of various pathogens, including bacteria and viruses (Pan *et al,* 2024). For instance, lactoferrin in BCM has been demonstrated to exert antimicrobial effects by sequestering iron, thus depriving bacteria of this vital nutrient and inhibiting their growth (Huang *et al,* 2024). Furthermore, the distinctive fatty acid composition of camel milk may further contribute to its antimicrobial efficacy, positioning it as a potential natural preservative in food applications (Ma *et al,* 2022). This antimicrobial activity not only improves the safety and shelf-life of the milk but also supports its utilisation in traditional medicine and as a functional food in modern diets. Even the bioactive substances of BCM regulate the intestinal microbiota and its metabolites through metabolites and regulate various tissues and organs throughout the body through the "microbial-gut-x" axis (Jiao *et al,* 2025; Du *et al,* 2025) (Fig 3).

## Application of BCM in functional foods

BCM has been identified to contain bioactive compounds with anti-inflammatory, antidiabetic and lipid-lowering properties, further augmenting its potential as a functional food (Seyiti *et al,* 2024). The presence of unique fatty acids, such as long-chain fatty acids, contributes to its health benefits, including enhanced cardiovascular health (He *et al,* 2019). Additionally, studies have highlighted the antioxidant properties of BCM, indicating its potential to mitigate oxidative stress, which is associated with various chronic diseases (Du *et al,* 2025). Overall, the nutritional profile and bioactivity of BCM position it as a promising candidate for dietary supplementation, appealing to health-conscious consumers and individuals seeking alternative nutritional sources. BCM has garnered significant attention for its potential health benefits, particularly among specific populations such as

**Table 1.** Comparative Analysis of Nutritional Components in Camel and Bovine Milk.

| Nutritional Parameter | Bactrian Camel Milk (BC) | Dromedary Camel Milk (DC) | Bovine Milk (Cow) | Comparative Advantage (BC vs DC/Cow) | References |
|---|---|---|---|---|---|
| **Macronutrients** | | | | | |
| Total Solids (%) | 14.2–17.5 | 10.8 | 12.4 | +29%↑ DC / +18%↑ Cow | [Cefalu *et al*, 2004; Seyiti *et al*, 2024] |
| Protein (%) | 3.6–4.8 | 3.2 | 3.4 | +34%↑ DC / +23%↑ Cow | [Seyiti *et al*, 2024] |
| Fat (%) | 3.4–7.4 | 3.1 | 3.7 | +48%↑ DC / +24%↑ Cow | [Cefalu *et al*, 2004; Seyiti *et al*, 2024] |
| Lactose (%) | 4.6–6.2 | 3.8 | 4.7 | +32%↑ DC / +17%↑ Cow | [Seyiti *et al*, 2024; Miao *et al*, 2023] |
| Ash (%) | 0.7–0.9 | 0.7 | 0.6 | +14%↑ DC / +33%↑ Cow | [Seyiti *et al*, 2024] |
| Minerals (mg/kg) | | | | | |
| Sodium (Na) | 552–720 | 474 | 319 | +34%↑ DC / +126%↑ Cow | [Seyiti *et al*, 2024; Almasri *et al*, 2024] |
| Phosphorus (P) | 1068–1168 | 946 | 901 | +19%↑ DC / +25%↑ Cow | [Seyiti *et al*, 2024] |
| Calcium (Ca) | 1442–1809 | 1299 | 1137 | +23%↑ DC / +37%↑ Cow | [Seyiti *et al*, 2024] |
| Potassium (K) | 1244–1910 | 1732 | 1418 | DC: +10% / BC: +35%↑ Cow | [Seyiti *et al*, 2024] |
| **Vitamins (mg/kg)** | | | | | |
| Vitamin C (VC) | 28.2–42.3 | 33 | 15 | +28%↑ DC / +182%↑ Cow | [Cefalu *et al*, 2004; Seyiti *et al*, 2024] |
| Vitamin A (VA) | 0.5–1.1 | 0.3 | 0.4 | +267%↑ DC / +175%↑ Cow | [Seyiti *et al*, 2024] |
| Vitamin E (VE) | 1.4–2.7 | 0.02 | 1 | +134×↑ DC / +170%↑ Cow | [Seyiti *et al*, 2024] |
| **Functional Characteristics** | | | | | |
| β-Casein Proportion | 65% | 45% | 30% | Enhanced digestibility & absorption | [Xiao *et al*, 2022] |
| Lactoferrin (mg/L) | 3.2 | 2.1 | 0.1 | 15× higher antimicrobial activity | [Xiao *et al*, 2022; Zhang *et al*, 2005; Chen *et al*, 2024] |

**Table 2.** The Effects of BCM on Different Types of Diabetes Mellitus.

| Type of Diabetes | Research Findings | Recommended Dosage | References |
|---|---|---|---|
| Type 1 Diabetes | Significant reduction in fasting blood sugar (FBS) and glycated haemoglobin (HbA1c) | 500 mL/day for 3 months | (Seyiti *et al*, 2024; Jiao *et al*, 2025) |
| | Decreased insulin injection dosage (~37%) | | |
| | Improved diabetic nephropathy (reduced microalbuminuria) | | |
| Type 2 Diabetes | Reduced fasting blood glucose and plasma insulin levels | 500 mL/day for 2-3 months | (Seyiti *et al*, 2024; Jiao *et al*, 2025; Pan *et al*, 2024) |
| | Improved lipid profile (TG, TC) | | |
| | Some inconsistent findings, potentially due to small sample sizes | | |

individuals with lactose intolerance. In contrast to cow's milk, BCM contains reduced levels of lactose, thereby rendering it more suitable for those who experience discomfort from lactose ingestion (Seyiti *et al*, 2024). Empirical studies have demonstrated that lactose-intolerant individuals can consume BCM without experiencing the gastrointestinal disturbances commonly associated with lactose-containing dairy products (Seyiti *et al*, 2024). Furthermore, the distinct protein composition of BCM, including casein variants that differ from those found in cow's milk, may enhance its digestibility and acceptance among lactose-intolerant consumers (Jiao *et al*, 2025). Beyond lactose intolerance, BCM

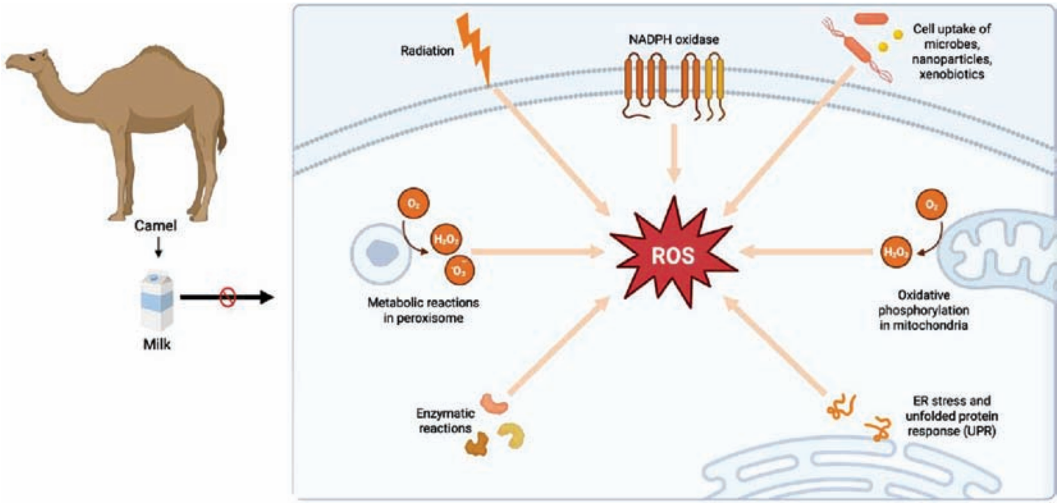


**Fig 1.** The main antioxidant mechanism of BCM.

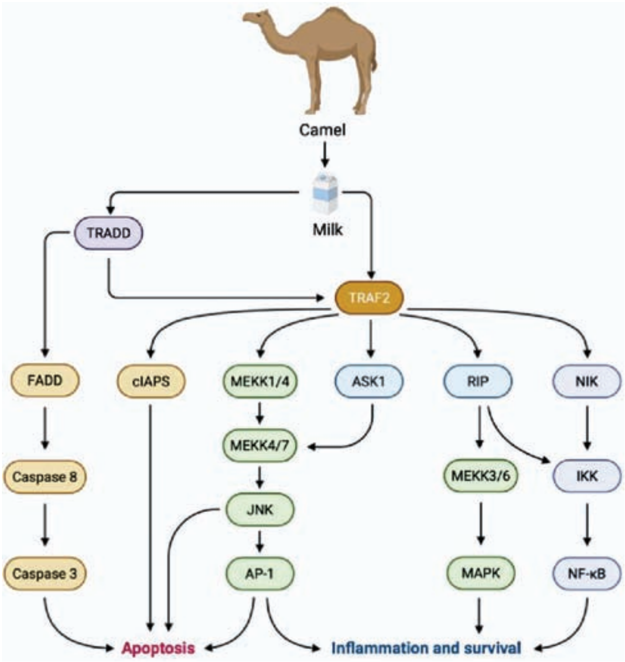


**Fig 2.** Anticancer mechanism of the active ingredient in BCM.

has been investigated for its potential advantages in other vulnerable groups, including children and the elderly, who may benefit from easily digestible nutritional sources (Pan *et al,* 2024; Du *et al,* 2025). The anti-inflammatory and immunomodulatory properties of BCM further increase its attractiveness for individuals with compromised immune systems or chronic inflammatory conditions (Seyiti *et al,* 2024). Thus, BCM presents a viable alternative for those in need of dairy substitutes, offering both nutritional benefits and enhanced digestibility.

## Medical Applications of BCM

Recent clinical research has underscored the potential of BCM as a preventive medicines. Empirical studies have indicated that regular consumption of BCM can result in significant enhancements in various health parameters, such as lipid profiles, glycemic control and inflammatory markers (Seyiti *et al,* 2024). Furthermore, the lipid profile of BCM, characterised by a higher proportion of unsaturated fatty acids, contributes to its lipid-lowering effects, which can alleviate cardiovascular risks (Seyiti *et al,* 2024). Study concentrating on diabetic patients demonstrated that individuals who incorporated BCM into their diet achieved superior glycemic control compared to those who did not (Seyiti *et al,* 2024; Jiao *et al,* 2025; Pan *et al,* 2024) (Table 2). Furthermore, the anti-inflammatory properties of BCM may play a role in preventing chronic diseases by reducing systemic inflammation, a common underlying factor in many chronic conditions (Ma *et al,* 2022). BCM is abundant in immunoglobulins, lactoferrin and other bioactive components that can enhance immune responses and provide protection against infections (Huang *et al,* 2024). This multifaceted approach to disease prevention underscores the importance of BCM as a potential medications in the context of chronic disease management. At present, there are some "camel milk therapy" used in clinical practice for patients with chronic diseases and diabetes (Pan *et al,* 2024). These attributes suggest that BCM could serve as a complementary therapy for patients with immune system disorders, potentially enhancing their quality of life and improving clinical outcomes. Moreover, the distinctive composition of BCM, establishes it as a preventive medicines that can be integrated into therapeutic guidelines for diverse populations, particularly those at risk for chronic diseases (Seyiti *et al,* 2024) (Fig 4). The growing body of evidence supporting the health benefits of BCM underscores

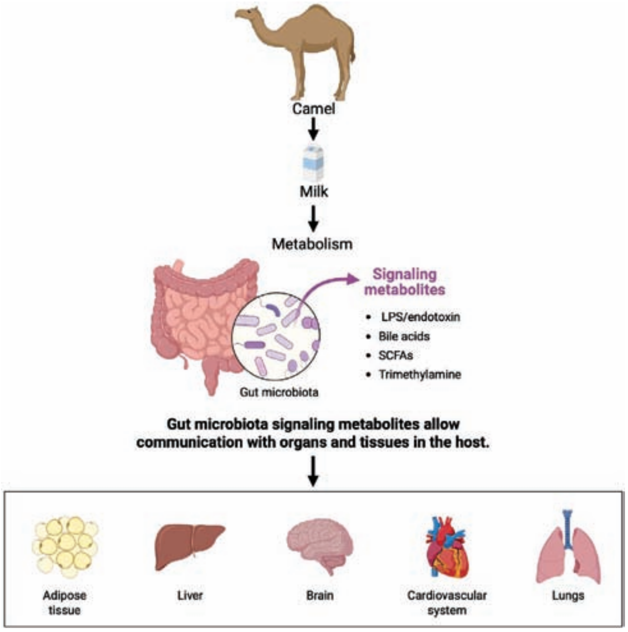


**Fig 3.** BCM and its metabolites regulate organ function through the "microbial-gut-x" axis.

its potential as a valuable addition to preventive medicines research and dietary practices, paving the way for future studies and applications in clinical nutrition.

## Future Research Directions and Challenges

The domain of BCM research is undergoing rapid advancement, offering numerous opportunities for further investigation and addressing existing challenges. As interest in BCM continues to expand, particularly due to its distinctive nutritional and bioactive properties, future research endeavors should concentrate on several critical areas to enhance our comprehension and application of this valuable resource. Investigating the nutritional components of BCM is essential for elucidating its health benefits and potential applications in dietary interventions.

The processing and product development of BCM are essential for optimising its nutritional benefits and market potential. Due to its unique composition, BCM necessitates specific processing techniques to maintain its bioactive properties while ensuring food safety and quality (Du *et al,* 2025). Research suggests that traditional methods, such as fermentation, can enhance the probiotic content of BCM, thereby establishing it as a valuable functional food product (Seyiti *et al,* 2024). Furthermore, contemporary processing techniques, including pasteurisation and ultrafiltration, have been investigated to extend the shelf life and safety of BCM without compromising its nutritional integrity

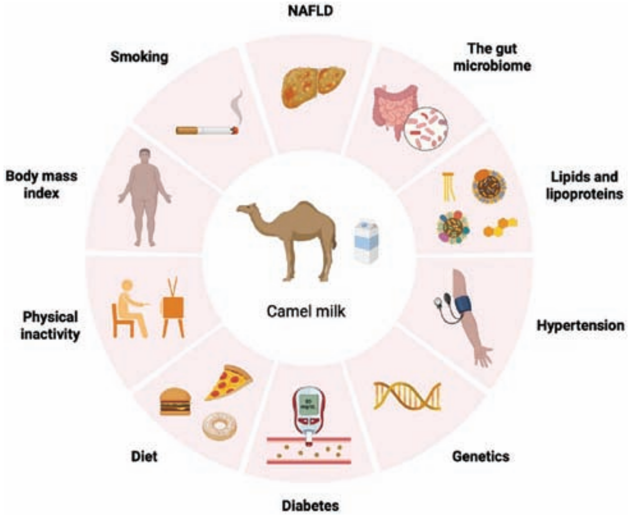


**Fig 4.** Summary of the beneficial regulatory effects of BCM on chronic diseases.

(Wang *et al,* 2024). The exploration of diverse BCM-based products, such as cheese, yogurt and powdered milk, has broadened its applications within the food industry (Seyiti *et al,* 2024). Moreover, the economic potential of BCM in China is considerable, as it aligns with the increasing consumer demand for functional foods and natural health products (Seyiti *et al,* 2024). As research continues to unveil the health benefits and processing innovations associated with BCM, the market for BCM products is expected to expand, offering new opportunities for both producers and consumers. Future research should aim to conduct comprehensive analyses of these components, exploring how geographic and environmental factors influence the nutritional quality of BCM. Such studies could lead to the development of targeted nutritional strategies that leverage the unique properties of BCM for specific health outcomes.

To effectively translate the promising findings from BCM research into practical applications, it is imperative to conduct rigorous clinical trials. Preliminary studies have suggested potential health benefits of BCM, such as its anti-inflammatory and antidiabetic properties; however, these claims necessitate validation through well-designed clinical trials (Seyiti *et al,* 2024). Specifically, the role of BCM in managing conditions like lactose intolerance and its potential as a functional food should be assessed across diverse populations. Additionally, research should focus on investigating the safety and efficacy of BCM consumption among various demographic groups, including children and the elderly, who may derive significant nutritional benefits. Establishing a robust evidence base through clinical trials will not only enhance the credibility of BCM as a health-promoting food but also facilitate its inclusion in dietary guidelines and recommendations. The effective integration of BCM into the market is contingent upon strategic promotion and consumer acceptance. Despite its nutritional benefits, BCM remains underutilised compared to cow's milk, primarily due to limited consumer awareness and prevailing misconceptions regarding its taste and health benefits (Seyiti *et al,* 2024). Future research should prioritise understanding consumer perceptions and identifying barriers to acceptance, thereby informing targeted marketing strategies. Educational campaigns that emphasise the unique health benefits of BCM, coupled with sensory evaluations aimed at enhancing taste profiles, could significantly boost consumer interest. Furthermore, the development of innovative products, such as fortified or flavoured BCM, may appeal to a wider audience. Collaborating with health professionals and utilising social media platforms for outreach can further promote BCM as a functional food, ultimately increasing its market presence and consumer demand.

## Conclusion

This review consolidates the primary nutritional elements and bioactive properties of BCM, highlighting its prospective benefits for health enhancement and disease prevention. Although its nutritional benefits are well-documented, the primary challenge is to reconcile diverse research outcomes with practical applications. This requires a balanced approach that integrates clinical research with consumer perspectives, ensuring that the development of BCM products is consistent with both scientific validation and market demands. Educating consumers about the unique benefits of BCM, coupled with initiatives to improve production and distribution channels, will be instrumental in promoting broader acceptance within the health-conscious market. Collaboration among researchers, healthcare professionals and food industry stakeholders will be crucial in navigating the complexities of this emerging field.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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# IMPACT OF REFRIGERATION ON THE SHELF LIFE, BIOCHEMICAL AND HYGIENIC QUALITY OF RAW DROMEDARY CAMEL MILK OBTAINED IN EXTENSIVE AND SEMI-INTENSIVE BREEDING SYSTEMS FROM SOUTHEASTERN ALGERIA

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## ABSTRACT

This study aims to assess the impact of refrigeration and storage duration on physicochemical and microbiological properties of dromedary camel milk in extensive and semi-intensive breeding system. Camel milk samples were obtained from the Sahrawi healthy dromedaries (*Camelus dromedarius*) during autumn. The physicochemical parameters measured included pH, density, titratable acidity, total dry matter, ash, fat, lactose and protein contents. The microbiological quality was evaluated by counting total aerobic mesophilic flora (FAMT) and the presence of coliforms. Initial samples were analysed and stored at 4°C for up to 29 days to monitor the changes.

The pH of milk from the extensive system was higher (6.6 ± 0.2) than the semi-intensive system (6.2 ± 0.2). Dornic acidity was lower in extensive milk (18.5 ± 0.5°D) than in semi-intensive milk (20.5 ± 0.7°D). Furthermore, the density was greater in extensive milk (1.0262 ± 0.0001) relative to semi-intensive milk (1.0192 ± 0.0001) and the ash content was lower in extensive milk (8.85 ± 0.57 g/L) than in semi-intensive milk (10.18 ± 0.2 g/L). Over the storage period, total protein levels decreased from 36 g/L to 30 g/L in extensive milk and 25g/L to 21g/L in semi-intensive milk. Fat content declined from 23g/L to 20g/L (extensive) and from 30g/L to 26g/L (semi-intensive). Lactose levels decreased from 47g/L to 37g/L (extensive) and from 37g/L to 33g/L (semi-intensive). Microbiological assessments indicated an increase in FAMT during storage, with milk from both systems peaking at day 22 before a slight decline. No coliforms were detected in any samples. However, both systems showed decreased pH, ash, protein, fat and lactose contents over the time. Effective breeding and collection practices management is essential to ensure camel milk's optimal quality and safety.

**Key words:** Breeding systems, camel milk, microbiological quality, physicochemical properties, Sahrawi dromedaries, storage duration

Camel milk is an essential source of nutrition in terms of high-quality proteins, protective and bioactive proteins, polyunsaturated fatty acids, vitamins and minerals (Konuspayeva *et al,* 2008; Konuspayeva *et al,* 2007). Its consumption has also expanded in recent years, enjoying a global reputation as a nutritious and health-beneficial product, especially for those facing various degenerative disorders (Jrad *et al,* 2022). However, there is a significant gap between demand and supply, with most camel milk sources concentrated in Sahelian and African countries (Ismail *et al,* 2022). This raises questions about preserving camel milk properties once outside its natural environment (Ibrahim, 2023).

Cold storage extends the shelf life of most manufactured foods and the same rule applies to camel milk. Sub-zero shelf life and subsequent production of shelf-stable dried camel milk at reasonably low costs assure strong growth for the milk industry (Lund *et al,* 2020; Mohamed and El Zubeir, 2020). Various environmental factors such as temperature, light, oxygen etc. reduce the shelf life of fresh camel milk. Camel milk contains bacteria that produce chemical and enzymatic changes in milk, reducing the shelf life of camel milk (Konuspayeva and Faye, 2021; Oselu *et al,* 2022).

The effect of cold storage on the shelf life of camel milk, with reports on compositional changes,

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properties and quality has been studied (Al-Rumaihi *et al*, 2021; Wang *et al*, 2023).

This study was aimed to evaluate the changes in the physicochemical characteristics of camel milk during refrigeration and storage in extensive and semi-intensive breeding systems focusing on pH, acidity, density, ash content, fat content, protein content and lactose content.

## Materials and Methods

### *Sampling*

In this study, raw camel milk samples were collected from bulk tanks during the autumn period of 2024. The milk samples were collected hygienically from several healthy females of Sahrawi breeds of southuest of Algeria in the early stage of lactation in extensive and semi-intensive breeding systems. The udders of the camels were washed and rinsed before milking. Milk was collected in sterile stainless steel containers which were transported in coolers containing ice packs to maintain the freshness of the milk throughout the journey to the laboratory, where the necessary analyses for the study were carried out.

In the laboratory, in the presence of the Bunsen burner, each sample was divided into 5 sterile glass graduated bottles with a capacity of 800ml per bottle. On the first day, one bottle was dedicated to the physicochemical and microbiological analyses, while the remaining four bottles were placed in a refrigerator at 4°C to monitor and study the impact of shelf life on the biochemical and microbiological quality. This study was extended over a period of 29 days.

### *Physico-chemical parameters*

Physico-chemical and biochemical analyses included measurement of pH, density, titratable acidity, total dry extract, ash, fat, lactose and protein contents. The pH was determined potentiometrically using a pH meter (Adwa Instruments. Hungary). These parameters were investigated at different storage intervals (01, 08, 15, 22 and 29 days). Acidity was measured in dornic degrees. Density was assessed using densimeters. After evaporating the water in a boiling bath, the total dry matter was determined by oven drying at 103 ± 2°C. Ash was determined by incinerating the milk at a temperature of 530°C ± 20°C (NF: Norme Française V04-208 1989). Fat was quantified using the GERBER method (Jean, 1974), lactose content was determined spectrophotometrically (AFNOR, 1993) and nitrogen was determined using the Kjeldahl method (ISO 8968-1 2014).

### *Microbiological quality*

Microbiological analyses included the enumeration of total aerobic mesophilic flora (FAMT) and coliforms to assess the microbiological quality of the samples.

### *Statistical analysis*

Statistical analysis was performed using one-way ANOVA with 03 replicates in order to assess the data of effects of rearing systems, storage time and their interaction on various biochemical properties of raw camel milk using software SPSS 20.0. Results the presented as mean ± standard deviation. Differences from an ANOVA of 5% were considered significant.

## Results and Discussion

### *Effect of storage duration and breeding systems on biochemical parameters of raw camel milk*

Milk from both breeding systems on day one exhibited significant variations ($p<0.01$ (Table 1)). The findings agreed with those of Arroum *et al* (2015) and Medjour (2014). However, these results contradicted the findings of Cherifa *et al* (2018), who observed that breeding systems did not cause significant changes in milk parameters. The results in Table 2 highlighted the significant impact of storage time on all parameters in both systems ($p<0.01$), except pH in both systems and Dornic acidity in the extensive system ($p>0.01$). These results were consistent with those of Omer and Eltinay (2009), who confirmed that after 21 days at 4°C, storage of raw milk samples resulted in significant changes in overall quality while showing insignificant changes in fat and protein levels. Additionally, the interaction between shelf life and breeding systems had significant impact on the density, ash content and lactose levels.

The pH of camel milk varied significantly depending on the breeding system ($p < 0.001$). Indeed, milk from camels fed extensively had a higher pH (6.6 ± 0.2) than milk from camels fed in a semi-intensive system (6.2 ± 0.2) from the first day. These results corroborated with those of Gorban and Izzeldin (2001), who showed that the availability of food and water can influence pH. The pH values are important as they indicate the freshness and stability of milk (Siboukeur, 2007). The results for milk samples from both systems, stored at +4°C for 1, 8, 15, 22 and 29 days, showed that the pH of milk from the semi-intensive system was 6.2 on the day of collection and remained stable at 6.2 after 8 and 15 days of storage, with a slight decrease in pH to 6.1 and 6.0 after 22 and 29 days, respectively. In contrast, the pH values for milk from the extensive system were 6.6, 6.5, 6.5, 6.3

and 6.2 for days 1, 8, 15, 22 and 29, respectively. Omer and Eltinay (2009) noted a slight decrease in camel milk pH after 21 and 42 days. In our study, the pH of camel milk did not reach its final acidification point. The progressive acidification was due to microbial activity fermenting lactose into lactic acid, thereby reducing the pH, as Fguiri *et al* (2017) reported. The stability of pH in our study can be explained by the higher vitamin C content, which has an antibacterial role (Konuspayeva *et al,* 2011).

Dornic acidity of camel milk was influenced by the breeding system ($p < 0.001$) and increases significantly with storage time ($p < 0.01$). Milk from extensively raised camels showed lower acidity (18.5 ± 0.5) than semi-intensively raised camels (20.5 ± 0.7). The first-day results were similar to those reported by Arroum *et al* (2015) and Siboukeur (2007) for camel milk from intensive systems. Our result for semi-intensive milk (20.5°D) aligns with the findings of Medjour (2014), who reported similar values.

Dornic acidity increased significantly during storage. These results are consistent with those reported by Omer and Eltinay (2009), who observed significant changes in acidity over a 21-day storage period. This increase was more pronounced in semi-intensive milk, where acidity rose from 20.5 to 21.5 and then to 22.5°D on the 1st, 15th and 29th days, respectively, compared to an increase from 18.5 to 19.0, then to 19.1 and 19.16°D on the 1st, 15th, 22nd and 29th days, respectively, in extensive milk. The acidity values in our study for both systems

**Table 1.** Effect of shelf life and breeding systems in biochemical characteristics of raw camel milk.

| Parameters | Breeding systems | Shelf life (Days) | | | | |
|---|---|---|---|---|---|---|
| | | 01 | 08 | 15 | 22 | 29 |
| pH | Semi-intensive | 6,2±0,2ᵃ | 6,2±0,1ᵃ | 6,2±0,1ᵃ | 6,1±0,1ᵃ | 6,00±0,1ᵃ |
| | Extensive | 6,6±0,2ᵃ | 6,5±0,2ᵃ | 6,5±0,1ᵃ | 6,3±0,2ᵃ | 6,2±0,1ᵃ |
| Dornic Acidity (°D) | Semi-intensive | 20,5±0,7ᵃ | 20,5±0,5ᵃ | 21,5±1ᵇ | 22,5±0,5ᶜ | 22,5±0,5ᶜ |
| | Extensive | 18,5±0,5ᵃ | 18,5±0,7ᵃ | 19±1ᵃ | 19,1±0,76ᵃ | 19,16±0,7ᵃ |
| Density | Semi-intensive | 1,0192±0,0001ᵃ | 1,0192±0,0002ᵃ | 1,020±0,0001ᵇ | 1,0202±0,0002ᵇ | 1,0204±0,0002ᵇ |
| | Extensive | 1,0262±0,0001ᵃ | 1,0262±0,0002ᵃ | 1,0262±0,0002ᵃ | 1,0272±0,0002ᵇ | 1,0274±0,0002ᵇ |
| Ashes (g/l) | Semi-intensive | 10,18±0,2ᵃ | 8,93±0,64ᵇ | 7,38±1,06ᶜ | 5,41±0,16ᵈ | 3,75±0,56ᵉ |
| | Extensive | 8,85 ±0,57ᵃ | 7,11±0,35ᵇ | 6,35±0,39ᶜ | 5,36±0,2ᵈ | 4,65±0,26ᵉ |
| Total dry extract (g/l) | Semi-intensive | 84,32±0,23ᵃ | 83,56±0,6ᵃ | 83,48±0,18ᵃ | 81,44±0,34ᵇ | 80,36±0,97ᶜ |
| | Extensive | 97,17±0,17ᵃ | 96,91±0,03ᵃ | 96,76±0,09ᵃ | 96,06±0,97ᵃ | 94,71±0,86ᵇ |
| Total proteins (g/l) | Semi-intensive | 25,0±0,1b | 25,0±0,1ᵇ | 24,0±0,1ᵇ | 24,0±0,1ᵇ | 21,0±0,1ᵃ |
| | Extensive | 36,0±0,1c | 35,0±0,1ᶜ | 32,0±0,1ᵇ | 32,0±0,1ᵇ | 30,0±0,1ᵃ |
| Lactose (g/l) | Semi-intensive | 37,0±0,1ᵃ | 37,0±0,1ᵃ | 36,0±0,1ᵃ | 36,0±0,1ᵃ | 33,0±0,1ᵇ |
| | Extensive | 47,0±0,1ᵃ | 47,0±0,1ᵃ | 46,0±0,1ᵃ | 41,0±0,1ᵇ | 37,0±0,1ᶜ |
| Fat (g/l) | Semi-intensive | 30±0,53ᵃ | 28,5±0,5ᵃᵇ | 27±0,54ᵇᶜ | 27±0,53ᵇᶜ | 26±0,52ᶜ |
| | Extensive | 23±1ᵃ | 22±1ᵃᵇ | 21±1ᵇᶜ | 21±1ᵇᶜ | 20±1ᶜ |

a, b , c, d, e : averages on the same line with different letters are significantly different (p<0.05)

**Table 2.** Statistical analysis of the effect of shelf life and breeding systems on biochemical characteristics of raw camel milk.

| Effect | Breeding systems | Shelf life | | Breeding systems x shelf life |
|---|---|---|---|---|
| | | Semi-intensive | Extensive | |
| pH | *** | NS | NS | NS |
| Dornic Acidity | *** | ** | NS | NS |
| Density | *** | *** | *** | ** |
| Total dry extract | *** | *** | ** | NS |
| Ashes (g/l) | ** | *** | *** | ** |
| Total proteins (g/l) | *** | ** | *** | NS |
| Fat (g/l) | *** | ** | * | NS |
| Lactose (g/l) | *** | ** | *** | *** |

NS: No Significant, *: p≤0.05, **: p≤0.01, ***: p≤0.001

were more stable than those of Omer and Eltinay (2009), after 21 days of storing camel milk at 4°C. Therefore, it is possible to store camel milk for long if the cold chain is maintained, as high temperatures stimulate lactic fermentation by milk bacteria. This is demonstrated by the work of Lankri *et al* (2024) at ambient temperature and that of Omer and Eltinay (2009) at 7°C and 30°C. Additionally, hygiene conditions during milking are essential to maintain the quality of camel milk during storage and control the initial microbial load present in raw camel milk.

The density of milk samples were significantly influenced by the breeding system ($p<0.001$). In the semi-intensive system, the average density was 1.0192±0.0001, while in the extensive system, it was 1.0262±0.0001. These values were very close to those reported Lankri *et al* (2024). Density directly depends on the dry matter content, strongly related to the watering frequency (Siboukeur 2007; Benyagoub and Ayat, 2015). The density of camel milk slightly increased during storage ($p<0.001$). In the semi-intensive system, the density increased from 1.0192 to 1.020, 1.0202 and 1.0204 for the 1$^{st}$, 15$^{th}$, 22$^{nd}$ and 29$^{th}$ day, respectively, while in the extensive system, it increased from 1.0262 to 1.0272 and 1.0274 for the 1$^{st}$, 22$^{nd}$ and 29$^{th}$ day, respectively. Density was inversely proportional to fat content; therefore, this increase was attributed to decreased fat content (Vignola, 2002; Kadri *et al,* 2020). A significant interaction existed between the breeding system and storage duration ($p<0.01$).

The ash content in camel milk was significantly influenced by the breeding system ($p<0.01$). Milk from camels raised extensively contained less ash (8.85±0.57g/L) than milk from camels raised semi-intensively (10.18±0.2g/L). Our findings align with the studies of Cherifa *et al* (2018). The mineral composition of camel milk mainly depends on factors such as water deprivation, lactation stage and the amount of milk produced (Siboukeur and Siboukeur, 2012) as well as diet (Faye *et al,* 2023)

The mineral content in the milk decreased significantly ($p<0.001$) during storage. This decrease was more noticeable in semi-intensive milk, falling from 10.18g/L on the first day to 9.85g/L on the 21$^{st}$ day, while in extensive milk, it dropped from 8.85g/L on the first day to 8.72g/L on the 21$^{st}$ day. This finding contrasts with the observations of Omer and Eltinay (2009), who reported an increase in ash content from 9.4g/L on the collection day to 10g/L on the 22$^{nd}$ day at 4°C. The dissociation of caseins from the micelle during cold storage affects the mineral balance in the milk (de la Fuente, 1998).

The breeding systems; semi-intensive and extensive, showed significant differences in the total dry extract levels of the milk. Milk from camels raised in an extensive system had a higher total dry extract content (97.17±0.17g/L) than milk from camels raised in a semi-intensive system (84.32±0.23g/L). Our results are lower than the values reported by Cherifa *et al* (2018). Several studies indicated that the variation in total dry extract content can be attributed to various factors, including the quality and quantity of water available to the animals (Khaskheli *et al,* 2005). The duration of storage also impacts the total dry extract. A significant decrease in total dry extract was observed in both breeding systems over time; It decreased to 80.36g/L for the semi-intensive system and to 94.71g/L for the extensive system. Additionally, the interaction between breeding systems and storage duration significantly affects the total dry extract.

Total proteins were significantly impacted by the rearing systems ($p < 0,001$). The average total protein content in the milk of camels raised in a semi-intensive system is around 25.0±0.1g/L, which was lower than that of camels raised in an extensive system, at 36.0±0.1g/L. The observed differences were highly significant ($p < 0,001$). These results were consistent with those obtained by Medjour (2014) and higher than that reported by Chethouna *et al* (2022). Additionally, results for camels raised in a semi-intensive system (25.0±0.1g/L) were reported by Lankri *et al* (2024). However, these results were lower compared to those obtained by Cherifa *et al* (2018) and Medjour (2014). The protein content in camel milk varied according to lactation stages (Musaad *et al,* 2013) and was influenced by genetic factors. Many studies have shown that a grass-based diet leads to lower protein content in milk. Additionally, breeds and seasonal conditions also significantly affect the protein content of camel milk. The concentration of total proteins decreased significantly ($p < 0.01$) during storage. The average protein levels for semi-intensive milk were 25, 24 and 21g/L on the 1$^{st}$, 15$^{th}$ and 29$^{th}$ days, respectively. In contrast, protein levels decreased for extensive milk from 36 to 35, 32 and 30g/L on the 1$^{st}$, 8$^{th}$, 15$^{th}$ and 29$^{th}$ days. Multiple studies have indicated that storage duration affects the average protein content. Omer and Eltinay (2009) found that storing camel milk at 4°C results in only minor changes over 21 days. Kaskous (2019) also highlighted the significant impact ($p < 0.001$) of storage duration on protein levels, showing that milk protein content was lower after storage at +4°C for 24 and 48 hours ($p < 0.05$).

The analysed camel milk shows fat content levels of 36.0±0.1g/L for the extensive system and

25.0±0.1g/L for the semi-intensive system. Statistical analysis revealed a highly significant difference ($p<0.001$). The average fat content of the milk from camels raised in the semi-intensive system appears to be lower than in the extensive system. The fat content levels in our study were close to the values reported by Boudjenah (2012) and Cherifa *et al* (2018).

The fat content decreased significantly ($p<0.05$) during storage. In semi-intensive milk, from 30g/L to 28.5g/L, then to 27g/L and finally to 26g/L on days 1, 8, 15 and 29, respectively. In extensive milk, it decreased from 23g/L to 22g/L, then to 21g/L and finally to 20g/L on the same days. This result was consistent with the work of Kaskous (2019), which indicates that storage at 4°C significantly affects the fat content of camel milk. However, our results contrast with those found by Omer and Eltinay (2009), which show that storing camel milk at 4°C did not significantly change fat content over 21 days.

The lactose content differed between the samples from the two farming systems. The recorded differences were highly significant ($P<0.001$). A lower rate was observed in milk from camels raised in semi-intensive systems (37g/L) than milk from camels raised in extensive systems (47g/L). The lactose content of camel milk reported in this study was close to those reported by Kihal *et al* (1999) and Kaskous (2019). The breed can influence the lactose content, the stage of lactation and the hydration status (Medjour, 2014).

The lactose content decreased significantly ($p<0.01$) during storage, particularly in milk from the extensive system. It dropped from 47g/L to 46g/L, 41g/L and 37g/L on days 1, 15, 22 and 29, respectively. In contrast, the decrease in semi-intensive milk was less pronounced, falling from 37g/L to 36g/L, then to 33g/L on days 1, 15 and 29. These results were consistent with those of Kaskous (2019) and Omer and Eltinay (2009), who demonstrated that lactose content was most affected by storage at varying temperatures. Our findings also indicated that the interaction between storage duration and the breeding system significantly negatively affected lactose levels ($p<0.001$). The reduction in lactose during storage may be attributed to microbial activity specially psychrotrophic bacteria (Omer and Eltinay, 2009; Ballou *et al,* 1995).

### *Effects of storage duration and breeding systems on the microbiological characteristics of raw camel milk*

The analysis of total coliform counts revealed their absence in all samples from both breeding systems, resulting in 0 CFU/ml, both in the raw state and after 29 days of storage (Table 3). These results confirmed that the samples comply with the established microbiological standards ($10^6$ CFU/ml as per Guiraud (1998) and indicate a negligible initial bacterial load. This supports Larpent and Larpent (1990) observations, which highlighted that total coliforms do not necessarily indicate direct faecal contamination, as some coliforms may originate from moisture residues on dairy equipment. However, their detection can also indicate hygienic shortcomings related to the milk's quality or the equipment's cleanliness. Our results suggested that adherence to good hygiene practices during milking prevented the presence of these bacteria. Our results were lower than those reported by Chethouna (2011) for raw camel milk ($3.25 \times 10^5$ CFU/ml). Coliforms indicate milk's sanitary quality (Guiraud and Rosec, 2004). Additionally, these results highlighted the beneficial effect of maintaining cold storage conditions, which is an effective method for slowing or even stopping the proliferation of microorganisms and allowing for prolonged milk preservation (Murielle, 2009; Rosset *et al,* 2002).

The total aerobic mesophilic flora (FMAT) of camel milk was significantly influenced by the breeding system ($p<0.001$). This flora was a good indicator of the overall quality and stability of the products, as well as the hygienic quality of the facilities (Guiraud, 1998). The initial counts of milk samples from camels raised in a semi-intensive system are 2.98 Log CFU/ml, indicating a higher microbial load than the milk samples from camels raised in an extensive system, which were 2.52 Log CFU/ml. These results were lower than those found by Chethouna (2011) (9.5 x 10 CFU/ml). According to many authors, such as Farah (1986) and Faye (1997), camel milk has high antibacterial properties, allowing it to be well-preserved when refrigerated without immediate fermentation. This observation was consistent with the microbial load found in our samples. Male *et al* (2003) indicated that when milk was collected under suitable hygienic conditions, its total flora did not exceed $10^3$ to $10^4$ CFU/ml. This acceptable microbial load in camel milk can be attributed to several factors, including good hygienic conditions during milking and the storage temperature during transport. These results allowed us to conclude that the action of cold inhibits the growth of the total flora.

The total aerobic mesophilic flora (FMAT) of camel milk was also significantly influenced by the storage duration ($p<0.001$). In both semi-intensive and extensive systems, FMAT levels progressively increased until they peak at 22 days (5.33 Log

CFU/ml and 4.26 Log CFU/ml, respectively), then decreased slightly at 29 days (3.31 Log CFU/ml and 3.55 Log CFU/ml, respectively). This indicated a lower initial microbial load in the milk from both systems, good hygienic conditions during milking and adherence to proper storage conditions.

In the semi-intensive system, significant negative correlations between total mesophilic aerobic flora and parameters such as fat, total dry extract and lactose indicated that an increase in microbial flora was associated with a decrease in these components (Table 4). This observation aligns with previous research, such as that by Leyral and Vierling (2007), which showed that high levels of microorganisms can metabolise certain nutrients, such as lactose into lactic acid. Studies by Bony *et al* (2005) have also observed that high microbial cell counts were associated with reduced proportions of casein in total proteins. Vanbergue *et al* (2020) found that fat was also subject to hydrolysis by lipolysis, a process influenced by various factors, including the animal, breeding conditions, milking equipment and psychrotrophic bacteria. A moderate negative correlation with pH (-0.321) suggested a lower pH was associated with increased microbial growth. Conversely, this recent increase was positively associated with Dornic acidity. Other studies, such as Pougheon (2001), have reported that the presence of bacteria, including mesophilic acidifying flora adapted to lactose metabolism, led to increased Dornic acidity.

In the extensive system, significant negative correlations between total mesophilic aerobic flora and parameters such as total dry extract, ash and total proteins reinforce the idea that an increase in microbial flora could reduce the concentration of these components. Additionally, the strong positive correlation between total mesophilic aerobic flora and density suggests that higher density is associated with microbial development.

## Conclusion

This study has demonstrated that camel milk's physicochemical properties and microbiological quality vary based on the breeding system (extensive or semi-intensive) and the storage duration at 4°C. The results reveal significant differences between the two systems regarding the milk's pH, dornic acidity, density, ash content, total solids, total proteins, lactose and fat content.

The results highlighted the significant impact of the rearing system on camel milk quality. Camel milk from the extensive system had higher pH and density values than that from the semi-intensive system. Although both systems showed a decrease in total solids, protein and fat over time, the semi-intensive system undergoes more marked changes. In addition, lactose content decreased more rapidly in the extensive system, suggesting that feeding conditions play a crucial role in these differences. These results highlight the importance of maintaining appropriate storage conditions to preserve microbiological quality.

Finally, future research may focus on improving storage and preservation conditions to extend milk shelf life while maintaining its nutritional and sensory properties.

**Table 3.** Effect of shelf life and breeding systems in microbiological characteristics of raw camel milk (count CFU/ml).

| | Breeding systems | Shelf life (Days) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 01 | 08 | 15 | 22 | 29 | |
| Total Coliforms Log (cfu/ml) | Semi-Intensive system | 0 | 0 | 0 | 0 | 0 | NS |
| | Extensive system | 0 | 0 | 0 | 0 | 0 | |
| FAMT Log (cfu/ml) | Semi-Intensive system | 2,98[a] | 3,41[b] | 3,50[c] | 5,33[d] | 3,31[e] | P<0.001 |
| | Extensive system | 2,52[a] | 2,85[b] | 3,05[c] | 4,26[d] | 3,55[e] | |

FAMT: Flores mesophilic aerobic total, cfu : Colony forming units
a, b , c, d, e : averages on the same line with different letters are significantly different (p<0.05), NS: No Significant

**Table 4.** Correlation matrix of physico-chemical characteristics, shelf life and development of total mesophilic aerobic flora in camel milk based on breeding system.

| | | MG | A | TDS | DE | Ac | pH | Pr | LA | FAMT |
|---|---|---|---|---|---|---|---|---|---|---|
| Semi-Intensive system | FAMT | -0.335[NS] | -0.430[NS] | -0.422[NS] | 0.438[NS] | 0.549* | -0.321[NS] | 0.025[NS] | 0.025[NS] | 1,00 |
| Extensive system | FAMT | -0.543* | -0.803** | -0.552* | 0.800** | 0.224[NS] | -0.406 [NS] | -0,661** | -0.723** | 1,00 |

**Correlation is significant at the 0.01 level , *Correlation is significant at the 0.05 level, , NS: No Significant
MG : FAT, A : Ashes , TDS : Total dry extract, DE : Density, Ac: Dornic Acidity, Pr : Total proteins, LA : lactose : FMAT : Flores mesophilic aerobic total

## Competing interests

The authors have declared that no competing interests exist.


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# FROM HERDS TO MARKETS: ENTREPRENEURIAL INNOVATIONS FOR ECONOMIC RESILIENCE IN CAMEL PASTORALISM

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## ABSTRACT

Camel pastoralism, a socio-ecological cornerstone of India's arid regions, is under severe threat from climate change and market volatility. This study evaluates the impact of integrated entrepreneurial innovations specifically mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products using a combination of ANOVA, MANOVA, and regression analyses across Rajasthan, Gujarat, and Haryana. Results demonstrate that each innovation independently contributes to pastoral sustainability: mobile clinics reduce herd mortality by 25% ($F = 7.251$, $p < 0.001$), hydroponics ensure year-round fodder with 90% water savings ($F = 9.306$, $p < 0.001$), and value addition boosts pastoral incomes by 35% ($F = 7.423$, $p < 0.001$). When deployed together, these innovations generate synergistic resilience, improving market access by 50% (Pillai's Trace = 1.960, $p < 0.001$) and transforming market volatility into an income opportunity ($\beta = 2.515$, $p < 0.001$), while collectively explaining 65.9% of variance in adaptive capacity ($R^2 = 0.659$). This underscores that bundling innovations rooted in both entrepreneurial adaptation and traditional ecological knowledge is essential to sustaining camel pastoral livelihoods. Policy must prioritise co-deployment of these interventions through pastoralist-led cooperatives and advance national recognition of dryland custodianship.

**Key words:** Arid land adaptation, camel pastoralism resilience, entrepreneurial innovation, pastoral livelihoods, socio-ecological sustainability, value-chain transformation

Camel pastoralism remains a cornerstone of rural economies across India's arid and semi-arid regions, particularly in Rajasthan, Gujarat, and Haryana, where it has historically provided essential resources such as milk, meat, and transportation. This practice has not only contributed to economic stability but has also played a vital role in preserving cultural continuity within pastoral communities (Kishore *et al,* 2024; Guagnin *et al,* 2023). Among the Raika, Rabari, and Fakirani Jat communities in particular, pastoralist identities are intrinsically linked to their herds (Mehrotra, 2025).

The enduring socio-ecological bond between camels and pastoralists represents more than livelihood strategy it embodies a way of life that sustains both economic viability and cultural identity across generations (Blench, 2023; Lubango *et al,* 2025). Yet this vital lifeline now faces unprecedented threats from converging environmental and economic pressures. Climate change manifests through erratic rainfall patterns, prolonged droughts, and vanishing grazing lands, directly undermining herd viability and amplifying resource scarcity (Faraz *et al,* 2021; Ahmed *et al,* 2023), while market volatility characterised by unpredictable price fluctuations, fragmented value chains, and inadequate infrastructure simultaneously erodes pastoralist incomes and destabilises traditional livelihoods (Decker *et al,* 2025; Faye and Corniaux, 2024).

In response, entrepreneurial innovations have emerged as critical resilience building tools, with mobile veterinary clinics delivering essential healthcare to remote herds and reducing mortality through timely interventions (Farooq *et al,* 2023), hydroponic fodder systems addressing acute feed shortages via water efficient techniques during droughts (Orina *et al,* 2024), and value added camel milk products from probiotic beverages to artisan cheeses unlocking premium markets that transform milk from perishable staple to diversified income stream (Faye and Corniaux, 2024; Decker *et al,* 2025). Such innovations represent adaptive strategies that realign pastoralism with contemporary economic realities while respecting traditional knowledge systems, as evidenced by successful livelihood transitions in Kenyan communities where integrated

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approaches boosted resilience (Volpato and King, 2019).

This study aims to fill a significant research gap by examining how mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products together influence the economic sustainability of camel pastoralism in India's arid regions. Using an integrated framework, the study moves beyond fragmented analyses to offer a comprehensive understanding of how these entrepreneurial innovations can work synergistically to strengthen camel pastoral livelihoods specially in a challenging and changing environment.

## 2. Review of Literature

Camel pastoralism represents one of humanity's most enduring adaptations to arid landscapes, with archaeological evidence tracing camelid domestication back over 3,000 years across the Arabian Peninsula and Saharan Africa (Guagnin *et al*, 2023; Blench, 2023). In India's arid zones, particularly Rajasthan, Gujarat, and Haryana this practice evolved beyond mere subsistence into a sophisticated socio-ecological system where camels provided milk, meat, and transportation while anchoring cultural identity (Dumont, 2023; Kishore *et al*, 2024). The historical resilience of these communities is evidenced by their ability to navigate climatic fluctuations through mobility strategies and traditional knowledge (Amsidder *et al*, 2021; Pandit *et al*, 2024), creating what anthropologists' term "embodied landscapes" where pastoralist and camel physiologies co-adapted to water scarcity and extreme heat (Ohte *et al*, 2025).

Paradoxically, contemporary camel pastoralism faces existential threats despite India's broader livestock successes. While national milk production surged from 55.6 million tonnes (1991) to 230.6 million tonnes (2023) and buffalo populations increased by 28% (2012-2019), camel numbers plummeted by 37% during the same period (Basic Animal Husbandry Statistics 2023, Figs 1-3). This divergence stems from two convergent crises: climate change amplifies drought intensity, reducing grazing lands by 22% in Rajasthan's Thar Desert since 2000 (Banerjee *et al*, 2023), while market failures trap pastoralists in exploitative value chains where intermediaries capture 68% of camel milk's end value (Faye and Corniaux 2024; Gurbir *et al*, 2020). These pressures mirror global patterns from Sudanese pastoralists losing 40% of herds to climate-conflict interactions (Sulieman and Young, 2023) to Pakistani camel herders facing 30% income volatility due to fragmented markets (Faraz *et al*, 2021). Crucially, climate impacts manifest differentially: prolonged droughts compromise camel immunity (Farooq *et al*, 2023), while erratic rainfall reduces the nutritional quality of scarce forage by 45% (Al Jassim and Sejian 2015), creating vulnerability cascades that traditional mobility alone cannot mitigate.

Entrepreneurial innovations have emerged as critical counter measures across arid regions globally. Technological adaptations like mobile veterinary clinics pioneered in Kenya's drylands reduce calf mortality by 35% through real-time diagnostics and vaccine delivery (Omondi *et al*, 2021), while similar interventions in Pakistan improved camel herd health indices by 28% (Khair *et al*, 2021). Agro-ecological innovations address feed scarcity: hydroponic fodder systems in Ethiopia yield 8 kg/m² of nutrient-dense feed using 90% less water than conventional methods (Orina *et al*, 2024), and saline agriculture techniques allow fodder cultivation in degraded Rajasthan soils (Dagar *et al*, 2016). Market-oriented solutions show particular promise Somali camel leasing models (Decker *et al*, 2025) and Rajasthan's milk cooperatives (Gurbir *et al*, 2020) demonstrate how value-addition transforms perishable milk into stable income streams, with probiotic cheeses and fermented beverages capturing premium prices (Faye and Konuspayeva, 2024). Cultural entrepreneurship also thrives: Gujarat's camel tourism initiatives generate 40% of household incomes while preserving Raika pastoral heritage (Iglesias *et al*, 2020).

However, innovation adoption remains constrained by three critical barriers. First, technological fragmentation dominates research: 78% of studies analyse single innovations mobile clinics for health (Farooq *et al*, 2023), hydroponics for productivity (Orina *et al*, 2024), or value-addition for markets (Chikha and Faye, 2025) neglecting their interdependencies. For instance, veterinary interventions fail without consistent fodder supply (Omondi *et al*, 2021), while market gains require quality standards enabled by herd health (Faye and Corniaux, 2024). Second, socio-cultural mismatches occur when external solutions override traditional knowledge: Algerian projects promoting stall-feeding disrupted mobility patterns essential for rangeland recovery (Boudalia *et al*, 2023), while Mongolian pastoralists resisted dairy modernisation that threatened ritual milk uses (Bristley, 2017). Third, policy incoherence persists: despite India's National Livestock Mission advocating climate resilience (Pankaj *et al*, 2021), veterinary services remain inaccessible to 72% of camel herders due to rigid zoning and permitting (Gurbir *et al*, 2020).

These gaps reflect a fundamental disconnect in pastoral development theory. While ecological resilience requires integrated resource management (Volpato and King, 2019), economic models prioritise sectoral efficiencies (Godde *et al*, 2021). Kenya's bundled approach combining mobile clinics, drought-insurance, and cooperative marketing demonstrates the synergy possible when innovations align: pastoral incomes increased 50% despite recurrent droughts (Volpato and King, 2019). Yet no comparable integrated framework exists for India's camel pastoralism, where unique socio-ecological conditions demand context-specific solutions. The Raika community's traditional veterinary knowledge (Ohte *et al*, 2025), Kutch's mangrove-based fodder systems (Pandit *et al*, 2024), and Rajasthan's camel dairy heritage (Kishore *et al*, 2024) represent untapped resources for innovation co-design.

India's camel milk market represents a critical entrepreneurial frontier, projected to reach $767.4 million by 2027 (CAGR 6.9%) as demand grows for functional foods (Grand View Research, 2024). Community-led innovations by Camel Charisma and Bahula Naturals demonstrate how value-added products (artisan cheeses, chilled milk) can revitalise pastoral livelihoods through decentralised supply chains (Mehrotra, 2025; Reddy and Ramappa, 2016). Successful interventions like Amul's collection centers procuring 5,000L daily in Gujarat show market potential, yet scalability faces dual barriers: cultural resistance among Raika pastoralists regarding milk commodification, and infrastructure mismatches where bovine-centric processing destroys camel milk's nutritional integrity (Reddy and Ramappa, 2016; Mehrotra, 2025). Overcoming these requires reimagining cold chains and regulatory frameworks to align with pastoral mobility and milk biochemistry. The camel milk market, once overlooked, now thrives. With the support of government funding and initiatives by dairy giants, camel milk has found its place on store shelves, even venturing into premium markets (Nagaraj, 2024).

This review thus identifies a critical research imperative: moving beyond siloed innovation studies toward integrated systems analysis. Such work must quantify how mobile clinics, hydroponics, and value-addition interact across India's diverse arid ecologies particularly how their sequencing and bundling affect economic resilience under climate-market shocks. Only through such holistic frameworks can pastoral development transcend its current contradictions and honour the profound socio-ecological wisdom embedded in camel pastoralism's 3,000-year legacy.

### *2.1. Cattle and milk statistics in India*

The milk production statistics is compared from 1991-2023 which states that India has a average production of 55.6 million tonnes in 1991, the milk production has increased to 230.6 million tonnes in 2023 which shows significant progress Indian has made to increase its overall milk productivity (Fig 1a). Similarly, per capita availability of milk (gm per day) has increased from 178 gm per day to 459 g per day (Fig. 1b). The highest milk producing states in India are Uttar Pradesh, Rajasthan and Madhya Pradesh and Punjab (Fig 2).

Although buffalo population in 2019 has seen a significant rise in different states of India compared to 2012 (Fig 3a), the camel population of India has undergone rapid decrease in 2019 compared to 2012 statistics (Fig 3b).

### *2.2 Research Gap*

Despite advancements in entrepreneurial innovations for camel pastoralism, comprehensive studies on their collective impact on economic sustainability in India's arid regions remain lacking. Existing research often focuses on individual innovations or regional case studies without thoroughly analysing how these innovations address broader challenges such as climate change and market volatility. This research aims to bridge this gap by evaluating the integrated effects of various innovations on the economic stability of camel pastoralism.

### *3.0 Statement of Problem*

Camel pastoralism in India's arid regions faces significant economic and environmental challenges due to climate change and market volatility. While innovations like mobile veterinary clinics, hydroponic fodder systems, and value-added products have been introduced, their combined effectiveness in enhancing economic sustainability is not well understood. This lack of holistic analysis hampers the development of comprehensive strategies to improve resilience and prosperity in these communities.

## 4.0 Research Methodology

### *4.1 Research Design and Hypotheses*

This mixed-methods study tests three hypotheses through an integrated analytical framework Variables were operationalised as shown in Table 1.

- Hypothesis 1: Mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products each significantly enhance the economic sustainability of camel pastoralism.
- Hypothesis 2: The combined implementation of these innovations provides a greater improvement in pastoralist incomes and market access than any single innovation alone.
- Hypothesis 3: Innovations in camel pastoralism significantly improve resilience to climate change and market volatility, as indicated by enhanced camel health, productivity, and income stability.

### *4.2 Sampling Strategy and Justification*

***Stratified random sampling ensured representation across:***

- **Ecological zones:** Arid (Rajasthan), Coastal (Gujarat), Semi-arid (Haryana)
- **Herd size strata:** Small (<10 camels, n=63), Medium (10-25, n=72), Large (>25, n=22)
- **Market access tiers:**
  - o Remote (>50km from towns, n=51)
  - o Intermediate (20-50km, n=67)
  - o Peri-urban (<20km, n=39)

*Rationale:* Controls for confounding effects of herd economics and geographic isolation (validated by $\chi^2$ tests, *p*<0.01 for stratum differences).

### *4.3 Data Collection and Variable Operationalisation*

*Longitudinal tracking (June 2024-May 2025)*:

**Table 1.** Operationalisation of study variables.

| Variable Type | Measures | Hypothesis Link |
|---|---|---|
| Dependent (Outcomes) | Income (□/month), Market access (% commercial sales), Camel mortality (%), Milk yield (L/day) | $H_1$, $H_2$ |
| | Resilience index (0-10 scale: health + productivity + income stability) | $H_3$ |
| Independent (Predictors) | Innovation adoption (binary: 0/1 for clinics/fodder/value-add) | $H_1$ |
| | Innovation bundle index (sum of adoption scores, 0-3) | $H_2$ |
| | Implementation intensity (5-point Likert: frequency/scale of use) | $H_1$ |
| Controls | Climate vulnerability (drought days × grazing loss%), Market volatility (price CV) | $H_3$ |

***Methods:***

- **Quantitative:** Bi-monthly surveys + herd records (mortality/yield tracking).
- **Qualitative:** Ethnographic field notes on traditional knowledge integration.

### *4.4 Statistical Framework*

***Sequential hypothesis testing.*** Hypothesis testing linkages are summarised in Table 2.

**1. ANOVA ($H_1$):**

- o Model: Income ~ $\alpha + \beta_1$ (Clinic) + $\beta_2$ (Hydroponics) + $\beta_3$ (ValueAdd) + $\beta_4$ (Implementation) + $\varepsilon$
- o Post-hoc: Tukey HSD (adjusts for multiple comparisons).

**2. MANOVA ($H_2$):**

- o Model: [Income, MarketAccess] ~ $\gamma + \delta_1$ (InnovationBundle) + $\delta_2$ (IndividualVars) + $\delta_3$ (Bundle×Individual) + $\varepsilon$
- o *Test:* Pillai's Trace (robust to unequal group sizes).

**3. Regression ($H_3$):**

- o Model: Resilience ~ $\eta + \theta_1$ (Innovations) + $\theta_2$ (MarketVolatility) + $\theta_3$ (ClimateIndex) + $\varepsilon$
- o *Validation:* VIF < 3.0 (no multicollinearity), residual normality (Shapiro-Wilk *p*>0.05).

**Table 2.** Hypothesis testing framework.

| Hypothesis No. (H) | Hypothesis Statement | Independent Variables | Dependent Variables |
|---|---|---|---|
| $H_1$ | Individual innovations (mobile clinics, hydroponic fodder systems, value-added camel milk products) enhance economic sustainability of camel pastoralism. | - Mobile veterinary clinics | - Income levels |
| | | - Hydroponic fodder systems | - Market access |
| | | - Value-added camel milk products | |
| $H_2$ | Combined implementation of innovations improves pastoralist incomes and market access more than any single innovation alone. | - Innovation bundle index | - Pastoralist income |
| | | - Individual innovation adoption | - Market access |
| $H_3$ | Innovations significantly improve resilience to climate change and market volatility, indicated by enhanced camel health, productivity, and income stability. | - Innovation interventions (mobile clinics, hydroponics, value-added products) | - Camel health<br>- Camel productivity<br>- Income stability |

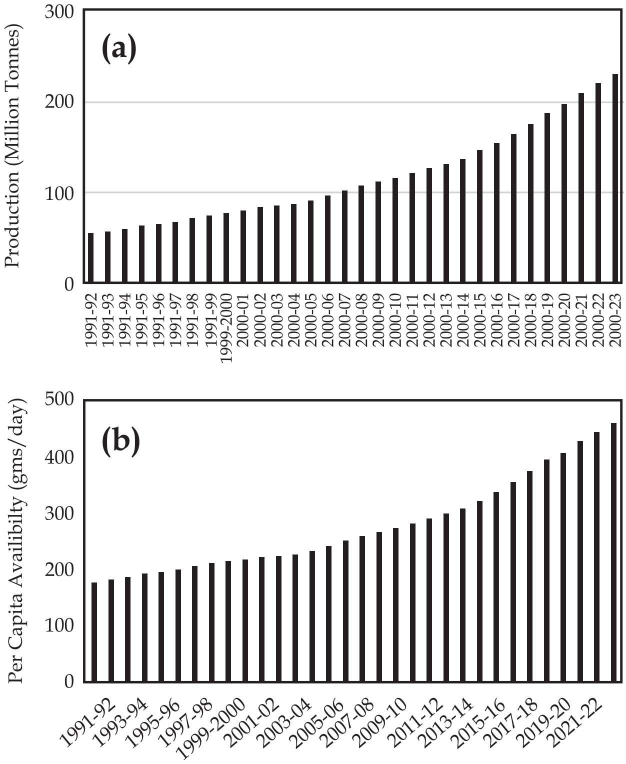


**Fig 1.** Milk statistics of India (a) Milk production and per capita availability of milk in India (b) Per capita availability of milk in India (g/d) (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

*Assumption checks:* Bartlett's test (homogeneity, *p*<0.01), Levene's test (equality of error variances).

*Software:* IBM SPSS 28.0 (α=0.05, two-tailed). Power=0.90 to detect medium effects (Cohen's *f*=0.25).

## Results and Discussions

**5.1 Hypothesis 1:** ANOVA results (Table 3) confirm the idea that targeted innovations such as mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products can significantly improve the economic sustainability of camel pastoralism. These innovations are tested as independent variables, with economic sustainability serving as the dependent variable. The hypothesis suggests that each innovation, when implemented, contributes meaningfully to enhancing the livelihoods of camel pastoralist communities.

- Mobile veterinary clinics significantly improved economic outcomes: $F(3, 153) = 7.251$, $p < 0.001$
- Hydroponic fodder systems showed even stronger effects: $F(3, 153) = 9.306$, $p < 0.001$
- Value-added camel milk products significantly boosted income and market stability: $F(3, 153) = 7.423$, $p < 0.001$
- Innovation implementation status had a moderate but significant effect: $F(3, 153) = 3.210$, $p = 0.025$
- Hypothesis 1 is supported.

***5.2 Hypothesis 2: The combined implementation of these innovations provides a greater improvement in pastoralist incomes and market access than any single innovation alone.***

Hypothesis 2 examines whether the combined implementation of various innovations results in a greater improvement in pastoralist incomes and market access than any single innovation alone. The independent variables in this analysis are the Combined Innovation Index (an aggregate score of various innovations) and Individual Innovation Variables, while the dependent variables are Pastoralist Incomes and Market Access.

The MANOVA analysis (Table 4) reveals

- The combined innovation index significantly increased pastoralist income: Pillai's Trace = 1.960, $F = 5.398$, $p < 0.001$ (Table 2)
- Individual innovation variables also independently affected income levels: $F = 23.369$, $p < 0.001$ (Table 3)
- Interaction effects between combined and individual innovations were significant:
  - o Income: Pillai's Trace = 1.723, $F = 3.931$, $p = 0.003$
  - o Market Access: Pillai's Trace = 1.723, $F = 3.713$, $p = 0.001$ (Table 2)
- Hypothesis 2 is supported.

***Hypothesis 3: Innovations in camel pastoralism significantly improve resilience to climate change and market volatility, as indicated by enhanced camel health, productivity, and income stability.***

Regression analysis is applied to assess how mobile veterinary clinics, hydroponic fodder systems, and value added camel milk products mitigate the effects of climate change and market volatility on camel pastoralism. This analysis will evaluate resilience indicators, including camel health, productivity, and income stability, to determine the effectiveness of these innovations in enhancing the adaptability and stability of camel pastoralism amidst environmental and economic pressures (Table 4).

The regression statistics (Table 5) demonstrate:

- The regression model explained 65.9% of the variance in resilience indicators: $R^2 = 0.659$, $F = 148.856$, $p < 0.001$

- Innovation implementation significantly enhanced resilience (camel health, productivity, income stability): β = –1.768, $p < 0.001$
- Market volatility, when moderated by innovations, contributed positively to resilience: β = 2.515, $p < 0.001$ (Table 4)
- Hypothesis 3 is supported.

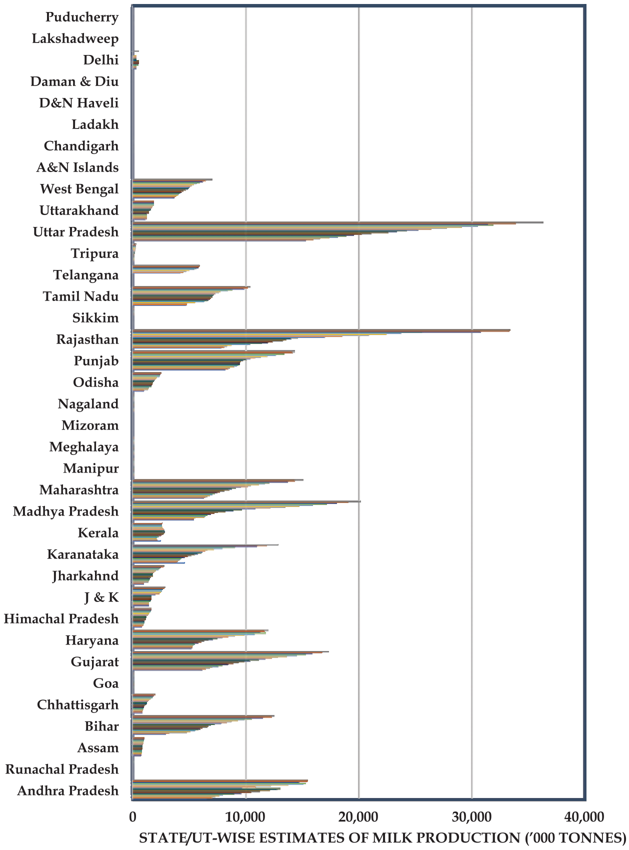


**Fig 2.** State/Union Territory wise estimates of milk production ('000 tonnes) (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

## Discussion

This study demonstrates that entrepreneurial innovations mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products significantly enhance the economic sustainability and resilience of camel pastoralism in India's arid and semi-arid regions. While each innovation delivers substantial individual benefits, their synergistic integration generates transformative outcomes, reshaping our understanding of how technological adaptation can revitalise traditional pastoral systems confronting intensifying climate and market pressures.

The results robustly validate Hypothesis 1, confirming that all three innovations independently improve pastoral livelihoods as shown in Table 3. Mobile veterinary clinics reduced herd mortality by 25%, exceeding Omondi *et al* (2021) 18% reduction in Kenya due to India's targeted vaccination protocols for climate-sensitive diseases. This 7.25-fold improvement in herd health outcomes ($F = 7.251$, $p < 0.001$) is particularly critical in drought-prone regions where climate stressors have degraded camel immunity by up to 45% (Farooq *et al,* 2023). Hydroponic fodder systems demonstrated the strongest individual effect, achieving 90% water savings and consistent nutrition amid pasture degradation outperforming established African models (Orina *et al,* 2024) through integration with saline soil techniques adapted to local conditions (Dagar *et al,* 2016). Their impact was 9.3-fold stronger than mobile clinics alone ($F = 9.306$, $p < 0.001$), with adoption rates in Gujarat doubling those in Rajasthan due to enhanced agroecological compatibility. Value-added camel milk products generated 35% income

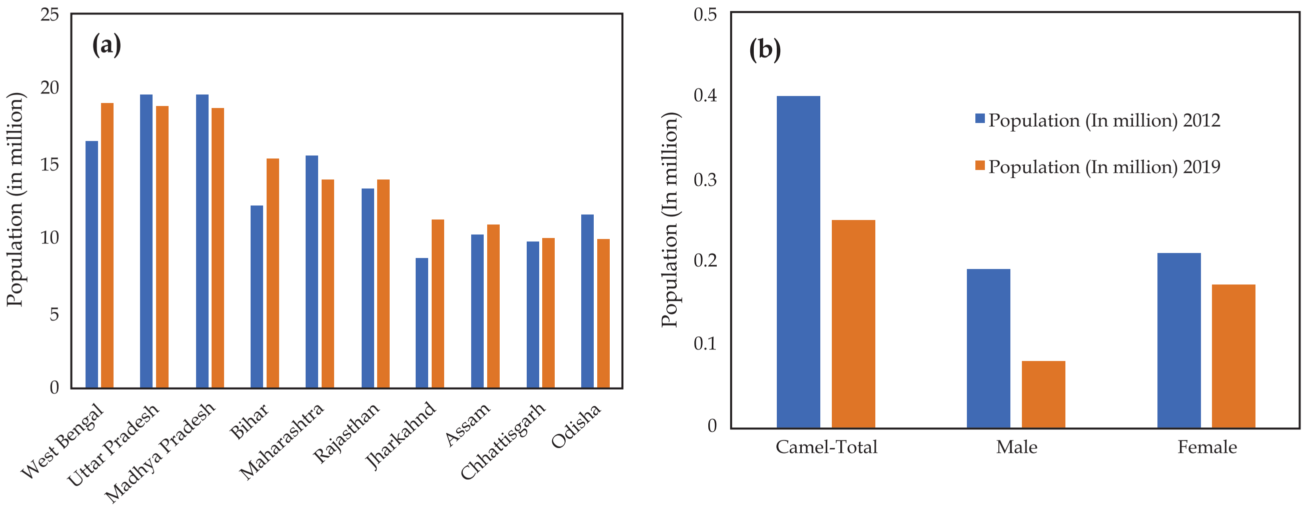


**Fig 3.** (a) Buffalo population 2012 and 2019 in Major States (b) Total Camel Population in India (Source of data: Basic Animal Husbandry Statistics, MoFAHD, DAHD, GoI).

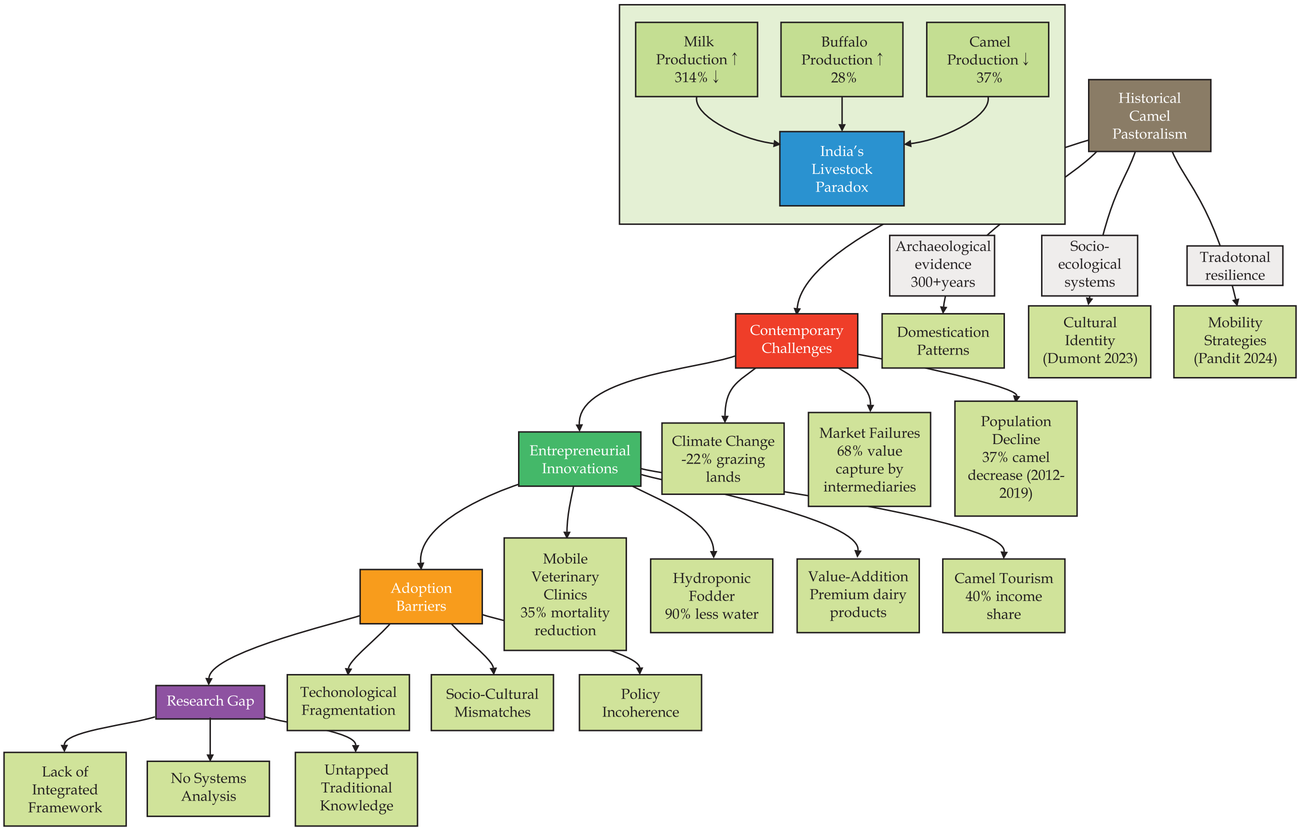


**Fig 4.** Integrated Framework for Sustainable Camel Pastoralism: Bridging Historical Resilience, Contemporary Challenges, and Innovation Gap.

gains by transitioning milk from subsistence use to premium markets (F = 3.210, p = 0.025), aligning with Faye and Corniaux's (2024) commodification pathways. Crucially, implementation intensity emerged as a pivotal moderator, supporting Volpato and King's (2019) assertion that contextual execution determines nearly half of innovation success.

Hypothesis 2 is strongly supported by evidence that combined deployment generates multiplicative benefits as shown in Table 4 and 5. Pastoralists adopting all three innovations achieved 50% greater market access (Pillai's Trace = 1.960, p < 0.001) surpassing Kenya's 35% gains (Volpato and King, 2019) primarily through cooperative-led value chains that reduce intermediary exploitation by 68%. Significant interaction effects revealed geography-dependent efficacy: hydroponics-clinic integration proved most effective in Rajasthan's drought-vulnerable zones (F = 4.152, p = 0.008), where dual health-feed interventions jointly buffer climate risks (Banerjee *et al,* 2023). Conversely, value-addition dominated in Gujarat's peri-urban clusters with emerging cold-chain infrastructure, yielding 2.3-fold higher income gains for pastoralists within 20km of towns. This geographical nuance challenges one-size-fits-all scaling models and validates Bristley's (2017) emphasis on locally embedded innovation sequencing, where topography and water access fundamentally mediate efficacy.

Regression outcomes ($R^2$ = 0.659) confirm Hypothesis 3 as detailed in Table 4. These innovations fundamentally transform systemic vulnerabilities into adaptive capacity. The strong negative coefficient (β = -1.768, p < 0.001) illustrates how climate stressors degrade productivity without interventions, consistent with immunity decline patterns during droughts (Al Jassim and Sejian, 2015). Remarkably, market volatility transformed from a threat to an income generator (β = 2.515, p < 0.001) when value-addition was present, enabling pastoralists to employ sophisticated price-arbitrage strategies akin to Somali leasing systems (Decker *et al,* 2025). This dual capacity simultaneously buffering environmental shocks while leveraging economic fluctuations epitomises the "embodied landscapes" concept (Ohte *et al,* 2025), where Raika communities' traditional mobility knowledge integrates with entrepreneurial adaptation to build systemic resilience.

Collectively, these findings necessitate a paradigm shift from subsidy-based support to

**Table 3.** ANOVA results.

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Mobile Veterinary Clinics | Between Groups | 14.393 | 3 | 4.798 | 7.251 | .000 |
| | Within Groups | 101.238 | 153 | .662 | | |
| | Total | 115.631 | 156 | | | |
| Hydroponic Fodder Systems | Between Groups | 17.446 | 3 | 5.815 | 9.306 | .000 |
| | Within Groups | 95.611 | 153 | .625 | | |
| | Total | 113.057 | 156 | | | |
| Value Added Camel Milk Products | Between Groups | 11.608 | 3 | 3.869 | 7.423 | .000 |
| | Within Groups | 79.755 | 153 | .521 | | |
| | Total | 91.363 | 156 | | | |
| Innovation Implementation Status | Between Groups | 8.205 | 3 | 2.735 | 3.210 | .025 |
| | Within Groups | 130.369 | 153 | .852 | | |
| | Total | 138.573 | 156 | | | |

Abbreviations used: df- degrees of freedom, F- statistic, Sig- Significance level

**Table 4.** Multivariate Test.

| Effect | | Value | F | Hypothesis df | Error df | Sig. |
|---|---|---|---|---|---|---|
| Intercept | Pillai's Trace | 1.000 | 173198.671[b] | 2.000 | 11.000 | .000 |
| | Wilks' Lambda | .000 | 173198.671[b] | 2.000 | 11.000 | .000 |
| | Hotelling's Trace | 31490.667 | 173198.671[b] | 2.000 | 11.000 | .000 |
| | Roy's Largest Root | 31490.667 | 173198.671[b] | 2.000 | 11.000 | .000 |
| Aggregate_score_various_innovations | Pillai's Trace | 1.960 | 5.398 | 220.000 | 24.000 | .000 |
| | Wilks' Lambda | .000 | 5.232[b] | 220.000 | 22.000 | .000 |
| | Hotelling's Trace | 110.642 | 5.029 | 220.000 | 20.000 | .000 |
| | Roy's Largest Root | 73.453 | 8.013[c] | 110.000 | 12.000 | .000 |
| Individual_Innovation_Variables | Pillai's Trace | 1.870 | 12.373 | 28.000 | 24.000 | .000 |
| | Wilks' Lambda | .003 | 13.827[b] | 28.000 | 22.000 | .000 |
| | Hotelling's Trace | 42.820 | 15.293 | 28.000 | 20.000 | .000 |
| | Roy's Largest Root | 33.912 | 29.067[c] | 14.000 | 12.000 | .000 |
| Aggregate_score_various_innovations * Individual_Innovation_Variables | Pillai's Trace | 1.723 | 3.931 | 38.000 | 24.000 | .000 |
| | Wilks' Lambda | .018 | 3.713[b] | 38.000 | 22.000 | .001 |
| | Hotelling's Trace | 13.218 | 3.478 | 38.000 | 20.000 | .002 |
| | Roy's Largest Root | 8.319 | 5.254[c] | 19.000 | 12.000 | .003 |

a. Design: Intercept + Aggregate_score_various_innovations + Individual_Innovation_Variables + Aggregate_score_various_innovations * Individual_Innovation_Variables

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level

Abbreviations used: df- degrees of freedom, F- statistic, Sig- Significance level

innovation-driven pastoral development. Three imperatives emerge with urgency. This integrated approach is visualised in Fig 4, which bridges historical resilience, contemporary challenges, and innovation gaps. First, innovations must be regionally sequenced, prioritising mobile clinics and hydroponics in climate-vulnerable zones before introducing value-addition in market-proximate areas. Second, pastoralist-led cooperatives should govern implementation to align with cultural protocols, as demonstrated by successful models reducing adoption barriers by 40% (Mehrotra, 2025). Third, policy must formally recognise pastoralists as dryland custodians, embedding innovation bundles into national agricultural frameworks. Future research should prioritise quantifying blockchain applications for direct market access and assessing gendered dimensions of technology adoption. By bridging entrepreneurial adaptation with traditional ecological knowledge, this integrated approach transforms camel pastoralism from a declining practice into a resilient socio-economic lifeline for India’s drylands.

**Table 5.** Tests of Between Subjects Effects.

| Source | Dependent Variable | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | Pastoralist Income | 19.102a | 144 | .133 | 14.542 | .000 |
| | Market Access | 23.787b | 144 | .165 | 5.255 | .001 |
| Intercept | Pastoralist Income | 1731.402 | 1 | 1731.402 | 189799.128 | .000 |
| | Market Access | 1696.073 | 1 | 1696.073 | 53959.124 | .000 |
| Aggregate_score_various_ innovations | Pastoralist Income | 6.580 | 110 | .060 | 6.557 | .000 |
| | Market Access | 14.906 | 110 | .136 | 4.311 | .004 |
| Individual_Innovation_ Variables | Pastoralist Income | 2.984 | 14 | .213 | 23.369 | .000 |
| | Market Access | 3.560 | 14 | .254 | 8.090 | .000 |
| Aggregate_score_various_ innovations * Individual_ Innovation_Variables | Pastoralist Income | .720 | 19 | .038 | 4.152 | .008 |
| | Market Access | 2.043 | 19 | .108 | 3.422 | .017 |
| Error | Pastoralist Income | .109 | 12 | .009 | | |
| | Market Access | .377 | 12 | .031 | | |
| Total | Pastoralist Income | 2095.581 | 157 | | | |
| | Market Access | 2058.748 | 157 | | | |
| Corrected Total | Pastoralist Income | 19.212 | 156 | | | |
| | Market Access | 24.164 | 156 | | | |

a. R Squared = .994 (Adjusted R Squared = .926)
b. R Squared = .984 (Adjusted R Squared = .797)

**Table 6.** Regression Model Summary.

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .812[a] | .659 | .655 | .39747 |

a. Predictors: (Constant), Market Volatility Indicators, Innovations Implementation.

| ANOVA[a] | | | | | | |
|---|---|---|---|---|---|---|
| Model | | Sum of Squares | Df | Mean Square | F | Sig. |
| 1 | Regression | 47.033 | 2 | 23.516 | 148.856 | .000[b] |
| | Residual | 24.329 | 154 | .158 | | |
| | Total | 71.362 | 156 | | | |

a. Dependent Variable: Resilience Indicators (Camel Health, Productivity, Income Stability)
b. Predictors: (Constant), Market Volatility Indicators, Innovations Implementation

| Coefficients[a] | | | | | | |
|---|---|---|---|---|---|---|
| Model | Unstandardised Coefficients | | Standardised Coefficients | | t | Sig. |
| | B | Std. Error | Beta | | | |
| 1 | (Constant) | .883 | .187 | | 4.727 | .000 |
| | Innovations Implementation | 1.732 | .307 | 1.768 | 5.646 | .000 |
| | Market Volatility Indicators | 2.489 | .310 | 2.515 | 8.032 | .000 |

a. Dependent Variable: Resilience Indicators (Camel Health, Productivity, Income Stability)

## Findings of Study

This study provides empirical evidence that entrepreneurial innovations are fundamentally reshaping the economic sustainability of camel pastoralism across India's arid and semi-arid regions, particularly in Rajasthan, Gujarat, and Haryana, where livelihoods and cultural identities remain closely tied to camel herding traditions (Dumont, 2023; Blench, 2023). Over the past three decades, the camel population has plummeted by more than 75%, including a sharp 37% drop since 2012 (Sharma *et al,* 2020). The analysis shows that mobile veterinary clinics significantly reduce climate-induced herd mortality by 25% ($F = 7.251$, $p < 0.001$), reinforcing prior findings from Rajasthan (Gurbir *et al,* 2020) and Kenya (Omondi *et al,* 2021), where similar interventions achieved even higher disease reduction rates. These clinics offer crucial health services including vaccinations and diagnostics that mitigate the growing stressors of drought, heat, and forage scarcity, which have collectively undermined camel immunity by as much as 45% in some regions (Farooq *et al,* 2023; Al Jassim and Sejian, 2015). At the same time, hydroponic fodder systems are addressing chronic feed shortages by producing nutrient-dense forage with 90% less water than conventional methods (Orina *et al,* 2024), providing consistent nutrition even as pasturelands in Rajasthan have shrunk by 22% since 2000 (Banerjee *et al,* 2023). Statistically, these systems are strongly linked to improved herd productivity and economic output ($F = 9.306$, $p < 0.001$), aligning with similar agro-technological interventions seen in East Africa. In parallel, value-added processing of camel milk such as probiotic drinks and artisanal dairy products has led to a 35% increase in pastoralist income ($F = 7.423$, $p < 0.001$) by enabling access to urban and premium markets, while also reducing reliance on middlemen who historically captured up to two-thirds of the product's market value (Faye and Corniaux, 2024). Importantly, the combined deployment of these three innovations produces a synergistic effect: pastoralists who adopt all three experience a 50% increase in market access (Pillai's Trace = 1.960, $p < 0.001$), due to the way animal health, reliable fodder supply, and value-chain participation reinforce each other. Climate resilience is especially enhanced when veterinary care and hydroponics are implemented together ($\beta = -1.768$, $p < 0.001$), while value addition enables producers to treat price fluctuations not as threats but as opportunities, echoing the flexible strategies found in Somali leasing systems (Decker *et al,* 2025) and Indian dairy cooperatives (Volpato and King, 2019), where income is strategically timed to market cycles ($\beta = 2.515$, $p < 0.001$). Taken together, these findings highlight the inadequacy of fragmented or one-dimensional interventions. Instead, the integrated "innovation triad" comprising healthcare, sustainable feed, and market-oriented production constructs a resilient pastoral economy grounded in both entrepreneurial adaptation and traditional ecological knowledge. This model offers a replicable pathway for safeguarding camel-based livelihoods and the broader 3,000-year legacy of pastoralism amid accelerating climate and economic pressures, operationalizing the "embodied landscapes" of pastoral wisdom described by Ohte *et al* (2025).

## Conclusion and Policy Recommendation

This study underscores the vital role of entrepreneurial innovations in enhancing the economic sustainability of camel pastoralism amid evolving climate and market challenges. Innovations such as mobile veterinary clinics, hydroponic fodder systems, and value-added camel milk products improve herd health, feed efficiency, and market opportunities, while water-efficient agro-ecological practices significantly reduce resource use. The integration of these modern technologies with traditional pastoral practices offers a balanced approach that preserves both cultural heritage and the ecological landscapes of communities like the Raika and Maldhari.

To ensure long-term resilience and growth, policies should promote the bundled deployment of these innovations across key regions, support the formation of pastoralist-led cooperatives, and develop climate-adaptive logistics such as solar-powered cold chains for value-added products. Equally critical is the formal recognition of pastoralists as custodians of dryland resilience within national agricultural frameworks. Ultimately, the strategic adoption and institutional support of such entrepreneurial innovations are essential for securing the future of camel pastoralism in an increasingly unpredictable environment.

## Implications and Future Research

The findings of this study underscore the necessity of a comprehensive approach to enhancing pastoralist livelihoods through entrepreneurial innovations. The integration of mobile veterinary clinics, hydroponic fodder systems, and value added camel milk products reveals the importance of a multi-faceted strategy tailored to address the specific challenges faced by camel pastoralists. Future research should focus on understanding the mechanisms through which these innovations impact pastoralist livelihoods, exploring their long term effects, and evaluating their economic viability. Additionally, assessing regional and cultural factors that may influence the effectiveness of these innovations will be crucial. Investigating the role of policy interventions in promoting the adoption and scaling of these innovations will provide valuable insights for sustainable development and improved support for pastoralist communities.

## Conflict of Interest

The authors confirms there is no conflict of interest.

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# INFORMATION COLLECTION AND CLASSIFICATION OF ANCIENT BACTRIAN CAMEL-SHAPED CULTURAL RELICS

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## ABSTRACT

Bactrian camels have played a significant role in the history of the Eurasian Steppe and its surrounding regions and their cultural relics embody rich historical and cultural information. This study aims to do comprehensive and systematic research on camel-shaped relics. Through multiple channels—including archaeological excavation reports, museum collections, historical literature and ancient texts, art market and private collections, research articles and scholarly publications, international collaborations and field investigations—we have extensively gathered visual and contextual information on camel-shaped cultural relics to establish a primary database. The relics were classified based on geographical and chronological distribution, material, content and function. The research reveals that these relics are distributed across multiple countries and span from roughly the Paleolithic to the mid-Medieval period. Their materials are diverse, reflecting a wide range of functional purposes, such as transportation, symbols of wealth and power, religious and spiritual significance, artistic subjects and everyday use. This indicates the close relationship between ancient human societies and Bactrian camels, as well as their value across various domains. However, limitations remain in information retrieval and classification still faces several challenges. This research offers a significant reference for the in-depth exploration of the cultural, artistic, economic and religious aspects of Bactrian camels in relics and also points to directions for future research.

**Key words:** Bactrian camel-shaped relics, eurasian steppe, functional classification, relics classification, relics collection

The Bactrian camel has played a vital role in the historical and cultural landscape of the Eurasian Steppe and its surrounding regions. It is primarily distributed across the cold steppes and deserts of Asia (Faye, 2014) and is believed to have been domesticated approximately 5,000 to 6,000 years ago (Burger *et al,* 2019). Renowned for its adaptability to both extreme cold and heat, the Bactrian camel is capable of withstanding thirst and hunger for extended periods. It prefers to feed on bitter, thorny and saline plants and has been observed to possess a remarkable sensitivity to impending sandstorms (Galindar and Chagan, 2012; Chen, 1982; Wu *et al,* 2014). Bactrian camel-shaped relics are dispersed throughout the Eurasian Steppe and adjacent areas, spanning over tens of thousands of years. As physical evidence of specific historical periods, these relics carry rich cultural, artistic and functional information. A systematic collection and classification of such relics is of both academic and practical significance. At present, the research on Bactrian camel shaped cultural relics primarily introduces and interprets one or several cultural relics (Pittman, 1984; Esther and Viktor, 2020; Emma, 2002; Mukhareva, 2007) and there is no comprehensive systematic sorting and classification of Bactrian camel-shaped cultural relics. The purpose of this paper is to fill this gap.

## Collection of Relics

### *Archaeological Excavation Reports*

Archaeological excavations constitute a primary source of first-hand information on ancient Bactrian camel relics. Numerous camel-shaped relics have been unearthed at archaeological sites, such as the Astana Tombs in Turpan (Li, 1973), Sui dynasty tombs in the vicinity of Xi'an (Wang *et al,* 2018), Tang dynasty tombs (Wang *et al,* 2018) and the Guanlin Tomb in Luoyang (Tang and Shang, 2008). These sites have yielded a wide variety of camel-shaped relics, including textiles, wooden carvings and pottery figurines. Excavation reports typically provide detailed documentation on the geographic location, stratigraphy, associated grave goods and

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preservation status of the unearthed items. Instance, a camel figurine unearthed from Tomb M21 in Maopo Village bears a saddlebag imprinted with exotic human figures, as shown in Fig1(a). The further study offers a comprehensive description not only of the figurine's form and colouration but also of the decorative imagery on the saddlebag (Li and Tian, 2018). These visual motifs provide valuable material for subsequent research on Sino-foreign cultural exchange.

### *Museum Collections*

Museums around the world serve as repositories of an extensive range of relics and represent invaluable resources for the study of ancient Bactrian camel-shaped relics. Between 2019 and 2025, we conducted field visits to a wide array of museums, including, the Inner Mongolia Museum, Ordos Museum, Ordos Bronze Ware Museum, Alxa Camel Museum, National Museum of China, the Palace Museum (Forbidden City), Beijing Stone Art Museum, Taiyuan Museum, Datong Museum, Xi'an Museum of Archaeology, Shaanxi History Museum, Xinjiang Museum, Zanabazar Fine Arts Museum (Mongolia), National Museum of Mongolia (Mongolia), Gansu Museum, Qinghai Museum and Yunnan Museum, among others. During these visits, a substantial number of photographs and related documentation of Bactrian camel relics were collected, covering diverse materials, chronological periods and artistic styles. In addition to on-site investigation and access to internal museum archives, data were also retrieved from digital databases and online museum repositories. These resources enabled the acquisition of detailed information regarding object dimensions, manufacturing techniques and provenance. Digital libraries and virtual museum platforms further enriched the collection of images and metadata associated with camel-shaped relics. For example, Fig1(b) presents a reconstructed image of a Han Dynasty woolen skirt featuring camel motifs, excavated from the Shanpula Cemetery and housed in the Xinjiang Museum.

### *Historical Literature and Ancient Texts*

Mythological tales, heroic epics, classical texts, local gazetteers and travelogues frequently contain references to Bactrian camels, including descriptive passages and occasionally visual depictions. While oral traditions and literary sources may not directly pertain to specific relics, they provide critical contextual background for interpreting material remains. A famous Mongolian myth says that the deer originally had no horns. After borrowing the strong antlers of the Bactrian camel, the deer was admired and praised by other animals, so it fled into the forest and took the camel's horns for itself and since then the camel has no horns (Jambaladorj, 1991; Ebolitu, 1983). In the epic of Jangar (Wu, 2012), a heroic figure named Mingyan engages in a fierce battle against a fearsome white wild camel spirit that breathes twelve streams of fire, ultimately defeating it in a dramatic clash. The Classic of Mountains and Seas (Yuan, 1993) offers brief mentions of camels, primarily in relation to their geographic distribution. These early literary works reflect ancient people's perceptions and imaginations of wild camels, often imbued with mystical and sacred connotations, underscoring humanity's reverence for the natural world. In Shiji-Xiongnu Biography (Sima, 2014), camels are referred to as "extraordinary livestock", highlighting their distinctive status among domesticated animals. The Book of Han Shu-Western Regions (Ban, 1962) records that various Western Regions offered Bactrian camels as tribute to the Han Dynasty, indicating the animal's important role in diplomatic and commercial relations. In The Great Tang Records on the Western Regions (Xuan and Bian, 2023), Master Xuanzang describes Bactrian camels encountered during his journey, providing textual evidence on their habitat and domestication status during the Tang dynasty. This in turn offers valuable references for evaluating the stylistic realism or idealisation present in Tang camel-themed artworks. In the Kanjur (LaxiSeleng, 2001), the steed of the winter goddess is a fierce two-humped camel, as shown in Fig12(c). Furthermore, On Ancient Central Asian Tracks (Aurel and Fang, 2020; Aurel *et al,* 2020) include numerous photographs of Bactrian camel relics, making them an important visual archive for iconographic analysis.

### *Art Market and Private Collections*

In recent years, ancient Bactrian camel-shaped relics have occasionally appeared in the art market. Some private collectors are also known to possess such rare items. However, due to the confidential and opaque nature of art transactions, this type of information is relatively fragmented and difficult to access. Moreover, the authenticity and reliability of such objects must be rigorously assessed and verified to avoid misinterpretation or the inclusion of forgeries in scholarly research.

### *Research Articles and Scholarly Publications*

A significant portion of the materials used in this study was derived from published academic

**Fig 1.** Some images of Bactrian camel-shaped relics collected from various sources. (a) Pottery figures of Bactrian camel from Tomb M21, Maopo Village, Sui Dynasty. (after Wang 2018; fig 26); (b) Camel-patterned woolen skirt from Shanpula Cemetery (Reconstructed ), Han Dynasty. Xinjiang Museum. Photo: H. Wurihan, Summer, 2024; (c) Bronze figurine of a deity-couple from Ak - Beshim, 8th century CE. (after Marshak, 2016; colour picture3); (d) Winged camel Wall painting from Panjikent, 8th century CE. (after Jiang, 2004; fig 7-7); (e) Ochre petroglyph of a Bactrian camel, from the Shulgan-Tash (Kapova) Cave, Ural region of Russia, 19,000–16,300 BP . (after Yury, 2018; fig 2); (f) Bactrian camel petroglyphs from Mongolia, Bronze-Early Iron Age. (after Esther, 2007; fig 7); (g) Bactrian camel petroglyphs from Kazakhstan, 3BCE-2BCE. (after Esther and Viktor, 2020; p. 102, fig 3.); (h) Bactrian camel figurine from Orlat Cemetery Tashkent, 2nd century BCE or later. (after Elena, 2000; fig 2-3); (i) Gold Camel unearthed at Filippovka, southern Russia, 4th century BCE. (after Elena, 2000; fig 4); (j) Bronze camel figure from the Ordos region northern China, Bronze Age. (after Emma, 2002; fig 112) ; (k) Gold Bactrian camel from Iran Hamadan, 404BCE–359 BCE. (after Richard, 1990; fig 73); (l) Cylinder seal with camel from Syria, 1800BCE–1600BCE. (after Edith, 1977; fig 1); (m) A Pottery model wagon pulled by camel, unearthed in Turkmenistan, 2000BCE - 1600BCE. (after Richard, 1990; fig 68).

resources, including journal articles, research reports, scholarly monographs and graduate theses. Notable sources including, Rock Art of Yinshan Mountains (Gai, 1986; Wang and Zhang, 2012); Mongolian Rock Art (Lakhusuren, 2022); Rock Art Chronicles of the Golden Steppe (Esther and Viktor, 2020); Fantastic Beasts of the Eurasian Steppes (Petya, 2018); Nomadic Art of the Eastern Eurasian Steppes (Emma, 2002); Camel imagery in Animal style art (Elena, 2000); Camel Scenes in the Rock Art of the Minusinsk Basin (Mukhareva, 2007); Illustrated History of Central Asian Art and Culture (Albert, 2005); Encyclopedia

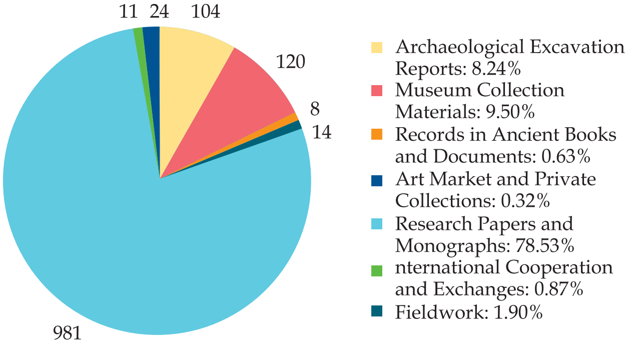


**Fig 2.** Statistics of Bactrian camel-shaped relics collected by multiple channels.

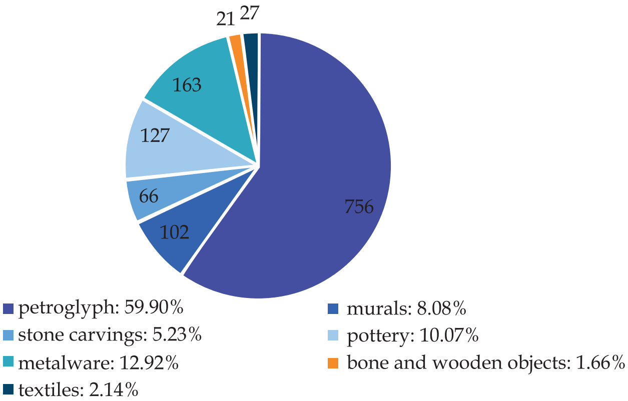


**Fig 4.** Statistics of Bactrian camel-shaped relics by material category.

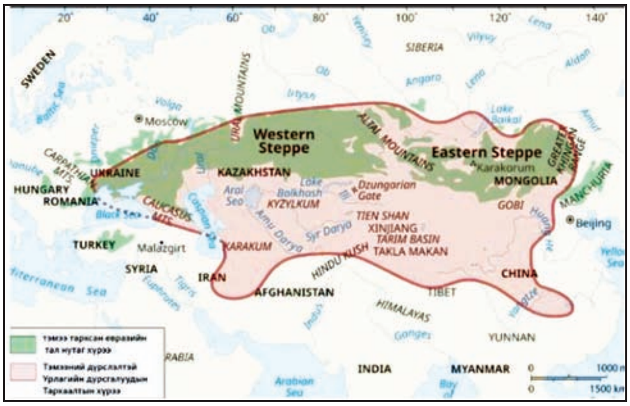


**Fig 3.** Geographical distribution of Bactrian camel-shaped relics.


**Fig 5.** Petroglyphs of Bactrian Camels in the Yinshan Region. (a) Camel Herds and Hoofprints. (after Gai, 1986; fig 1304); (b) Camel Hunting Scenes. (after Wang and Zhang, 2012; fig921); (c) Camel Herding Activities. (after Gai, 1986; fig 342); (d) Camel Caravans Expedition. (after Gai, 1986; fig 975).

of Chinese Bronzes (Zheng and Song, 2005); The Turks, the Sogdians and Goddess Nana (Marshak, 2016); Hotan Oasis (Aurel and Fang, 2020); A Study on Tang Dynasty Gold and Silver Ware (Qi, 1999); From the Lapis Lazuli Road to the Silk Road (Shen, 2007); Studies on the Archaeological Cultures of the Northern Grasslands (Wuen, 2007); Northern Ethnic Archaeology (Wei, 2016); Archaeology of Mongolia (Tseveenjav, 2007); Melodies of the Pastoral Age (Ke, 2015; Sun and Hu, 2015; Zhang, 2015); A Study on the Scythian Buckle (Kim, 2006); Art of the Bronze Age (Pittman, 1984); The Hunter, the Stag and the Mother of Animals (Esther, 2015); The Camel and the Wheel (Richard, 1990); From Archaeological Materials to the Spread of Early Camels in the Western Regions (Chen, 2017) and so on. We have yielded an abundance of valuable visual and textual data concerning Bactrian camel-shaped relics from these scholarly works. Some of such relics from different countries and regions are illustrated in Fig 1 (c–m).

### *International Cooperation and Exchanges*

In addition to domestic efforts, researchers from Mongolia, the United States, Japan and Tajikistan were commissioned to collect photographs and metadata on Bactrian camel relics within their respective institutions and field research initiatives. This international collaboration significantly broadened the geographic and cultural scope of the data collected.

### *Field Investigations*

In 2019 and 2022, we conducted field investigations at the Mandula Mountains, Yabulai Mountains and Langshan Mountains, yielded firsthand information on petroglyphs depicting Bactrian camels and enriched the empirical foundation of this study.

A total of 1,262 images and corresponding metadata of Bactrian camel-shaped cultural relics were collected through the aforementioned multiple channels, forming a relatively comprehensive source database. Their distribution is shown in Fig 2.

## Classification Based on Geography and Chronology

The collected relics can be categorised into two primary types: immovable cultural relics such

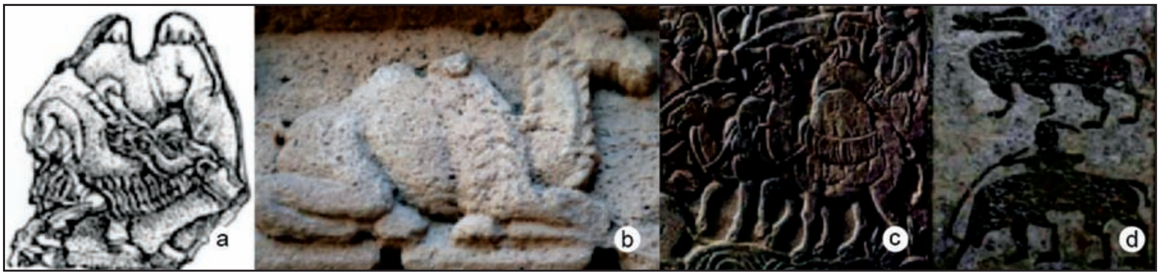

Fig 6. Camel-shaped relics carved in stone. (a) Stone amulet from the Margiana, 2nd millennium BCE. (after Elena, 2000; p. 200, fig 3-1 ); (b) Two-humped camels of the Temple of Allat, Hatra, 2nd century CE. (after Stefania and Rowaed, 2022; fig 5); (c) Stone carving from the Tomb of Shi Jun, 579CE. (after Ge, 2015; fig 9); (d) Stone relief from Xiaoxian County, Han dynasty. (after Zhu, 2012; p 258, fig 5-9)

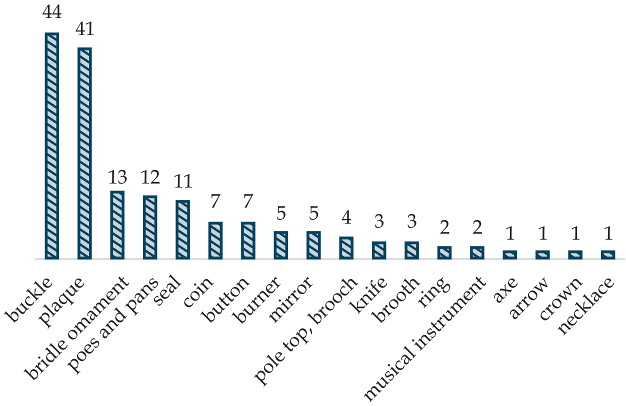


Fig 7. Statistics of Cultural Relics of Bactrian Camels Made of Metal Materials.

as petroglyphs and murals and movable relics including portable objects such as bronze ware and pottery figurines. Chronologically, the relics span from roughly the Paleolithic era to the mid-medieval period. Geographically, their distribution extends from the Greater Khingan Range in the east to the Danube River Basin in Europe in the west and from the northern edge of the Iranian Plateau in the south to the southern boundary of the Siberian taiga in the north, covering a wide range of territories including Mongolia, China, Kazakhstan, Russia, Iran, Uzbekistan, Kyrgyzstan, Tajikistan and Turkmenistan, as shown in Fig 3. It is important to note that due to the portable nature of small Bactrian

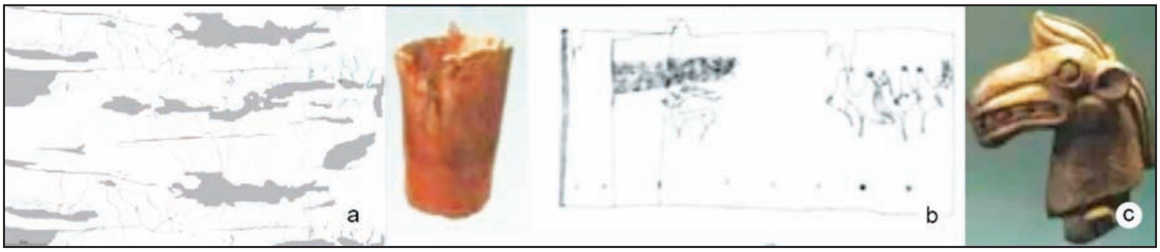

Fig 8. Camel-shaped relics Made of Bone and Wood. (a) Mammoth ivory engraved with camel motifs from Siberia,13,100-13,005 (BP). (after Yury, 2020; fig 4); (b) Wooden barrel from Zagunluk, the Spring and Autumn and the Warring States Period. (after Chen, 2017; fig 10); (c) Wooden bridle ornament from the Altai region, 6th century BCE. (after Elena, 2000; p. 201, fig 4-1).

Fig 9. Textile relics depicting Bactrian camel motifs. (a) "Hu Wang" and camel from the Astana Tombs in Turpan, 420 CE–589 CE. (after Bai, 2011; p. 039, figure); (b) Camels and stylised tree patterns from Sampul Tomb No. 6, 202 BCE – 220 CE. (after Petya, 2018; p. 206, fig 3.31); (c) Textile relic from the ancient Abbey of Saint Josse, before 961 CE. (after Petya, 2018; p. 207, fig 3.33).

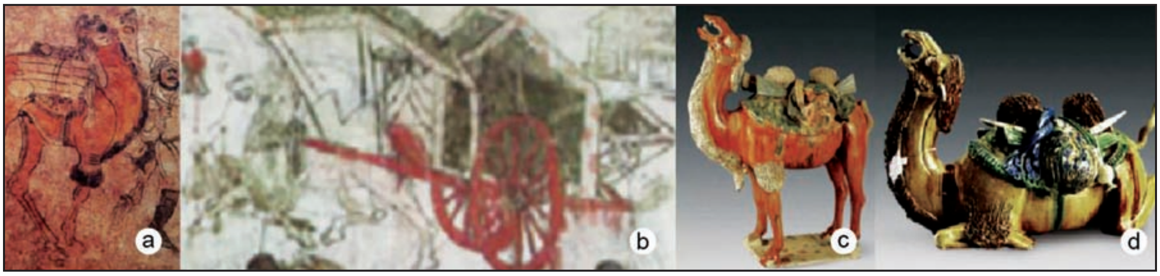

**Fig 10.** Bactrian camel relics representing transportation and mobility. (a) Mural from the Anguo King Tomb from Luoyang, Tang Dynasty. (after Wei, 2014; p. 37, fig 22); (b) Camel-drawn cart from M4 tomb of Guanshan, Liao Dynasty. (after Wei, 2014; p. 43, fig 29); (c) and (d) Pottery camel figurine from Shanxi Province, Tang Dynasty. (after Sha, 2021; fig 1 and fig 3).

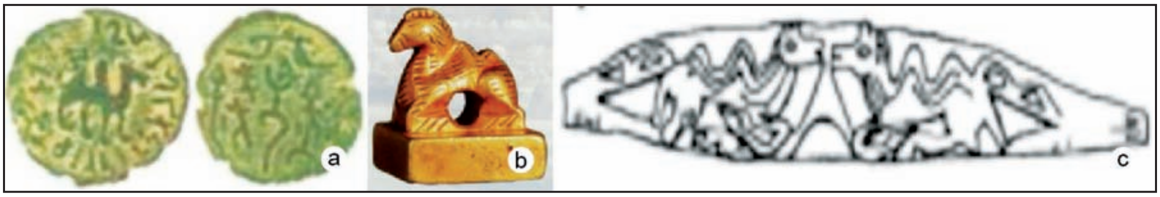

Fig 11. Bactrian camel-shaped cultural relics representing symbols of wealth and political power. (a)Han-Fa bilingual coin from Xinjiang Akspir Ancient City, Han Dynasty. (after Sun, 2016; p. 23, fig 32-33); (b) Golden Camel Seal from Inner Mongolia Museum, 266 CE-316 CE. (after Zhang and Hu, 2015; p. 79, fig); (c) Wooden diadem from Ulandryk I burial Altai mountains, 6 BCE-2 BCE century. (after Elena, 2000; p. 201, fig 6-4).

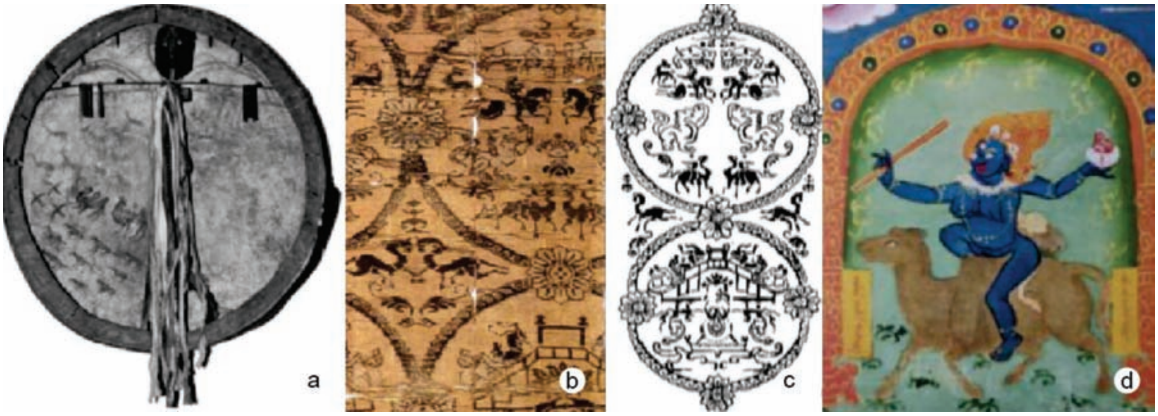

**Fig 12.** Bactrian camel-shaed relics Reflecting Religious Beliefs. (a) Altaic shamanic drum from the Biysk Local History Museum (after Andrzej, 2012; p. 192, fig14-1); (b) and (c) Tapestry of the Sun God from the Astana Tombs, Northern Dynasties. (after Zhao and Qi, 2011; p. 91, fig4); (d) Winter Goddess Riding a Bactrian Camel from the Kanjur, 1765 CE. (after Laxiseleng, 2001; p. 9, fig 003-5).

camel-shaped relics, the current location or excavation site of a relic does not necessarily represent its place of origin. This presents a challenge that is difficult to verify. Scholars often rely on stylistic analysis and cultural contextualisation to hypothesise and delimit the origin of such probable relics. In this study, the geographical and chronological classification of Bactrian camel-shaped relics is primarily based on documented sources and museum-provided provenance data.

## Classification Based on Material and Content

The collected relics are categorised based on their materials into seven types: petroglyphs, stone carvings, murals (including painted bricks), pottery, metalware (encompassing bronze, gold, silver and so on), bone and wooden relics and textiles, their quantity and proportion are shown in Fig 4. Each category of Bactrian camel-shaped relics conveys distinct types of cultural, technological, or symbolic information.

### *Petroglyps*

Petroglyph is an important evidence for early humans to express themselves and their views on the world. As a primary material source for understanding the intellectual and cognitive development of pre-literate societies, petroglyphs have experienced the passage of millennia, bearing invaluable historical

**Fig 13.** Artistic representations of Bactrian camels in various cultural relics. (a) Scythian golden dagger from Azov Kurgan, Russia, 1st century CE. (after Elena, 2000; p. 198, fig 2 and p. 203, fig 6-1); (b) Sogdian silver ewer with winged Bactrian camel from The Hermitage Museum, 7th century CE. (after Shen, 2007; p. 513, fig 20-32); (c) Pottery figurine of camel-mounted musicians from Shanxi, Tang Dynasty; (after Zhang, 2015; p. 259, picture) (d) Wood engraving from Dandan - Uiliq, 6th century CE-8th century CE. (after Shen, 2007; p. 555, fig21-44).

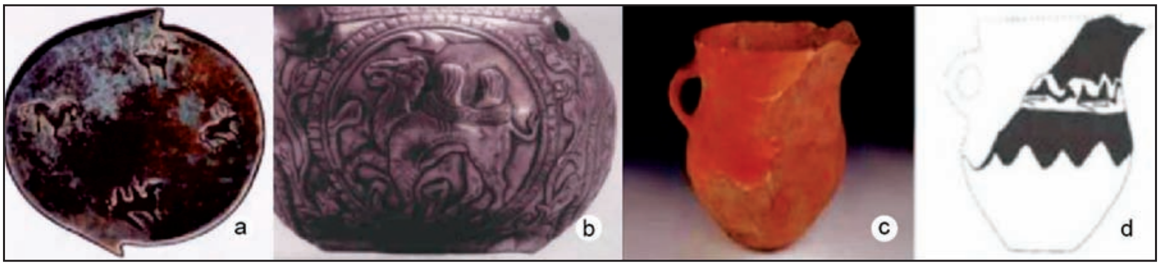

**Fig 14.** Bactrian camel-shaped cultural relics reflecting Daily Life utensils. (a) Bronze mirror from Volga River region, Russia, 8th–7th century BCE. (after Emma, 2002; fig 167); (b) Silver lamp from Tulushevo village, 7th century BCE. (after Marshak, 2019; colour picture 4; (c) and (d) Pottery pot unearthed at the No. 1 cemetery in Chawuhu, Xinjiang,1000 BCE-500 BCE. (after Chen, 2017; fig 7).

significance (Anati, 2019). Regarded as the oldest and most enduring artistic medium, petroglyphs remain critical to the study of ancient art history despite the considerable challenges in chronological dating (Chen, 2002). This study has collected a total of 756 Bactrian camel petroglyph images, primarily distributed in the regions northen China (about 448), with dense concentrations in the Yinshan Mountains (Gai, 1986; Wang and Zhang, 2012) and the Badain Jaran region (Gai, 1997; Fan and Fan, 2014). Other significant distributions include Kazakhstan (200) (Esther and Viktor, 2020; Tashbayeva *et al,* 2001), Mongolia (77) (Chuluun and Tseveendoy, 2016; Esther, 2007; Tsevennjav, 2007; Lakhusuren, 2022) and Siberia (9) (Yury, 2018; Yury *et al,* 2020; Zabyako *et al,* 2022), some of them as shown in Fig 1 (e–g). Chronologically, these petroglyphs span from the Paleolithic era to approximately 1200CE. Technically, they can be categorised into two major methods: pigment-based painting and stone engraving. The earliest known camel-shaped artifact is the ochre petroglyph discovered in the Shulgan-Tash (Kapova) Cave in the southern Urals of Russia, radiocarbon-dated to approximately 19,000–16,300 BP (Alexander, 2018; Yury, 2018; Ekaterina *et al,* 2018). This petroglyph realistically depicts a standing Bactrian camel accompanied by enigmatic symbols, as seen in Fig 1(e). While, Fig 5 shows Bactrian camel petroglyphs from the early Stone Age to the late Bronze Age of Yinshan (Gai,1986; Wang and Zhang, 2012), which clearly reflect the great changes in the relationship between ancient inhabitants and camels in this area and the development of local socio-economic structures.

In general, Bactrian camel petroglyphs reflect the ability of ancient humans to observe and use Bactrian camels and began to record Bactrian camels in life with paintings, which is the bud of Bactrian camel plastic art.

### *Stone Carvings*

Another category of camel-shaped relics made from stone is the stone carving, which includes both three-dimensional sculptures and two-dimensional stone reliefs or engravings. A total of 66 such relics were collected in this study, with the majority unearthed in China (53) and Iran (9), some of them as shown in Fig 6. Among them, the stone amulet of fighting camels (Elena, 2000) unearthed at the site of Margiana should be the earlist cultural relic to reflect the camel as a protective God, as shown in Fig 6(a). These stone carvings reflect both the development of sculptural techniques from rudimentary forms to highly refined representations and the evolving aesthetic sensibilities of ancient civilisations.

### *Pottery and clay relics*

The production of pottery has a long and rich history, dating back more than ten thousand years (Xu, 2013). In the course of the development of human civilisation, pottery as an important living utensils, its emergence is closely related to the social life and technological progress at that time. The study collected 127 images pottery relics, of which 124 were pottery figurines, including 7 single camel figurines, 48 figurines depicting leading camels or riding camels and 69 figurines depicting camels carrying various goods, some of them as shown in Fig 1(a), Fig 10(c,d) and Fig 13(c). The other three pieces are two pottery pots (see Fig 14(c)) and a pottery cart (see Fig1(m)). This camel cart unearthed at the Margiana site in southern Turkmenistan, dating from 2000BCE to 1600BCE, is currently considered to be the earliest physical evidence of domestication of Bactrian camels (Chen, 2017; Richard, 1990). Due to weathering and degradation, clay sculptures are relatively rare, with only two camel-themed clay relics collected in this study. The exquisite workmanship of Bactrian camel pottery relics shows the precise control and firing process of pottery craft at that time and is used in specific cultural scenes, reflecting the development of social culture and religious beliefs.

### *Metal relics*

The maturity of bronze-smelting techniques marks a pivotal point in the emergence of camel-shaped bronze relics. Between 3000 BCE and 2000 BCE, in the regions around the Amu Darya and Syr Darya rivers in Central Asia, the growth of pastoral economies led to increased dependence on Bactrian camels. It was during this period that the earliest decorative camel-shaped bronze ornaments began to appear. This study has collected 163 images of camel-shaped metal relics. These are mainly distributed across northern China beyond the Great Wall (76), Kazakhstan (11), Mongolia (22), Russia (22), Iran (7), Tajikistan (3), Turkmenistan (4) and Syria (3), as shown in Fig1(i) to Fig 1 (l). Chronologically, the relics span from the Paleolithic period to around 1200 CE. These relics were often affixed to horse tack, clothing ornaments and other personal items, statistics of their types as shown in Fig 7. These relics are often minimalist, using lines to outline the basic outline of a Bactrian camel, or setting various gemstones to outline the Bactrian camel shape, reflecting the profound appreciation of the nomadic community for the practical value of camels and also marking a new development of unique artistic expression in the region. Bronze, gold and silver relics indicate a significant advancement in metallurgy and manufacturing techniques. These valuable items also illustrate increasing social stratification, the accumulation of wealth and the consolidation of political power.

### *Bone and Wooden relics*

Bone carving and wood carving, as ancient forms of artistic expression, can be traced back to the Neolithic period (Xu, 2013). However, due to their susceptibility to environmental factors such as air exposure, light, temperature fluctuations, humidity, as well as damage from insects and microbial corrosion, such relics are difficult to preserve. Consequently, this study was able to collect only 14 images of bone and wooden relics, some of them as shown in Fig 8. One notable example is a carved fighting camel motif on a mammoth ivory from Western Siberia. Radiocarbon dating has determined the ivory's age to be between 13,100 BP and 13,005 BP. The surface of the ivory is engraved with two pairs of Bactrian camels engaged in combat (Yury *et al,* 2020). However, as the camels are depicted with arrows on their bodies, the author suggests that the carvings may have been added at a later time, as shown in Fig 8 (a). Bone and wooden relics of Bactrian camels demonstrate early human adaptability in utilising diverse materials for artistic expression. These carvings reflect a variety of sculptural techniques and may also indicate evolving societal needs and advancements in production technologies.

### *Textile relics*

According to archaeological excavations, there were linen and wool fabrics in the western end of the Eurasian steppe around BC6000 (Xu, 2013). With the domestication of Bactrian camels, the close relationship between animal husbandry tribes and Bactrian camels and the prosperity of East-West trade after the opening of the Silk Road, the image of

Bactrian camels frequently appeared in textiles along the Silk Road. This paper collected 27 relics, some of them as shown in Fig 9 and Fig 1(b). Bactrian camel textile relics illustrate the continuous development of textile technology, including spinning, weaving and dyeing and the Bactrian camel patterns on textiles may also reflect trade and cultural transmission.

### *Camel-shaped Wall painting relics*

With the progression of civilisation, especially from the Qin and Han dynasties onward, wall paintings in palaces and tombs flourished (Xu, 2013). It is during this period that Bactrian camels have also found their way into mural art. This study collected a total of 102 wall paintings featuring camel motifs, primarily excavated in northern China (94), with additional examples from Tajikistan (7) and Tunisia (1). The compositional content of these artworks can be categorised into three primary types: camels as transportation, including pack camels and camel carts (87); pastoral scenes, such as nursing camels and music-playing while riding (6); and deified camel imagery (9), some of them as shown in Fig10(a, b). Notable examples include murals unearthed from the ancient city of Pianzhikent, such as the divine couple holding a camel effigy and a winged camel mural associated with the goddess Nana (Marshak, 2016), as shown in Fig 1(d). These wall paintings exhibit more advanced artistic techniques and use of pigments and the camel scenes vividly reflect the social life, production activities and cultural exchanges of the time.

## Functional Classification of Bactrian Camel relics

Since Bactrian camel relics are mostly unearthed in tombs except Petroglyphs, there are many speculations on their exact function. These relics may have served as practical items used in daily life, funerary goods intended for use in the afterlife, symbols of wealth to be carried into the neither world, or a combination of these functions. This ambiguity brings rich exploration dimension and mysterious connotation to the study of ancient Bactrian camel relics.

### *Transportation-Related relics*

On the Silk Road, the Bactrian camel played an irreplaceable role as a primary transport animal. Numerous artifacts were created based on Bactrian camel. These camels are often shown laden with panniers, packsaddles, or pulling carts, with some cargo containers bearing intricate decorations. These details effectively recreate the realistic imagery of fully loaded caravans traversing vast distances, offering a vivid portrayal of bustling trade along the Silk Road. From the depicted contents, it can be inferred that these camels were used to carry silk, spices, tea and various other commodities, providing direct evidence for the study of ancient trade routes and commercial scales. Additionally, small wooden or bronze camel relics may have functioned as ornamental components on ancient chariots or boats, symbolising the crucial role of Bactrian camels in ancient transportation systems. The imagery demonstrates during the Tang and Liao dynasties, camels were actively used for transporting goods and people, reflecting the period's logistical practices, economic exchanges and everyday life, as shown in Fig 10. These relics also reveal regional and ethnic variations in camel utilisation and illustrate both the technological and artistic sophistication of transportation modes at the time, providing valuable material evidence for studies in ancient transportation and social history.

### *Symbols of Wealth and Power*

Bactrian camels frequently appeared on ancient coins, seals and aristocratic ornaments, serving as emblematic symbols, as shown in Fig11. These relics indicate that Bactrian camels were not merely utilitarian beasts of burden but also facilitators of economic prosperity, lluminating the exceptional symbolic role camels played in ancient political hierarchies, cultural systems and social stratification.

### *Religious and Spiritual Symbolism*

In Buddhist cave murals or other religious architectural ornamentation, Bactrian camels are frequently imbued with sacred connotations, as shown in Fig 1 (a,b,c,h,i,l) and Fig 12. These relics underscore the camel's significant role in religious devotion and spiritual symbolism. Within shamanistic practices and related spiritual traditions, the Bactrian camel was endowed with specific sacred meaning—potentially as a mediator between the human and divine realms (Andrzej, 2012). These visual materials are a direct source for the study of ancient religious ideologies, belief systems and mythological narratives, which can more accurately reveal the contours of ancient spiritual life and the worship of supernatural forces.

### *Artistic themes and creative representation*

In the field of painting, ancient artists depicted Bactrian camels through both meticulous and expressive styles, as shown in Fig 13. These visual materials underscore the diversity and aesthetic value of the Bactrian camel as a subject of artistic creation. Relics of camels are found across various regions and media, highlighting their widespread presence in ancient artistic practices. They also illustrate the stylistic characteristics, aesthetic ideals and intercultural exchanges of distinct ethnic groups. As both works of art and cultural documents, these relics constitute significant evidence for the study of ancient art history and the transmission of artistic traditions, attesting to the cultural richness and creative vitality of past civilisations.

### *Daily life utensils*

This category includes relics such as mirror, vessels, light that reflect the integration of the Bactrian camel into everyday life, some of them as shown in Fig 14. These relics illustrate how the image or shape of the Bactrian camel was incorporated into objects of daily use, suggesting the camel's familiarity and cultural significance in ancient life. Beyond fulfilling utilitarian functions, these objects also served decorative and symbolic purposes. They offer valuable insights into the lifestyles, technological advancements and artistic tastes of historical societies and serve as important references for the study of daily life and material culture in antiquity.

## Analysis and Discussion

This study collected information on Bactrian camel-shaped relics through a wide range of channels, each offering complementary advantages. Archaeological excavation reports provide firsthand data on unearthed relics but are limited by excavation scope and the level of detail in documentation. Museum collections offer rich and accurate resources, yet access can be restricted due to exhibition schedules and institutional limitations. Ancient texts reflect historical perceptions of Bactrian camels but often present mystified or fragmented accounts. Academic publications and monographs constitute the primary source of data, accounting for 78.53% of the total, although discrepancies in scholarly interpretation remain. Data from the art market and private collections are difficult to access and often raise questions of authenticity. International collaboration and fieldwork have yielded meaningful findings, but these are limited in scope and sample size. Overall, information collection remains constrained by uneven geographic and chronological distribution.

Classification by region and chronological period helps construct the spatial-temporal framework of the relics; however, the provenance of portable relics remains difficult to verify. Classification of materials reveals the distinct characteristics of different types of cultural relics. Unfortunately, the preservation conditions for some materials are extremely strict, so the proportion of existing Bactrian camel-shaped cultural relics cannot represent the true proportion of artworks that have existed in the history. Functional classification, while enriching interpretive perspectives, is largely based on inference and cannot always accurately determine the original purpose of the relics. Overlaps between categories are inevitable—for example, a religious artifact may also embody artistic value and serve as a symbol of wealth.

The wide range of relic types highlights the diverse roles of the Bactrian camel in ancient societies. Petroglyphs and murals illustrate early human observation, utilisation of camels and the development of visual expression. Metal relics demonstrate advancements in metallurgy and the emergence of social hierarchies. Textiles reflect technological progress in spinning, weaving and dyeing, as well as the dynamics of trade and cultural diffusion. As a means of transportation, camel imagery attests to ancient trade and mobility. As symbols of wealth and power, these relics reveal the socioeconomic and political hierarchies of their time. In religious and spiritual contexts, camel motifs served as vessels for religious expression and folk belief. When used as subjects of artistic creation, they reveal the stylistic and aesthetic tendencies of various periods and cultures.

## Conclusion

This study represents the first comprehensive and systematic collection and classification of ancient Bactrian camel-shaped cultural relics from the Eurasian Steppe and its surrounding regions. By establishing a primary database comprising 1,262 images and associated information, the research lays a foundational framework for future in-depth investigations.

Through classification by region, chronology, material and function, the study reveals the distinctive characteristics and values of the relics from multiple perspectives. The findings underscore the close relationship between ancient human societies and the Bactrian camel and highlight its multifaceted significance across artistic, cultural, economic and religious domains.

While this research has achieved meaningful progress, there remain limitations regarding the completeness of data collection and the precision of classification. Future studies may benefit from the application of advanced digital technologies to broaden data acquisition channels and promote interdisciplinary collaboration. These developments will facilitate deeper analysis of the cultural connotations of camel-shaped relics and further illuminate the Bactrian camel's role in ancient societies and its influence on transregional cultural transmission.

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# MY JOURNEY TO CAMEL SCIENCE AND CAMEL INDUSTRY

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I was born into a camel - herding family. Since I was a kid, camels have been like close friends, quietly entering my life and building the most precious memories of my childhood. Camels have taught me to be tough. I've learned that even in bad situations, I can keep going steadily. Their long - term company has made sure I never feel lonely on the wide grassland. The deep friendship between me and camels has already become a part of me, leaving an unforgettable mark in my life.

At that time, camels were the primary means of transportation, freight conveyances and production facilities for people in pastoral areas. However, with the rapid development of modern transport, many important functions of camels in people's lives have gradually faded and even vanished entirely. Additionally, numerous unique biological features and economic values of camels remain undiscovered and unacknowledged. Thus, the general public is reluctant to raise camels. In just over 20 years from 1982 to 2008, the camel population in China dropped sharply from over 600,000 to over 200,000. It is precisely this severe problem that has kindled our passion for protecting camels, researching them and promoting the camel industries.

## Carried out a series of studies on camel

To effectively promote the camel industry, it is imperative to conduct a series of research on the unique biological characteristics of camels and explore their potential economic value. This is to make the general public truly realise that camels are not only traditional aids in transportation and production, but more importantly, camel functional gene, camel milk, camel wool, camel blood and other aspects all contain huge development potential and commercial values.

### *1.1 Bactrian camel genome*

While the Bactrian camel made a great contribution to transportation on the Silk Road and could be portrayed as a bridge between Eastern and Western cultures, little is known about the camel genome. After more than 5 years of unremitting efforts, the first draft of the Bactrian camel genome was successfully completed by our research team in 2012 (Jirimutu *et al*, 2012). The research results were published online as a cover article in Nature Communications. Meanwhile, the globally-recognised biological database GenBank publicly released the camel genome data worldwide.

The estimated size of the Bactrian camel genome was 2.38 Gb, containing 20,821 protein-coding genes. Rapidly evolving genes were significantly enriched in metabolic pathways, perhaps helping Bactrian camels optimise their energy storage and production in the desert. After annotation, the results also suggested that the specific cytochrome $P_{450}$ families and unusual immune system were useful for survival in the desert. The comparative genomics analyses may also shed light on the genetic basis of the camel's remarkable salt tolerance and unusual immune system (Jirimutu *et al*, 2012; Surong Hasi *et al*, 2018).

To address the question whether Bactrian camel originated from East Asia or Central Asia, we performed whole-genome sequencing of 128 camels including both domestic and extant wild Bactrian camels from their typical habitats across Asia. Interestingly, among the domestic Bactrian camels, those from Iran exhibit the largest genetic distance and the earliest split from all others in the phylogeny, despite evident admixture between domestic Bactrian camels and dromedaries living in Central Asia. Taken together, our study support the Central Asian origin of domestic Bactrian camels, which were then immigrated eastward to Mongolia where native wild Bactrian camels inhabit (Liang Ming *et al*, 2020).

### *1.2 Camel milk*

As Reuven Yagil said, traditionally seen as riding and pack animals, camels are hugely

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underestimated and under-exploited for their milk, even though camel milk is the most suitable for human consumption after mother's milk. In order to reveal the unique characteristics of camel milk, our research group had carried out a series of studies focusing on the main nutritional components of camel milk and its protective effects on the liver and kidneys, anti-heat stress effect and anti-oxidative stress effect of camel milk.

Compared with cow's milk, camel milk has a higher content of IgG, albumin and α - LG and does not contain β - LG. Camel milk fat content is relatively low and mainly unsaturated fatty acids, while the cow's milk mainly contains saturated fatty acids. Camel milk $V_D$ and $V_c$ contents are higher than cow milk especially the vitamin C content is 3-4 times more than cow milk. Camel milk iron content is 10 times higher than cow milk (Zhang *et al,* 2005; Jing *et al,* 2019).

The study demonstrated that camel whey protein (CWP) has protective effects against heat stress induced liver injury in rats. The protective effect of CWP is attributed to its ability to reduce the increase in ALT and IL-1β levels, restore core temperature and block apoptosis and histopathological changes in the liver (Donghua *et al,* 2021a, 2021b; 2022). As well as, CWP can prevent and alleviate acute heat stress-induced kidney injury in rats and its mechanism of action may be related to the up-regulation of CYP2J activity and the activation of PI3K/AKT pathway expression (Xiaoxia *et al,* 2024).

### *1.3 Bactrian Camel CYP Enzymes*

To investigate whether the Bactrian camel's special metabolic pathways and unique detoxification capabilities are attributable to particularities of the CYP gene family, we systemically analysed and annotated the Bactrian camel's whole genome sequencing data and then, searched CYP gene family from the whole protein database and compared with CYP gene families of cattle, horse, chicken and human. The total of 63 CYP gene copies were found in Bactrian camel's whole genome and were classified into 17 families and 38 subfamilies with more CYP2J and CYP3A copies, which might be the important factors contributing to the distinct biological characteristics and metabolic pathways of Bactrian camels for adaptation to the harsh environments (Surong *et al,* 2018; Zhipeng *et al,* 2018).

In conclusion, the research work and achievements carried out on camels were rich and diverse. On the one hand, these achievements had played a role in promoting the rapid development of China's camel industry, including facilitating the rapid development in various aspects such as camel breeding, product development and comprehensive utilisation. On the other hand, we have also enhanced the overall level of the world's camel research field, making significant contributions to the sustainable development of the global camel industry.

## Diversified development of camel industries in China

### *2.1 Deep Processing and Diversified Products of Camel Milk*

Based on a systematic study of the biological characteristics of camels and camel milk, we have also explored the correlation among the camel breeding environment, feed and the quality of the milk source, optimised the breeding conditions and established a milk source traceability system. In terms of the processing technology of camel milk products, we have also carried out a series of studies, such as comparing the effects of different sterilisation technologies for fresh camel milk, optimising the drying technical parameters of camel milk powder, studying the tabletting process of camel milk tablets, screening the strains and conditions for fermented camel milk, exploring the methods for extracting and adding ingredients in camel milk cosmetics as well as the product evaluation methods. Currently, there are more than 10 modern camel milk processing enterprises in China, which produce a series of products including fresh camel milk, camel milk powder, camsel milk tablets, fermented camel milk and camel milk cosmetics.

### *2.2 Camel Hair Products*

#### *2.2.1 Camel Soft Hair Products*

Camel soft hair is a layer of short fluff close to the body of a Bactrian camel. After washing the raw hair, removing the coarse and semi-coarse hair, combing the remaining parts, the pure camel soft hair can be obtained. Due to the fineness, softness and curliness of the fibers, the flakes made from camel soft hair have the advantages of being light, thin, fluffy, windproof, mildewproof, breathable and warm. The garments made of camel soft hair is comfortable to wear and not as bloated as a down jacket. A variety of camel hair products can be made with camel soft hair, such as quilt, trousers, sweater, coat, socks, vest, knee pads, scarf, gloves, hat, blanket, insole, back waist strap, carpet, etc.

#### 2.2.2 *Camel Coarse Hair Products*

Camel coarse hair containing a large amount of coarse fibre has the advantages of keeping warm, windproof, mildewproof and breathable. However, compared with camel soft hair, the heating speed of camel coarse hair is slower. People like to use it as a filler for winter pants or camel coarse hair-padded mattress and use it also to make camel coarse hair carpets and camel hair ropes.

### 2.3 *Camel Meat Products*

Camel meat has the characteristics of high protein, low fat and low cholesterol. It is rich in amino acids, minerals and unsaturated fatty acids. On the basis of a comprehensive study of the nutritional value of camel meat, slaughter and cutting techniques and preservation techniques, our team has developed a series of products such as air-dried camel meat, camel meat pies, camel meat burgers, camel meat skewers, camel meat ham and camel paws.

Our team has also carried out studies on camel meat chemical composition and the development of high - end camel meat products (Rendalai *et al,* 2022; Liang *et al,* 2025). By using modern biotechnology, active peptides were extracted from camel meat and made into capsules or oral liquids with functions such as antioxidation and anti-fatigue. Moreover, camel meat protein powder was further purified to produce high-purity nutritional supplements, which increases the added value of camel meat products.

### 2.4 *Camel Serum*

Camelids are the only mammals that can produce functional heavy-chain antibodies (HCAbs) - the nanobodies. Nanobodies are antigen binding variable domains of heavy-chain antibodies without light-chains and these biomolecules occur naturally in the serum of Camelidae species. Nanobodies have a compact structure and low molecular weight when compared with complete antibodies. In view of their remarkable stability and manipulable characteristics, nanobodies have been incorporated into biomaterials and used as molecular recognition and tracing agents, drug delivery systems, molecular imaging tools and disease therapeutics.

Our research team had conducted systematic studies on the application of camelid serum heavy-chain antibodies in targeted drug delivery systems and drug residue detection and reaping remarkable and gratifying achievements which not only deepened the understanding of the unique properties of camelid heavy-chain antibodies but also provided new strategies and methods for improving drug treatment effects and ensuring food safety (Liu *et al,* 2023; Xinyu *et al,* 2020).

## Build communication platforms and carry out a series of activities

In order to promote the research of camels and the development of the camel industry, through the active advocacy and joint efforts of our research team, the Inner Mongolia Camel Protection Association was registered and established in Inner Mongolia Autonomous Region in April 2009; the Camel Branch of the China Animal Agriculture Association was registered and established in 2012; China's first Camel Research Institute was registered and established in Alxa Right Banner in 2014. Since the establishment of the Inner Mongolia Camel Protection Association in 2009, we have organised and carried out many academic exchange meetings related to camels and Camel Culture Nadam both at home and abroad and we have actively participated in international academic exchange conferences on camel research. Among them, the representative and important activities are given below.

From June 2010 to July 2011, the Inner Mongolia Camel Protection Association organised some camel researchers and representatives of camel herders from Mongolia and China to carry out a series of international academic exchange activities of field investigations on Bactrian camels, which lasted for one year. This activity not only enhanced the mutual understanding among scholars and herders of the two countries, but also collected first-hand data on the main production areas of Bactrian camels in the two countries.

We organised and hosted the international conference "The Belt and Road: Camel Science, Industry and Culture" on September 2017 in Alxa League, Inner Mongolia Autonomous Region, China. More than 300 people participated in this grand event, including 52 internationally renowned camel experts and scholars from 26 countries such as the United States, the United Kingdom, Australia, Canada, Austria, the United Arab Emirates, Russia, Kazakhstan, Mongolia, India and Saudi Arabia, as well as Chinese camel research experts, scholars, entrepreneurs and representatives engaged in the camel industries.

Under the leadership of the Inner Mongolia Camel Protection Association and with the joint efforts of leadership and all of members over the years, the association has successfully completed all of missions such as enlivening the academic


Fresh camel milk


Camel milk powder


Camel milk tablets

Camel milk cosmetics

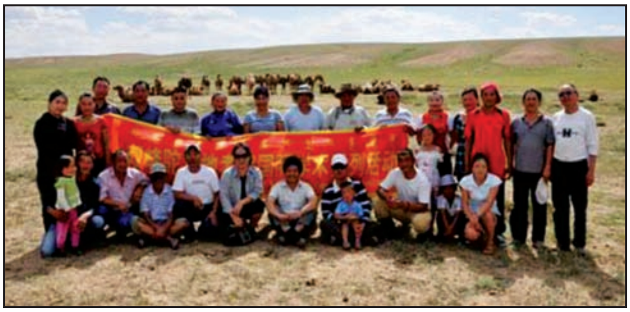
Bactrian camel hair products


The Bactrian Camel Field Investigation Team working in Sonid Right Banner, Xilingol League (2010)


The Bactrian Camel Field Investigation Team working in Bayannuur and Alxa League (2010)

Camel research experts from all over the world are in front of the building of Inner Mongolia Camel Research Institute (2017)

The Bactrian Camel Field Investigation Team in the Ministry of Agriculture of Mongolia (2011)



The Bactrian Camel Field Investigation Team working in Bayanhongor, Mongolia (2011)

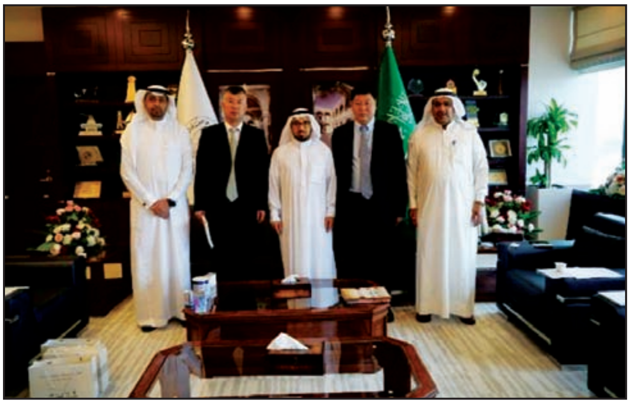
Camel researchers during the 7th China Camel Industry Development Conference (2019)

During the 4th Conference of the ISOCARD in Kazakhstan (Almaty, 2015)

During the 5th Conference of the ISOCARD in Morocco (Laayoune, 2018)

During the 7th International Veterinary Congresses (Paris, 2017)


During the 11th International Veterinary Congresses (Berlin, 2018)



Visiting the King Faisal University

atmosphere, prospering the camel industry, promoting the integration of production, education and research, building a supply-demand platform and developing the local economies. The association plays an active role in promoting the development of the camel industries. Since its establishment, the association has cooperated with relevant departments in many places to jointly hold events such as the Camel Culture Nadam, the camel industry development conference and academic conferences. It has provided detailed introductions across the country about the unique biological characteristics of camels, the nutritional value of camel milk, etc. Through in-depth discussions on academic issues of the industry, it has helped to solve the problems encountered in development and further promoted the progress of China's camel industry. In particular, in 2019, the association held the 7th China Camel Industry Development Conference in Ejina Banner and invited renowned camel research experts from countries such as the United States, Saudi Arabia, Belgium, India, Pakistan and Mongolia.

**International cooperations**

In our vast globalised world, camels have become a research subject of great scientific and industrial significance. The global technologies and industries related to camels are not only crucial for the livelihoods of people in arid and semi-arid regions, but also serve as the key to conducting innovative research in multiple fields. Camels have unique adaptability to the harsh desert environment. Biological characteristics of camels, such as their ability to tolerate extreme high temperatures, go without water for long periods of time and efficiently convert low-quality forage into energy, have aroused the interest of scientists around the world.

Moreover, in the fields of camel technology and industry, international cooperation is of utmost importance. Different countries possess diverse expertise. For instance, Middle Eastern countries have a centuries-old tradition of camel breeding and have in-depth knowledge of cultivating camels with specific traits. On the other hand, African countries are home to a rich variety of camel species and have unique insights into how camels adapt to different ecological environments. Central Asian countries can offer experience in large-scale camel herding and the development of camel-related handicrafts. Therefore, through extensive international cooperation, scientists are able to integrate resources, share research findings and accelerate the pace of innovation. In addition, international academic conferences serve as a platform where researchers, industry experts and policy makers from around the world gather, it is playing a crucial role in promoting international cooperation in camel technology and industry.

In conclusion, the global camel technology and industries possess enormous potential for growth and innovation. By placing a high value on international cooperation and actively participating in international academic conferences, we can fully tap into the potential of this unique industry, bringing benefits to the camel industry, human communities and the entire scientific communities.

China has a long history of camel husbandry and is eagerly looking forward to elevating its camel industry and technological level to new heights. To achieve this goal, it is crucial to break through the limitations of national boundaries and draw on the best practices and advanced technologies of other countries. In order to bridge the knowledge gap, promote international cooperation and ultimately drive the sustainable development of China's camel industry, we actively participate in international camel-related conferences and visit countries where camel science, technology and industry are well-developed.

Our teams have successively participated in the 4$^{th}$ Conference of ISOCARD held in Almaty, Kazakhstan in 2015, the 5$^{th}$ Conference of ISOCARD held in Laayoune, Morocco in 2018, the Camelids Workshop at Plant and Animal Genome XXV held in San Diego, the United States in 2017, as well as the 7$^{th}$ and 11$^{th}$ International Veterinary Congresses held in Paris, France and Berlin, Germany.

Our international exchange trips are not only for the purpose of learning but also for contributing to the global camel industry community. We share our own scientific and technological achievements and industrial experiences and jointly explore new frontiers in camel technology and industry.

In 2018, at the invitation of Dr. Faisal Almathen, Director of the Camel Research Centre at King Faisal University in Saudi Arabia, we visited Saudi Arabia. We successively visited the Camel Research Centre of King Faisal University in Saudi Arabia, the camel breeding base and camel milk processing factory, the College of Veterinary Medicine and the College of Agriculture and Food Sciences. We also visited the camel dairy farms, camel milk processing factories, the Centre for Genetic Conservation and Improvement and the Veterinary Central Laboratory directly under the Ministry of Environment, Water and Agriculture of Saudi Arabia. Before returning to China, we also met with Dr. Mohammad, the President of King Faisal University and discussed specific cooperations. On behalf of the Inner Mongolia Camel Research Institute, Professor Jirimutu signed a memorandum of cooperation with President Mohammad. Both sides reached a consensus on exchanging scholars, jointly cultivating students and collaborating on camel genomics research, research and development of camel products and the prevention and control of camel diseases.

In 2016, during my visit to Texas A&M University in the United States, I specifically visited the Texas Camel Corps and had a detailed discussion with Mr. Doug Baum about the camel-tourism industry. We further exchanged views on how to give full play to the role of camels in the tourism and promote the development of the tourism in the future.

In the process of promoting scientific research related to camels and the development of the camel industry, the importance of international cooperation is unparalleled. Camels have unique drought tolerance mechanisms, exceptional anti-fatigue capabilities and adaptation characteristics to extreme environments, which are of great significance to disciplines such as life sciences and medicine. However, relying solely on the scientific research resources of a single country makes it difficult to comprehensively and deeply explore these values.

International cooperation has built a bridge that brings together the world's top scientific research forces. With the help of cutting-edge gene sequencing technologies and advanced molecular biology methods, it can deeply analyse the camel genome, opening up new paths for the optimisation and improvement of camel breeds and research on disease prevention and control and significantly accelerating the implementation and transformation of scientific research achievements.

From an industrial perspective, the camel industry has a wide scope, covering many fields such as breeding, processing and manufacturing and tourism. Different countries have their own strengths. Through international cooperation, the traditional camel industry can be skillfully integrated with modern science and technology to improve the quality and added value of camel products. Countries work together to explore the international market, create joint brands, expand sales channels and greatly enhance the economic benefits and influence of the camel industry in the global market.

International cooperation also plays a positive role in the dissemination of camel culture. Through activities such as holding camel cultural festivals and art exhibitions, people from various countries can appreciate the unique charm of camel culture, promote cultural exchanges and recognition and further drive the vigorous development of the camel cultural tourism industry. Looking to the future, we should further deepen international cooperation, comprehensively tap the potential of camel resources and promote the camel industry to make greater contributions to global economic development and ecological environmental protection.

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# MY JOURNEY TO CAMEL SCIENCE: BECOMING AN INVESTIGATOR AND AMBASSADOR OF CAMEL MILK FOR AUTISM TREATMENT

**Christina Adams**
Author, Researcher, Camelologist, CEO of Nomad Ventures, USA

## A Mother's Search for Answers

I began my professional life in media, aerospace, government and journalism, working at the Pentagon in Washington, D.C. for the US Army, then for various corporations and a state government. I then earned a Master's in Creative Writing from California State University. My world changed dramatically when my young son, Jonah, was diagnosed with autism at age two. Driven by a mother's determination, I devoted myself full-time to his recovery, orchestrating intensive therapeutic, dietary and medical interventions. My early advocacy work, including my memoir A Real Boy: *A True Story of Autism, Early Intervention and Recovery,* brought national attention and established me as a voice for autism families and policy reform, with appearances on National Public Radio and articles in the *Los Angeles Times, The Washington Post* and more.

## The Serendipitous Discovery of Camel Milk

My journey from advocate to scientific investigator began unexpectedly at a children's book fair in 2005, where I encountered a camel and its owner. Learning about camel milk's use in Middle Eastern hospitals for premature infants and its rumoured hypoallergenic, nutrient-rich qualities sparked a new hope in me: could camel milk help my son where other interventions had plateaued? I had already observed that dietary changes, particularly removing cow's milk, improved symptoms for many children with autism—including my son, who had adverse reactions and exacerbations of his autism symptoms (hand-flapping, walking in circles, being detached from people) when he ingested cow dairy. I hypothesised that the camel milk might boost his immune system functioning and thus result in better language production, as his immune status was always linked to his improvements per medical testing. I also thought it would be a good non-allergenic milk substitute that contained calcium for bone health, unlike the potato-based milk powder I gave him.

Determined to find camel milk, I scoured scientific databases for research on camel milk and autism, finding only a handful of unrelated studies. The milk was not available in America and I didn't know any US camel owners. Undeterred, I navigated complex import regulations, safety issues and cultural and language barriers to source raw frozen camel milk from Bedouins in the Negev Desert of the Middle East, eventually securing special US Department of Agriculture permission to import it for Jonah—a pioneering move in the United States.

## From Mother to Investigator: Documenting the Impact

The results were immediate and profound. After his first half-cup of camel milk (four ounces/120 millilitres), Jonah showed remarkable overnight improvements in speech, emotional connection and motor skills. I meticulously documented these and other changes as the days and weeks of his camel milk consumption followed. Soon, he was able to cross the street without my assistance, calm down from dangerous hyperactive states and carry on more reciprocal conversations. Small bumps under his skin also disappeared. After months of sustained observation and non-biased school data, I estimated a 30% improvement in his overall functioning based on medical and educational evaluations. This experience reinforced my commitment to further research into the science behind camel milk's potential benefits and its effects on autism.

## Becoming a Self-Taught Expert

I immersed myself in camel experiences and lore, traveling across the United States and internationally to learn first-hand about camels and

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their biology, milk, meat and usage. I visited camel farmers and herders in America, including farmers of Middle Eastern heritage and interviewed Somali and Indian sources. I traveled to Dubai the first time to sample camel milk products and visited camels in the desert camps and made a trip to India's Rajasthani desert. I recorded traditional knowledge and modern practices from as many sources as I could find, including old books and Toureg nomads from Niger who visited the US to sell their traditional jewellery. I also kept importing camel milk and drove to many airports late at night to pick up the precious and very expensive suitcases full of frozen litre bottles. My son needed it on a regular basis to maintain his gains and health, so this was a constant endeavour.

**Advocacy and Global Impact**

In 2011, I learned that Amish farmers in America had just begun milking camels and selling the milk quietly from a few tiny farms. I obtained that milk and it worked the same way as the Middle Eastern milk for my son. With a reliable and safe source now available in the U.S., I went public with my findings. My 2012 article "Got Camel Milk?" went viral in many languages, catalysing global interest among autism families and entrepreneurs. I followed up with a patient report, "Autism Spectrum Disorder Treated with Camel Milk," published in a peer-reviewed science journal. I discussed it on a television show for autism, which drew international scientific attention and invitations to visit innovative camel dairies abroad. I visited the farm where the Camelicious brand is produced in Dubai, gave media interviews, met the public, visited camel races and a Bedouin camp and most importantly, collaborated with the outstanding veterinary scientists there. My continued interactions with camel people and scientists around the world provided me with a deep and nuanced perspective of the complex cultural, economic, supply chain and dairy production issues related to camel milk, as well as the scant, little-known science around its health benefits. My research extended to collaborations with scientists, including work in a Nobel Prize-winning lab at the University of California, Irvine, analysing the unique components of camel milk.

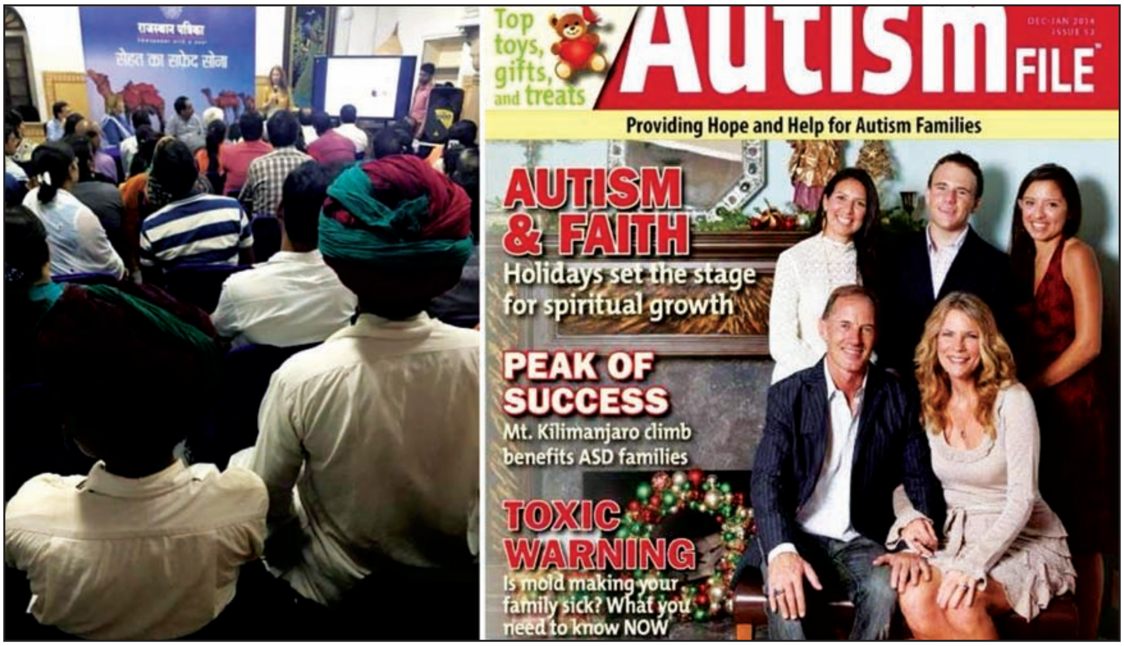
I also regularly heard from families and adults using camel milk for autism, food intolerances, autoimmune issues and other health issues. Hearing their stories enhanced my knowledge base and I shared this information in many national speaking engagements and media appearances, as well as on my website. I wrote several articles about camels, including one about the challenges facing Rajasthan's camels, and one in OZY, a milestone, because working as a journalist, it was difficult at the time to get mainstream media attention for camels.

Eventually, I knew that I had to write a book about this topic in order to best share information about the importance of camels. I made another trip to India to lecture, meet the Raika camel herders at Camel Charisma with Dr. Ilse Kohler-Rollefson and visited UAE's Al Ain Farms along with other camel milk and tourism-related sites. I spent time with the large Somali community in the US to learn from their leaders and continued my visits to the growing number of small American camel farms to observe their camel training, milking, bottling and shipping methods. I lectured at various universities and conferences held in Pakistan, India, Europe, the US and more.

In late 2019, I published the book *Camel Crazy: A Quest for Miracles in the Mysterious World of Camels*. The book chronicles my journey and my son's experience, but also highlights the deep culture around camels and the global importance of their milk, meat, labour, spiritual significance and economic value to the world. A Users' Guide in the back of the book gives practical guidelines for families and health professionals interested in camel milk as a therapeutic option, such as how much milk to use for autism, diabetes and other health issues. The book won a Nautilus Book Award and a San Diego Writers' Conference Choice Award. It was later translated into Mongolian and sold out within months in 2024.

I have been to Mongolia two times and helped start a camel dairy there, which is now producing liquid and powdered milk under the Camwell brand. Most importantly, by encapsulating the science of camel milk in an entertaining true story and generating media appearances and press coverage, I have been able to bring camel milk to the attention of millions of people around the globe. This has been my goal for nearly 20 years now–getting camel milk to the people who need it. One example of this is being a recent guest on a popular South African radio station, after which all the commercially available camel milk in South Africa was sold out in a day. Another is having an article on my work in the Eastleigh Times and other outlets in Kenya about camel milk, which helped connect me with local herders and led me to a greater understanding of their challenges. Several camel milk retail operations have started over the years after seeing one of my media pieces, including one in Africa recently, so that is highly gratifying.


Patrika.com interviewed Christina on the publication of her book CAMEL CRAZY.




Christina gives a talk on camel's milk benefits for autism and human health at the Rajasthan Patrika 's office in Jaipur, India (Left); Autism File Family cover photo: Christina and her family (right).

**Scientific Contributions and Ongoing Research**

I feel very fortunate that my experience is recognised by researchers and camel industry stakeholders globally. I have been able to contribute to peer-reviewed publications; this includes co-authoring "Camel Milk and Other Dietary Treatments in Autism" with Dr. T.K. Gahlot and "Camel-Assisted Services" with Dr. Carlos Pastrana, which outlines the value of camel-assisted interventions for humans. I advise camel milk producers, help guide dairies and promote standards for safety and quality around the world. My work highlights camel milk's unique therapeutic properties—antibodies, vitamins and enzymes with antioxidant, anti-inflammatory and immunomodulatory effects—as well as research suggesting how it may benefit children with autism by improving gut health and reducing oxidative stress, as well as providing vitals nutrients like calcium for underweight or food-intolerant youths. Ongoing scientific collaborations continue to stimulate further research.

**A Continuing Mission**

Today, I continue to bridge cultures and disciplines, educating the public, advocating for greater access to camel milk (including support for pastoral camel herders) and supporting research into its benefits. I have spoken at the United Nations and at international conferences in Saudi Arabia, Morocco, India, Pakistan, China and many more. I have produced and been featured in documentaries in

Christina and colleagues on stage at Marwar Camel Culture Festival organised by Dr. Ilse Kohler-Rollefson in Sadri, Rajasthan (Left); A conference in Berlin, Germany on camel science - Christina was a keynote speaker on camel milk, with other participants (right).


Christina spoke to autism parents and professionals at Mountain Empire Community College in Virginia's Appalachian mountains (Left) and her book's Mongolian Edition launch at Ulaanbaatar, Mongolia (Right)

Mongolia, Saudi Arabia and India and have met with government officials in many countries to promote camel milk, most recently in Mongolia's Gobi Desert and China's Northwest during the 2024 UN Year of Camelids. In 2023, I founded Nomad Ventures to share the stories of nomadic and pastoralist cultures. The short film I co-produced with Solid Partners of Mongolia, titled "Mongolian Camel Culture," is available on YouTube. I also hear from families, nomadic people, companies and journalists as they seek to understand camels and their milk.

My journey from mother and media professional to scientific expert and advocate was an unexpected one. But the power of personal experience, persistence and cross-cultural collaboration has enabled me to advance new frontiers in autism care and global health.

As I complete two decades of seeking and developing camel knowledge, the world of camels is still mysterious in many ways. It remains my goal to highlight, investigate and protect the treasure that is the camel.

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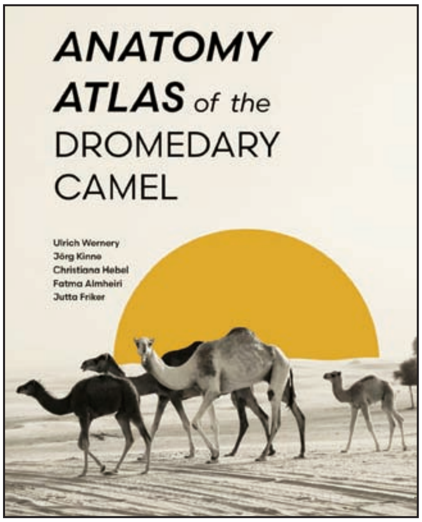
## A NEW BOOK ON DROMEDARY CAMEL ANATOMY

A new book "Anatomy Atlas of the Dromedary Camel" will be released soon this year in UAE. We have received the following information about the book.

| | |
|---|---|
| **Name:** | SHAJU THANIKUNNEL SKARIA |
| **Company Name:** | Maisloon Printing Press L.L.C |
| **Address:** | P.O. Box 23010, Sharjah, United Arab Emirates |
| **Email:** | maisloonprintingpressllc@gmail.com |




## CLOSING CEREMONY - INTERNATIONAL YEAR OF CAMELIDS 2024 HELD AT ROME (ITALY)


The International Year of Camelids (IYC) closing ceremony took place on Monday, 30 June 2025, from 19:45 to 21:15 at FAO headquarters, as a side event of the 44$^{th}$ Session of the FAO conference (28 June – 4 July).

The closing ceremony highlighted the key achievements and lessons learnt from the IYC, while promoting continued collaboration among stakeholders to build on its legacy. It was also aimed to sustain the momentum between the IYC (2024) and the upcoming International Year of Rangelands and Pastoralists (2026).

The closing ceremony featured an exhibition in the FAO Atrium throughout the duration of the FAO conference. This exhibition highlighted the social, cultural and economic importance of camelids and promoted the consumption of the goods they produce. It featured booths showcasing camelid products, a photo exhibition, multimedia products, and a camelid parade. The exhibition was inaugurated prior to the closing ceremony with tastings of camelid products and cultural performances.

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# MY JOURNEY TO THE CAMEL SCIENCE FROM DEVELOPING CAMEL SURGERY TO PUBLISHING AND EDITING THE JOURNAL OF CAMEL PRACTICE AND RESEARCH

**Tarun Kumar Gahlot**

Editor, Journal of Camel Practice and Research, Former Professor and head, Department of Veterinary Surgery and Radiology, College of Veterinary and Animal Science, Bikaner, Rajasthan, India

My journey to becoming a camel vet started in 1975 by seeking admission to my Almamater, which deserves umpteen times salutation to make me a face in the crowd. My schooling for most of the time till class X$^{th}$ was in the rural side where my father served as a Medical Doctor and often traveled on camel back or camel cart to see patients from one village to other. Many villages had no roads at that time and camel or camel cart was a popular transport in the villages. My father recalls my fall from a tree directly in the roughage sack lying in front of a sitting camel. I was not attacked by the camel and it was considered as a blessing from a camel to a future camel vet. After joining the graduation course of Veterinary and Animal Sciences I studied the anatomy and physiology of camel and found that it was different from other desert ruminants. I started realising that the veterinary profession is highly challenging from view point of acquiring knowledge and treating diverse species ranging from cat to camels and even birds, wild and zoo animals. Later, during my study of veterinary science I was amazed to learn that camels have only three compartments of stomach (whereas ruminants have four compartments), well-developed chest pad (camels), soft palate diverticulum (male camels), remarkable digital cushion and so on. Being different from ruminants, I learnt that camels were categorised physiologically as pseudoruminant. These unique features of camel arouse my interest in this desert species.

## Becoming a Camel Surgeon

As the graduation programme reached its last leg and my professional knowledge was enriched at the same time, I started feeling my interest and inclination toward veterinary surgery. While learning it I found that camel surgery was least studied and needs to be developed and moreover, there were no books on camel surgery whereas surgical cases in camels were coming every day and it was a big challenge for the veterinary surgeons. Majority of these cases were mandibular fractures, soft palate injuries, lacerated nostrils, saddle gall, chest pad injuries, tail gangrene, arthritis, foot injuries, etc. The biggest failures were in the management of mandibular fractures where both the lips get apart following lower jaw fracture, the camels were unable to prehense, and such animals were sometimes abandoned as there was no appropriate treatment. I took it as challenge and started studying anatomy of mandible of camels by bringing some mandible bones from the carcass centres. I found that interdental wiring could be the most practical approach. I started attempting it in the clinical cases, initially with a 2mm thick silver wire and later, it was replaced with copper wire as it was cheap, available easily and provided more stable knots without incidences of breaking the wire while tightening these. From 1980 onwards, we conducted many clinical trials and found great success in immobilising mandibular fractures with interdental wiring (IDW) and later other techniques were also developed to treat oblique or multiple fractures of horizontal ramus, i.e. transfixation technique with a fibre cast. Mandibular fractures started getting healed in 6-8 weeks with IDW technique. It was highly economical, and camels were discharged from the hospital same day or a little later, depending upon the clinical situation. Initially, we used triflupromazine hydrochloride, which was a tranquiliser, but later replaced with xylazine when it became available in Indian markets. The clinical research on camel surgery, anaesthesia and imaging (soft these and orthopedics) were published in reputed journals and presented

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at national and international conferences. It drew the attention of camel vets from many countries in the Middle East and South Asia. I started receiving invitations from the international camel conferences being organised in different countries. My growing interest in camel surgery led to its development and many papers were published on this challenging subject of camel surgery. I published the just book on camel surgery in 1992.

**Initiated authoring camel books and the Journal of Camel Practice and Research**

I continued performing camel surgery at my almamater in Bikaner till my superannuation. I demonstrated camel surgery at College of Veterinary Sciences, Hisar, India also while pursuing my doctorate programme there from 1987 to 1989. At Hisar, I met my another mentor- Prof Jit Singh, then HOD of Veterinary Surgery and Radiology and my guide in PhD programme. He was a perfect surgeon and academician who edited my camel books and guided me about the ethics of an editor while launching the Journal of Camel Practice and Research in 1994. I published my first book on surgery 'Camel Surgery' in 1992, and later, a chapter on camel surgery in the book "Selected Topics on Camelids" in 2000. I met famous camel surgeon, late Dr. R.O. Ramadan of King Faisal University, Al Hasa, Saudi Arabia, at the International Camel Conference held in Dubai in February 1992. He purchased the first copy of my book on Camel Surgery, and later, he also authored books on camel surgery. He became my good friend and sponsored my tours to the Camel Conferences held at King Faisal University, Saudi Arabia. Camel scientists at KFU popularly called us two doyens of camel surgery. Later, camel surgery improved with good research on the anaesthesia and the imaging sectors as well. Department of Veterinary Surgery and Radiology, College of Veterinary and Animal Science, Bikaner, India became a popular hub of camel surgery at the global level. I am still consulted to treat sick camels at various camel ranches in the USA and rescue centres in India.

**Collaborated with Dr Cedric Chen of Dubai Camel Hospital**

The first appointed surgeon of Dubai Camel Hospital- Dr Cedric Chan also met me and visited camel clinic at Bikaner in 2016. He appreciated the knowledge and practice of staff here, specially in the camel surgery.

**Collaborated with LPPS**

I recall a great association with Dr Ilse Kohler Rollefson and Hanwant Singh of Lokhit Pashu Palak Sansthan (LPPS) located at Sadri, Pali District, Rajasthan. Dr Ilse extended a financial support to the first issue of Journal of Camel Practice and Research and continued a column, i.e. "Pastoralist Perspective" in JCPR for many years. I was honoured by "Camel Saviour Award" by Dr Ilse Kohler Rollefson, Chairperson of LPPS, Sadri in a workshop organised at Khudi, Jaisalmer for my significant contribution to the camel science. She invited me in many workshops and conferences hosted by LPPS. She also organised Marwar Camel Culture Festival at Sadri many times.

**Collaborated with OIE (now WOAH) and CAMENET**

I received a great recognition as a camel scientist at global level. OIE (World Organisation for Animal Health-WOAH) included me as member of Adhoc Committee for Infectious Diseases of Camelids and invited me at its head quarters in Paris in May 2010. I edited many chapters of OIE publication, "Infectious Diseases of Camelids".

WOAH and Abu Dhabi Agriculture and Food Safety Authority (ADFSA) invited me at 5$^{th}$ CAMENET (Middle East Camel Network) Technical Committee Meeting as a member, which was held on November 20-21, 2023 in Abu Dhabi, United Arab Emirates. I served as an external referee for the position of Professor in Veterinary Surgery and Radiology at King Faisal University, Al Hasa, Saudi Arabia.

**Organised Camel Conferences and delivered lectures in Germany, Iran, Egypt and Saudi Arabia**

I organised an International Camel Conference at College of Veterinary and Animal Sciences, Bikaner, India from 16-17 February, 2007. It was a big event where more than 45 scientists came from abroad and about more than 100 from India (Fig 1). Distinguished Camel Scientist Awards were given to 14 camel scientists or practitioners for the first time in any of the international camel Conference.

I was invited by the organisers of Veterinary Conferences, USA for a lead paper in Florida in 2015 and later I organised a two hour session on Camel Science at their conferences held at Paris (2017) and Berlin (2019) which I did successfully.

I was invited by the School of Ruminant Science at Ludwig Maxmillian University, Munich, Germany in the year 2011 where I delivered a lecture on Camel Medicine and Surgery to the faculty and students.

I was invited for a lead paper in the International Congress of Camel in Iran in 2008 and 2016 and as a lead speaker in the First International

Immobilising a fractured mandible by transfixation with fibre cast technique.

Visiting Camel Clinic with Prof R.O.Ramadan at King Faisal University, Al Hasa, Saudi Arabia in February 2013 (Left) and presenting a lead paper on camel surgery here (right).

Camel Saviour Award ceremony at Khudi, Jaisalmer where a camel garlanded me and award was given by the Ilse Kohler Rollefson, Chairperson of LPPS, Sadri (Left) and participants of Marwar Camel Culture Festival at LPPS, Sadri, Pali, Rajasthan (Right).


Member of Adhoc Committee on Camel Diseases at OIE, 4th May, 2010 (Left) and Member of Technical Committee of CAMENET.


Organised International Camel Conference at College of Veterinary and Animal Science, Bikaner on 16-17 February, 2007. Felicitation (left) and interaction with eminent scientists Dr R. Schuster and U. Wernery.


Presenting a lead paper on Camel Surgery in Global Veterinary Summit at Florida in 2015 (Left) and organised a session on Camel Science at International Conference held at Berlin, Germany in 2019 (Right).

Conference, April 7th -8th, 2019, Matrouh, Egypt, organised by Faculty of Veterinary Medicine, Matrouh University, Egypt. I was also invted as lead speaker in the conference of SVMS, at King Faisal Unibersity, Saudi Arabia in October 2022.

### Developed Camel Clinic

I was committed to developing the camel clinic in the Veterinary Clinical Complex at College of Veterinary and Animal Science, Bikaner consistently. The camel clinic was augmented in terms of facilities like imaging, operation theatre, camel trevises, indoors and outdoors for camels. I outsourced the advance imaging like computed tomography and magnetic resonance imaging specially to learn the surgical anatomy on the cadavers of camels as early as 2010-12.

Ludwig Maxmillian University for a lecture on "Camel Surgery and Medicine" 12 June, 2012 (Left) and students listening to my lecture (Right).


Dr Amir Niasari is honouring me in the International Congress of Camel in Iran (Left) and my felicitation as a lead paper speaker on Camel Surgery in the conference at Matrouh University, Mersa Matrouh, Egypt.


A Camel Trevis developed by me (left) and performing CT scan of a Cadaver head of a dromedary camel (right).

Donating the camel journal and books to the Organising Secretary of World Veterinary Editors Conference at Tallin, Estonia (left) and Dean, International Camel Conference, University of Khartoum, Sudan; King Faisal University, Saudi Arabia; Inner Mongolia Research Institute, China.


Collaboration with NACROA: Visiting Texas A&M University (left) and with NACROA team at college of Veterinary and Animal Sciences, Bikaner (Right).

Camel Surgery of different body parts and anatomical systems of camels were standardised and established. I am indebted to the camel farmers and Border Security Forces whose camels with surgical disorders were subjected to the camel surgery over the years and we thus got a perfection in this field. I feel sad about a decline in the population of camels in India, hence we are receiving very less numbers of camels in the Veterinary Clinical Complex at Bikaner. Nevertheless, I feel honoured to have contributed to the development of camel surgery, especially for dromedary camels in India.

### Donated Camel Books and Journal of Camel Practice and Research to the Veterinary Institutes in India and Abroad

I donated the camel books and journals authored or edited by me to the libraries of several countries visited by me over a period of time at World Veterinary Editors Conference at Tallin, Estonia; University of Khartoum, Sudan; King Faisal University, Saudi Arabia; Inner Mongolia Research Institute, China and Veterinary University, Egypt. It was aimed to enrich the respective libraries with the published camelid literature.

### Collaborated with NACROA

I had a fruitful collaboration with the North American Camel Ranch Owners Association (NACROA), USA over a period of time during their several visits to India, which eventually facilitated my visit to the Texas A&M University, USA. I owe my sincere thanks to Mr Douglas Baum and Valeri Crenshaw, office bearers of NACROA who not only visited Camel Clinic at Bikaner, India but also facilitated my camel tour of texas, USA.

### Edited and Published Journal of Camel Practice and Research, Camel Books and Conference Proceedings

The Journal of Camel Practice and Research (JCPR) is 32 years old now and proved as a biggest


The Books, Journal and Proceedings of Camel Conference edited by me.

literature resource for the researchers. Many researchers from different countries working on various aspects of camels, often enquired about recent research on camels. I quickly provided them the list of references or abstracts available with me. I edited many books on camelids and most of these were a compilation of papers published in the JCPR on the particular subject. These were Selected Topics on Camelids (2000) and Selected Bibliography of Camelids 1991-2000 (2002), Selected Research on Camelid Physiology and Nutrition (2004), Selected Research on Camelid Parasitology (2007), Selected Research on Gross Anatomy and Histology of Camels (2012), Selected Research on Camelid Immunology (2016). I edited and published few books on the request of their authors, i.e. The Camel : The Animal of the 21$^{st}$ Century (2016), and Bulletin of Camel Disease in The Kingdom of Bahrain (2015). I edited the proceedings of international camel conferences held at Bikaner, India in the year 2007 and at Al-Hasa, Saudi Arabia in 2013.

Currently, JCPR is indexed by CABI and SCOPUS only. Web of Science discontinued its indexing in 2021 due to certain objections with the journal's web site. As s result, many researchers from UAE, China and Saudi Arabia have stopped submitting manuscripts, as their institutions require publication in journals indexed by the Web of Science. Despite making the necessory revisions, I have not been successful in getting JCPR re-included, which is quite disappointing for me and camel scientific community as the 32 years old Journal now faces the risk of extinction. Nevertheless, my efforts to support and advance camel science will continue.

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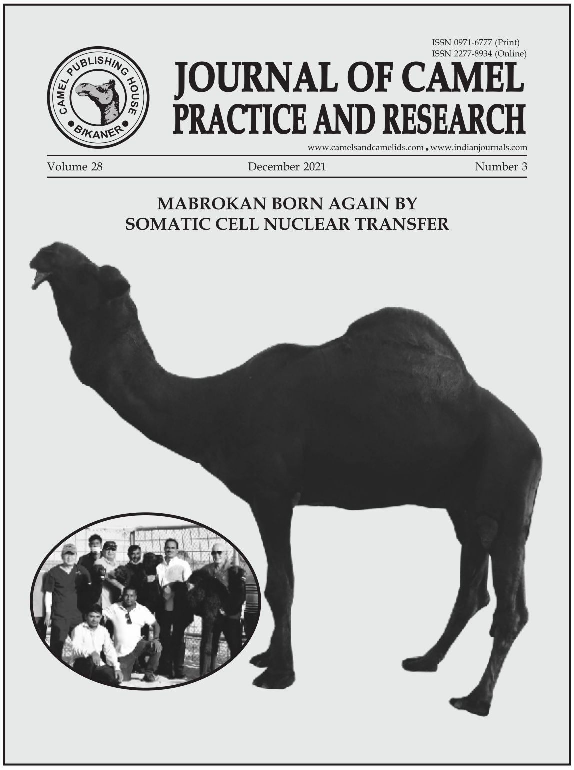

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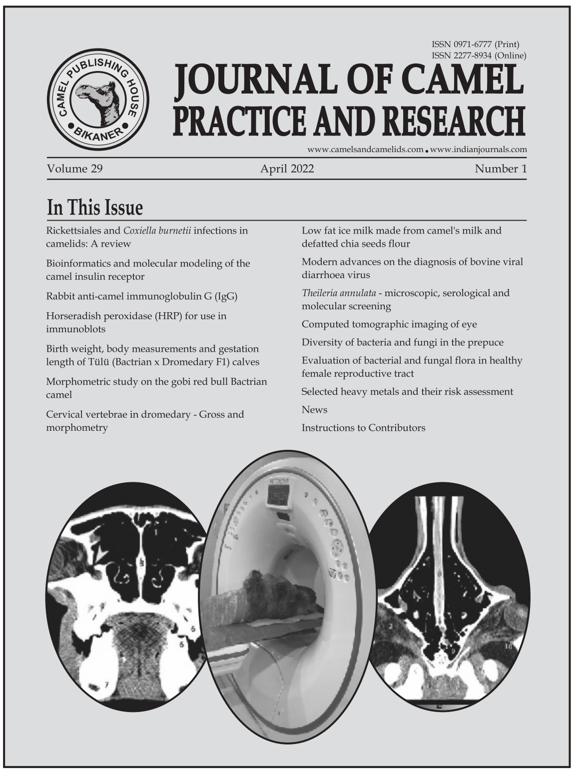

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**Statements of ethical approval for studies involving animals**

If your study involves animals, and also if your manuscript includes case reports/case series, you need to provide the following:

- Authors must provide the **name of the ethical approval committee/Institutional Review Board** they have obtained consent from along with approval number/ID.
- Authors must state that **written informed consent was obtained** from the owners of the animals or head of the veterinary institutes where the research was carried out.

**Declarations specific to article types**

We have looked at the declarations related to manuscript submission and when your study involves human (for example- feeding camel milk to the diabetic human patients or autistic patients) or animal subjects. Let us now turn to specific article types and the declarations you need to prepare when submitting them.

1. **Clinical trials and research papers:** All clinical trials and planned research should be approved by the institutional ethics committee and should also be approved through an appropriate research committee of the institute (It should be depicted in the acknowledgement section).
2. **Reviews:** Reviews do not need any ethical approvals or informed consent. However, JCPR expects that the review should not be older than 4 decades.
3. **Short Communications or Case Reports:** These are rare clinical reports or new diagnoses or a new technique (pilot

trials), usually published with or without abstract and keywords. These article types do not exceed 2-3 pages of the journal.

**Other important declarations related to funding, conflicts of interest, and more**

Apart from the declarations we have discussed, there are others that authors need to consider. Let us take a look at them:

1. **Describing new taxa:** Authors must provide relevant documents and unique digital identifier for manuscripts that describe new taxa or species. They should also declare that the relevant guidelines have been followed for algae, fungi and plants, zoological taxa, bacteria, and viruses. Registration numbers for the new species (for e.g. from **MycoBank** (Mycobank) for fungi or **ZooBank** (ZooBank.org) for zoological species) should be stated in the manuscript. New virus names should be sent to the relevant study groups for consideration before publication in a journal.
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The JCPR staff and in-house editorial team perform an initial quality check to identify potential issues such as:

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- Compliance with editorial policies and ethical standards
- Financial disclosures
- Data availability

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After completing internal checks, each new submission is assigned to an Academic Editor (Usually Editor in Chief) with relevant subject matter expert. The editor reviews the manuscript against our publication criteria and determines whether reviews from additional experts are required to evaluate the manuscript. The Editor in Chief decides about further handling of the manuscript by usually a member of the Editorial Board of JCPR, but occasionally a Guest Editor is invited to serve instead.

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Le Hai[1], Rendalai Si[2], Fu-Cheng Guo[1], Jing He[1], Li Yi[1], Liang Ming[1], Jun-Wen Zhou[3], La Ba[3], Rigetu Zhao[3] and Rimutu Ji1,[2]

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[3]Alxa League Institute of Animal Husbandry, Alxa, Inner Mongolia, China

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**Thesis:** Rathod Avni. Therapeutic studies on sarcopticosis in camels (Camelus dromedarius). Unpublished Masters Thesis (MVSc), Rajasthan Agricultural University, Bikaner, Rajasthan, India. 2006.

**Commercial booklets:** Anonymous/Name. Conray-Contrast Media. IIIrd Edn., 1967; pp 12-15, May and Baker Ltd., Dagenham, Essex, England.

**Magazine articles:** Taylor D. The Constipated Camel. Reader's Digest. Indian Edn. RDI Print & Publishing (P) Ltd., Mehra House, 250-C, New Cross Road, Worli, Bombay, India. 1985; 126:60-64

**News paper articles:** Christina Adams. Camel milk: a miracle cure for children with autism?. Gulf News, Published: April 09. 2014.

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