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## In This issue



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# CONTENTS

**Volume 33** **August 2026** **Number 2**

EDITORIAL

# PIONEERING GLOBAL ADVANCES IN CAMEL CHEESE TECHNOLOGY AND COMMERCIALISATION

The development of camel cheese technology represents one of the most remarkable achievements in camel dairy science over the past four decades. Once considered technically impractical because of the unique physicochemical properties of camel milk, camel cheese has evolved into a commercially successful dairy product through the pioneering efforts of visionary scientists and entrepreneurs.

Among these pioneers, Jean-Paul Ramet is universally acknowledged as the scientific architect of modern camel cheese technology. During his work with the Food and Agriculture Organisation (FAO) in the late 1980s and early 1990s, he developed practical methods for coagulating camel milk, overcoming a long-standing technological barrier to cheese manufacture. His pioneering work culminated in the FAO manual ''The Technology of Making Cheese from Camel Milk (*Camelus dromedarius*)'', which remains a landmark reference in camel dairy science.

The commercialisation of camel cheese was subsequently pioneered by Nancy Jones Abeiderrahmane, founder of Tiviski Dairy in Mauritania. Working in close collaboration with the FAO and Jean-Paul Ramet, she established the world's first successful commercial camel cheese production unit and introduced Caravane (Camelbert), the first internationally recognised camel milk cheese. This achievement demonstrated the commercial feasibility of camel cheese and opened new avenues for value addition in the camel dairy sector.

Another landmark contribution was made by Dr. Stefan R. Kappeler (Switzerland). During his doctoral research at ETH Zurich under the supervision of Prof. Zakaria Farah, Dr. Kappeler characterised recombinant camel chymosin and demonstrated its superior milk-clotting properties. This breakthrough provided the scientific basis for the development of the commercial camel rennet Chy-MAX® M by Chr. Hansen, making reliable industrial-scale production of camel cheese possible and revolutionising camel cheese manufacture worldwide.

In recent years, Prof. Gaukhar Konuspayeva and Dr. Bernard Faye have emerged as the leading international authorities in camel cheese research and technology development. Their collaborative studies have significantly advanced the understanding of camel milk composition, coagulation properties, and cheese-making processes. Through systematic investigations involving camel chymosin, calcium supplementation, controlled acidification, starter cultures, and optimised processing conditions, they have substantially improved cheese yield, texture, sensory quality, and production efficiency.

Beyond research, Prof. Konuspayeva and Dr. Faye have made outstanding contributions to knowledge dissemination through numerous scientific publications, book chapters, and the Springer volume 'Large Camel Farming' (2023). Their practical training workshops on camel milk processing and cheese manufacture, conducted across Africa, Europe, the Middle East, and Central Asia under the auspices of the FAO and the European Union-funded CAMELMILK Project, have played a pivotal role in strengthening technical capacity and promoting sustainable camel dairy industries worldwide.

Collectively, the pioneering contributions of Jean-Paul Ramet, Nancy Jones Abeiderrahmane, Stefan R. Kappeler, Gaukhar Konuspayeva, and Bernard Faye have transformed camel cheese production from an experimental concept into a scientifically robust and commercially successful enterprise. Their combined efforts have established the technological foundation for the modern camel dairy industry, facilitated global technology transfer, improved product quality, and created new economic opportunities for camel pastoralists and dairy entrepreneurs.

The August issue of the Journal of Camel Practice and Research presents another diverse and scientifically rich collection of articles. It features the continuing series "Journey to Camel Science" by Dr.

Alex Tinson and Dr. Mohammed Bengoumi, together with contributions from researchers representing the United Arab Emirates, Ethiopia, Morocco, Algeria, Saudi Arabia, Sudan, Tunisia, and Australia.

The issue covers a broad spectrum of contemporary camel research, including the anatomy, histology and electrophysiology of the dromedary heart; camel-centric proverbs from the Berhale District of Ethiopia; the effects of camel and cow milk powder on camel soft white cheese; nutritional supplementation and milk quality; the influence of ginger and acetic acid marinades on the Biceps femoris muscle; multimodal diagnostic imaging and electromyographic assessment of cosmetic tampering in camels; indigenous knowledge systems and traditional camel meat preservation; the pro-apoptotic and anti-proliferative antilarval effects of ivermectin on camel nasal bots; proximate analysis of rangeland plants grazed by camels in the Butana Plain; and the relationship between drought severity and camel population dynamics in Ethiopia.

On behalf of the Editorial Board, I express my sincere gratitude to all authors, reviewers, editorial board members, and readers for their continued support and commitment to the Journal of Camel Practice and Research. Their dedication has established JCPR as one of the leading international forums for disseminating high-quality camel research. I am confident that, with your continued cooperation, the journal will further strengthen its contribution to advancing global camel science.

(Dr. Tarun Kumar Gahlot)
Editor

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# ANATOMY, HISTOLOGY AND ELECTROPHYSIOLOGY OF THE DROMEDARY CAMEL HEART: A REVIEW

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## ABSTRACT

Like other mammalian species, the dromedary camel (*Camelus dromedarius*) heart consists of specialised structures responsible for generating and propagating electrical impulses to coordinate myocardial contraction. The electrical conduction system embedded within the atria and ventricles plays a crucial role in regulating cardiac function and ensuring efficient blood circulation in the challenging desert environment. The conduction system is composed of the sinoatrial node (SAN), atrioventricular node (AVN), the bundle of His, the right and left bundle branches, and the Purkinje fibres. These structures work in tandem to maintain a consistent heartbeat, adjusting to physiological demands such as dehydration, prolonged exertion, and temperature extremes.The SAN, often referred to as the heart's primary pacemaker, initiates electrical impulses that trigger each heartbeat. The AVN delays transmission of electrical impulses from the atria to the ventricles. The bundle of His and its branches facilitate rapid transmission to the Purkinje fibres, ensuring synchronised ventricular contractions. The aim of this review is to describe and synthesise current knowledge on the anatomical, histological, and electrocardiographic (ECG) features of the dromedary camel (*Camelus dromedarius*) heart, with particular emphasis on its specialised conduction system and physiological adaptations that facilitate resilience in arid desert environments.

**Key words:** Anatomy, arid environment, dromedary camel, electrical conduction system, heart

The dromedary camel (*Camelus dromedarius*) has long been recognised as a species uniquely adapted to arid environments, with its cardiovascular system playing a central role in supporting survival under conditions of heat, dehydration, and prolonged exertion. The camel heart, while sharing the fundamental mammalian design of four chambers and specialised conduction pathways, exhibits distinctive anatomical, histological, and electrocardiographic features that distinguish it from other domestic ruminants. Previous studies including the pivotal work of Sunao Tawara who made the discovery of the AVN in 1906 have documented and reviewed the cardiac electrical conduction system in various animal species (De Almeida *et al,* 2020; Padala *et al,* 2021; Sánchez-Quintana *et al,* 2022; Lee *et al,* 2024; Sánchez-Quintana *et al,* 2024). Of particular note is the article by De Almeida *et al* (2020) in which they compared the cardiac conduction tissue of ox heart with the arrangement in man. The ox heart shares the human atrioventricular conduction structure but shows anatomical features that explain the difference in arrangement of the conduction axis between the two species, confirming Tawara's descriptions with minor species-specific anatomical variations. Tawara's original depiction of the AV conduction axis remains anatomically precise and recent studies have confirmed its accuracy, while other researchers have suggested the presence of a paraspecific system for AV conduction (Mahaim, 1947). Macías *et al* (2022) reported differences in the cardiac conduction system, and in particular the arrangement of the atrioventricular conduction axis in different mammalian species including human, murine, porcine, bovine and canine hearts (Macías *et al,* 2022). Early anatomical investigations, notably those by

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Hegazi (1954), reported that the average proportion of the weight and size of the camel heart to its body is much less in comparison with the proportions in other domesticated animals. Its average weight is about 0.6% of body weight, yet morphologically distinctive, with a broad base, tapering apex, and abundant epicardial fat. Structural specialisations such as a single *ossa cordis*, a prominent moderator band in the right ventricle, and the robust fibrous composition of the mitral and tricuspid valves were also highlighted (Hegazi, 1954). Subsequent studies expanded this knowledge through echocardiography, computed tomography (CT), and magnetic resonance imaging (MRI), providing refined morphometric standards for ventricular wall thickness, chamber dimensions, and coronary fat distribution (Dehghan *et al,* 2011; Alsafy *et al,* 2023; Aref *et al,* 2024).

Histological examinations have deepened our understanding of myocardial organisation and conduction pathways. Early reports debated the presence of Purkinje fibres, but later studies confirmed their existence and functional arrangement within the sub-endocardium, contributing to rapid impulse transmission in the thick-walled left ventricle (Ghonimi *et al,* 2014). Investigations of the SAN and AVN revealed distinctive features, including elongated nodal architecture, collagen-rich frameworks, and Purkinje-like atrial cells with high glycogen content, underscoring conduction efficiency and autonomic regulation (Ghazi and Tadjalli, 1993, 1996; Ghonimi *et al,* 2015). ECG studies provide a functional counterpart to these anatomical and histological findings. Early work by Braun *et al* (1958) and Geddes *et al* (1973) identified hallmark features of the camel ECG, including lower amplitude signals and prolonged atrioventricular conduction time compared to man (Braun *et al,* 1958; Geddes *et al,* 1973). More recent studies using base–apex lead placement established reference values across age groups and reported normal heart rate was 48-69 and 74-89 bpm in adults and calves, respectively. A long atrioventricular node conduction time (P-R interval) was also an important finding in this study (Pourjafar *et al,* 2011b). Al-Haidary *et al* (2016) investigated the effects of circadian rhythmicity on a wide variety of physiological parameters including heart rate, body and skin temperature, sweat rate, respiratory rate. Pourjafar *et al* (2011a) reported a case of atrial fibrillation in 5-year old camel. Al Khamis *et al* (2023) investigated the practicality and usability of wearable monitoring technologies compared to standard base-apex electrocardiography in camels. Collectively, the anatomical, histological, and electrocardiographic studies of the dromedary camel heart illustrate a cardiovascular system finely tuned for resilience in extreme environments. From classical dissections to advanced imaging and electrophysiological recordings, these investigations highlight both the uniqueness of camel cardiac biology and its importance as a comparative model within veterinary and biomedical research. The aim of this review is to describe and synthesise current knowledge on the anatomical, histological, and ECG features of the dromedary camel (*Camelus dromedarius*) heart, with particular emphasis on its specialised conduction system and physiological adaptations that facilitate resilience in arid desert environments.

**Anatomy and histology of the camel heart**

The camel heart structure is like that of other large ruminants, it exhibits key morphological, structural, and functional adaptations that contribute to the camel's ability to withstand extreme temperatures, dehydration, and prolonged exertion. Various anatomical studies, including echocardiography, MRI, CT imaging and histological examinations, have provided detailed insights into the camel heart's structural complexity and efficiency (Hegazi, 1954; Lapiccirella and Abboni, 1962; Karkoura *et al,* 1995; Dehghan *et al,* 2011; Tharwat *et al,* 2012; Ghonimi *et al,* 2014; Esmailinejad *et al,* 2022; Alsafy *et al,* 2023; Aref *et al,* 2024). The gross anatomy of the camel heart is shown in Fig 1.

The camel heart constitutes approximately 0.6% of body weight, making it proportionally smaller than in most domesticated animals (Hegazi, 1954). MRI scans in adult camel cadavers showed that the heart is conical-shaped and found to be located in the ventral third of the thoracic cavity between the 3rd and 5th intercostal spaces. The mean heart weight was 2.4 kg. The heart weight/body weight ratio was 0.004 kg/kg (Aref *et al,* 2024). It is broad at the base and tapers into a slender, pointed apex resembling a funnel (Figs 1A and 1B). The heart lies obliquely on the left side of the thorax, extending from the second intercostal space or third rib anteriorly to the end of the fifth intercostal space or sixth rib posteriorly. The average weight of the heart ranges from 2.5 lb in young camels to 5 lb in adults. The camel's heart is covered by a large amount of fat, especially along the coronary and longitudinal grooves. The thickest accumulation is on the left side, filling the coronary groove between the auricles and forming a fatty belt around the roots of the pulmonary artery and aorta. From there, the fat

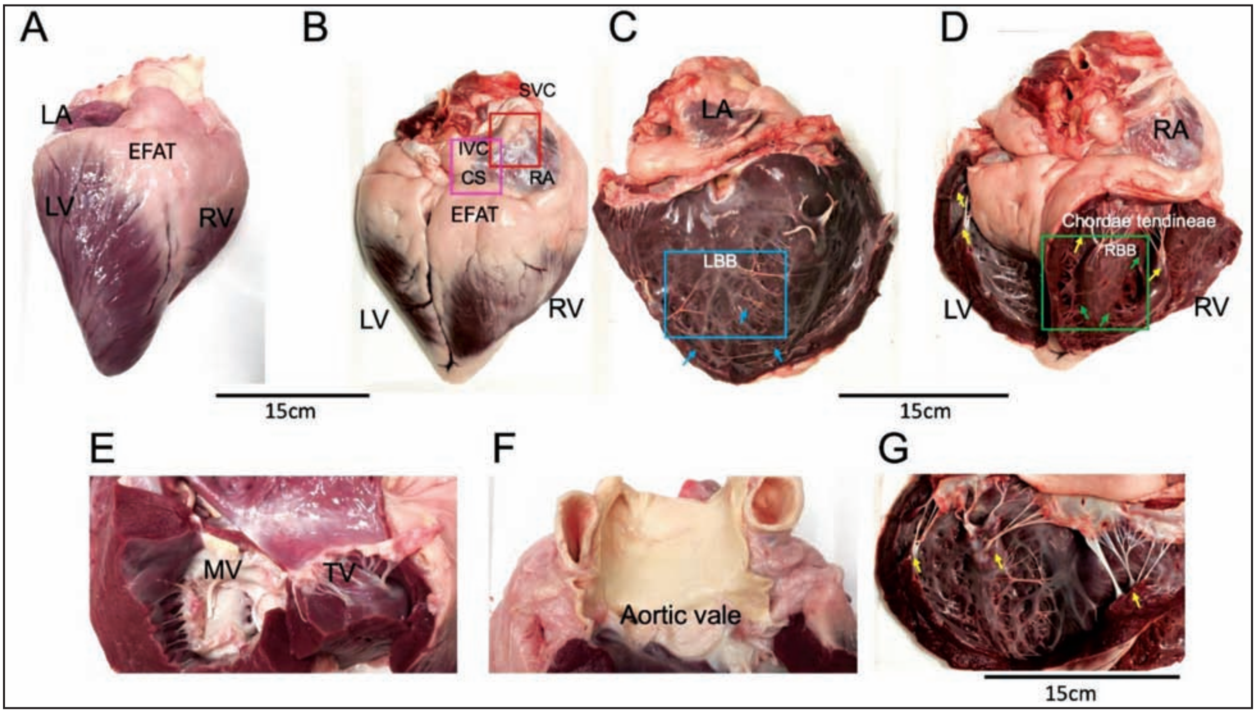


**Fig 1.** Gross anatomy of camel heart. A, Left ventricle (LV), right ventricle (RV) and left atrium (LA) are shown. B, LV and RV and right atrium (RA) are shown. Red and pink squares in B are regions used to dissect the sinoatrial node (SAN) and atrioventricular node (AVN) regions shown in Fig 2. C, view from inside the LV to visualise fine hair-like structures representing Purkinje fibres (PF) (blue arrows). Blue square is the region of left bundle branch (LBB) with closer illustration in Fig 3B. D, view from inside RV to visualise chordae tendineae connecting tricuspid valve (TV) to papillary muscles (yellow arrows) and fine hair-like structures representing PFs (green arrows). Green square is the region of right bundle branch (RBB) with closer illustration in Fig 3C. E, view from inside showing mitral valve (MV) and TV. F, view from inside to show three cusps of aortic valve. G, view from inside the LV to visualise the chordae tendineae connecting the mitral valve (MV) to papillary muscles (yellow arrows). (Hearts were collected from a local abattoir, dissected, and photographed).

extends along the left longitudinal groove, gradually thinning toward the apex, where it connects with the right longitudinal groove (Hegazi, 1954). Recent CT-based morphometric analysis of hearts from 6 to 9 year old camels confirmed this groove architecture and quantified coronary fat, which represented nearly 29% of the cross-sectional area at the coronary groove (Alsafy *et al,* 2023).

The large quantity of fat surrounding the camel heart serves several adaptive functions essential for survival in arid environments. It acts as an energy reserve, providing a readily available lipid source for cardiac metabolism during periods of food scarcity or dehydration. This fat also offers thermal insulation against extreme desert temperatures and cushions the heart from mechanical shocks during movement. Moreover, it supports the myocardium by supplying fatty acids, the preferred energy substrate for cardiac muscle, ensuring continuous contraction under metabolic stress. Finally, lipid oxidation yields metabolic water, contributing to the camel's remarkable ability to endure prolonged water deprivation (Hoter *et al,* 2019; Ali *et al,* 2020).

The right atrium (Fig 1D) is small, with a thin and flabby wall. Its auricle is triangular, narrow-necked, and internally lined by a dense network of pectinate muscles (Hegazi, 1954). The left atrium (Fig 1C), although smaller in volume, is notable for its thick fibrous lining. Its auricle is rounded and serrated, receiving blood from four to five pulmonary veins. The right ventricle (Fig 1B) is triangular, relatively small compared with ox or horse, and thin-walled. The tricuspid valve (Fig 1E) comprises three broad cusps supported by numerous chordae tendineae, with a prominent moderator band ending in the middle part of the septum. The left ventricle is narrow and very thick-walled, with an oblique cavity at the apex (Fig 1B). The bicuspid (mitral) valve has two strong fibrous cusps supported by robust chordae tendineae arising from both wall and septal papillary muscles (Fig 1E). The papillary muscles of the camel heart are distinct and well developed. In the right ventricle, a large, strong, broad papillary muscle arises near the apex and divides into two branches,

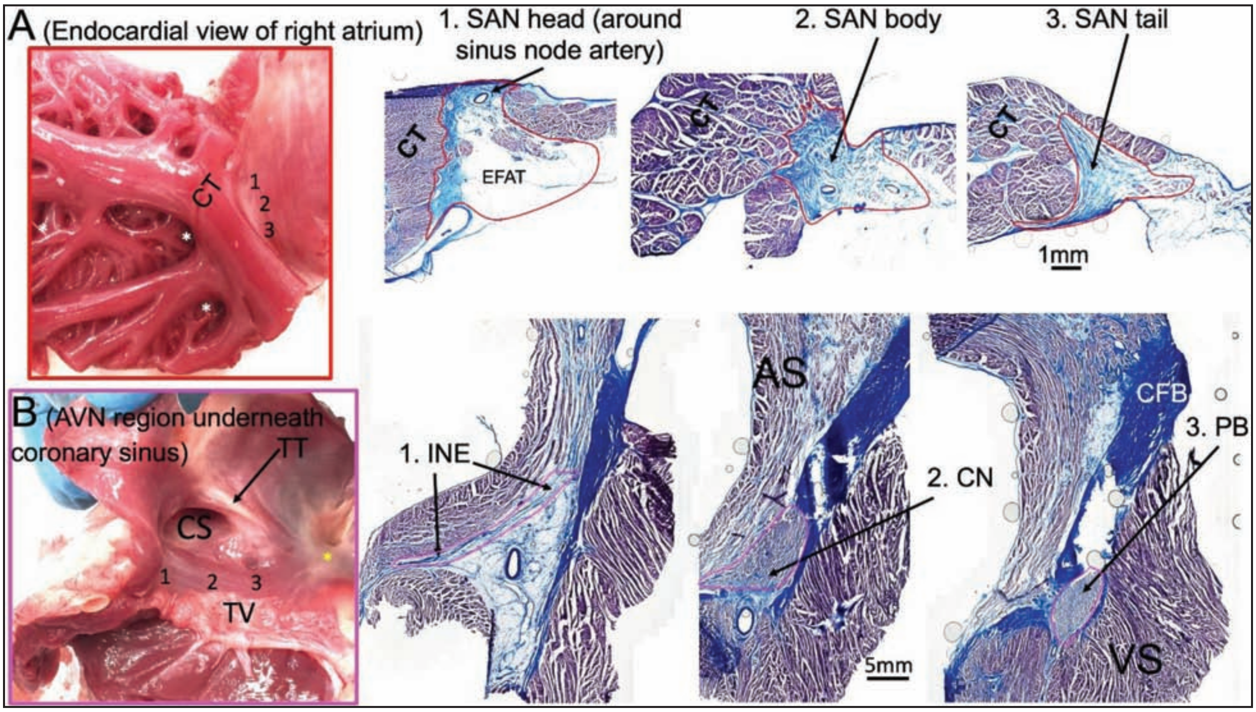


**Fig 2.** Dissection of the sinoatrial node (SAN) and atrioventricular node (AVN) regions within the right atrium. A, SAN region with numbers indicating position of the SAN head, body and tail in histological slices (outlined in red in Fig 2A 1, 2 and 3). The SAN region appears to be insulated from its surrounding right atrial myocardium. SAN myocytes (stained in purple) are small and embedded in the network of stained blue connective tissue. B, AVN region (dissected pink region in Fig. 1B) with numbers indicating position of components of the atrioventricular conduction axis, consisting of the 1. Inferior nodal extension (INE) 2. Compact node (CN) and 3. Penetrating bundle (PB) (outlined in pink). Myocytes of AVN cells, located within triangle of Koch are stained purple. A yellow star is situated on the membranous septum. Hearts were collected from a local abattoir. Tissues were fixed and histological sections were stained with Masson's trichrome stain. CS, coronary sinus; CT, crista terminalis, EFAT, epicardial fat; TT, tendon of Todaro; TV, tricuspid valve.

one giving rise to the chordae tendineae that attach to the valve cusps and the other forming a large moderator band extending to the interventricular septum. Additional smaller papillary muscles are found near the entrance of the conus arteriosus. In the left ventricle, two large papillary muscles arise opposite each other, one from the wall and one from the septum, with numerous additional papillary muscles scattered over the wall and septum except near the aortic entrance (Hegazi, 1954). Modern histological work confirmed the layered structure of the left ventricular wall, endocardium, myocardium, and epicardium, and demonstrated the distribution of Purkinje cardiomyocytes within the subendocardium (Ghonimi *et al,* 2014). The anatomical detail of the Purkinje fibres is shown in Fig 3. The aorta is notably large and thick-walled, giving rise to two vessels from its arch: a smaller left axillary artery and a larger brachiocephalic trunk. Both the aortic and pulmonary valves consist of three large semilunar cusps (Fig 1F). The pulmonary artery bifurcation is connected to the aortic arch by a strong ligamentum arteriosum. The pericardium is thick and opaque, containing an unusually large volume (~200 mL) of gelatinous pericardial fluid (Hegazi, 1954). Unlike oxen, which possess paired *ossa cordis*, camels consistently have a single ossified bone in the right fibrous aortic ring. This triangular ossa-cordis is partly cartilaginous and partly ossified, serving as an anchoring site for the posterior cusp of the aortic valve (Hegazi, 1954). Histological studies have revealed myocardial fibres with cross-striations and single nuclei, surrounded by distinct vascular connective tissue (Hegazi, 1954). Microanatomical investigations have demonstrated the presence and specialised organisation of Purkinje fibres within the left ventricular subendocardium, where they contribute to conduction efficiency (Ghonimi *et al,* 2014). Moreover, Lapiccirella and Abboni (1962) identified the AVN (Fig 2B) and bundle of His fibres in camel hearts, supporting the existence of a specialised conduction system (Lapiccirella and Abboni, 1962). Recent CT and MRI studies have advanced understanding of camel heart morphology. Alsafy *et al* (2023) showed that the camel heart is an elongated cone (Figs 1A and 1B) with a curved apex, and quantified ventricular wall thickness and

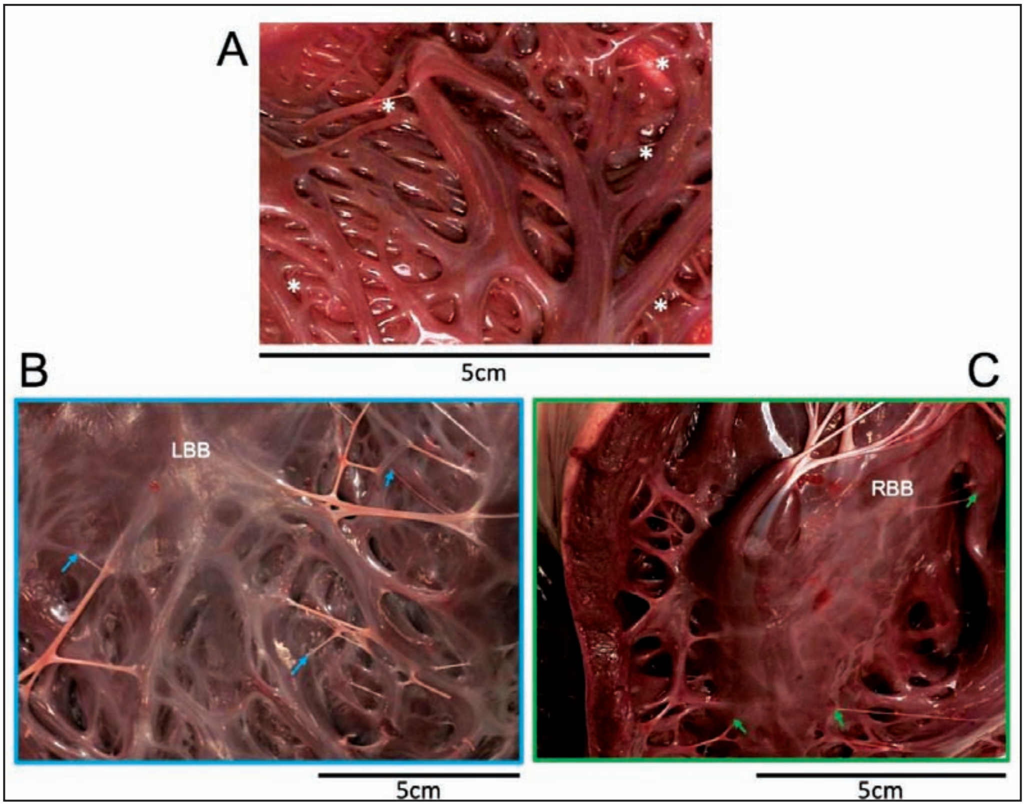


**Fig 3.** Gross anatomy of endocardial view of heart chambers. A, left atrium with location of atrial like Purkinje fibres/myocardial bridges (white stars) B, left bundle branches (LBB) and Purkinje fibres (blue arrows). C, right bundle branches (RBB) and Purkinje fibres (green arrows). (Hearts were collected from a local abattoir, dissected, and photographed).

coronary fat distribution. Aref *et al* (2024) provided the first MRI-based morphometric standards for adult camels, confirming chamber dimensions and wall thicknesses consistent with gross anatomical findings. Echocardiographic studies have also established baseline functional values, such as ejection fraction (~85%) and fractional shortening (~54%) in young healthy camels (Dehghan *et al,* 2011). Ultrastructural investigations have reported age-related alterations in camel myocardium. Karkoura *et al* (1995) documented hypertrophic Z-lines in aged camels, along with loss of myofibrils and mitochondrial disruption, paralleling senescent changes seen in humans.

The camel heart is proportionally small but morphologically distinctive, characterised by its pointed, oblique apex, contrasting right and left ventricular morphology, prominent grooves, abundant epicardial fat, and a single *ossa cordis*. Advances in histology, CT, and MRI have refined earlier descriptions, confirming the presence of specialised conduction fibres and providing precise morphometric standards. From early classical dissections to modern imaging-based analyses, the camel heart emerges as a unique cardiovascular model among domestic mammals, with adaptations likely reflecting the species' ecological niche and physiological resilience.

**Generalised electrical conduction system in the mammalian heart**

The mammalian cardiac electrical conduction system ensures the coordinated contraction of the heart, enabling efficient blood circulation. It begins with the SAN, the heart's primary pacemaker, which spontaneously generates action potentials. These electrical signals travel through the atria, causing contraction, before reaching the AVN, where the signal is delayed in order to facilitate ventricular filling. In humans the SAN consists of the head, body and tail (Chandler *et al,* 2011; Stephenson *et al,* 2017; Chen *et al,* 2024). The atrioventricular conduction axis, which provides continuity between the atrial and ventricular chambers, consists of the Inferior Nodal Extension (INE), Compact Node (CN) and the Penetrating Bundle (PB) of His (Greener *et al,* 2011; Stephenson *et al,* 2017). The impulse then passes through the right and left bundle branches, which conduct signals to the Purkinje fibres. These fibres rapidly distribute the impulse, triggering synchronised ventricular contraction. This system maintains rhythmic heartbeats which are essential for circulation and homeostasis (Lee *et al,* 2024).

### Electrical conduction system of the camel heart

The camel heart possesses a conduction system that is broadly comparable to other ungulates but demonstrates distinctive structural features. The SAN has been identified as the primary pacemaker, situated beneath the epicardium at the cranial end of the terminal sulcus, close to the junction of the superior vena cava, the right atrium, and the right auricle (Fig 2A, 1-3).

Histological studies by Ghazi and Tadjalli (1996) demonstrated that the node is elongated, bent-oblong in shape, with mean dimensions of 28.25 mm in length, 5.75 mm in width, and 5.38 mm in thickness (Ghazi and Tadjalli, 1996). It contains a central artery arising from the left circumflex branch of the left coronary artery, surrounded by a dense collagenous framework. Two major cellular types, pacemaker ("P") cells with a perinuclear clear zone and transitional cells with more abundant myofibrils, form the nodal parenchyma, while a peripheral ganglion and nerve fibres provide autonomic regulation (Ghazi and Tadjalli, 1996). Further ultrastructural work by Ghonimi *et al* (2015) emphasised the gland-like architecture of the camel SAN, in which connective tissue septa divide the node into lobes and arms, producing an "octopus-like" appearance. Three specialised myocyte populations were described: P cells, transitional cells, and atrial Purkinje-like cells. The latter are larger, glycogen-rich, and pale-staining, extending into SAN "arms" that serve as internodal and interatrial conduction pathways (Ghonimi *et al,* 2015). The conduction pathway continues through the atrioventricular (AV) node and bundle of His. In camels, the AV bundle is a direct continuation of the AV node, with no sharp demarcation between the two structures. According to Ghazi and Tadjalli (1993), the bundle runs through the fibrous trigone, enters the membranous septum beneath the right endocardium, and then bifurcates into right and left bundle branches. The AV bundle (Fig 2B, 1-3) in camels measured on average 4.12 mm in length, 3.66 mm in width, and 1.13 mm in thickness, with a maximum sectional area of 12.68 mm$^2$. Histologically, the AV bundle in camel heart is composed of multiple strands of Purkinje cells separated by collagen fibres surrounded by connective tissue. It resembles that found in human and dog heart except, in camels, the intercalated discs (connections between cardiac myocytes) were present at the intercellular connections in the AV bundle (Ghazi and Tadjalli, 1993). The Purkinje fibre system is particularly extensive in the camel heart. Both atrial and ventricular Purkinje fibres are present. Within the atria, Purkinje-like myocytes were reported by Ghonimi *et al* (2015) as contributing to rapid conduction from the SA node into the atrial myocardium, while in the ventricles, subendocardial Purkinje fibres distribute widely, especially within the thick left ventricle, ensuring coordinated depolarisation (Ghonimi *et al,* 2015). Electrocardiographic findings corroborate the anatomical organisation. Daily rhythm studies by Al-Haidary *et al* (2016) demonstrated that camels maintain robust rhythmicity of heart rate and body temperature under both natural desert conditions and controlled laboratory environments, highlighting the stability of the conduction system under thermal stress.

### Electrocardiography of the camel heart

Electrocardiographic investigations in the dromedary camel have revealed characteristic features that distinguish this species from other large domestic animals. Early studies demonstrated that camels show relatively low ECG amplitudes in limb leads, a prolonged atrioventricular conduction time (PR interval ≈0.26 s), and a QRS axis oriented toward +250°, reflecting the unique morphology and conduction pattern of the camel heart (Braun *et al,* 1958; Geddes *et al,* 1973). The QRS complex corresponds to ventricular depolarisation. Subsequent work confirmed that the heart rate in adult camels generally ranges between 48–69 beats per minute, whereas calves may have higher rates of 74–89 beats per minute (Pourjafar *et al,* 2011b). A typical recording of a camel ECG is shown in Fig 4A, the various ECG intervals are shown in Fig 4B, and the positioning of electrodes are shown in Fig 4C. The P wave is typically positive, though variable in amplitude, and corresponds to atrial depolarisation. The QRS complex is often biphasic and corresponds to ventricular depolarisation. The T wave may be negative, positive, or biphasic (Fig 4A) depending on lead placement and physiological state and corresponds to ventricular repolarisation (Geddes *et al,* 1973; Pourjafar *et al,* 2011b). The prolonged PR interval is a consistent finding across studies and has been interpreted as evidence of relatively slow atrioventricular conduction compared with other ruminants (Pourjafar *et al,* 2011b). The base–apex lead system has become the standard for recording ECGs in camels, offering clearer waveforms and minimising movement artifacts. Using this approach, normative reference values for ECG parameters across age groups were established, providing a basis for clinical and research applications (Pourjafar *et al,* 2011b). In addition, modern comparisons between base–apex ECG and wearable devices such as the Equimetre™ fitness tracker have demonstrated acceptable agreement in measuring heart rate and intervals, though differences in P- and T-wave polarity were observed between methods (Al Khamis *et al*, 2023).

Electrocardiography has also proven useful in detecting arrhythmias in camels. For example, atrial fibrillation was described in a clinically healthy five-year-old camel, with absence of P waves, irregular R–R intervals, and tachycardia, though the condition was considered a functional arrhythmia not requiring intervention (Pourjafar *et al,* 2011a). Typical measures of ECG in male and female camels of varying age are shown in Table 1.

Similarly, pharmacological studies have shown that administration of diuretics such as furosemide did not significantly alter ECG indices in dromedary calves, suggesting stability of the camel cardiac conduction system under such interventions (Samimi and Sanjarinejad, 2021).

In summary, the camel ECG is characterised by a relatively low amplitude, prolonged PR interval, and variability in QRS and T-wave morphology. The base–apex lead system provides the most consistent recordings, while newer wearable technologies show promise for use in remote or field conditions. Together, these findings highlight the features and the clinical utility of electrocardiography in the camel.

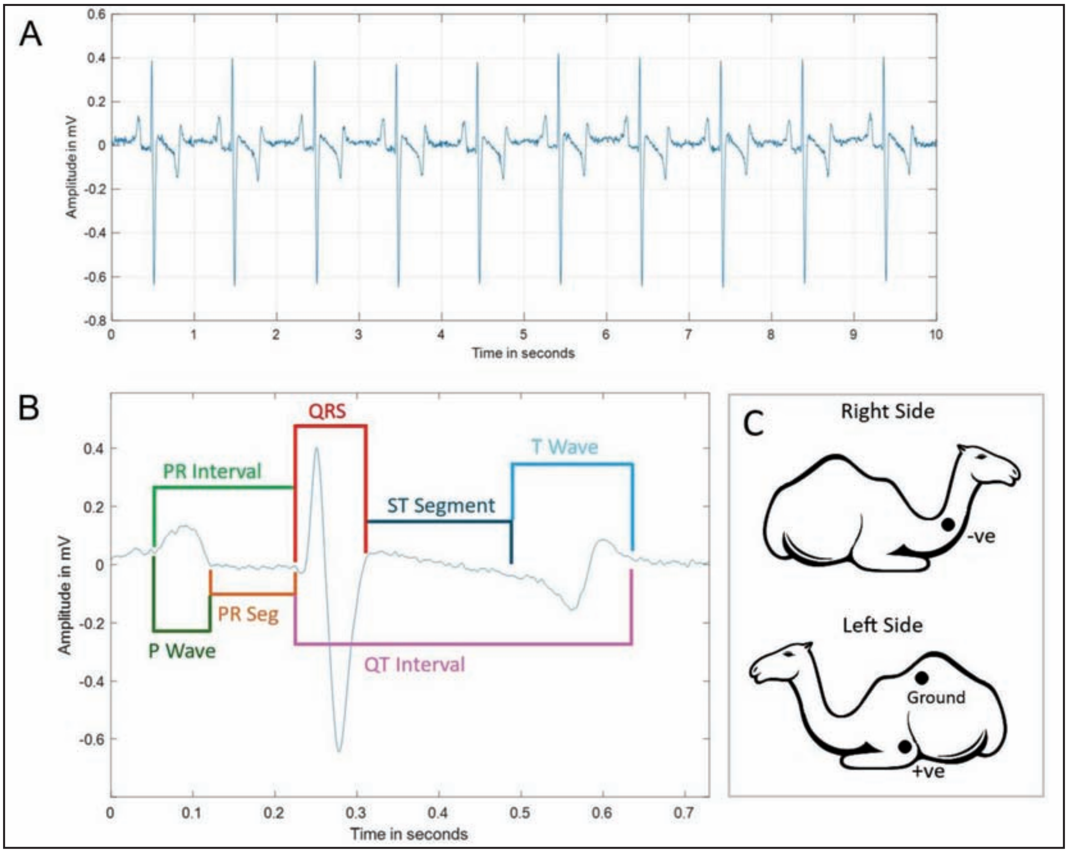


**Fig 4.** Dromedary camel electrocardiogram. (A) Typical recording of an ECG in an adult, 10-year-old female camel. (B) One cycle on an expanded scale with indicated wavelet intervals. Recordings were made in modified base-apex lead configuration. (C) After shaving and cleaning the skin with 75% ethanol, ECG adhesive button electrode pads were placed as follows: Negative electrode to the right side of the neck in the jugular groove, about one-third the distance from the mandible to the thoracic inlet; Positive electrode to the left side of the thorax, just caudal to the olecranon, the point of the elbow and slightly above the cardiac apex; Ground electrode placed on the highest point of the withers. The ECG recording was performed at the Camel Research Centre, Al Ain. Data was acquired with a PowerLab 26T (Model ML856, ADInstruments, Australia). Noise reduction was implemented with a 150 Hz low pass filter using MATLAB (MathWorks, USA).

**Table 1.** Various measures of ECG in healthy camels.

| HR (bpm) | P wave Duration (sec) | P wave Amp (mV) | P-R interval (sec) | QRS Duration (sec) | QRS Amp (mV) | Q-T Interval (sec) | R-R Interval (sec) | T wave Amp (mV) | T wave Duration (sec) | Animal characteristics | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-30 | 0.10 | 0.20 | 0.24-0.26 | 0.09 | 1.5 | 0.54-0.60 | | 0.9 | | M, n=1, 265 Kg | Braun et al, 1958 |
| 80 | 0.08 | 0.10 | 0.18 | 0.1 | 0.72 | 0.38 | 0.75 | 0.21 | 0.08 | M, n=21, 95 Kg, 5 months | Samimi 2021 |
| 60 | | | 0.20 | 0.11 | | 0.38 | 1.10 | | | M + F, n=5, 8-10 yrs | Al Khamis 2023 |
| 69 | 0.06 | 0.06 | 0.22 | | | | 0.83 | 0.12 | 0.10 | n=25, 7-9 yrs | Pourjafar 2011 |

M=Male, F=Female, n=number of camels, yrs=years

## Adaptation of the camel to an arid environment

The dromedary camel exhibits several cardiac adaptations that support survival in the arid desert environment. Anatomically, its heart is proportionally small yet structurally robust, with a thick-walled left ventricle (Fig 1B) (Hegazi, 1954), abundant epicardial and coronary fat that provides insulation, metabolic energy, and a source of metabolic water, and a single *ossa cordis* that reinforces the aortic ring during thermal and circulatory stress (Hegazi, 1954; Hoter *et al,* 2019; Ali *et al,* 2020). The conduction system shows specialised features, including an elongated, collagen-rich sinoatrial node containing glycogen-laden Purkinje-like cells and a well-developed Purkinje network within the ventricles, enabling stable pacemaker activity and efficient impulse transmission even during dehydration or heat exposure (Fig 2) (Ghazi and Tadjalli, 1996; Ghonimi *et al,* 2015). Electrocardiographically, the camel displays a consistently prolonged PR interval, reflecting slower atrioventricular conduction that may help maintain coordinated filling and output during fluctuations in blood volume (Braun *et al,* 1958; Geddes *et al,* 1973; Pourjafar *et al,* 2011b). Together, these morphological and electrophysiological features form an integrated cardiovascular strategy that preserves cardiac function under extreme temperatures, prolonged exertion, and significant water deprivation.

## Conclusion

The camel heart exhibits a suite of structural and physiological adaptations that enable survival in arid environments. Anatomically, it is proportionally smaller (about 0.6% of body weight) yet morphologically robust, with a thick left ventricle, extensive coronary and epicardial fat (Hegazi, 1954), and a single *ossa cordis* that supports valve integrity under thermal and circulatory stress. Histologically, the myocardium contains well-organised Purkinje fibres and conduction tissues optimised for efficient electrical transmission, maintaining rhythmic contractions despite dehydration or temperature extremes. The conduction system, including an elongated sinoatrial node with abundant connective tissue and glycogen-rich Purkinje-like cells, ensures stable pacemaker activity and slow atrioventricular conduction, reflected in the camel's distinctive ECG pattern with prolonged PR intervals and biphasic QRS complexes. Physiologically, camels can tolerate substantial dehydration without circulatory collapse due to osmotic regulation, deformable elliptical red blood cells, and precise neurohumoral control of vascular tone (Hoter *et al,* 2019; Ali *et al,* 2020; Haben and Wondwossen, 2020). These integrated adaptations, structural reinforcement, efficient conduction, and fluid homeostasis, allow the camel heart to sustain cardiac output, oxygen delivery, and thermoregulatory balance in the extreme heat and dehydration of desert conditions.

## Future studies in camel heart

The anatomy and histology of the camel heart is relatively well understood. However, much of the electrophysiology of the camel heart is derived from ECG recordings. There remains a significant gap in understanding the electrophysiology at the cellular level and in particular the mechanisms involved in excitation-contraction (E-C) coupling. Future studies should focus on assessing and quantifying E-C coupling related proteins, particularly those involved in the cardiac myocyte action potential and the process of calcium-induced calcium release (CICR). Developing reliable techniques for isolating viable camel cardiomyocytes will enable single-cell electrophysiological and calcium imaging studies to characterise the ion channels responsible for action potential generation and elucidate the molecular mechanisms underlying CICR. These investigations will provide valuable scientific benefits by deepening our understanding of species-specific cardiac physiology and the adaptive mechanisms that allow camels to thrive under extreme environmental stress. Furthermore, such research will establish a comparative framework for studying ion channel regulation and calcium handling in other mammals, offering translational insights into mechanisms of cardiac resilience relevant to both veterinary and human cardiovascular health.


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## Ethical Statement

Ethical approval for the project was obtained from the UAE University Animal Ethics Committee.

## Data Availability

The data presented in the study can be requested from the corresponding author.

## Conflict of Interest

The authors declare no conflict of interest.

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# EFFECTS OF GINGER AND ACETIC ACID MARINADES ON PH, COLOUR, COOKING LOSS AND MICROSTRUCTURE OF CAMEL *BICEPS FEMORIS* MUSCLE

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## ABSTRACT

Camel meat remains underutilised due to its inherent toughness. While marinades containing plant extracts and organic acids are used empirically, the specific effects of acetic acid alone or combined with ginger extract on camel meat quality traits remain underexplored. Furthermore, previous studies have relied primarily on physicochemical assessments without systematic histological validation. This study characterised the individual and combined effects of ginger extract (9%) and acetic acid (1%) on some physicochemical and histological properties of camel biceps femoris after 48 h marination at 4°C. Acetic acid alone markedly decreased pH (4.83), whereas ginger extract showed moderate acidification (5.40), with the combination exhibiting an intermediate value (5.15) ($p < 0.05$, Kendall's $W$ = 0.678). Cooking loss was highest in ginger-treated samples (47.05%) ($p < 0.05$, Kendall's $W$ = 0.395), while acetic acid-treated samples (36.00%) and the combination's samples (37.94%) remained comparable to controls (33.25–35.53%) ($p > 0.05$). All marinades significantly increased brightness ($L^*$) (Kendall's $W$ = 0.790), but redness (a*) was preserved only in ginger-containing treatments ($p > 0.05$). Yellowness ($b^*$) increased exclusively with ginger ($p < 0.05$, $W$ = 0.714). Histological measurements showed no significant differences in fibre diameter (Kendall's $W$ = 0.029) or extracellular space (Kendall's $W$ = 0.114) (all $p > 0.05$), despite qualitative evidence of structural modifications, notably muscle and collagen fibres disintegration. These effects are especially apparent in the ginger-marinated group, while mix marinades group displayed intermediate modifications, with less pronounced fragmentation. The ginger–acetic acid combination emerged as the most balanced formulation, achieving moderate acidification, preserved water-holding capacity, and stabilised colour. These findings establish a mechanistic basis for optimising camel meat quality and support sustainable protein diversification. Future research should validate sensory outcomes for industrial adoption.

**Key words:** Acetic acid, *Biceps femoris*, camel, ginger, histology, meat quality

Global population growth continues to widen the gap between meat supply and demand, driving the need to enhance the palatability of underutilised sources such as meat from aged animals and tough cuts (Moon, 2018). Camel meat represents a promising solution to this deficit (Boukrouh *et al,* 2025), offering superior nutritional value, including high levels of polyunsaturated fatty acids, low cholesterol, a balanced profile of amino acids with high essential amino-acid index and B vitamins (Bougherara *et al,* 2023; Kadim *et al,* 2018; Raiymbek *et al,* 2015). However, camel meat, typically sourced from older animals, suffers from excessive toughness that limits consumer acceptability and industrial application (Djenane and Aider, 2024; Moeini *et al,* 2024).

Traditional marination with organic acids; including citric acid (He *et al,* 2015; Abd Elgadir *et al,* 2025), lactic acid (Aktaş *et al,* 2003; Chang *et al,* 2010), and acetic acid (Goli *et al,* 2014), as well as fermented products (Latoch *et al,* 2023) has proven effective for meat tenderisation. Notably, acetic acid offers additional antimicrobial properties (Chai and Sheen, 2021). Complementing acidic approaches, plant-derived proteases, particularly ginger cysteine proteases, have emerged as natural, cost-effective tenderisers (An and Kim, 2024), demonstrating

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efficacy across various meat types (Naveena and Mendiratta, 2004; Kumar *et al,* 2017; Erdem and Gökmen, 2025) including camel (Hoda and Ali, 2014; Jafari *et al,* 2020). While enzymatic treatments have been studied independently, both acetic acid alone and their combined effects on camel meat remain poorly characterised. Furthermore, most previous works have relied solely on physicochemical assessments without systematic histological validation. This study addresses these gaps by integrating histological and some physicochemical analyses to evaluate how ginger and acetic acid marinades, alone and in combination, affect camel thigh muscle structure and quality. Given that meat tenderness depends on myofibrillar protein integrity, connective tissue organisation, and intramuscular lipid content (Roy and Bruce, 2024; Kim *et al,* 2025; Xie and Grossmann, 2025), histological techniques provide precise quantification of structural changes induced by tenderisation treatments (Ghisleni *et al,* 2010; Sereda and Tatarnikova, 2019). By systematically mapping the relationship between marinade formulations and muscle microstructure, this research establishes a scientific foundation for optimising camel meat quality and expanding its potential for high-value industrial applications.

## Materials and Methods

***Ethical Statement:*** This study did not involve live animal experimentation or sacrifice for research purposes. Camel meat samples were obtained from commercially slaughtered dromedaries at local butcheries, where animals were processed according to standard commercial and Islamic halal slaughter practices.

### *Ginger extract preparation*

Fresh rhizomes of *Zingiber officinale roscoe* were purchased from the central market of Batna, Algeria. Rhizomes were washed, peeled and finely sliced before homogenisation with an equal volume (1:1, w/v) of distilled water at 4°C for 2 minutes. The crude ginger extract (GE) was obtained by filtering the suspension through sterile muslin cloth.

### *Marinade solutions*

Four marinade solutions were prepared fresh on the day of treatment: distilled water (C48+), 9% GE (v/v) as described by Naveena and Mendiratta (2004), 1% (v/v) acetic acid (AA), and a mixture of 9% GE + 1% AA (AG). Two controls without additives were included: one analysed immediately (C-) and another after 48 hours (C48-).

### *Meat samples and experimental design*

Eighteen samples of *biceps femoris* muscle were taken from male dromedaries aged 3–7 years and collected 24–48 hours post-slaughter from the same local butchers throughout the study. These samples were transported to the laboratory using ice packs in an icebox under aseptic conditions. After carefully removing connective tissue and visible fat, portions from each animal were randomly assigned to the six treatment groups using a complete block design with the animal as the blocking factor. This repeated-measures design ensured that inter-animal variability was controlled. Excluding the C- and C48- control groups, all samples were uniformly sprayed with 15% marinade (15 mL/100 g meat, v/w) followed by manual massaging for 2 min to ensure even distribution. The pieces were then individually sealed in labelled storage bags and refrigerated at 4°C for 48 hours. C48- was stored under the same conditions without marinade application. After draining the exudates with absorbent paper, the raw samples were subjected to histological, pH, and colour analyses. The cooked samples were then assessed for their cooking loss. Sample preparation and physicochemical analyses were performed at the food science laboratory (LSA) of the Institute of Agricultural Sciences and Veterinary Sciences at the University of BATNA 1, Batna, Algeria, while histology was conducted at the histology-histopathology laboratory of the same institute.

### *Physicochemical analyses*

**pH *measurements***. Five gm of samples were homogenised with 50 ml of distilled water (1:10) (w/v) (Dolores Romero De Ávila *et al,* 2014), and the pH of the homogenates was measured by a pH meter (Bante-210).

***Cooking loss determination.*** Five gm of each sample was placed in a cooking bag and cooked for 75°C for 25min until the sample temperature reached 72°C (Choi *et al,* 2017). After cooking, the samples were slightly dried with paper towels and weighed 4 hours later. Cooking loss was determined by weighing samples before and after cooking, and calculated as follows:

$$\text{Cooking Loss (\%)} = [(W_{raw-} W_{cooked}) / W_{raw}] \times 100.$$

Where $W_{raw}$ and $W_{cooked}$ represent the sample weights before and after cooking, respectively

***Colour evaluation.*** Each sample was assessed using the CIE *L*a*b** system, illuminant D65, and 10° for the standard observer, with a Chroma-meter

(Minolta) calibrated against a white standard, as stated by (Oliveira *et al,* 2021).

### *Histological analysis*

For a more accurate assessment of the histological structure, three pieces from each sample were fixed for no less than 48h in buffered formalin (10%), dehydrated at increasing concentrations of ethanol, and then embedded in paraffin. The 5 µm sections were stained with hematoxylin-eosin (HE) to observe the muscle fibres and with Masson's trichrome (MT) to reveal the connective tissue. Both stains were performed according to the protocols mentioned in Manual of histological staining methods (1968). For quantitative and qualitative microstructural analysis, images were captured with a DMK33UX265 camera mounted on a LEICA DM 100 LED microscope and analysed using ImageJ 4.0 software to quantify fibre diameter and extracellular space, and to detect morphological changes in muscle components.

### *Statistical analysis*

Statistical analysis was performed using IBM SPSS STATISTICS version 26. The dromedary was considered the experimental unit ($n$ = 18); technical replicates were averaged prior to analysis. The effect of marinade treatment on meat quality parameters was evaluated using the Friedman test, with animal considered as the blocking factor. Effect size was quantified using Kendall's coefficient of concordance ($W$). When the Friedman test indicated significant differences ($p < 0.05$), pairwise comparisons were conducted using Wilcoxon signed-rank tests, with p-values adjusted for multiple testing using the Holm–Bonferroni method. Relationships between physicochemical and histological parameters were explored using Spearman's rank correlations (non-parametric, 21 pairwise variable combinations, k = 21). The results are presented as median (Q1-Q3).

## Results and Discussion

Marinade treatments exerted a large effect on the pH values of camel meat (Kendall's $W$ = 0.68, $X^2$= 61.02, $p < 0.001$). The highest pH was recorded in the fresh control group (C-: 5.88) (Table 1). After 48 h of storage, non-marinated (C48-: 5.52) and distilled-water-marinated controls (C48+: 5.37) exhibited a slight, non-significant decline ($p > 0.05$) reflecting mild post-mortem acidification. Ginger-marinated samples (GE: 5.40) showed comparable values to these controls. In contrast, marination with acetic acid (AA: 4.83) and the ginger–acetic acid combination (AG: 5.15) induced a pronounced pH drop, with AA exhibiting the lowest value among all treatments ($p < 0.05$).

The modest pH decrease observed in untreated samples aligns with the slow post-mortem glycolytic rate characteristic of camel muscle, which proceeds more gradually than in other red meats (Soltanizadeh *et al,* 2008). This natural acidification is primarily driven by residual lactic acid accumulation rather than proteolytic activity (Soltanizadeh *et al,* 2008). The absence of significant pH reduction in GE-treated samples suggests that the ginger extract, at the concentration applied, lacked sufficient acidifying potential to overcome the muscle's inherent buffering capacity. This finding contrasts with studies reporting significant pH decreases in ginger-marinated meat (Abdel-Naeem *et al,* 2022), y*et al*igns with others observing neutral effects attributed to the relatively high pH of ginger extracts themselves (Cruz *et al,*

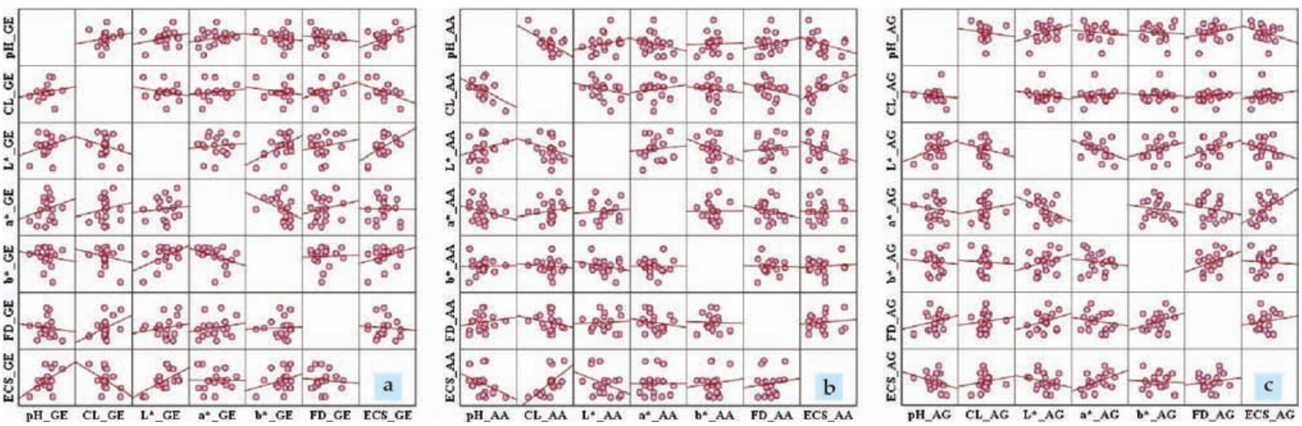


**Fig 1.** Matrix of pairwise Spearman correlations between pH, cooking loss, colour and histological parameters of camel meat treated with different marinades (n = 18 camels). **a.** GE group. **b.** AA group. **c.** AG group. Diagonal labels indicate variables: pH, CL (cooking loss), $L^*$ (lightness), $a^*$ (redness), $b^*$ (yellowness), FD (fibre diameter), ECS (extracellular space).

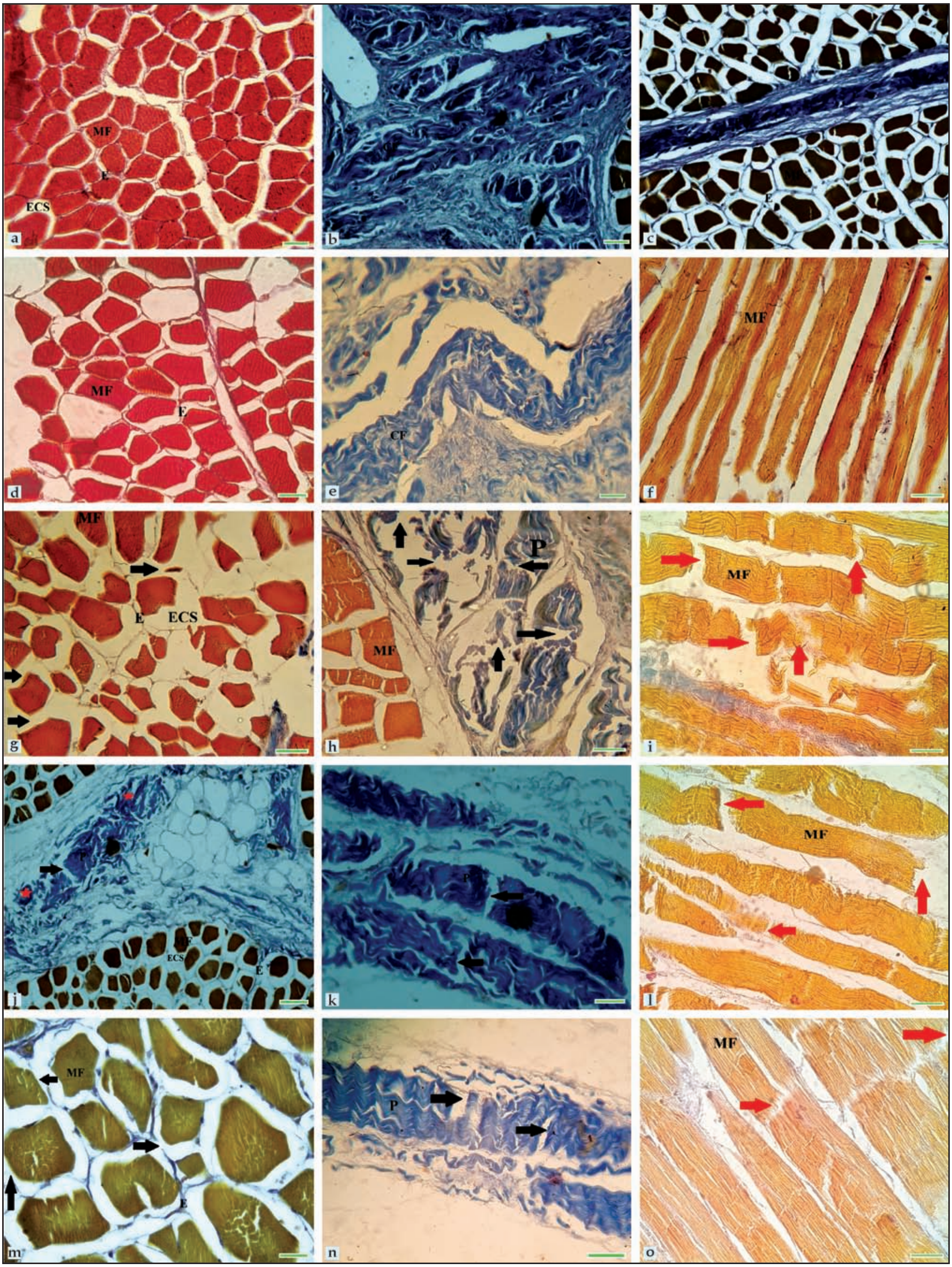


**Fig 2.** Effects of different marinades on muscle structure under the light microscope.

**a:** Cross-section of the control (C-) showing the typical organisation of muscle fibres (MF) with uniform diameter separated by minimal extracellular space (ECS), and well-preserved endomysium (E). Staining: H&E. Scale bar: 50 µm. **b:** Detailed view of the intact connective tissue architecture of C- with well-preserved collagen fibres (CF) and endomysium (E) surrounding the muscle bundles. Staining: Masson's trichrome. Scale bar: 50 µm. **c:** Cross-section of C48- revealing preservation of muscle architecture (MF) and Perimysium (P) with a slight increase in extracellular space compared to C-. Staining: Masson's trichrome. Bar: 50 µm. **d:** Cross-section of C48+ showing preserved muscle fibre organisation (MF) and relatively reduced extracellular space (ECS). H&E staining. Scale bar: 50 µm. **e:** Cross-section of C48+ revealing the integrity of connective structures (CF). Staining: Masson's trichrome. Scale: 50 µm. **f:** Longitudinal section of C48+ showing preserved muscle fibre organisation (MF). Staining; Masson's trichrome. Scale bar: 50 µm. **g:** Cross section of GE revealing fraying and cuts (black arrows) in the endomysium (E). Staining: Masson's trichrome. Scale bar: 50 µm. **h:** Cross-section of GE showing massive degradation (black arrows) of collagen fibres in the perimysium (P). Staining: Masson's trichrome. Bar: 40 µm. **i:** Longitudinal section of GE showing the disintegration (red arrows) of muscle fibres (MF). Staining: Masson's trichrome. Bar: 50 µm. **j:** Cross section of AA showing disorganisation (red asterisks) of collagen fibres in the perimysium (P). Staining: Masson's trichrome. Bar: 50 µm. **k:** Cross-section of AA showing collagen breakdown (black arrows) in the perimysium (P). Staining: Masson's trichrome. Bar: 30 µm. **l:** Longitudinal section of AA showing the disintegration (red arrows) of muscle fibres (MF). Staining: Masson's trichrome. Bar: 50 µm. **m:** Cross section of AG revealing fraying and cuts (black arrows) in the endomysium (E). Staining: Masson's trichrome. Bar: 30 µm. **n:** Cross-section of AG showing collagen breakdown (black arrows) in the perimysium (P). Staining: Masson's trichrome. Bar: 40 µm. **o:** Longitudinal section of AG showing the disintegration (red arrows) of muscle fibres (MF). Staining: Masson's trichrome. Bar: 50 µm.

**Table 1.** Impact of marinades on pH, cooking loss, and colour ($L^*$, $a^*$, $b^*$) of camel meat ($n=18$).

| Parameter | Treatments | | | | | | Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| | **C-** | **C48-** | **C48+** | **GE** | **AA** | **AG** | $W$ | $X^2$ | $p$ |
| pH | 5.88 (5.61 – 6.02)$^{a}$ | 5.52 (5.25 – 5.6)$^{a}$ | 5.37 (5.24 – 5.61)$^{a}$ | 5.40 (5.28 – 5.53)$^{ac}$ | 4.83 (4.60 – 4.91)$^{bc}$ | 5.15 (4.99 – 5.32)$^{c}$ | 0.68 | 61.02 | <0.001 |
| Cooking loss (%) | 33.25 (31.95 – 35.18)$^{a}$ | 36.01 (34.59 – 37.99)$^{a}$ | 35.53 (33.39- 39.45)$^{a}$ | 47.05 (44.90- 50.05)$^{b}$ | 36 (28.53- 37.88)$^{a}$ | 37.94 (31.43- 41.09)$^{a}$ | 0.40 | 35.52 | <0.001 |
| **Colour ($L^*$, $a^*$, $b^*$)** | | | | | | | | | |
| $L^*$ | 38.30 (37.25 – 41.23)$^{a}$ | 39.20 (38.08 – 42.25)$^{ab}$ | 38.40 (37.33 – 39.98)$^{b}$ | 42.85 (41.75 – 43.95)$^{c}$ | 42.80 (41.28 – 44.33)$^{c}$ | 42.90 (41.50 – 43.88)$^{c}$ | 0.79 | 71.07 | <0.001 |
| $a^*$ | 16.30 (15.10 – 17.60)$^{a}$ | 15.90 (14.98– 17.18)$^{a}$ | 16.15 (15.43 – 17.28)$^{a}$ | 16.20 (14.25 – 17.95)$^{a}$ | 13.85 (11.68 – 15.98)$^{b}$ | 15.70 (14.88 – 16.60)$^{ab}$ | 0.32 | 28.59 | <0.001 |
| $b^*$ | 8.30 (7.38 – 9.10)$^{a}$ | 8.75 (7.43 – 9.33)$^{a}$ | 8.30 (8.20 – 8.85)$^{a}$ | 11.55 (10.55 – 12.18)$^{b}$ | 9.20 (8.68 – 9.73)$^{a}$ | 11.85 (10.55 – 12.70)$^{b}$ | 0.71 | 64.29 | <0.001 |
| **Histological changements** | | | | | | | | | |
| FD (µm) | 51.49 (44.67 – 74.66)$^{a}$ | 42.19 (34.71 – 74.54)$^{a}$ | 53.09 (33.98 – 67.93)$^{a}$ | 47.59 (35.38 – 59.96)$^{a}$ | 54.14 (35.18 – 72.10)$^{a}$ | 56.13 (31.16 – 78.92)$^{a}$ | 0.03 | 2.64 | 0.76 |
| ECS (%) | 24.35 (19.95 – 28.81)$^{a}$ | 27.92 (19.91– 34.08)$^{a}$ | 25.26 (18.31 – 29.22)$^{a}$ | 30.24 (26.08 – 34.16)$^{a}$ | 25.8 (14.62 – 31.12)$^{a}$ | 23.99 (19.62 – 30.35)$^{a}$ | 0.11 | 10.22 | 0.07 |

Data presented as median (Q1–Q3). Different superscript letters (a, b, c) within rows indicate significant differences ($p$ < 0.05) based on Wilcoxon signed-rank tests with Holm-Bonferroni correction. $W$ = Kendall's coefficient of concordance (effect size). $\chi^2$ = Friedman test statistic with $df$ = 5 for all parameters.

C-: Fresh sample analysed immediately; C48-: Control after 48h refrigeration; C48+: Control with distilled water after 48h. GE: 9% ginger extract; AA: 1% acetic acid; AG: 9% ginger extract + 1% acetic acid. FD: Fibre diameter. ECS: Extracellular space.

2020). These discrepancies likely stem from variations in ginger concentration, extraction methods, and species-specific muscle properties.

The marked acidification in AA-treated samples directly results from the exogenous addition of protons from acetic acid (He *et al,* 2015), consistent with reports on organic acids (Unal *et al,* 2022; Abd Elgadir *et al,* 2025) and fruit juice marinades (Ünal *et al,* 2020).

Notably, the intermediate pH of the AG samples compared to AA samples indicates a partial buffering effect when ginger extract is mixed with acetic acid. This phenomenon may involve interactions between acetic and ginger bioactive compounds (such gingerols, polysaccharides) (Yang *et al,* 2024) which modulate the net acidifying capacity and potentially protect muscle proteins from excessive denaturation (He *et al,* 2015).

### *Cooking loss*

Marinade treatments exerted a medium-to-large effect on cooking loss (Kendall's $W$ = 0.40, $X^2$= 35.52, $p$ < 0.001) (Table 1). Cooking loss ranged from 33.25% to 47.05% across treatments. The lowest value was observed in the fresh control group (C-: 33.25%), although it did not significantly differ from C48- (36.01%), C48+ (35.53%), AA (36%), or AG (37.94%) (all $p$ > 0.05). Only GE-treated samples (47.05%) displayed significantly higher cooking loss compared to all other groups ($p$ < 0.05), indicating a markedly reduced water-holding capacity during thermal processing.

The substantial increase in cooking loss observed with ginger marinade alone is likely related to extensive structural modifications that compromise the meat's ability to retain moisture during heating (Abdel-Naeem and Mohamed, 2016). This effect is essentially attributed to enzymatic proteolysis. Ginger's cysteine protease (zingibain) likely targets both myofibrillar proteins and connective tissue components, weakening the structural matrix and facilitating moisture release upon heating (Maqsood *et al,* 2018; Naqvi *et al,* 2021a; Vaskoska *et al,* 2021). The potential contribution of reduced fat retention, as suggested by Abdel-Naeem and Mohamed (2016) may further exacerbate this phenomenon. These findings align with reports on ginger treated beef (Naqvi *et al,* 2021b) and camel meat (Abdel-Naeem *et al,* 2022) where enzymatic tenderisation similarly increased cooking losses.

In contrast, the absence of significant cooking loss variation in AA and AG treatments, despite their marked acidifying effect, suggests that acid-induced protein denaturation alone was insufficient to substantially compromise water holding capacity under the applied conditions. This observation is consistent with (Cruz *et al,* 2020) who found that acidic marinade did not necessarily exacerbate cooking loss in chicken breast.

Notably, the intermediate cooking loss value in AG group compared to GE suggests that acetic acid may partially inhibit ginger's proteolytic activity, possibly through pH-dependent enzyme modulation (He *et al,* 2015) or interactions between bioactive compounds. Divergent observations in the literature, including improved cooking yield with ginger (Hoda and Ali, 2014) or increased losses of beef with citric acid (Klinhom *et al,* 2015), underscore the influence of intrinsic meat characteristics (species, age, fat distribution) and processing conditions (aging time, cooking parameters, marinade composition) on treatment outcomes (Tian *et al,* 2013; Sukada *et al,* 2019). These variations highlight the importance of optimising marinade formulations according to species-specific muscle properties.

### *Colour evaluation*

Significant differences in colour parameters were observed among treatments (Table 1).

***Lightness* (*L**)**. Marinade treatments exerted large effects on $L^*$ of camel meat (Kendall's $W$ = 0.79, $X^2$ = 71.07, $p$ < 0.001). Lightness ($L^*$) ranged from 38.30 to 42.90 across groups. Control samples (C : 38.30) showed no significant variation after 48 h storage, whether non marinated (C48 : 39.20) or distilled water marinated (C48+: 38.40) ($p$ > 0.05). In contrast, all marinated samples (GE, AA, AG) ranging from 42.80 to 42.90 exhibited significantly higher $L^*$ values compared to controls ($p$ < 0.05), indicating a marked brightening effect. No significant differences in $L^*$ were detected among the three marinated groups ($p$ > 0.05). In ginger-marinated samples (GE), a positive correlation was observed between lightness ($L^*$) and extracellular space (ECS) (ρ = 0.51, $p$ = 0.031) (Fig 1a). No other significant correlations were detected among the 21 pairwise comparisons tested in the GE group (all $p$ > 0.05).

***Redness* (*a**).** Redness ($a^*$) varied between 13.85 and 16.30 (Kendall's $W$ = 0.32, $X^2$ = 25.59, $p$ < 0.001), indicating a medium effect of treatments on this parameter. Controls (C, C48, C48+) displayed comparable values (15.90 - 16.30; $p$ > 0.05). Among marinated samples, GE (16.20) and AG (15.70) maintained redness similar to controls ($p$ > 0.05), whereas AA (13.85) showed significantly lower redness than all other groups ($p$ < 0.05) except AG ($p$ > 0.05).

***Yellowness* (*b**)**. Yellowness ($b^*$) ranged from 8.30 to 11.85 (Kendall's $W$ = 0.71, $X^2$ = 64.29, $p$ < 0.001), representing a large treatment effect. Control groups displayed similar values (8.30–8.75; p > 0.05). GE (11.55) and AG (11.85) showed significantly higher $b^*$ than all controls and AA (9.20) ($p$ < 0.05). AA did not differ from controls ($p$ > 0.05), while AG yielded the highest yellowness among all treatments.

The systematic brightening indicates a common effect of marination on the optical properties of camel muscle, independent of marinade composition, although the underlying mechanisms may differ. The underlying mechanism may probably involve protein denaturation (Jankowiak *et al,* 2021), which alters light scattering properties of myofibrillar structures and promotes surface moisture accumulation, both enhancing reflectance (Hughes *et al,* 2020; Purslow *et al,* 2020). Similar brightening effects have been reported in poultry marinated with citric acid (Unal *et al,* 2022), ginger-treated goat meat (Putra *et al,* 2019) and camel meat burgers (Abdel-Naeem and Mohamed, 2016), confirming that both acidification and enzymatic treatments influence meat lightness. Notably, in ginger-marinated samples (GE), the positive correlation observed between $L^*$ and extracellular space confirms that structural modifications induced by ginger proteolysis, which enlarge intercellular gaps, concurrently enhance light scattering properties, resulting in a brighter appearance independently of direct pH effects. This finding aligns with previous reports showing that myofibrillar degradation increases light reflectance in marinated meats (Hosseini and Esfahani Mehr, 2015; Gagaoua *et al,* 2020). The absence of this correlation in AG marinade further supports the hypothesis that acetic acid moderates enzymatic activity, preserving structural integrity and limiting excessive light scattering relative to GE and decoupling light scattering from excessive proteolysis.

The marked reduction observed in redness ($a^*$), with acetic acid alone, indicates accelerated myoglobin oxidation, converting cherry red ferrous oxymyoglobin ($Fe^{2+}$) to brown ferric metmyoglobin ($Fe^{3+}$), which leads to meat browning (Gagaoua *et al,* 2020; Hughes *et al,* 2020). This pro oxidant effect is characteristic of acidic environments, where oxymyoglobin destabilisation releases free iron that generates pro-oxidant radicals, catalysing pigment oxidation (Ke *et al,* 2009). However, the stability of redness in samples containing ginger (GE and AG) demonstrates the antioxidant capacity of ginger polyphenols (Yang *et al,* 2024). These compounds neutralise free radicals and reactive oxygen species, limiting lipid peroxidation and protecting myoglobin from oxidation (Mancini *et al,* 2017; Ivane *et al,* 2022). The preservation of redness in AG despite the presence of acetic acid, indicates that ginger's antioxidant activity effectively counteracts the pro oxidant effect of acidification, a finding with direct implications for consumer acceptability, as redness is a primary visual cue for meat freshness. This protection contributes to preserving red meat colour, thus improving its overall acceptability (Mancini and Hunt, 2005).

The significant increase in the yellowness index ($b^*$) in samples containing ginger (GE and AG) is directly attributable to the deposition or extraction of coloured phenolic compounds from the rhizome, particularly curcuminoids and related pigments (Mancini *et al,* 2017; Unal *et al,* 2022). The absence of $b^*$ elevation with acetic acid alone confirms that this yellowing is not pH dependent but rather reflects direct pigment transfer from the marinade. These findings corroborate previous work on ginger marinated camel meat burgers (Abdel-Naeem and Mohamed, 2016) and goat meat (Putra *et al,* 2019).

### Histological changes

*Quantitative measurements.* Marinade treatments exhibited negligible to small effects on the histological parameters of camel meat. Neither fibre diameter (Kendall's $W = 0.03$, $X^2 = 2.64$) nor extracellular space (ECS) (Kendall's $W = 0.11$, $X^2 = 10.22$) differed significantly among groups (all $p > 0.05$; Table 1). Although GE samples displayed a numerically higher median ECS (30.24%) compared to controls (24.35–27.92%) and other marinades (23.99–25.80%), the small effect size indicates that treatments explained only 11.4% of the variance in ECS. This suggests that quantitative fiber-level changes were limited, despite evidence of molecular-level modifications. Detailed median values for all groups are presented in table 1.

Correlation analysis. For acetic acid-treated samples (AA), cooking loss (CL) was positively correlated with extracellular space (ρ = 0.57, $p$ = 0.014) (Fig 1b). This moderate correlation supports a mechanistic link between acid-induced structural reorganisation and variation in water retention within the group. Despite pronounced pH reduction in AA samples, pH itself did not correlate significantly with any other parameter (all $p > 0.05$), suggesting that acidification effects are mediated through intermediate mechanisms.

Notably, no significant correlations were detected in the combination treatment (AG) (all $p$ > 0.05 for 21 pairwise comparisons) ((Fig 1.c)). This absence of correlations, contrasting with GE ($L^*$-ECS) and AA (C$L^*$ECS), suggests that combining ginger with acetic acid modulates their respective effects, possibly through pH-dependent enzyme inhibition or buffering interactions.

***Qualitative microscopic examination.*** Qualitative microscopic examination revealed a treatment-specific pattern of structural modification that complements the quantitative measurements. Control samples (C-, C48-, C48+) exhibited well preserved muscle architecture, characterised by intact, tightly bound muscle fibres surrounded by a regularly organised connective tissue matrix with uniform collagen distribution around bundles (Fig 2. a-f). This structural integrity confirms the absence of significant exogenous degradation and provides a valid baseline for assessing marinade induced modifications.

Ginger treated samples (GE) displayed visual evidence of connective tissue and myofibrillar protein alterations, including fragmentation of collagen fibres, reduced sarcolemma and apparent gaps between fibres (Fig 2. g-i). Although, these changes did not translate into statistically significant differences in fibre diameter or ECS measurements, they are consistent with zingibain activity, a cysteine protease that preferentially hydrolyses collagen and myofibrillar proteins (Kim *et al,* 2013; Kumar *et al,* 2017; Naqvi *et al,* 2021b). The resulting structural disruption may facilitate the expulsion of intracellular water into the extracellular matrix (Kahraman *et al,* 2012; Sharedeh *et al,* 2015), which can probably explain the elevated cooking loss observed in this group despite unchanged quantitative histology. Similar ginger induced structural changes have been documented across species (Abdel-Naeem and Mohamed, 2016; Abdel-Naeem *et al,* 2022; An and Kim, 2024), confirming the conserved proteolytic action of zingibain.

Acetic acid treated samples (AA) exhibited a different pattern, characterised by fibre fragmentation and slight expansion of intercellular spaces, accompanied by disorganisation of collagen fibres (Fig 2 j-l). These changes are primarily attributable to acid activated cathepsins, lysosomal enzymes with optimal activity in the pH range 3.5–5.0, that degrade both myofibrillar and connective tissue proteins (Mazaheri Kalahrodi *et al,* 2021; Latoch *et al,* 2023). The positive correlation between cooking loss and ECS observed specifically in this group provides direct mechanistic support for the link between acid induced structural loosening and impaired water retention, a relationship absent in controls where structure remained intact. Similar acid mediated degradation has been reported with various organic acids (Dilek *et al,* 2023; Zheng *et al,* 2024), underscoring the direct impact of pH reduction on muscle ultrastructure.

The combination treatment (AG) displayed intermediate modifications, with less pronounced fragmentation than GE alone but more evident changes than controls (Fig 2 m-o). This attenuated effect likely reflects pH dependent modulation of zingibain activity, as the acidic environment may partially inhibit this cysteine protease (He *et al,* 2015). Consequently, proteolytic potential is tempered while acid activated cathepsins remain active, producing balanced structural modification that preserves water holding capacity while still promoting tenderisation. The absence of significant correlations in the AG group, despite observable structural changes, suggests that multiple interacting mechanisms create heterogeneous responses that linear correlation may not capture. The 48 h treatment duration likely amplified these modifications, as marinating time strongly influences proteolytic and acid induced changes (Santos *et al,* 2020).

Collectively, these histological observations demonstrate that ginger and acetic acid exert their tenderising effects through distinct but complementary mechanisms. Interestingly, the dissociation between significant effects on cooking loss and colour parameters and the lack of statistically significant differences in histological measurements suggests that ginger and acetic acid marinades primarily affect meat quality through molecular-level modifications (protein denaturation, enzymatic hydrolysis) rather than through gross structural changes detectable at the fibre level.

This study characterised the individual and combined effects of ginger extract and acetic acid on some camel meat physicochemical and histological properties. Acetic acid alone induced pronounced acidification with moderate structural disorganisation but preserved water-holding capacity. Ginger alone exhibited effects consistent with proteolytic activity, increasing cooking loss and altering colour, with qualitative histological modifications despite non-significant quantitative changes. The combination treatment balanced these effects, achieving moderate acidification, preserved water-holding capacity, stabilised redness, and intermediate structural modifications. Quality modifications occurred primarily at the molecular level rather than through detectable fibre-level morphological changes. This finding advances beyond previous physicochemical-only assessments and provides mechanistic insight into tenderisation pathways. The combination treatment emerged as the most balanced formulation for potential industrial applications. These findings establish a scientific foundation for optimising camel meat quality and support sustainable protein diversification. Future research should validate sensory outcomes and optimise treatment parameters for industrial adoption.

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## Author Contribution

Conceptualisation: SB. Methodology: SB. Investigation: SB and MHD. Data analysis: SB and MHD. Writing-Initial draft writing: SB, MHD, OB and HB. Editing, proofreading, and corrections: SB, MHD, HB and OB.

## Conflict of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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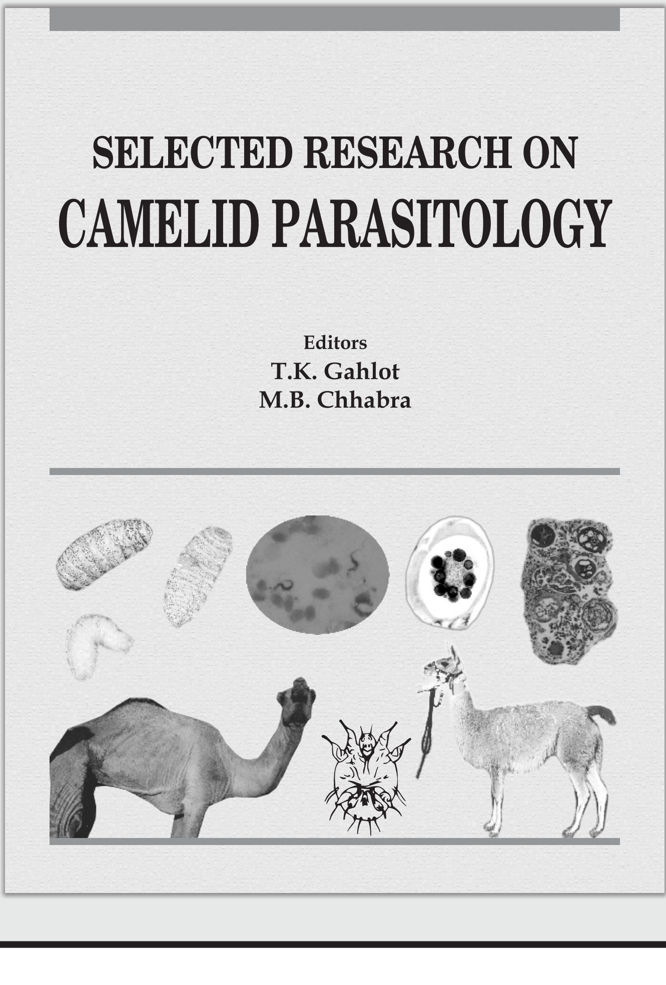

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# INTRAVENOUS INFECTION OF DROMEDARY CAMELS WITH *Anaplasma marginale*

**U Wernery[1], F Al Hammadi[1], Ch Hebel[1], S Sivakumar[1], R M George[1] and MWT Ismail[2]**

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## ABSTRACT

Three dromedary camels were infected with the Rickettsia, *Anaplasma marginale*. One American Type Culture Collection strain was intravenously injected into the jugular veins of two adult dromedary camels. Additionally, EDTA blood from a bovine bull naturally infected with *Anaplasma marginale* was also intravenously injected into the jugular vein of a third camel. All three camels were tested for *A. marginale* using PCR, Giemsa staining and serology. All tests were negative and the dromedary camels remained healthy throughout the study.

**Key words:** *Anaplasma marginale* infection, dromedary camels

Anaplasmosis, formerly known as "gall disease" refers to a bacterial disease of ruminants and human beings, caused by obligate intraerythrocytic pathogens. These bacteria belong to the order Rickettsiales family *Anaplasmataceae*, genus *Anaplasma*. The second and third family within Rickettsiales are named Orientia and Midichloriaceae, which infect human beings. The bacterial classification of Rickettsiales is complex and continuously evolving. It follows hierarchical systems which consist of morphological, physiological, staining, biochemical and nowadays DNA homology criteria. Most of these obligate bacterial species – totalling more than 100 are either unclassified, uncultured or "candidatus", awaiting formal classification, (Wernery, 2022).

The family *Anaplasma*taceae comprises of 5 genera which are:

*Anaplasma*

Ehrlichia

Neorickettsia

Aegyptianella and

Wolbachia

Only few species of the genus *Anaplasma* are pathogens of veterinary importance, which are listed by Markey *et al* (2013) and four intraerythrocytic species of *Anaplasma* are included in the list of bacterial names with standing in nomenclature (Euzéby, 2005).

*Anaplasma (A.) marginale, A.centrale* in cattle and *A. ovis* in sheep and goats.

*Although (A.) marginale, A.centrale, A. platys, A. phagocytophilum, A. canis, A.ovis and A. canditatus cameli* have been identified in Old World Camels (OWCs) by several researchers using molecular biological techniques, none of the investigated camels exhibited clinical signs indicating a possible asymptomatic carrier status (Wernery, 2022).

To determine whether dromedaries develop disease caused by *Anaplasma* species, three dromedaries kept at the Central Veterinary Research Laboratory (CVRL), Dubai were infected with one strain of *A. marginale* received from American Type Culture Collection, USA and with 1.8ml EDTA blood from a Pakistani bovine bull naturally infected with *A. marginale*.

## Materials and Methods

### *Dromedary camel*

The *Anaplasma marginale* Theiler strain VR-1436, ordered from ATCC, USA was intravenously injected into two female adult dromedary camels housed at CVRL. The strain was sent on dry ice to CVRL in vials containing 1ml of bovine blood diluted in 5ml NaCl in each vial. Both camels received 5 ml of this diluted suspension into their jugular veins. A small aliquot of 100µl was retained for PCR testing and microscopic staining. Twenty-four hours before injection baseline EDTA blood samples were tested by PCR and serum samples were tested using an antibody ELISA. Following infection, blood

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samples were collected daily and tested for the presence of *A. marginale* via stained blood smears and PCR. Antibody response was evaluated using the ELISA.

A third dromedary camel housed at CVRL premises was injected intravenously with 1.8ml EDTA blood collected from a Pakistani bovine bull, naturally infected with the pathogen (Fig 1).

Diagnostic testing for this dromedary camel blood followed the same procedure as mentioned above: daily microscopic staining and PCR were performed for 14 days. The ELISA test was performed three times (one prior to infection and twice post-infection).

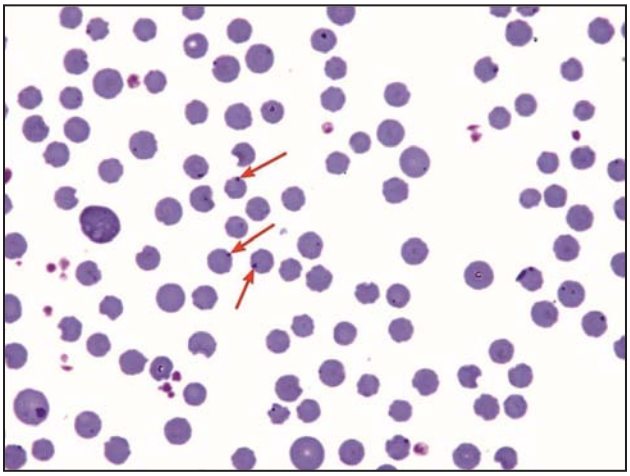

**Fig 1.** Blood smear stained with Giemsa showing *Anaplasma marginale* in the bovine erythrocytes (arrow, x 100 oil)

### *Stain*

EDTA blood was drawn from the jugular veins of all three dromedaries, carefully mixed and prepared as thin blood smears on glass slides and stained with Giemsa. The stained slides were examined on oil immersion light microscope at a magnification of 1000 (100x objective).

### *Serology*

For the investigation whether antibodies against *A. marginale* were produced, a commercial competitive ELISA from US was used (VMRD), which detects antibodies against *A. marginale, A.centrale* and *A.ovis*.

The serum of all three dromedary camels were tested three times, one time before infection and twice after infection.

### *PCR*

PCR test was performed according to Stuen *et al* (2003).

Genomic DNA was extracted from whole blood samples using the QIAsymphony DNA Mini Kit (Cat. No. 931236; Qiagen) on the QIAsymphony automated platform, according to the manufacturer's instructions.

The extracted DNA was then subjected to polymerase chain reaction (PCR) using species specific oligonucleotide primers (16S ANA-F and 16S ANA-R) targeting a fragment of the *Anaplasma* 16S rRNA gene, as previously described by Stuen *et al* (2003), with modifications to the thermal cycling conditions. The cycling protocol consisted of an initial denaturation at 95°C for 5 min, followed by 40 cycles of 95°C for 30 s, 61°C for 30 s, and 72°C for 30 s, with a final extension at 72°C for 5 min. The primer pair amplifies a product of 421 base pairs (bp), excluding the primer-binding regions. PCR amplicons were separated by agarose gel electrophoresis, and the presence of a target fragment of approximately 468 bp, inclusive of primer sequences, was evaluated against a positive control.

## Results

No *A. marginale* organisms were detected in any of the Giemsa-stained blood smears and all PCR assays for *A. marginale* remained negative across all sampling days. Furthermore, no antibodies against *A. marginale* were detected by cELISA. However, PCR confirmed the presence of *A. marginale* in the incoclum and *A. marginale* bacteria were clearly visible in the bovine bull's EDTA blood (Fig 1).

## Discussion

Rickettsiae are obligate bacteria, that replicated inside the host cells particularly within endothelial cells of small blood vessels and blood cells. Their requirement for an invertebrate vector distinguishes these microorganisms from other bacterial species. Transmission typically occurs as a result through the bite of an infected arthropod, primarily ticks. Rickettsiae are Gram-negative coccobacilli or short rods, that cannot grow in cell free media; they require living host cells for their replication and are cultured in cell lines or in yolk sac of embryonated hen eggs.

Anaplasmosis occurs in tropical and sub-tropical regions worldwide including South and Central America, USA, Southern Europe, Africa, Asia and Australia. At least 17 different tick species have been reported to transmit this pathogen to human beings and animals.

Bovine anaplasmosis, caused by *A. marginale* is an economically important tick-borne disease of cattle, which invades cattle red blood cells (Fig 1) and causes anaemia, fever and weight loss. 40-50% of red blood cells can become infected; however, haemoglobinaemia or haemoglobinurea do not typically occur and which helps in differentiating anaplasmosis from babesiosis. In camelid literature, clinical anaplasmosis disease has not been reported. The primary vector in cattle is the hard tick *Rhipicephalus* spp., which does not infest dromedary camels in the UAE.

Furthermore, Perveen *et al* (2021), examined 562 *Hyalomma* ticks collected from different ruminants including camels from different areas of the UAE and detected no *Anaplasma* bacteria via PCR.

These findings suggest, that camel anaplasmosis is absent in the UAE due to the lack of a suitable vector. Moreover, our experimental infection demonstrates that dromedary camels are refractory to *A. marginale* infection, showing no signs of bacterial propagation, PCR positivity or seroconversion. Dromedary camels appear to be innately resistant to *Anaplasma marginale*.


## Acknowledgement

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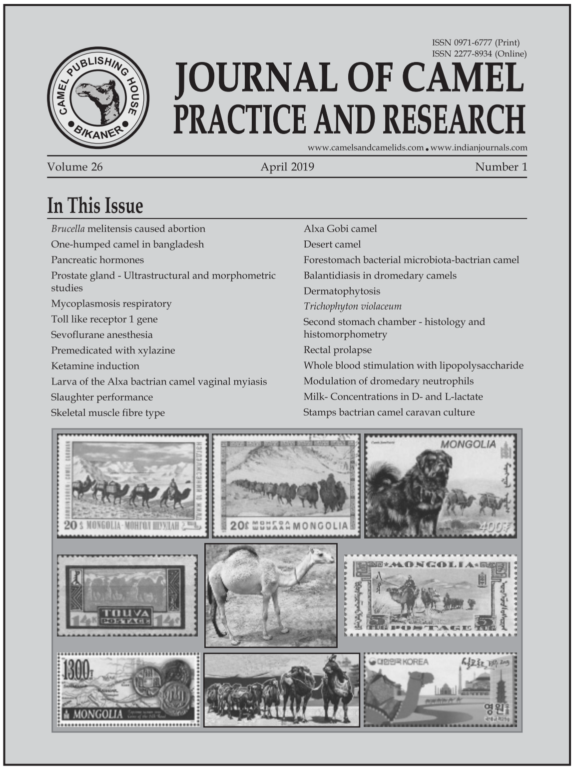

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*Brucella* melitensis caused abortion
One-humped camel in bangladesh
Pancreatic hormones
Prostate gland - Ultrastructural and morphometric studies
Mycoplasmosis respiratory
Toll like receptor 1 gene
Sevoflurane anesthesia
Premedicated with xylazine
Ketamine induction
Larva of the Alxa bactrian camel vaginal myiasis
Slaughter performance
Skeletal muscle fibre type
Alxa Gobi camel
Desert camel
Forestomach bacterial microbiota-bactrian camel
Balantidiasis in dromedary camels
Dermatophytosis
*Trichophyton violaceum*
Second stomach chamber - histology and histomorphometry
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*Brucella abortus* RB51 Vaccine- Serological response
*Brucella melitensis* Rev 1 Vaccine
*Cysticercus tenuicollis* in a dromedary
Acaricide resistance in *Hyalomma dromedarii*
Microsatellites and parentage testing development of bactrians
Neuropeptides in the pancreas: immunohistochemical localisation
Preslaughter stress responses
Teat characteristics
Comparative transcriptome analysis of liver tissues in bactrians
Chronic peritonitis
Endometritis- bacterial isolation with endometrial cytology
Trace elements-assessment in meat, hump and liver
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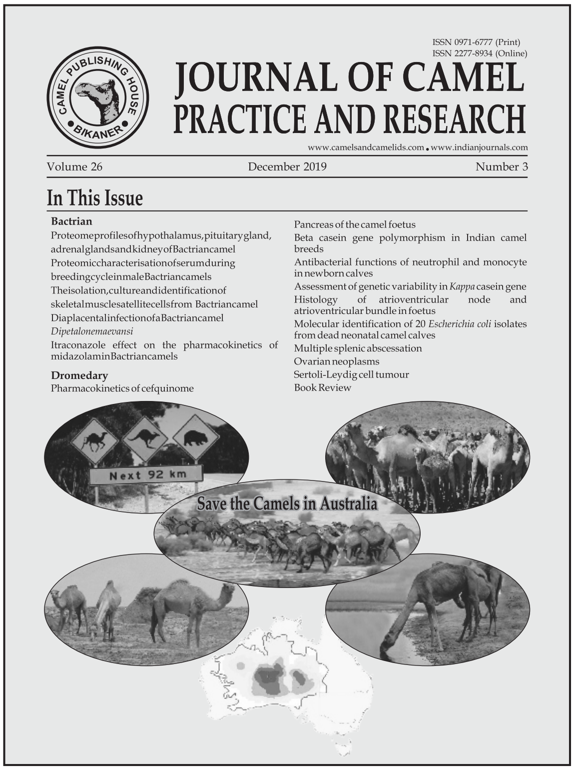

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**In This Issue**

**Bactrian**
Proteome profiles of hypothalamus, pituitary gland, adrenal glands and kidney of Bactrian camel
Proteomic characterisation of serum during breeding cycle in male Bactrian camels
The isolation, culture and identification of skeletal muscle satellite cells from Bactrian camel
Diaplacental infection of a Bactrian camel *Dipetalonema evansi*
Itraconazole effect on the pharmacokinetics of midazolam in Bactrian camels

**Dromedary**
Pharmacokinetics of cefquinome
Pancreas of the camel foetus
Beta casein gene polymorphism in Indian camel breeds
Antibacterial functions of neutrophil and monocyte in newborn calves
Assessment of genetic variability in *Kappa* casein gene
Histology of atrioventricular node and atrioventricular bundle in foetus
Molecular identification of 20 *Escherichia coli* isolates from dead neonatal camel calves
Multiple splenic abscessation
Ovarian neoplasms
Sertoli-Leydig cell tumour
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Dromedary camel in Somaliland
Trichomonosis in dromedary bulls
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Biomarkers of bone metabolism- a review
Microsatellite markers for camels in Qatar
Genotyping and parentage exclusion
Poll glands- Immunohistochemical localisation of S-100 and alpha smooth muscle actin proteins
Milk- Altitude effect on physiochemical properties
-Antioxidant properties and insulin content, heat treatment effect
- Endotoxin level
- Skimmed, Lactobacillus CM36, CW40
Uridine 5-triphosphate (UTP) metabolising enzymes
Nucleoside diphosphate kinase
Cytidine triphosphate (CTP) synthase
*Trypanosoma evansi*
CYP2E1 gene -Cloning and bioinformatics
Whole-genome resequencing
SNPs and InDels detection and selection signals identification
Uridine 5′-monophosphate (UMP)
Uracil phosphoribosyltransferase
Orotidine-5′-phosphate decarboxylase/ump synthase
Bulbourethral or Cowper's gland –Ultrastructure
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*Short communication*

# SELENIUM TOXICITY IN DROMEDARY CAMELS CAUSES ABORTIONS

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Central Veterinary Research Laboratory, Dubai, UAE

## ABSTRACT

Two of six dromedary camels aborted due to high selenium values found in their blood. Selenium toxicity has not been reported in camels, including abortions. Both aborted dromedary dams had serum selenium values of 6 µmol/L. Normal serum selenium values are 1.5 to 2.6 µmol/L. Evidence for an infectious cause of the abortion was not identified in these camels.

**Key words:** Abortions, dromedary camels, selenium toxicity

All animals are susceptible to selenium toxicosis, but it is more common in cattle, sheep, horses, and other herbivorous animals. Selenium toxicity has never been reported in camels under natural conditions. However, selenium deficiency in camels has been described by many researchers, and the clinical signs, primarily in young camels, are known as white muscle disease (WMD) (Abdelrahman *et al*, 2022). The etiology of selenium poisoning in ruminants is the ingestion of or injection with excessive amounts of selenium. Outbreaks in ruminants occur where soils and pastures contain toxic concentrations of selenium or following errors in feed supplementation, oral administration, or injectable dosing. Clinical signs include dyspnoea, diarrhoea, prostration, and eventually death (Radostits *et al*, 2007). Considerable variability in blood selenium concentrations has been reported for several reasons, including breed, age, sex, feeding practices, environmental and management conditions, as well as differences in analytical methodology. In addition, results are often reported in different units, such as ppm (liver), ng/mL, and µmol/L, making comparisons between studies difficult. At CVRL, selenium concentrations in animal serum are measured by graphite furnace atomic absorption spectrophotometry (GFAAS; Thermo Scientific, UK). The analytical method was described by Wernery *et al* (2009). In that study, selenium concentrations were measured in serum samples from 15,000 dromedary racing camels aged 2-8 years between 2004 and 2009. The mean selenium concentration was 1.91 ± 0.61 µmol/L (reference range: 1.5-2.6 µmol/L) (Wernery *et al*, 2009). Abdelrahman *et al* (2022) reported a normal plasma selenium concentration of 100 ng/mL in camels, which corresponds to 1.26 µmol/L. This value is comparable to that reported by Wernery *et al* (2009).

EDTA blood and serum samples from six dromedary camels were submitted to CVRL for disease investigation after two of the animals had aborted. The results of this investigation are presented here.

## Materials and Methods

To investigate the cause of abortions in two dromedary camels from a breeding herd in one of the Northern Emirates, EDTA blood and serum samples from six camels were submitted to CVRL. The samples were tested for antibodies against *Brucella* spp. and *Trypanosoma evansi* using routine serological methods. In addition, Giemsa-stained blood smears prepared from EDTA blood were examined for blood parasites. Serum samples were analysed for copper and selenium concentrations. Copper was measured by flame atomic absorption spectrophotometry (FAAS; Thermo Scientific, UK), and selenium by graphite furnace atomic absorption spectrophotometry (GFAAS). Haematological and biochemical analyses were performed according to the method described by Wernery *et al* (1999).

## Results

No antibodies against *Trypanosoma evansi* or *Brucella* spp. were detected in any of the six serum

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samples. Haematological values for all six camels were within the reference range, and no blood parasites were detected in the Giemsa-stained blood smears. However, the muscle enzyme creatine kinase (CK) was mildly elevated at 183 U/L (reference range: up to 120 U/L). The serum copper and selenium concentrations are summarised in Table 1.

**Table 1.** Serum copper and selenium concentrations in six dromedary camels.

| Test | Cu | Se |
|---|---|---|
| **Unit** | µmol/l | µmol/l |
| **Reference Range** | 9.000 – 14.000 | 1.500 – 2.600 |
| **Method detection limit** | 0.47 | 0.2 |
| **Animal Name** | | |
| 1. Pregnant 1 | 8.100 | 2.700 |
| 2. Pregnant 2 | 9.800 | 4.200 |
| 3. Pregnant 3 | 11.100 | 4.000 |
| 4. Aborted camel 4 | 11.300 | 6.000 |
| 5. Aborted camel 5 | 14.600 | 6.000 |
| 6. Pregnant 6 | 13.200 | 4.000 |

As shown in Table 1, serum copper concentrations were within the reference range, whereas selenium concentrations were elevated.

## Discussion

Our investigations demonstrated elevated serum selenium concentrations in pregnant dromedary camels, while other potential causes of abortion, including trypanosomosis and brucellosis, were excluded by negative laboratory findings. Despite extensive investigations, the source of selenium intoxication could not be identified. Common causes of selenium overdose include excessive supplementation in feed rations, accidental overdosing due to miscalculation of highly concentrated injectable selenium preparations, grazing on selenium-rich soils, or ingestion of selenium-accumulating plants such as Astragalus species. The latter can be excluded as a cause of selenium intoxication in the UAE.

Selenium toxicosis has been reported to cause abortions, stillbirths, and weak calf syndrome in cattle (Yaeger *et al*, 1998), but, to our knowledge, it has never been reported in camels.

Two of the six pregnant dromedary camels aborted and had serum selenium concentrations of 6.0 µmol/L, the highest values recorded among the six camels examined. No evidence of an infectious cause was identified in any of the animals. These findings suggest that excessive selenium exposure may have contributed to the abortions, although a definitive causal relationship could not be established.

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# FROM DECEPTION TO DETECTION: MULTIMODAL DIAGNOSTIC IMAGING AND ELECTROMYOGRAPHIC ASSESSMENT OF COSMETIC TAMPERING IN CAMELS (*Camelus dromedarius*)

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## ABSTRACT

Cosmetic tampering in dromedary camels at beauty competitions remains inadequately documented. This comprehensive study evaluated 5,365 camels using integrated diagnostic imaging and electromyography to assess tampering prevalence and detection methods. One thousand and ninety-five camels (20.4%) showed cosmetic tampering, predominantly lip stretching, followed by subcutaneous air injection, nasal fillers, elevated testosterone, and lip binding, with less frequent cases of lip filler injection, nostril abscessation, ear cropping, nerve anaesthesia, and hump filler injection. Ultrasonography was the most sensitive diagnostic tool, discriminating normal from manipulated tissues by identifying hypoechoic or anechoic foci. Radiography revealed radiolucent areas in acute cases and soft tissue opacities with calcifications chronically, while CT imaging delineated tissue tearing, oedema, and hyperdense deposits. Infrared thermography showed thermal asymmetry in manipulated regions, and EMG demonstrated progressive muscle activity decline, with near-complete suppression in locally anaesthetised animals. Multimodal imaging combined with electrodiagnostic techniques reliably detected cosmetic tampering, with ultrasonography as the primary diagnostic tool while radiography, CT, infrared thermography, and EMG provided complementary assessment enabling differentiation between recent and chronic manipulations. This multimodal protocol constitutes a comprehensive diagnostic framework, in which each technique targets specific forms of cosmetic tampering, ensuring that the combined application minimises the likelihood of any manipulation or fraudulent practice remaining undetected. These findings highlight significant health and welfare risks, supporting the need for routine screening and regulatory enforcement at camel competitions to detect and regulate such unethical practices.

**Key words:** Computed tomography, cosmetic tampering, diagnostic imaging, dromedary camels, electromyography, radiography, thermography, ultrasonography

The tradition of evaluating camel beauty has its roots in Bedouin culture, where camels have long been valued not only for their utility but also for their aesthetic qualities. The practice evolved from informal gatherings where Bedouin tribes would showcase their finest animals to today's highly organised festivals, with the King Abdulaziz Camel Festival in Saudi Arabia emerging as one of the most prestigious events in the region (Ahmad *et al,* 2010). The festival includes camel beauty contests where camels are judged based on their physical appearance, including attributes like long, droopy lips and a shapely hump. However, the pursuit of winning has led to unethical practices, including the use of cosmetic enhancements such as Botox and fillers to alter the appearance of camels (Bieh *et al,* 2019). Recent years have witnessed growing concerns about artificial enhancement methods in camel beauty contests, not only due to their potential use in unfair competition, but also of their associated adverse health and welfare effects, including tissue damage, inflammation, functional impairment, and long-term structural alterations (Tharwat, 2025).

The Salam Veterinary Group (Salam Camel Hospital) has also taken a leading role in preserving the integrity of camel beauty competitions by developing and implementing the region's first comprehensive veterinary protocol for detecting

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all forms of cosmetic tampering. The present study employed using advanced diagnostic tools including X-rays, ultrasound, thermal imaging cameras, CT scans, blood tests for hormone analysis, and neurological diagnostic devices to accurately identify various forms of manipulation and unethical practices in dromedary camels.

## Materials and Methods

### *Camel population*

The research took place at Salam Veterinary Group's Camel Hospital, focusing on cases admitted from July 5, 2020, to February 5, 2026, to identify unlawful practices and alterations to camels to improve their appearance (Fig 1). A thorough evaluation was conducted on 5,365 dromedary camels (*Camelus dromedarius*), ranging in age from 2 months to 10 years and weighing between 100 and 650 kg, to assess these modifications. All cases were initially subjected to detailed visual clinical examination to detect any external abnormalities, including visible clinical signs suggestive of elevated testosterone levels, followed by assessment using diagnostic imaging modalities. Different camel breeds were included in the study, such as black camels (Majaheem) and coloured camels (Maghateer) which comprised Waddah (white), Homor (red-coated), Sofor (yellow-brown), Shaele (gray to brown-red), and Shageh (light or luminous-coated) camels. As a control group, 60 camels of different breeds, matched by age and weight and not subjected to any cosmetic enhancements, were examined concurrently.

Clinical and imaging examinations were conducted, and in cases requiring sedation for computed tomography (CT) scanning, camels were sedated using intravenous administration of xylazine (Bomazine 2%, BOMAC Laboratories Ltd., New Zealand) at a dose of 0.2 mg/kg IV (Al-Mubarak *et al,* 2008).

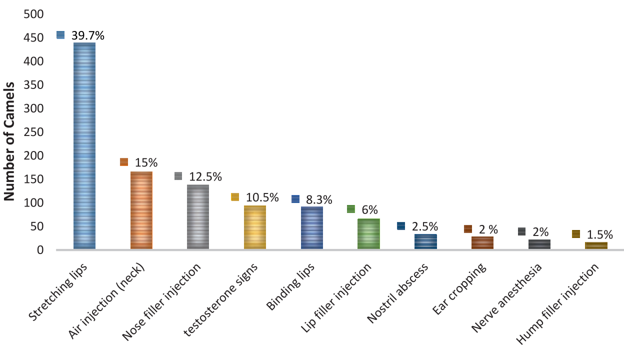


**Fig 1.** Distribution of different forms of tampering among examined camels (n = 1,095) from July 5, 2020, to February 5, 2026, expressed as numbers and percentages.

### *Radiographic Investigations*

Radiographic examination of the head, neck and hump regions was carried out using Atomoscope HF400V portable x-ray unit (DLC Vet Pty Ltd., Japan).

Lateral views of the hump, head, and neck, along with dorso-ventral views of the head and neck, were obtained for all camels, with radiographic setting 76kVp, 1.6mAs, 15mA and a 70 cm focal film distance were used to examine all camels. All obtained radiographs were subjectively interpreted. Each radiograph was interpreted while blinded as to which camels received air injections in head and neck or not.

### *Computed Tomography Investigations*

The CT examinations were conducted using the robot, also called EDAMIS (Equine Dual-Arm Multi-modality Imaging System), which was developed in the United States by Orimtech LTD. The robot was more than 3 metres tall and weighed almost 6 tonnes.

Prior to image acquisition, machine-specific calibration and warm-up protocols should be followed; this takes approximately 30 min. A fast calibration and tube warm-up should be performed on a daily basis only if the machine is to be used for scanning. It is preferable to maintain the temperature of the CT room at 20–28°C with humidity of 30–60%. A requirement of 7.1 kW peak heat output is necessary to support the equipment in the CT scanning room.

After the CT machine setup, the camels were loaded after immobilisation in sternal recumbency on Haico's adjustable height feature surgical table after slight sedation as mentioned before. A head collar was used substituted for a blindfolded rope or webbing halter to avoid metal image artefacts. Once the camel was sedated, the head and neck were extended onto a cradle to perform CT to avoid muscle overlap with placement of cushions under the body and neck to maintain alignment and avoid motion artefacts.

The area of clinical interest dictated the extent of the scan in the present study. For camel head and neck imaging, the starting point was starting from the mandibular ramus and scan caudally to the thoracic inlet (top of chest) to capture the common injection zones (lips, cheek, jawline, neck, ears and shoulder area). For hump assessment, scanning was extended over the dorsal thoracic region, encompassing the entire hump from its cranial to caudal margins to evaluate subcutaneous and adipose tissues.

Once the position of the scan was confirmed, the room was cleared of additional personnel, and the scan was commenced once the camel handler was safely positioned. CT images were obtained using the following parameters: cranial vision of image (V.V.F.), 3 s exposure time, 120 kV, 130 mA and 1-3 mm slice thickness and 3 mm image spacing. Best image quality for soft tissue was obtained by adjusting window widths and window levels. For visualising soft tissue lip structures, a soft-tissue window setting (window width, 1500; window level, 100) was used.

The scanner consists of two robotic arms and several cameras that register the camel's movements. The arms of the robot rotate around the blindfolded and sedated camel taking a series of images in as little as 30 seconds. These images were converted by a computer system into a detailed three-dimensional image, as in a conventional CT scan. The cameras allowed movement correction to be made. Mild movements were thus filtered out in order to guarantee razor-sharp image quality.

### *Ultrasonography Investigations*

After positioning the camels in sternal recumbency, hand palpation of the lips, throat, hump, clitoris and skin region preceded the ultrasonographic examination for further identifying any abnormal structures or sounds. High-resolution ultrasound (MyLabTMOMEGA, Esaote S.P.A., Italy) was used for scanning. The ultrasound unit was equipped with 4 probes (microconvex 11R, 3.0– 11.0 MHz; linear T-shaped 50mm (appleprobe), 4.2– 15 MHz; and linear array probe, 10–22 MHz). The linear T-shaped and the linear array transducers were used for scanning the lips, throat, neck, clitoris and hump region. The examination was performed after applying alcohol then ultrasound gel to the scanning area. A fixed distance of about 5 mm between the area to scan and the probe was set. Both upper and lower lips were scanned from medial to lateral and from dorsal to ventral and the changes were stored and analysed. Both right and left sides of head and neck were scanned from the lower part of the head (below the jawline) to the thoracic inlet, Scanning the areas that are swollen or suspected of air injection, paying attention to any abnormal pockets or changes in tissue texture and the changes were stored and analysed. Images were acquired in B-mode and Colour Doppler at the maximum transmit frequency (18 MHz, harmonic), and a gain set to 45 and 60 dB of dynamic range.

### *Infrared Thermography Investigations*

The thermographic camera used was a Hti-Xintai (China) (Infrared resolution 256x192, thermal sensitivity of 0. 07°C, temperature range of -20°C degrees to 550°C, automatic hot/cold detection). The infrared camera was also equipped with laser pointer, LaserSharp® Auto Focus for consistently in-focus images and laser distance meter that calculates distance to the target for precisely focused images and displays distance on screen. After cleaning the neck, lips, clitoris and hump region from any dirt, the thermographic measurements of all animals were taken with ambient temperature was minimum 6-17°C (11.5±4.7°C) and maximum 20-27°C (24.5±3.0°C) and relative humidity 26-80% (50.7±18.7%).

A period of 10-15 minutes was allowed for all animals before scanning for rest and to avoid 'stress-induced hyperthermia' (SIH) which is a common response to acute stress or to repeated stressing episodes. The thermographic camera was positioned perpendicularly at a distance of 0.2 metres from throat and neck area and the images were obtained in triplicate by a trained researcher. Thermographic profiles were analysed using Hti-Xintai® IR Image Tools software (China) where the experimental parameters and emissivity □ = 0.95 were assumed. After processing, maximum, minimum, and average temperature values of each animal's lips, hump, head and neck region were obtained. Abnormal or asymmetrical temperature distributions have been used as indicators of underlying problems with blood circulation or inflammatory responses.

### *EMG of the camel lips*

ES (electric stimulation) was performed according to a standardised diagnostic protocol using biphasic multipulse trains of constant voltage generated by an intraoperative neurophysiological monitoring system (The Neuro-MEP-Micro, Ivanovo, Russia).

Two cable, colour coded red and black for disposable electrode with 2 Alligator clip - touch-proof (L 0.2 m, Russia) were mounted with 5 cm apart and parallel to each other on the upper and lower lips on each side and stimulation electrode with steel stimulation points (2.5 m) was applied to nerve supply at its emergence from infraorbital foramen and mental foramen at the upper and lower lip, respectively.

Multipulse ES was performed with 3 biphasic pulses per train (ppt), pulse width (pw) of 0.1 ms/ phase and interpulse interval (ipi) of 1.0ms. The stimulation voltage was increased using a stepwise protocol: 0, 2, 4, 6, 8, V. At each voltage, transcranial stimulation was performed twice. The diagnostic MEP parameters were retrieved at 2, 4, 6 and 8 V respectively above motor threshold (MT). No further ES stimulations were added to the clinical diagnostic protocol for the present study.

When motor thresholds (MT) were reached for both muscle groups of lips, stimulation was continued to MT + 2 V or otherwise stopped at 8 V. At each occasion of stimulation, the motor responses were recorded for later retrieval of MEP (myogenic evoked potentials) amplitudes, MLTs (motor latency time) and waveform morphology.

## Results

Camels under investigation tolerated the procedure as a number of well-trained assistants for camels were used during clinical and imaging using different devices to ensure the safety of the examiner and ease of the procedure. The average age of the camels ranged from 2 months to 10 years, and their weights ranged from 100 to 650 kg.

Out of a total of 5,365 examined camels, 4,903 were females and 462 were males. Among these, 1,095 camels (20.4%) including 906 females and 189 males were confirmed to exhibit various forms of tampering (Fig 1). The most prevalent form of tampering was lip stretching, recorded in 439 camels (39.7%). This was followed by air injection in the throat and neck region in 166 cases (15%), and nasal injection with filler materials in 138 camels (12.5%). On physical examination, visible clinical signs suggestive of elevated testosterone levels were identified in 94 camels (10.5%), including clitoral enlargement accompanied by a noticeable protrusion of the dulla, ranging from small to moderate size in female camels (Fig 18). While lip binding was identified in 92 cases (8.3%). Less frequently observed practices included lip injection with filler materials (66 camels, 6%), nostril abscessation as a complication from nasal injection with filler materials (33 camels, 2.5%), ear cropping (28 camels, 2%), nerve anaesthesia (22 camels, 2%), and hump injection with filler materials (17 camels, 1.5%). Notably, none of these abnormalities were detected in the control group.

### *Radiographic Investigations*

In control groups, the skin, subcutaneous tissue and muscles of throat and neck region appeared with radiography examination appeared as light gray thin outer margin, medium gray band under skin and medium to dark gray homogeneous area, respectively (Fig 2). Radiographic findings of the examined camels detected air trapped in deeper tissues where air pockets in the acute stage, appeared as black radiolucent areas in the skin or subcutaneous tissues. These pockets showed up as spread in a diffuse and lacy pattern (Fig 3). While in advanced cases, after air absorption, X-rays revealed the presence of well-defined, round soft tissue opacities with calcifications seen as white specks in scarred areas in the X-ray. These can sometimes contained gas from secondary infection which indicted fluid collections and abscesses formation (Fig 4). Whereas, in most advanced and complicated cases the radiographic findings showed scar tissue (fibrosis) which appeared as whiter and radio-opaque due to its increased density and the throat area appeared denser on the X-ray (Fig 5).

Radiographic evaluation of the injected perinasal region by fillers in camels revealed variable soft tissue swelling corresponding to injected filler materials, which appeared as grayish areas with heterogeneous soft tissue density (Fig 6).

Radiographic assessment of the hump region demonstrated abnormal soft tissue changes consistent with the presence of exogenous filler materials. These changes were characterised by focal to multifocal areas of increased radiopacity relative to adjacent soft tissues, often exhibiting irregular margins and heterogeneous internal architecture. The injected materials produced nodular or diffuse radiodense

**Fig 2.** Radiograpic examination in control groups, the skin, subcutaneous tissue and muscles of throat and neck region-appeared as light gray thin outer margin, medium gray band under skin and medium to dark gray homogeneous area, respectively.

patterns, indicating variable distribution within the subcutaneous tissues (Fig 7). In some cases, these alterations were associated with contour irregularities and localised enlargement of the hump, reflecting cosmetic augmentation. In contrast, control animals exhibited homogeneous soft tissue opacity with no evidence of abnormal radiographic features.

### *Computed Tomography Investigations*

On a CT scan, the normal dermis in the control group appeared as an isodense structure as illustrated in Fig 8. While in animals with stretched lips the tearing in tissues and oedema appeared hypodense areas within isodense structure of the dermis as seen in Fig 9, with formation of hyperdense structure appeared as bright white shades with white spots within soft tissue (Fig 10).

CT imaging of the lips and perinasal region in the examined camels revealed the presence of filler materials within the submucosal and subcutaneous tissues of the upper, lower lips and nasal bridge (rhinarium). These materials appeared as well-defined or slightly ill-defined hyperdense areas relative to the surrounding soft tissue, often forming nodular or elongated deposits. No involvement of the oral cavity or underlying musculature was observed.

A CT scan of a normal camel's cervical region skin in control group appeared as thin outer soft

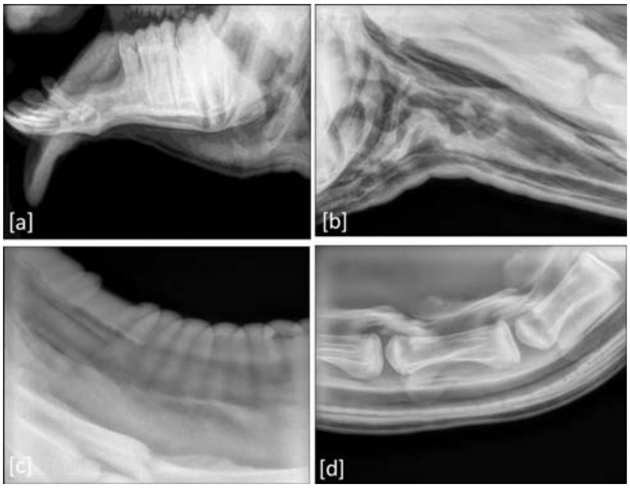


**Fig 3.** Radiographic findings of the camel's throat and neck region detected air trapped in deeper tissues where air pockets appeared as black radiolucent areas in the skin or subcutaneous tissues of lower mandible[a], throat[b], dorsal[c] and ventral[d] aspect of neck. These pockets showed up as spread in a diffuse and lacy pattern.

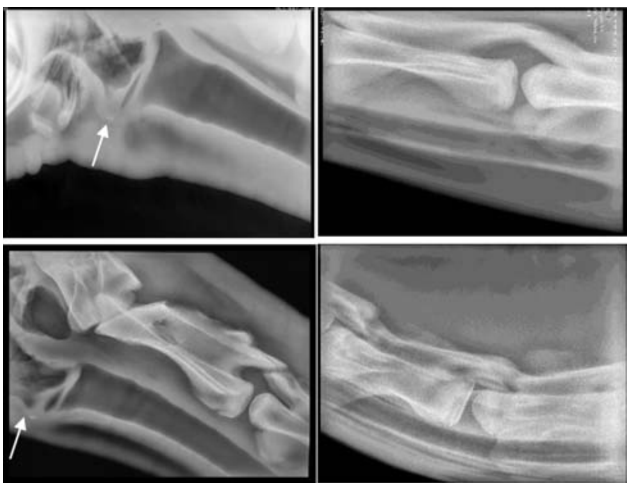

**Fig 4.** X-rays revealed in advanced cases, after air absorption, the presence of well-defined, round soft tissue opacities with corrugated skin and calcifications seen as white specks in scarred areas in the X-ray and the throat area appeared denser on the X-ray.

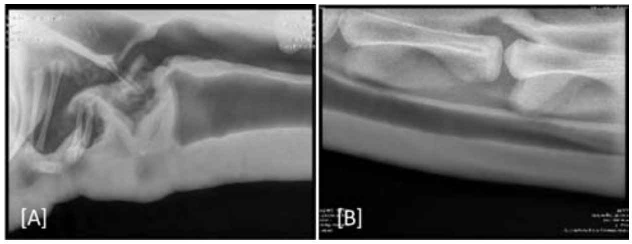


**Fig 5.** Radiographic findings in most advanced and complicated cases they showed whiter and radio-opaque increased density which indicates fibrosis at the throat[a] and neck area[b] appeared denser on the X-ray.

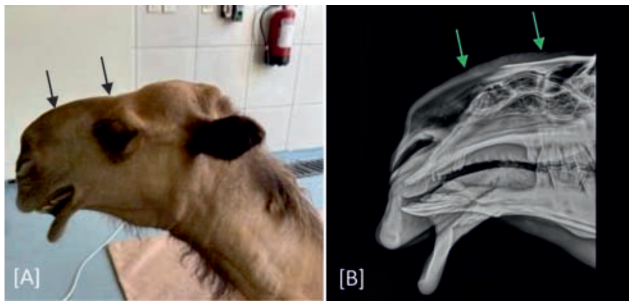


**Fig 6.** Enlargement of the perinasal area (black arrows) in a female camel due to injection of filler material (A). Image (B) shows a lateral radiographic view of the same camel, showing the gray-coloured injected filler material (green arrows) in the perinasal region.

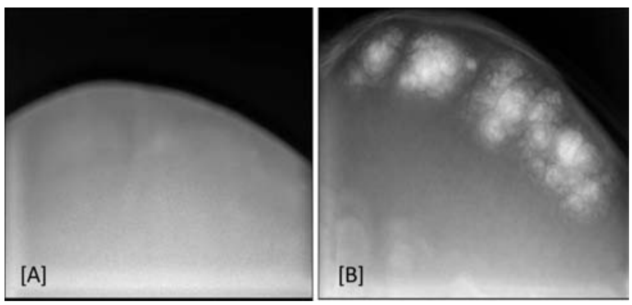


**Fig 7.** Lateral radiographic view of dromedary camel hump: (A) control animal showing homogeneous soft tissue density with normal hump contour; (B) demonstrating abnormal soft tissue opacity with nodular filler deposits and irregular contours.

tissue layer isodense to other soft tissues while fat appeared darker grey, with Hounsfield Units (HU) around -100 to -50. Homogenous with no air bubbles appeared in normal cases. Whereas the muscles (e.g., *sternocephalicus, brachiocephalicus, longus colli*) appeared light grey, uniform in texture with slightly higher HU than fat (~40–60 HU) and clearly separated by fascial planes (Fig 11). The injected camels on CT examination showed very low attenuation, black, irregularly distributed, non-encapsulated areas and typically measuring ~ -1000 Hounsfield Units (HU) with streaky or bubbly shape that follow the fascial planes, separating muscle bundles or collecting under the skin in the ventral, lateral, or caudal neck regions and can tracked cranially toward the mandible (Fig 12). The tissues

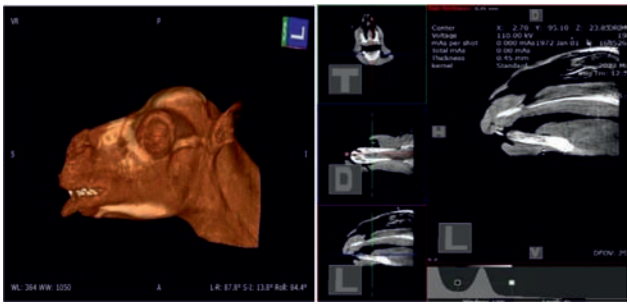

**Fig 8.** Computed tomography showed normal lips appeared as an isodense structure (gray shades) for a female camel.

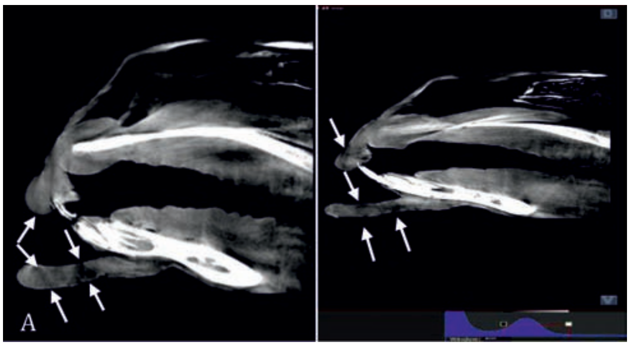


**Fig 9.** Computed tomography showed tearing tissue in stretched lips appeared as hypodenisity black shade areas (white arroaws) within normal isodense gray shade muscle of camel's lips.

appeared normal, aside from the air which may indicate that the injection was recent.

In some cases of injected camels found with increased soft tissue density compared to normal fat and fat planes become hazy or blurred which looked like a diffuse, cloudy or 'ground-glass' appearance — due to fluid accumulation and oedema formation (Fig 13). and the Hounsfield Units (HU) typically shift from normal fat values (-100 to -50 HU) to higher values (0 to +20 HU), depending on severity with less distinct muscular borders due to surrounding fluid and with thickened denser skin and subcutaneous layer and neck diameter appeared increased, irregular contours and asymmetry compared to camels in control groups.

CT imaging of the hump region demonstrated abnormal soft tissue alterations indicative of exogenous filler injection. These changes were characterised by focal and multifocal areas of increased attenuation compared to the surrounding adipose tissue, often exhibiting heterogeneous internal characteristics and irregular margins. The injected materials were frequently observed as nodular or diffusely distributed hyperattenuating

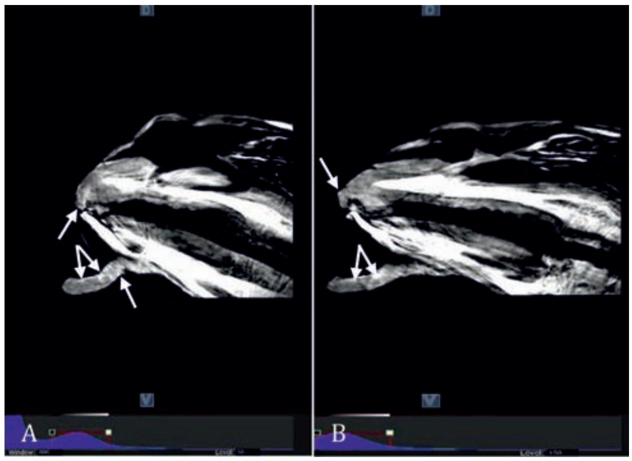


**Fig 10.** Computed tomography showed fibrosis in stretched lips appeared as hyper density lesion within normal isodense gray shade muscle of camel's lips.

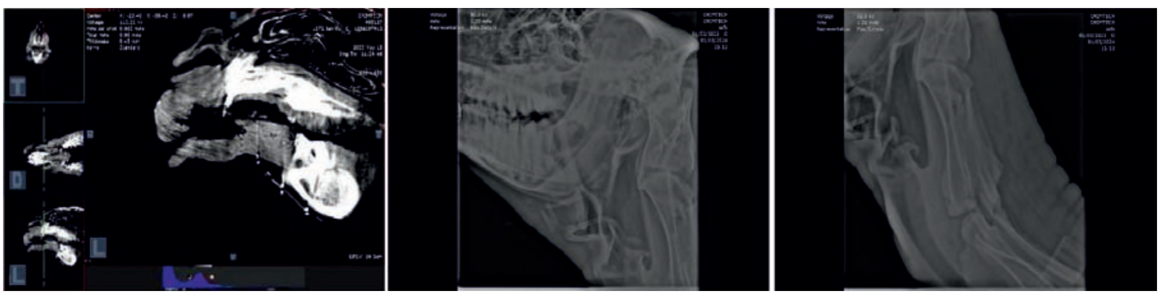

**Fig 11.** A CT scan of a normal camel's cervical region skin in control groups appeared as thin outer soft tissue layer isodense to other soft tissues while fat appeared darker grey, homogenous with no air bubbles in normal cases.

**Fig 12.** A CT examination of injected camels showed very low attenuation, black, irregularly distributed, non-encapsulated areas with bubbly shape that collecting under the skin in the ventral, lateral, or caudal neck regions and can tracked cranially toward the mandible (white arrow).

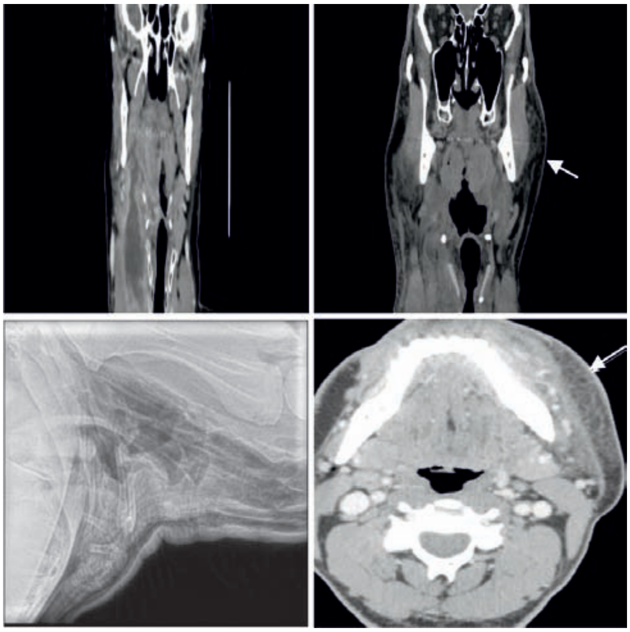

**Fig 13.** CT imaging revealed cervical cellulitis with increased soft tissue density compared to normal fat which looked like a diffuse, cloudy or 'ground-glass' appearancedue to fluid accumulation and oedema formation (white arrows).

deposits within the subcutaneous layer, disrupting the normal fat architecture (Fig 14). In some instances, these deposits were associated with structural distortion, including asymmetrical enlargement and contour deformities of the hump. In contrast, control animals showed uniform, low-attenuation adipose tissue with no evidence of focal lesions or structural abnormalities.

### *Ultrasonography Investigations*

Ultrasonographic examination proved valuable for assessing the various cosmetic procedures performed on camels. Upon ultrasound, the normal dermis in the control groups appeared as a hyperechoic structure easily differentiated from the hypoechoic subcutaneous tissue. In camels with stretched lips, it was difficult to distinguish the subcutaneous tissue from the dermis. The stretched lips appeared anechoic and/or hypoechoic and was imaged as small or large, single or multiple areas of tissue tearing and oedema formation. In the injected lips, the filler materials appeared as areas of low echogenicity, producing heterogeneous images with increased overall lip thickness. In cases of lip binding, the lip tips presented either as isoechoic areas with a hypoechoic rim or as hypoechoic areas with an echogenic centre. In the perinasal region, the filler material appeared as hypoechoic or anechoic foci within the soft tissues as illustrated in Fig 15.

In control groups, the skin and subcutaneous tissue of head and neck region appeared with ultrasound examination as a layered, bright hyperechoic line with dark hypoechoic fat beneath. While neck muscles layers showed up as relatively homogeneous, striated, hypoechoic structures. With

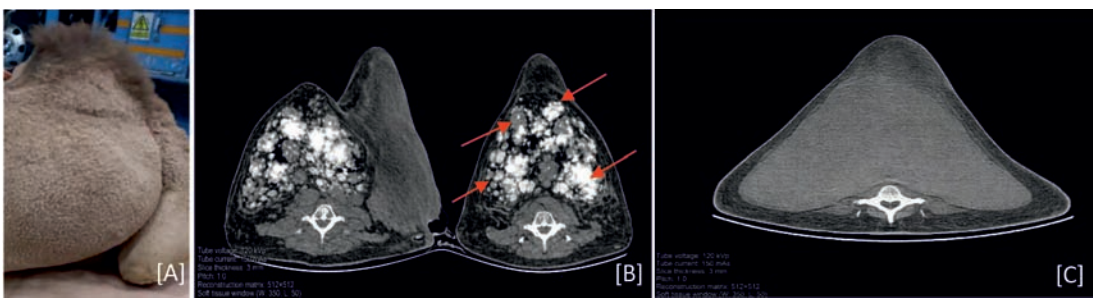


**Fig 14.** CT imaging of the camel hump(A); revealed abnormal soft tissue changes consistent with exogenous filler injection, characterised hyperattenuating subcutaneous deposits with irregular, heterogeneous appearance disrupting normal fat architecture and causing hump deformity (red arrow) (B), compared to normal uniform adipose tissue in controls (C).

the ultrasound examination, the injected air in throat and neck region appeared as bright hyperechoic areas where air is trapped under the skin. In some cases, Aair typically showed as small pockets with well-defined borders and created dirty shadowing artifacts appeared as lines behind the air pockets but in others, the ultrasound imaging identified multiple small bubbles which appeared in a cluster and gives off a grainy pattern on the scan which indicate recent air injection in these sites whereas in advanced cases, the scanned images showed dark, anechoic areas which indicated fluid buildup in the tissues and oedema formation, which could be present after air absorption as shown in Fig 16.

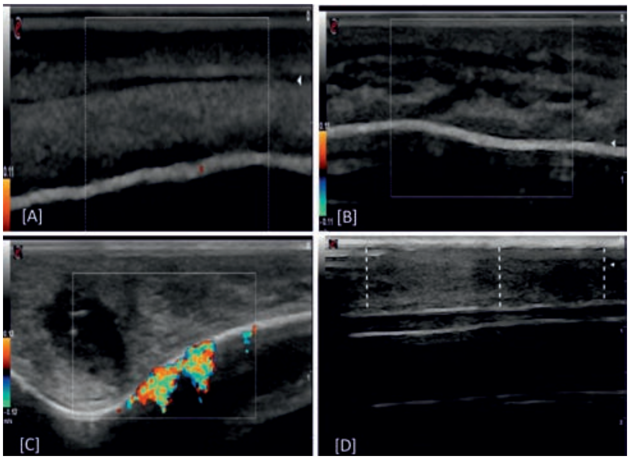


**Fig 15.** Ultrasonographic findings of cosmetic procedures in camels: (A) control showing normal hyperechoic dermis and hypoechoic subcutaneous tissue; (B) stretched lips showing anechoic/hypoechoic areas with tissue tearing and oedema; (C) injected lips showing hypoechoic, heterogeneous filler deposits with increased lip thickness; (D) perinasal region showing hypoechoic/anechoic filler foci within soft tissues (white dots).

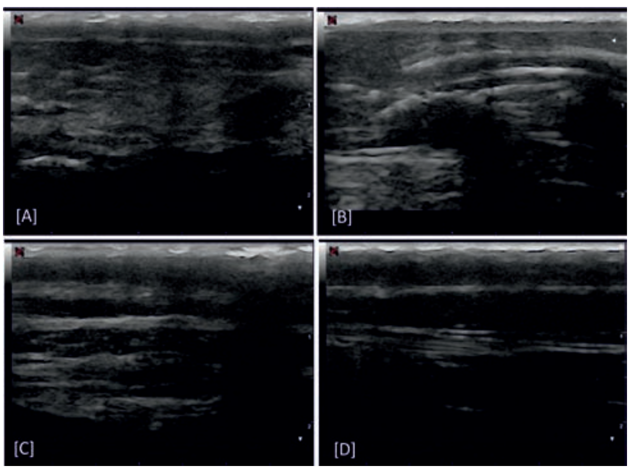


**Fig 16.** Ultrasonography demonstrates; (A) control showing layered hyperechoic cervical skin with underlying hypoechoic fat and homogeneous, striated hypoechoic muscles; (B) air injection showing hyperechoic subcutaneous pockets; (C) Ssmall air pockets with dirty shadowing or clustered echogenic bubbles indicating recent injection; (D) advanced cases showing anechoic areas consistent with fluid accumulation and oedema.

Ultrasonographic examination of the camel hump revealed the presence of injected filler materials within the subcutaneous and fatty tissues. These materials appeared as hypoechoic or anechoic nodules, often heterogeneous in echotexture, causing localised thickening of the hump. The filler deposits were irregular in shape and distributed along the subcutaneous fat, without involvement of the underlying musculature. No vascular flow was detected within the injected areas compared to hump of control group (Fig 17).

Ultrasound examination of the normal female camel clitoris revealed a small, well-defined, homogeneous structure with moderate echogenicity and uniform surrounding tissues, while Doppler imaging showed normal vascular flow. Whereas ultrasonography of the clitoris in hormonally treated female camels revealed pronounced enlargement, appearing as a moderately echogenic, homogeneous structure with well-defined margins, causing protrusion and mild thickening of the surrounding soft tissues causing protrusion, whereas in some cases, the clitoral tissue appeared disrupted or partially absent on ultrasound, presenting as irregular, heterogeneous hypoechoic to anechoic areas with ill-defined margins and localised thinning of the surrounding tissues (Fig 18).

### *Infrared Thermography Investigations*

Infrared thermography (IRT) proved useful for detecting injected filler substances in the lips and for assessing stretched or elongated lips. The injected sites appeared darker than the surrounding tissue, reflecting relatively higher temperatures compared to healthy, non-injected lip tissue. In contrast, stretched

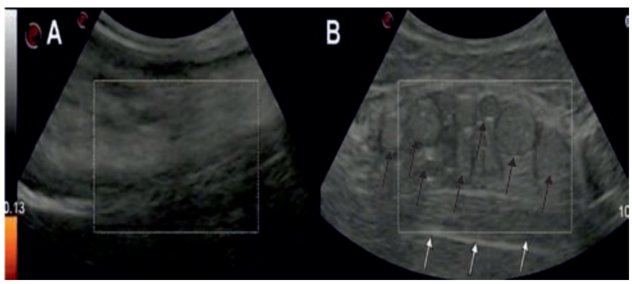


**Fig 17.** Ultrasound of the camel hump shows homogenous subcutaneous fat in control group (A), compared to hypoechoic/anechoic heterogeneous nodules of injected filler within thesubcutaneous fat (black arrow), causing localised thickening without muscle involvement or detectable vascular flow (white arrow) (B).

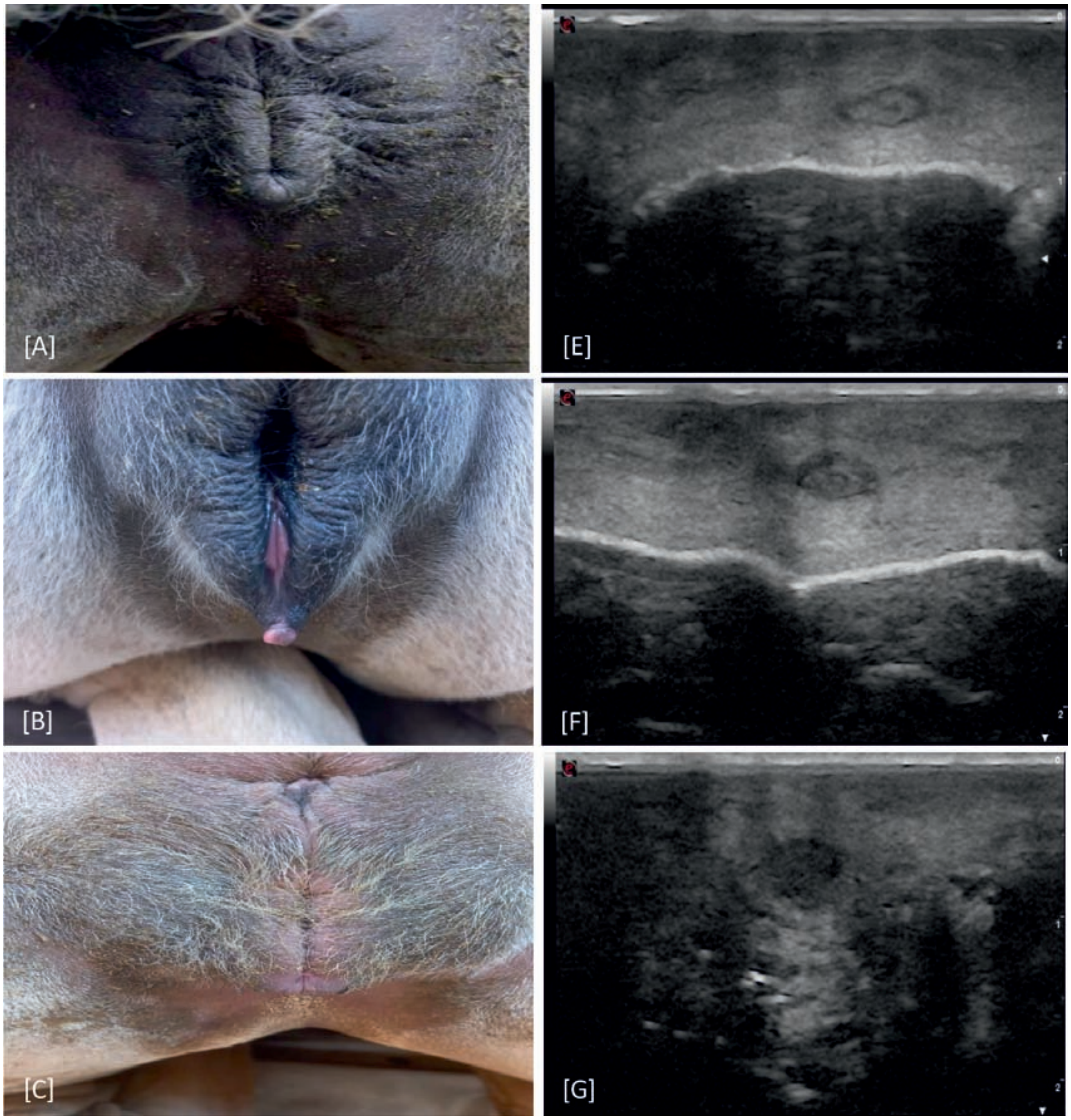


**Fig 18.** Visible clinical signs indicative of elevated testosterone levels (A) normal size and shape of clitoris; (B) enlarged and protruded clitoris; (C) partial cutting of external part of clitoris, with development of the dulla (white arrow) in a female camel (D). ultrasound of the female camel clitoris shows: (D) normal: small, homogeneous, well-defined, moderate echogenicity, normal vascular flow; (E) hormonally treated: enlarged, homogeneous, well-defined, mild protrusion/thickening of surrounding tissues; (F) severe cases: disrupted or partially absent tissue; (G) irregular heterogeneous hypoechoic/anechoic areas, ill-defined margins, localised thinning.

lips exhibited a lighter and more heterogeneous thermal pattern compared to the darker, homogeneous appearance of healthy lips (Fig 19).

With Infrared thermal camera the normal tissue of head and neck appeared as uniform warm colour (red-orange) with bilateral symmetrical pattern. While the injected animals by air showed irregular cool patches (blue-purple) temperatures than surrounding tissue with asymmetrical zones, often with sharp or unnatural edges in one-sided or localised swelling with temperature variation. While in cases that developed fluid buildup and abscess formation showed moderate to higher heat (red, orange or yellow rim around cooler area or white) (Fig 20).

Infrared thermography of normal female clitoris demonstrated a uniform thermal pattern, with temperatures comparable to surrounding tissues and no focal thermal anomalies. Whereas, infrared thermography of the clitoris in hormonally treated female camels revealed either pronounced protrusion appearing as a relatively darker, warmer area reflecting increased blood flow, or partial/complete disruption showing irregular thermal patterns with mixed lighter and darker regions

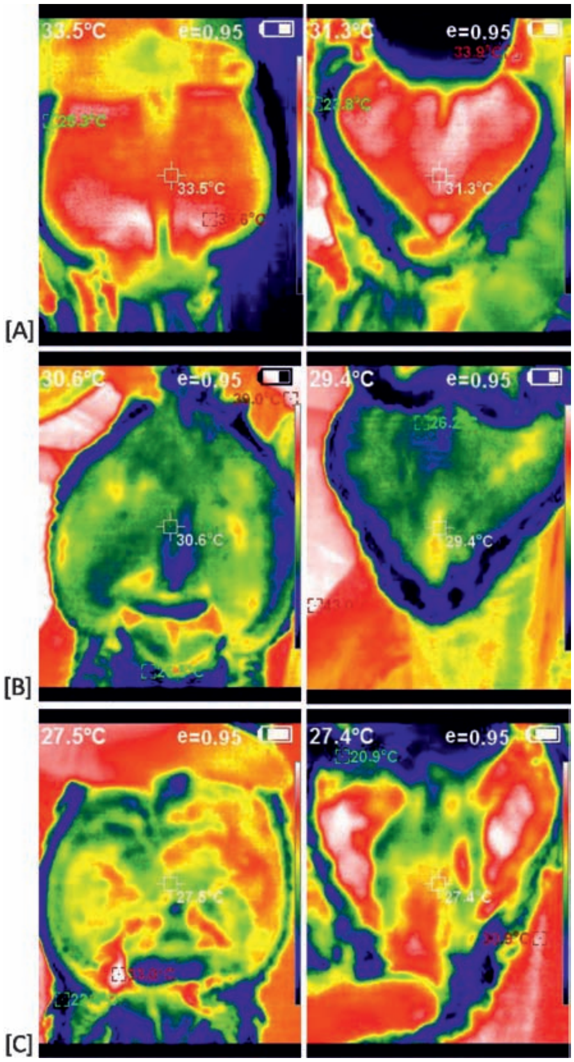


**Fig 19.** Infrared thermography (IRT) of the lips shows: (a) normal lips (upper and lower): dark, homogeneous thermal pattern; (b) injected filler sites: darker areas indicating relatively higher temperature than surrounding tissue; (c) stretched lips: lighter, heterogeneous thermal pattern compared to normal lips.

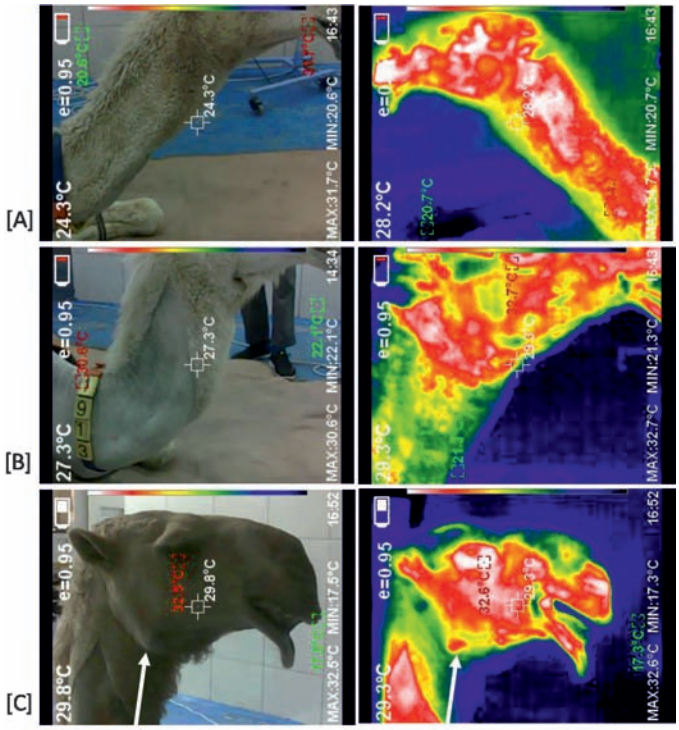


**Fig 20.** Infrared thermography of the head and neck shows: (a) normal tissue: uniform warm (red–orange), bilaterally symmetrical pattern; (b) air-injected cases: irregular cool patches (blue–purple), asymmetrical with sharp or localised edges; (c) abscess: moderate to high heat (red–orange–yellow rim) surrounding cooler or white areas.

corresponding to tissue loss and altered heat distribution (Fig 21).

Infrared thermographic examination of the camel hump revealed clear differences between normal and silicone-injected cases. In control animals, the hump exhibited a homogeneous and symmetrical thermal pattern, with uniform temperature distribution comparable to adjacent body regions, reflecting normal vascularisation and tissue integrity. In contrast, silicone-injected humps demonstrated heterogeneous and

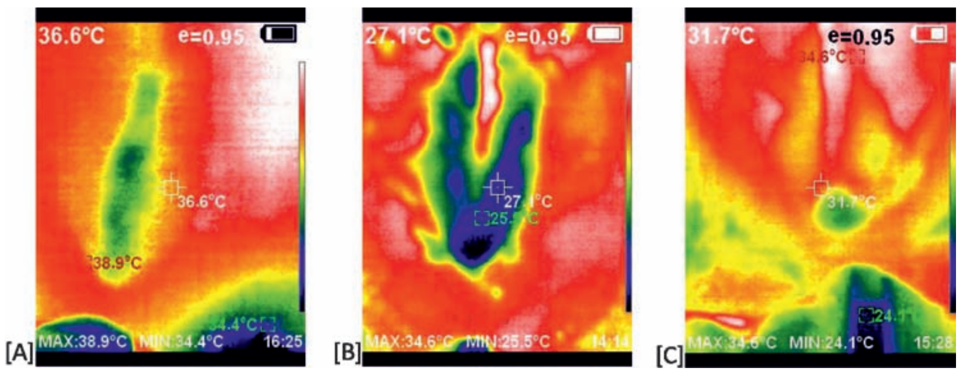


**Fig 21.** Infrared thermography of the female camel clitoris shows: (a) normal: uniform thermal pattern with no focal anomalies; (b) hormonally treated: protruded clitoris appearing as a darker, warmer area (increased blood flow); (c) severe cases: partial/complete disruption with irregular, heterogeneous thermal pattern (mixed lighter and darker areas).

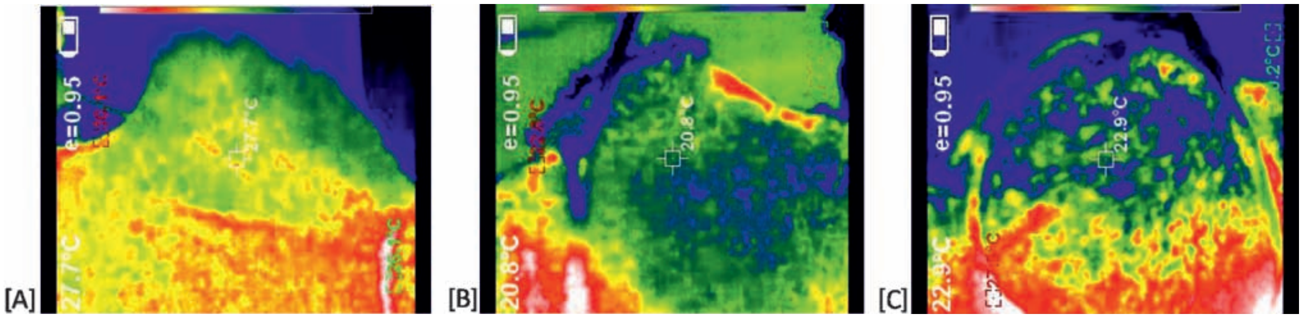


**Fig 22.** Infrared thermography of the camel hump shows: (A) normal: homogeneous, symmetrical thermal pattern with uniform temperature distribution; (B)silicone-injected: heterogeneous, asymmetrical pattern with focal hypothermic areas and occasional warmer zones; (C) advanced changes: thermally irregular contour with mixed temperature distribution, reflecting altered morphology and tissue reaction.

asymmetrical thermal patterns, characterised by focal areas of reduced temperature (hypothermic regions) interspersed with occasional localised warmer zones. The hypothermic areas likely correspond to the presence of silicone material, which has low thermal conductivity and limited vascular interaction, while the warmer regions may indicate localised inflammatory reactions or tissue irritation surrounding the injected material. Additionally, the overall contour of the hump appeared thermally irregular, correlating with the altered morphology and increased thickness observed clinically (Fig 22).

### *EMG of the camel lips*

Electromyographic (EMG) assessment of lip muscles in camels revealed distinct patterns across the examined camels (Fig 23). In the control group, healthy lips with pathologically intact muscles exhibited spontaneous activity that was recorded and quantified as amplitude, with an average of 1.036 µV. In camels with stretched lips, spontaneous activity of the *M. Orbicularis Oris, M. Mentalis, M. Incisivus Superioris* and *M. IncisivusInferioris* was significantly reduced ($P < 0.05$) compared to the control group, with an average amplitude of 0.2 ± 0.15 µV, reflecting diminished neuromuscular function due to mechanical stretching. In camels whose lips were injected with filler materials, EMG recordings showed a further reduction in spontaneous muscle activity compared to the stretched lips group. The amplitudes were lower and more variable depending on the amount and location of the injected material. Conversely, lips subjected to local

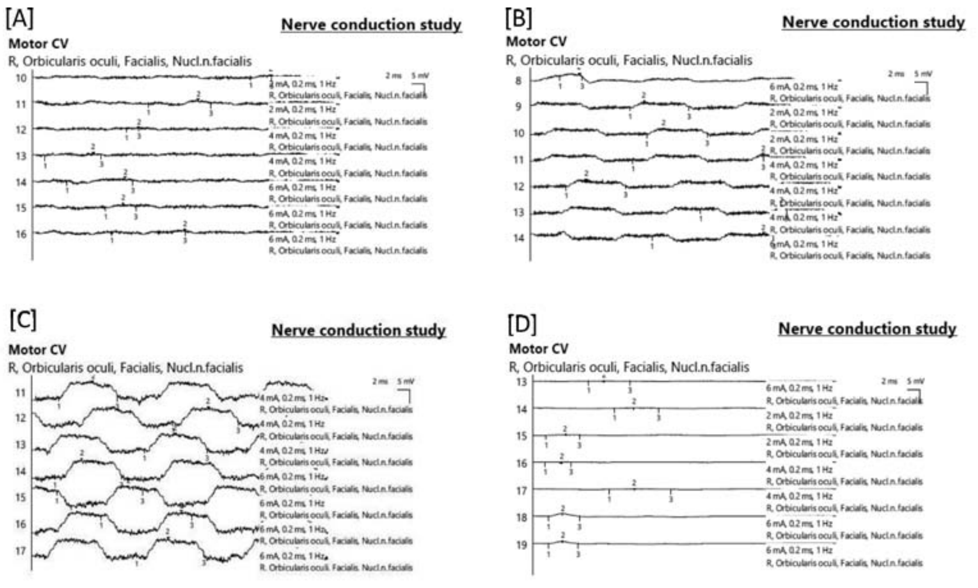


**Fig 23.** EMG of lip muscles in camels shows: (A) control: normal spontaneous muscle activity; (B) stretched lips: significantly reduced activity (low amplitude); (C) filler-injected: further reduced and variable activity; (D) local anaesthesia: near-complete suppression of activity (amplitude ≈ 0).

anaesthesia demonstrated near-complete suppression of spontaneous activity in all assessed muscles, with amplitudes approaching zero. This finding confirms effective blockage of neuromuscular transmission due to the anaesthetic agent, preventing voluntary or spontaneous muscle contractions.

## Discussion

The present study provides a comprehensive evaluation of various forms of tampering in dromedary camels using multiple diagnostic imaging modalities (radiography, computed tomography, ultrasonography, infrared thermography) and electromyography (EMG), and offers insight into the prevalence, imaging characteristics, and neuromuscular consequences of these practices. Out of 5,365 camels examined, 20.4% were confirmed to have undergone some form of tampering, with lip stretching being the most prevalent method recorded, followed by air injection in head and neck region, nasal injection with fillers, signs of elevated testosterone, and lip binding. Less frequently observed manipulations included lip filler injection, nostril abscessation, ear cropping, nerve anaesthesia, and hump filler injection.

Consistent with previous reports from large-scale surveys at camel beauty festivals, stretching of the lips and perinasal filler injections represent major forms of cosmetic manipulation in camels and can be reliably detected using clinical examination supported by diagnostic imaging techniques. Ultrasonography has been shown to precisely discriminate between normal and manipulated tissues, with injected fillers appearing as hypoechoic or anechoic foci in both the lips and perinasal region, corroborating earlier findings in similar camel populations (Tharwat *et al,* 2024).

Radiographically, the presence of air pockets in the soft tissues of the throat and neck produced diffuse radiolucent areas in acute stages, whereas chronic or complicated cases with secondary infection exhibited soft tissue opacities and calcifications, reflecting progressive tissue reaction and fibrosis. These findings align with reports that soft tissue alterations due to fillers may exhibit heterogeneous densities on X rays, potentially influenced by filler composition and quantity (Ouyang and Branstetter, 2010; Scrivani, 2022; Tharwat and Al-Hawas, 2025). Although, radiographic density varies with filler type, previous work also emphasises the variable radiographic appearance of dermal fillers based on composition (Valiyaparambil *et al,* 2009), supporting our interpretation that hyaluronic acid derivatives may present differently from other compounds. Radiographic assessment of the camel hump revealed distinct differences between normal and filler-injected cases. Normal humps showed homogeneous soft tissue opacity reflecting intact tissue architecture, while injected humps exhibited focal to multifocal radiopaque areas with irregular margins and heterogeneous internal patterns, corresponding to the presence and variable distribution of exogenous materials, sometimes causing contour irregularities and localised enlargement, consistent with cosmetic augmentation (Kwon *et al,* 2018; Valiyaparambil *et al,* 2009). Variations in radiographic appearance are influenced by filler composition, such as silicone, calcium-based compounds, or hyaluronic acid derivatives, producing different radiodensity profiles, as reported in both veterinary and human imaging studies (Alsufyani *et al,* 2022; Mundada *et al,* 2017).

CT imaging further delineated the anatomical changes associated with tampering. In animals with stretched lips, binding lips, tissue tearing and oedema manifested as hypodense regions within the dermis, whereas filler materials appeared as well defined hyperdense deposits within submucosal and subcutaneous layers. The variations in attenuation and architectural disruption seen on CT scans reflect the diverse physical properties of injected materials in lips and perinasal region and the degree of associated soft tissue reaction, observations that are also described in the limited literature on filler imaging in both veterinary and human medicine (Alsufyani *et al,* 2022; Nahas *et al,* 2024; Rubinstein *et al,* 1996). The observed CT attenuation differences in tissues with oedema, fat plane disruption, and filler nodules align with known imaging features of foreign material deposition in soft tissue, similar to reports of dermal fillers presenting radiographically as distinct densities (Kwon *et al,* 2018; Mundada *et al,* 2017). CT examination of the camel cervical region showed normal soft tissue and fat distribution in controls, while injected cases exhibited low-attenuation areas, irregular contours, and occasional diffuse soft tissue density changes due to fluid accumulation and oedema (Alsufyani *et al,* 2022; Kwon *et al,* 2018; Valiyaparambil *et al,* 2009). These findings indicate that CT effectively detects exogenous material and associated tissue alterations. CT imaging of the camel hump revealed normal uniform low-attenuation fat in controls, whereas injected cases showed focal or multifocal hyperattenuating deposits with irregular margins, heterogeneous internal structure, and occasional contour deformities, reflecting exogenous filler presence (Lee *et al,* 2022; Mundada *et al,* 2017). These findings confirm that CT effectively detects both filler material and associated soft tissue alterations.

Ultrasonography proved valuable in delineating filler material as hypoechoic or anechoic foci, and in identifying additional soft tissue abnormalities such as oedema and fluid accumulation. This aligns with early veterinary studies that first documented the utility of ultrasound for localising cosmetic filler injections in camel lips and perinasal region, highlighting a pattern of heterogeneous echotexture and variable echogenicity (Marzok *et al,* 2025; Tharwat and Al-Hawas, 2021; Young *et al,* 2008). Ultrasonography can detect hyperechoic foci with posterior dirty shadowing, corresponding to gas within soft tissues, and is useful for identifying both gas collections and inflammatory changes in soft tissue infections. This has been demonstrated in sonographic evaluations of necrotising soft tissue infections in cervical region, where gas pockets and fluid collections produce characteristic artifacts and echogenic patterns on real time ultrasound (Butcher *et al,* 2011; Gan *et al,* 2023; Nahas *et al,* 2024; Wortsman and Wortsman, 2011; Yoo, 2024). Ultrasonographic assessment in the present study revealed distinct differences between normal and filler treated tissues. In controls, the hump subcutaneous and fatty layers demonstrated typical soft tissue echotexture, whereas injected filler material appeared as hypoechoic or anechoic heterogeneous nodules with irregular distribution and localised thickening, consistent with documented ultrasound patterns of dermal fillers (e.g., anechoic/hypoechoic filler deposits and mixed echotexture seen on high frequency US) in human imaging studies (Chiang and Liao, 2025; Urdiales-Gálvez *et al,* 2021). Similarly, normal camel clitoris exhibited a small, homogeneous structure with uniform echogenicity and normal Doppler flow, while hormonally altered clitoral tissue showed pronounced enlargement or disrupted heterogeneous hypoechoic/anechoic areas, reflecting alterations in tissue architecture analogous to pathological changes described in soft tissue ultrasonography (Thomaz *et al,* 2026). Overall, these findings support the utility of ultrasound for identifying exogenous material and associated soft tissue alterations in both hump and genital regions.

Infrared thermography (IRT) offered additional functional information. Normal head and neck tissues exhibited uniform thermal symmetry, whereas injected or stretched regions showed thermal asymmetry, cooler or hotter areas, and heterogeneous patterns. When assessing a thermal image, asymmetry of 1°C or more is often significant and indicates possible pathology. The darker thermal signatures of injected lips observed in our study indicating relatively higher local temperature likely reflect superficial inflammation, consistent with thermographic findings described in camels with injected or stretched lips (Redaelli *et al,* 2014; Schaefer *et al,* 2004; Stelletta *et al,* 2012; Tharwat, 2025; Tharwat *et al,* 2021). Infrared thermography proved useful in differentiating normal from silicone-augmented humps. The uniform thermal distribution observed in normal camels reflects intact vascular perfusion and consistent tissue composition. In contrast, silicone injection resulted in disrupted thermal patterns, with predominantly hypothermic areas due to the insulating properties of silicone and its lack of metabolic activity. The presence of adjacent hyperthermic zones may be attributed to secondary inflammatory responses or altered local blood flow. These findings are consistent with previous studies demonstrating that infrared thermography is sensitive to variations in tissue perfusion and inflammatory processes, where hyperthermic regions are associated with increased blood flow and inflammation, while hypothermic areas may reflect reduced vascularity or the presence of non-biological materials (Brothers *et al,* 2025; Stelletta *et al,* 2012). Moreover, the altered thermal distribution observed in silicone-injected tissues of hump aligns with reports describing the impact of foreign materials on local heat patterns and tissue physiology (Ring and Ammer, 2012). Collectively, these findings highlight the sensitivity of IRT in detecting subtle physiological alterations associated with cosmetic tampering and support its role as a non-invasive diagnostic tool in field conditions. Infrared thermography in this study effectively distinguished normal from altered clitoral tissue patterns. Normal clitorises exhibited a uniform thermal distribution without focal anomalies, whereas hormonally treated animals showed areas of increased surface temperature corresponding to protrusion and enhanced blood flow, as well as irregular mixed thermal zones reflecting tissue disruption and altered heat distribution. These findings are consistent with previous thermographic studies demonstrating that changes in vascularity and soft tissue integrity produce measurable thermal pattern alterations, with warmer regions indicating increased perfusion or inflammation and heterogeneous patterns associated with structural disruption (Chava *et al,* 2023; Whittaker *et al,* 2023; Xu *et al,* 2025).

Electromyography (EMG) is a sophisticated electrodiagnostic-neurophysiological method, which serves to diagnose neuromuscular system diseases which may be due to using a local anaesthetic, either in the form of injections or ointments, to induce laxity in the lips is one of the methods of tampering in camels, as it leads to the drooping of the lower lip and changing the appearance of the camel. It is based on the measurement of the electrical potentials created by the skeletal muscle activity. From a neurophysiological standpoint, EMG recordings revealed a progressive decline in spontaneous muscle activity from control camels to those with stretched or filler injected lips, and near complete suppression in locally anaesthetised animals. This pattern is biologically plausible given the impact of mechanical stress on neuromuscular recruitment and the inhibitory effect of local anaesthetics on nerve conduction. Local anaesthetics block voltage gated sodium channels, preventing action potential propagation and resulting in significantly reduced EMG activity in anaesthetised muscles compared with control and stretched conditions (Strichartz, 1976). Clinical studies have demonstrated that regional nerve blocks markedly suppress motor nerve conduction and EMG amplitudes, consistent with our findings of near complete EMG suppression in locally anaesthetised lip muscles (Byram *et al,* 2020; Luo *et al,* 2020). Although, direct veterinary EMG comparisons are limited, similar trends have been documented in the assessment of facial muscles following cosmetic interventions in human patients, where fillers and neuromuscular modifiers alter baseline electrophysiological activity (Tharwat and Al-Hawas, 2025).

This study provides comprehensive clinical and diagnostic evaluation of various cosmetic enhancements in camels, including lips stretching, lips binding, injection of the lips and nose by a filler material, visible clinical signs indicative of elevated testosterone levels.

The findings clearly demonstrated the substantial health risks and significant welfare concerns associated with various cosmetic enhancements, reinforcing the introduction's assertion regarding these dangers. Notably, this study documents severe tissue damage, inflammation, functional impairment, and long-term structural alterations, particularly in the chronic cases of air injection and the widespread use of fillers. These abnormalities constitute direct evidence of the suffering inflicted upon the animals, justifying the rigorous implementation of diagnostic examinations to not only eliminate cheating and ensure fair competition but also, crucially, to safeguard the welfare and health of camels.

Clinically, this multidimensional approach enhances detection sensitivity and aids in differentiating between recent versus chronic manipulations, inflammatory versus non inflammatory changes, and mechanical versus pathological tissue alterations. This integrated protocol represents a comprehensive diagnostic approach, as each modality is capable of detecting specific forms of cosmetic tampering; therefore, its combined application ensures that no form of manipulation or fraud in camels can go undetected.


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## Author contribution

The authors confirm contribution to the paper as follows: study conception and design, data collection, analysis and interpretation of results and draft manuscript preparation: Ellawatty WAE. Margreet V. and Ellawatty WAE. reviewed the results and approved the final version of the manuscript.


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## Institutional Review Board Statement

This is a retrospective study conducted in a commercial medical imaging centre in the 2020–2026. All of the procedures were approved by the local ethical committee of Salam Camel Hospital, Salam Veterinary Group, Co., Qassim, Saudi Arabia (Approval code: SVG 0316202237).

## Informed Consent Statement

Not applicable.

## Data Availability Statement

Data availability is possible upon request.

## Conflicts of Interest

Author Waleed Elsayed Ahmed Ellawatty was employed by the company Medical Imaging Department, Salam Veterinary Group Co. The remaining author declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# CAMEL CENTRIC PROVERBS OF THE BERHALE DISTRICT, AFAR REGION, ETHIOPIA: A COLLECTION, ANALYSIS AND SYNTHESIS OF PASTORAL WISDOM

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## ABSTRACT

This study explores the rich oral traditions of the Berhale District in the Afar Region of Ethiopia, focusing specifically on camel-centric proverbs. In this arid landscape, the dromedary camel is not only a biological necessity for survival but also a foundational pillar of cultural identity. Using a purposive sampling approach across 5 kebeles and 90 households, the research collected proverbs in the Afar language, which were subsequently translated into Amharic and English. The results, analysed through narrative synthesis, revealed that these proverbs function as a vital Indigenous Knowledge System (IKS) for resilience, conflict resolution and camel management. A key finding of the study is the direct link between oral camel-centric proverbs and practical husbandry, categorised into five thematic areas: (1) Social Status, Wealth and Identity; (2) Intelligence and Navigation; (3) Biological Nature and Psychology; (4) Medicinal and Life-Sustaining Value; and (5) Legal Integrity and Traditional Law. The study concludes that documenting these linguistic treasures is essential for preserving pastoral wisdom. Furthermore, it suggests integrating this indigenous knowledge into modern camel management and regional educational policies to enhance camel productivity and safeguard cultural heritage.

**Key words:** Afar region, Berhale district, camel proverbs, indigenous knowledge systems (IKS), paremiology

At the heart of the arid Afar Region, the Berhale district serves as a gateway to the Danakil Depression, one of the most inhospitable yet culturally rich environments on Earth. In this landscape of extreme heat and salt-crusted plains, the dromedary camel (*Camelus dromedarius*) is far more than a head of livestock; it is a foundational pillar of economic survival, social status and cultural identity. For Afar pastoralists, the camel represents a living archive of resilience, providing the principal vocabulary for their moral, philosophical and ecological worldview (Tadesse *et al,* 2014).

This study explores the intricate relationship between the Afar people and their camels through the lens of paremiology: the systematic study of proverbs. In Berhale, proverbs are not merely decorative speech; they function as a communal survival manual. These short, meaningful sayings capture hundreds of years of desert experience and community rules in a way that is easy to understand. Whether they are teaching the necessity of patience during a drought or the nuances of tribal leadership, the camel serves as the ultimate metaphor for the human experience in the desert (Balehegn, 2016).

Despite the rapid modernisation of agricultural practices, these oral traditions remain the primary vehicle for transmitting Indigenous Knowledge Systems (IKS) within pastoralist communities. They provide a practical framework for survival by teaching the community how to interpret climate signals, read weather patterns and provide specialised care for their animals. Beyond physical survival, these proverbs facilitate social harmony and conflict resolution by utilising traditional metaphors to mediate disputes and maintain communal cohesion (Abokar, 1987). Ultimately, they reflect a deep ethno-veterinary philosophy and a profound respect for the camel's biological endurance and its essential role in the household.

Contemporary research frequently focuses on the biological and physiological aspects of camel productivity, such as genetics, nutrition and disease. However, the rich oral traditions and indigenous narratives surrounding them are often overlooked and rarely documented. This research gap is critical because, as the Afar region faces increasing climatic volatility and the rapid erosion of traditional

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oral cultures, this living data is at risk of being permanently lost.

Without systematic documentation, the specialised ecological and veterinary insights embedded in Afar proverbs remain inaccessible to modern livestock management frameworks. Furthermore, there is a lack of localised research that treats paremiology as a functional diagnostic tool for understanding pastoral resilience. This study aims to fill this critical gap by collecting and analysing specific camel-centric proverbs from the Berhale district. By explaining their deep meanings in clear language and preserving them in their original Afar context, this work seeks to safeguard the unique voice of the Berhale people and integrate desert wisdom into the broader discourse of modern livestock management and cultural preservation. The primary objective of this study is to document, categorise and analyse camel-centric oral proverbs in the Berhale district of the Afar Region, evaluating their role as a functional Indigenous Knowledge System (IKS) for pastoral resilience and livestock management.

## Materials and Methods

### *Study Area and Environmental Context*

The research was conducted in the Berhale district of the Afar Regional State, Ethiopia, a strategic pastoralist corridor located approximately 647 km northeast of Semera and 908 km from Addis Ababa. Geographically, Berhale serves as a critical transition zone to the Danakil (Dallul) depression, characterised by one of the most extreme thermic environments on earth. Situated at a mean altitude of 621 meters above sea level, the district is defined by its hyper-arid climate and fragmented volcanic landscapes. These environmental constraints render the area largely unsuitable for diverse livestock production; consequently, the dromedary camel (*Camelus dromedarius*) has emerged as the dominant species. According to recent livestock census data, the camel population in Berhale is the most significant in the region (Afar BoFED, 2024), providing a unique socio-ecological laboratory for investigating the intersection of indigenous pastoral wisdom and desert survival.

### *Research Design and Sampling*

To ensure data reliability, this study employed a purposive sampling approach. Five administrative units (kebeles) were selected from the district's nine units based on high camel density and geographic accessibility. Within these kebeles, households were randomly identified, resulting in a total of 90 participating households. To deepen qualitative insights, the study utilised Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). Key informants included respected community elders, clan leaders and experienced herders recognised for their mastery of Afar oral literature. Focus group discussions were conducted in each kebele with 6 to 8 participants per session. This layered strategy allowed for the triangulation of data and ensured a representative communal perspective.

### *Data Collection and Language*

Primary data were acquired through direct field visits and systematic interviews. These sessions prioritised the documentation of oral traditions, focusing on the historical origins of specific proverbs and their application in traditional Afar law. To preserve cultural nuance, all proverbs were first recorded in the native Afar language. Subsequently, recordings were translated into Amharic and English. This process included a communal validation phase, where local informants reviewed the translations to ensure they accurately reflected collective wisdom. Qualitative data was further enriched by field observations of traditional camel husbandry to verify how oral proverbs align with real world management practices.

### *Data Analysis*

Following data collection, the qualitative data were organised, transcribed and coded. Narrative analysis was employed to map the prevalence and spatial distribution of camel traditions. These findings were interpreted through narrative synthesis, revealing how these proverbs function as a vital Indigenous Knowledge System (IKS) for resilience and conflict resolution. By establishing a direct correlation between oral traditions and practical husbandry, the analysis provides a robust framework for understanding the camel's multifaceted role in Afar society.

## Results and Discussion

The findings of this study demonstrated a profound and direct correlation between Afar oral proverbs and the practicalities of camel management. These proverbs were not merely linguistic artifacts; they function as a living manual for survival in the arid Danakil corridor. The results were categorised into five thematic areas that represented the multidimensional role of the camel in Afar society and direct link between oral camel-centric proverbs and practical husbandry, categorised into five thematic areas: (1) Social Status, Wealth and Identity; (2) Intelligence and Navigation; (3) Biological Nature and Psychology; (4) Medicinal and Life-Sustaining Value; and (5) Legal Integrity and Traditional Law.

### *Social Status Wealth and Identity*

The results of this study demonstrated that in the Berhale District, the dromedary camel is not merely a biological entity but the primary architect of social hierarchy and individual identity. The proverb *"Gala ittu mayyu num, abba mayyu"* (A father is not a father if he fails to leave a camel) suggests that fatherhood is defined by the successful transmission of pastoral assets. In Afar tradition, a father's legacy is measured by his ability to provide his offspring with the means of survival in the Danakil depression. Without this transfer of living capital, the patriarchal bond is viewed as functionally incomplete, echoing the findings of Tadesse *et al* (2014), who noted that livestock remains the most vital inheritance in pastoralist societies.

Furthermore, the categorisation of human status based on livestock ownership *"Gala itta num numma num"* (A man with a camel is a complete man) versus *"Beera itta num, gilaal num"* (A man with goats is half a man) reveals a sophisticated socio-economic ranking. While goats and cattle provide immediate subsistence, only the camel offers the long term resilience and mobility required for the salt trade caravans of Berhale. The economic disparity expressed in the proverb *"Gala laaqi inki taba qidimmay"* (One camel is equal to twelve goats) is not just a calculation of market price, but a reflection of the camel's superior buffer capacity against the recurrent droughts of the 21$^{st}$ century (Balehegn, 2016).

The psychological weight of camel ownership is summarised in the rhetorical question: *"Gala mayyu num, mannal giclo?"* (Why would a man without a camel carry himself with pride?). In the Afar customary law, camels are the currency of blood wealth and legal guarantees. A man without a camel lacks legal insurance necessary to navigate communal disputes. Thus, the camel acts as a social shield; its absence renders an individual vulnerable, reinforcing the conclusion that in the Afar Region, the camel is the ultimate symbol of human dignity and community standing (Abokar, 1987).

*"Gala mayyu num, haxaat mayallu."* "ግመል የሌለው ሰው ስለዛፍ ብዙ አያወራም።" meaning a man without a camel does not talk much about trees. This finding highlights that ecological knowledge in the Afar region is a direct function of ownership. Because camels are specialised browsers that rely on high altitude acacia and desert shrubs, the owner must possess an intimate, expert level understanding of the local flora to ensure herd health and productivity. A man without a camel is effectively silenced in communal discussions regarding land management, grazing rights and resource allocation. This suggests that environmental literacy is not merely a skill, but a social privilege and a prerequisite for having a voice in the community's decision making processes (Balehegn, 2016).

*"Beera deeclat gala ma-deeclan."* "የፍየልን ቀልድ ለግመል አይቀለድም።" meaning the jokes made about goats are never made about camels. This proverb establishes a clear cultural distinction between different livestock species. While goats are viewed as common, replaceable assets and are often the subject of lightheartedness or jokes in pastoral discourse, the camel is treated with a specific gravity and dignity. This reflects the species' superior economic and survival value in the Danakil corridor. In the Berhale district, this translates to specialised management practices where the camel's welfare is prioritised above all other animals. To treat a camel with the levity of a goat is to disregard the foundation of Afar survival, emphasising that the camel occupies a sacred, high status category within the pastoral psyche (Abokar, 1987; Getachew, 2001).

### *II. Intelligence and Navigation*

The results in this category illustrate that the Afar people do not view the camel as a passive beast of burden, but as an active, intellectual partner in desert survival. The proverb *"Gala gita iyyu"* (The camel is a pathfinder and surveyor) highlights the animal's cognitive ability to navigate the featureless and dust-choked terrains of the Danakil Depression. In a landscape where sandstorms can erase human-made landmarks, the camel's spatial memory provides the primary security for salt caravans. This aligns with the ethno-ecological observation that camels possess a biological compass, allowing them to identify seasonal grazing routes and trek across vast distances without losing their orientation.

One of the most striking findings is the designation of the camel as *"Gala lee injinier iyyu"* (The camel is a water engineer). In the hyper arid Berhale District, where water sources are often hidden or subterranean, pastoralists rely on the camel's acute sensory perception to locate water. This engineering refers to the animal's ability to sense moisture in the air and detect underground aquifers long before human observers. By following the camel, the Afar pastoralist accesses a natural sensor for life sustaining resources, a practice that forms a critical part of their Indigenous Knowledge System (IKS) for drought adaptation (Balehegn, 2016).

Furthermore, the characterization of the camel in the proverb *"Gala massoyya, kalah massoyisih mayyu"* (The camel is a leader, not a follower) reflects a deep respect for the animal's independent decision making. Unlike cattle or sheep, which require constant prodding, the camel is trusted to lead the way. This inherent leadership, coupled with the wisdom that *"Gala gita yaaxige"* (The camel knows the way), suggests a relationship of mutual trust. As Abokar (1987) noted in comparative pastoral studies, the camel's navigation is seen as divinely or instinctively guided, making it the moral and physical leader of the caravan. Ultimately, these proverbs prove that the Afar's survival in one of the world's harshest environments is technically supported by the camel's superior environmental intelligence.

### *III. Biological Nature and Psychology*

The findings in this category reveal a sophisticated Afar understanding of camel psychology, moving beyond simple animal husbandry into the realm of animal sentience and emotional intelligence. The proverb *"Gala mecla yaaxige"* (The camel is both merciful and vengeful) serves as a primary behavioural guideline for herders in Berhale. It suggests that the camel possesses a long term memory for both kindness and mistreatment. This psychological complexity requires the pastoralist to maintain a relationship based on reciprocal respect rather than force, as a slighted camel is believed to harbor a grudge (Balehegn, 2016).

Furthermore, the observation that *"Gala qidimih yidwiye"* (A camel weeps when it senses its own slaughter) humanises the animal, reflecting a deep ethno-biological empathy. This proverb underscores the Afar belief that the dromedary possesses a high level of self-awareness and premonition. This spiritual connection is further evidenced in the maternal proverbs *"Gala isí baxa naba xagaruk yaaxige"* (A camel can identify its offspring from a distance). These sayings highlight the camel's superior sensory and intuitive capabilities.

A particularly significant finding for the ethno-veterinary section of this study is the proverb *"Gala*

**Table 1.** Categorised Camel Proverbs Representing Social Status, Wealth and Identity in the Berhale District (Afar, Amharic and English).

| **Afar Language (Qafár af)** | **Amharic Translation** | **English Synthesis** |
|---|---|---|
| *Gala ittu mayyu num, abba mayyu* | ግመል ያልተወልህን አባት አባት አትበለው፡፡ | A father is not a father if he fails to leave a camel as heritage. |
| *Gala itta num numma num* | ግመል ያለው ሰው ሙሉ ሰው ነው፡፡ | A man with a camel is a complete man (full status). |
| *Gala beertih faldem, kasare* | ግመልን በፍየል የቀየረ ከሰረ፤ ፍየልን በግመል የቀየረ ከበረ፡፡ | Trading a camel for a goat is the path to economic ruin. |
| *Gala laaqi inki taba qidimmay* | አንድ ግመል የአስራ ሁለት ፍየል አቻ ነው፡፡ | One camel is [economically] equal to twelve goats. |
| *Gala mayyu num, mannal giclo?* | ግመል የሌለው ሰው ምን ወዲያ ወዲህ አስባለው? | A man without a camel has no reason to carry himself with pride. |
| *Gala naba sadaqa iyyu* | ግመል ትልቁ ሰደቃ ነው፡፡ | The camel is the highest form of social capital and religious merit. |
| *Gala mayyu num, haxaat mayallu* | ግመል የሌለው ሰው ስለዛፍ ብዙ አያወራም፡፡ | Ownership dictates environmental literacy; without a camel, one lacks a social voice. |
| *Beera deeclat gala ma-deeclan* | የፍየልን ቀልድ ለግመል አይቀለድም፡፡ | Reflects the dignity and gravity of the species; it is never treated with the levity of goats. |

**Table 2.** Categorised camel proverbs representing intelligence and navigation in the Berhale district (Afar, Amharic and English)

| **Afar Language (Qafár af)** | **Amharic Translation** | **English Synthesis** |
|---|---|---|
| *Gala gita iyyu* | ግመል መንገድ ቀያሽ ነው፡፡ | The camel is a natural pathfinder and surveyor |
| *Gala lee injinier iyyu* | ግመል የውሀ መሀንዲስ ነው፡፡ | The camel is a "water engineer" (finding hidden sources) |
| *Gala massoyya, kalah massoyisih mayyu* | ግመል መሪ እንጅ ተመሪ አይደለም፡፡ | The camel is a leader by nature, not a follower |
| *Gala gita yaaxige* | ግመል መንገድ ያውቃል፡፡ | The camel possesses an innate map of the desert |
| *Gala isí gubax yaaxige* | ግመል የራሱን ሀገር ያውቃል፡፡ | A camel always knows the way back to its home territory |

*isí abbah xagaruk raqte"* (A camel may withhold milk if its specific milker is absent). This points to a unique individual to individual bond between the camel and its primary caretaker. It suggests that milk let down is an emotional response triggered by the presence of a trusted human partner. In the Berhale district, this behavioural trait reinforces the importance of the owner's physical presence and constant care. As noted by Tadesse *et al* (2014), such indigenous observations of animal behaviour are not mere myths but are grounded in the biological reality of how stress and trust affect oxytocin and milk production in dromedaries.

### *IV. Medicinal and Life Sustaining Value*

The findings in this category underscore the specialised role of camel milk as a biological and cultural asset in the Berhale District. The proverb *"Gala han dawa iyyu, maane hinna"* (Camel milk is medicine, not just only food) is a cornerstone of Afar ethno-medicine. It reveals that pastoralists do not view the milk as a simple calorie source, but as a prophylactic and therapeutic agent. In the harsh environment of the Danakil Depression, where modern medical facilities are often distant, camel milk serves as a vital resource for treating ailments ranging from gastrointestinal issues to nutritional deficiencies. This indigenous perspective is increasingly supported by modern biochemistry, which identifies camel milk as having high concentrations of insulin-like proteins and protective antibodies (Tadesse *et al,* 2014).

The social vitality linked to the dromedary is captured in the proverb *"Gala han aqbi, isí xonit mawaara"* (A camel herder never quarrels with his lover). This subtle yet powerful saying links the consumption of camel milk to physical stamina and reproductive health. In the Berhale community, this is understood as a reflection of the milk's high mineral and vitamin content, which sustains the herder's vigor through long treks in extreme heat. The peace in the relationship mentioned in the proverb is a metaphor for the herder's overall wellbeing and strength, derived from his unique diet.

Furthermore, the observation that *"Gala han madidda, mabullo"* (Camel milk is neither boiled nor churned) highlights a deep understanding of the milk's unique chemical properties. Unlike cow or goat milk, camel milk does not easily coagulate or curdle under traditional processing methods, nor is it typically boiled, as the Afar believe this kills its medicinal potency. This indigenous knowledge aligns

**Table 3.** Categorised camel proverbs representing biological nature and psychology in the Berhale district (Afar, Amharic and English).

| Afar Language (Qafár af) | Amharic Translation | English Synthesis |
|---|---|---|
| *Gala mecla yaaxige* | ግመል አዛኝም፤ ቂመኛም እንስሳ ነው። | The camel is emotionally complex both merciful and vengeful |
| *Gala qidimih yidwiye* | ግመል ሊታረድ ሲል ያለቅሳል። | A camel weeps when it senses its own slaughter |
| *Gala isí baxa naba xagaruk yaaxige* | ግመል ልጇን ከርቀት የመለየት ችሎታ አላት። | A camel can identify its offspring from a great distance |
| *Gala isí abbah xagaruk raqte* | ግመል ባለቤቱ ካልመጣ ወተቱን አይሰጥም። | A camel may withhold milk if its specific milker is absent |

**Table 4.** Categorised camel proverbs representing medicinal and life sustaining value in the Berhale district (Afar, Amharic and English).

| Afar Language (Qafár af) | Amharic Translation | English Synthesis |
|---|---|---|
| *Gala han dawa iyyu, maane hinna* | የግመል ወተት ምግብ ብቻ አይደለም መድኃኒትም እንጅ ። | Camel milk is a therapeutic medicine, not just only basic nutrition. |
| *Gala han aqbi, isí xonit mawaara* | የግመል እረኛ ከፍቅረኛው አይጣላም። | Camel milk provides the herder with vitality and health. |
| *Gala han madidda, mabullo* | የግመል ወተት አይፈላም፣ አይገፋም። | Camel milk has unique properties; it is neither boiled nor churned. |

**Table 5.** Categorised camel proverbs representing legal integrity and traditional law in the Berhale district (Afar, Amharic and English).

| Afar Language (Qafár af) | Amharic Translation | English Synthesis |
|---|---|---|
| *Gala gembisah madaayay* | ውሸት ግመልን ያቆማል እንጅ አይገዛም። | Emphasises absolute truth; deception cannot grant legitimate legal ownership. |
| *Gala mada gaba maqaane* | ግመል ካሳ የሚሆነው በተገደለው ነው። | Establishes the camel as the blood price. |

with scientific findings regarding the heat sensitive protective proteins in camel milk. As noted by Balehegn (2016), these specific handling practices are essential components of an Indigenous Knowledge System (IKS) that preserves the nutritional integrity of the desert's most valuable liquid resource.

### *V. Legal Integrity and Traditional Law*

A significant finding of this study is the integration of the camel into the structural framework of Afar Customary Law. In the Berhale District, the camel is not merely an economic asset but a supreme judicial and ethical instrument. This role is demonstrated through two primary legal functions: the regulation of ethical trade and the settlement of major criminal offenses.

*"Gala gembisah madaayay, baxissam hinna."* "ውሸት ግመልን ያቆማል እንጅ አይገዛም።" meaning lies may stop a camel, but they cannot buy it. This proverb serves as the primary moral regulator for the local camel market and the salt caravan logistics of the Danakil Depression. The community elders maintain that while a lie may cause a temporary delay in a transaction, it can never confer a socially recognised title of ownership. This finding emphasises that the Berhale camel industry is built on a foundation of Absolute Truth. In high-stakes pastoral environments, contractual honesty is essential for maintaining the communal trust required for long distance trade and resource sharing (Abokar, 1987; Getachew, 2001).

*"Gala mada gaba maqaane."* "ግመል ካሳ የሚሆነው... በተገደለው ነው።" meaning a camel is not compensation for [minor] loss, but only for a life taken. This finding highlights the highest legal status of the camel as the exclusive currency for blood price. In Berhale, livestock are categorised by their sensible utility; while goats or cattle may be used to settle minor civil disputes, the camel is reserved strictly for the loss of a human life. By establishing the camel as the biological and legal equivalent of a person. This serves as a powerful deterrent against inter-clan violence and ensures communal harmony (Kassa, 2001; Kelemework, 2011). The camel, therefore, acts as a specialised tool for restorative justice, where its high value is used to heal the ultimate social disagreement.

## Conclusion

This study in the Berhale District of the Afar Region underscores that the dromedary camel is far more than a biological asset; it is a profound cultural institution and a sophisticated Indigenous Knowledge System (IKS). Through a paremiological analysis of camel-centric proverbs, this research reveals a deep-seated ecological intelligence. The community's recognition of the animal as a water engineer and a pathfinder demonstrates an environmental literacy that is essential for survival in the hyper-arid Danakil depression. Furthermore, these proverbs function as a communal survival manual, providing a robust framework for social hierarchy, conflict resolution through traditional law and ethno-veterinary medicine.

A significant finding is that while modern agricultural science focuses primarily on livestock productivity and genetics, Afar pastoralists prioritise the emotional and psychological bond with their animals, valuing the camel's mercy, memory and leadership. The status of camel milk as a therapeutic agent rather than a simple food source further highlights the specialised role this species plays in human health and regional resilience. Ultimately, these linguistic treasures are the primary vehicles for transmitting centuries of environmental observation. Their erosion due to modernisation poses a direct threat to the resilience of pastoralist communities.

Based on the findings of this study, several strategic interventions are proposed to bridge the gap between indigenous wisdom and modern livestock management. First, the institutionalisation of Indigenous Knowledge Systems (IKS) is essential; Ethiopian agricultural and livestock policy frameworks should move beyond purely biological metrics to formally incorporate the socio-ecological wisdom found in oral traditions. By utilising traditional figure of speech for camel behaviour and water sourcing as early warning indicators, national drought resilience and climate adaptation strategies can be significantly enhanced. Second, to prevent the extinction of this desert wisdom, the Afar Bureau of Education and Culture and regional universities should prioritise curriculum based preservation and digitalisation. Integrating camel-centric proverbs into local primary school curricula and systematically archiving these traditions will ensure that the unique linguistic heritage of Berhale is preserved for future generations. Finally, collaborative extension services should be established through a systematic program for continuous training that facilitates a two way knowledge exchange between veterinary services and community elders. Rather than a top down approach, this model recognises that pastoral environmental literacy is a sophisticated diagnostic tool that effectively complements modern meteorological data.

In summary, the digitalisation and documentation of these linguistic treasures is far more than an act of cultural archiving; it is a mechanical necessity for preserving pastoral wisdom in a rapidly changing climate. This research suggests that integrating indigenous knowledge into modern camel management and regional educational policies is the most viable and sustainable path toward a resilient future for the Afar people and their unique heritage.

## Declarations

### Availability of Data and Materials

To maintain academic transparency and accountability, the primary datasets generated and analysed during this study are available from the corresponding author upon reasonable request.


### Funding

This research was entirely self-funded. The author received no specific grants or financial support from public, commercial, or non-profit funding agencies.


### Ethics Approval

This study was executed following the established ethical protocols for agricultural and social research. All participating pastoralist households provided informed verbal consent after being briefed on the study's purpose. Participants were assured of complete anonymity and the confidentiality of their responses prior to the data collection process.

### Manuscript Status and Originality

The author certifies that this manuscript is an original work that has not been published elsewhere, in part or in full and is not currently under consideration by any other journal.

### Conflict of Interest

The author declares that the research was conducted without any commercial, financial, or personal affiliations that could represent a potential conflict of interest. No external influence or funding impacted the objectivity of the presented findings.

### Author's Contribution

KA was solely responsible for end to end which includes the initial conceptualisation, study design and primary field data acquisition in the Berhale district. Performed all qualitative and statistical analyses, interpreted the results and drafted the original manuscript to be published.


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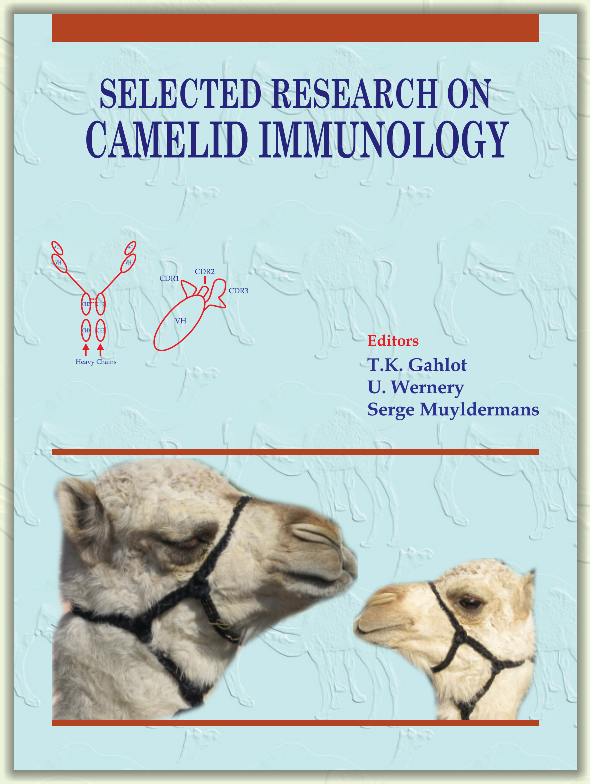
# SELECTED RESEARCH ON CAMELID IMMUNOLOGY

**(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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# EFFECT OF CAMEL AND COW MILK POWDER ADDITION ON ACIDIFICATION, PHYSICOCHEMICAL PROPERTIES, YIELD, AND SENSORY QUALITY OF CAMEL SOFT WHITE CHEESE

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## ABSTRACT

Camel milk is a nutritionally valuable resource with considerable potential for dairy processing; however, its transformation into cheese remains limited due to its specific physicochemical characteristics, particularly its low content of coagulable caseins and atypical micellar structure, which impair coagulation efficiency and cheese yield. This study was aimed to evaluate the effect of enriching camel milk with different levels of cow milk powder (CWMP) and camel milk powder (CMP) on the manufacture, composition and sensory quality of fresh soft white cheese. Camel milk was supplemented with CWMP or CMP at 2%, 5% and 10% (w/v), alongside a non-enriched control. The acidification kinetics, coagulation behaviour, physicochemical composition, cheese yield and sensory properties of the resulting cheeses were analysed. Enrichment with CWMP, particularly at 5% and 10%, resulted in a faster acidification rate, lower final pH values, improved curd firmness and significantly higher cheese yields compared with CMP-enriched and control samples. Cheeses enriched with CMP exhibited slower acidification and weaker curd structure, reflecting the intrinsic compositional properties of camel milk. Sensory evaluation revealed that moderate enrichment levels were critical for consumer acceptance. Cheeses supplemented with 2% and 5% CWMP achieved the highest scores for colour, appearance, taste and overall acceptability, while preserving the characteristic camel milk flavour. In contrast, high incorporation levels, especially 10% CMP, negatively affected sensory perception and overall acceptance. Overall, the results indicate that moderate supplementation of camel milk with cow milk powder, particularly at a level of 5%, represents an optimal strategy to improve the technological performance and yield of camel milk fresh soft white cheese while maintaining its desirable sensory attributes. This approach offers a promising pathway for the valorisation of camel milk in arid and semi-arid regions through the development of acceptable and high-quality dairy products.

**Key words:** Acidification, camel milk, camel milk powder, cheese yield, fresh soft cheese, sensory quality

In arid and semi-arid regions, camel milk represents a strategically important resource due to its high nutritional value and its potential for valorisation within local agri-food systems. Despite these advantages, the conversion of camel milk into cheese remains technically challenging and is still poorly developed. These limitations are primarily associated with the specific physicochemical characteristics of camel milk, notably its low content of coagulable caseins, reduced κ-casein proportion and atypical casein micelle structure, all of which impair enzymatic coagulation efficiency and result in low cheese yields.

In this context, the enrichment of camel milk with milk powder may constitute a relevant technological approach to improve its cheese making performance. The incorporation of either cow milk powder or camel milk powder has the potential to increase the total solids and functional protein content of the milk, to modify its buffering capacity and, consequently, to enhance acidification kinetics, curd formation and cheese yield. However, such enrichment strategies must be carefully controlled to ensure that the characteristic sensory attributes of camel milk cheese, particularly its distinctive flavour profile, are preserved, as these features play a crucial role in consumer acceptance.

The present study was aimed to evaluate the effect of enriching raw camel milk with different concentrations of cow milk powder (CWMP) and

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camel milk powder (CMP) on the production of a camel soft white cheese, in comparison with a non-enriched control. Particular attention was given to assessing the impact of these enrichments on the evolution of acidification during fermentation, on coagulation behaviour and cheese yield, as well as on the sensory quality and consumer preference of the resulting cheeses. In addition, this work sought to identify an optimal enrichment level capable of improving technological performance while maintaining the typical sensory characteristics associated with camel milk cheese.

## Materials and Methods

### *Materials*

Samples of camel milk were collected from eight she-camels in their 2nd to 4th lactation, reared by a local producer located on the outskirts of the city of Aïn El Aouda, in the Rabat–Salé–Zemmour–Zaer region of Morocco. Milk was obtained directly during milking and transported to the laboratory within one hour, where it was stored at 4±1°C until use. Three independent batches of 5 L of camel milk were collected for the purposes of this study.

The camel milk powder used in this study was obtained from the commercial brand Golden Camel (carbohydrates: 3.12 g/100 g, fat: 3.16 g/100 g, protein: 2.40 g/100 g), while the cow milk powder was supplied by the brand NIDO (carbohydrates: 3.65 g/100 g, fat: 2.82 g/100 g, protein: 2.57 g/100 g).

The camel chymosin used, supplied by the company Chr. Hansen, had a clotting activity of 1000 IMCU/g. Appropriate dilutions were prepared by adding distilled water to the rennet in order to obtain the required concentrations. The starter cultures used consisted of selected and mixed mesophilic strains capable of producing aroma compounds and $CO_2$. The reference starter culture was FD-DVS-CHN-11 (Chr. Hansen), composed of *Lactococcus lactis subsp. cremoris, Leuconostoc* spp., *Lactococcus lactis* subsp. *lactis,* and *Lactococcus lactis subsp. lactis biovar diacetylactis.*

### *Milk Composition*

Milk pH was measured using the potentiometric method described by Kaur *et al* (2020) employing a pH meter (Eutech pH 700). Titratable acidity was determined by acid–base titration using a magnetic stirrer (Fisherbrand) and an analytical balance (OHAUS Pioneer). Milk density was measured at 20°C using a portable densitometer (Density2Go, Mettler Toledo).

Total solids content was determined by drying 10 g of milk in a drying oven (Thermo Fisher Scientific, Model 5160) at 103±2°C. Ash content was measured by incineration of the dried milk sample in a muffle furnace at 525±25°C, according to the standard method NF V04-208. (NF V04-208 s. d.). Milk fat content was determined using the Gerber acid–butyrometric method.

Lactose content was determined according to the Bertrand method (Bourdon and Gielfrich, 1972). Protein content was measured using the Kjeldahl method (Pointurier *et al,* 2003), based on the determination of total nitrogen and applying a conventional conversion factor of 6.39 for milk. Vitamin C content was quantified using a calibration curve prepared with standard ascorbic acid solutions of known concentration (Tomovska *et al,* 2018). Analyses were performed in triplicate.

The composition of the raw camel milk used in this study was as follows: pH 6.67±0.07, titratable acidity 16.70±0.22, protein content 3.34±0.21 g/100 mL, fat content 4.56±0.43 g/100 mL, total solids 13.62±0.79 g/100 g, ash content 0.74±0.08 g/100 mL, density 1.030±0.002, and lactose content 3.71±0.38 g/100 mL. These values are consistent with those previously reported for camel milk (Konuspayeva *et al,* 2009; Badidja and Djellabi, 2014; Learoussy *et al,* 2020).

### *Manufacture of soft white cheese*

Soft white cheese was produced from camel milk following a method adapted from that described by Bekele *et al* (2019). A total volume of 24 L of camel milk was used and divided into three batches of 8 L each. For each batch, seven cheese making trials were conducted by varying the level and type of milk powder addition: three concentrations of camel milk powder (2%, 5% and 10%), three concentrations of cow milk powder (2%, 5% and 10%), and a control without milk powder addition.

Whole milk was first filtered through a muslin cloth and then pasteurised at 65°C for 30 min in a stainless-steel vessel equipped with a thermostatically controlled water bath, under continuous stirring provided by an electric agitator. Cooling was achieved by immersing the pasteurisation vessel in a larger container filled with water and ice cubes (approximately 70% by volume), with continuous agitation to accelerate temperature reduction to 32°C. The milk was then distributed into seven 1-L containers. Calcium chloride was added to each container at a concentration of 0.3 mL/L (33%

anhydrous $CaCl_2$ solution). The average pH of the milk at the time of calcium chloride addition was 6.6±0.13, a value considered favourable for optimal coagulation, in agreement with the observations of Hailu *et al* (2016).

After an initial stirring period of 5 min, the starter culture was added at a temperature of 29°C. For inoculation, one sachet of commercial starter culture containing 50 units (U) was dissolved in 200 mL of fresh camel milk previously heat-treated at 100°C for 35 min. This preparation was stored at –22°C until use. The amount of starter culture added corresponded to the manufacturer's recommended dose, namely 10 U per 100 L of milk. Following a moderate acidification phase of 42 min at 27°C, the control milk reached an average titratable acidity of 17.2±0.2 °D, corresponding to a mean pH of 6.58±0.03. At this stage, camel-specific chymosin was added at a concentration of 80 international milk-clotting units per litre, as reported by Bekele *et al* (2019) and Hailu *et al* (2016).

Milk from each container was subsequently divided into two 500 mL portions, one used for cheese making and the other for monitoring acidification kinetics. The containers were then placed in an incubator set at 27°C for 3.5 h to allow complete coagulation and to reach a target pH for the control between 6.0 and 5.9. During fermentation, pH and titratable acidity were measured every 30 min.

After coagulation, the curd was cut vertically using a stainless-steel curd cutter into cubes of 1.2 cm in width and length, followed by a horizontal cut at mid-height (3 cm). Gentle stirring was applied, followed by a resting period of 10 min to promote whey expulsion. Moulding was carried out by transferring the curd into plastic moulds previously lined with a filtration cloth. The moulded curd was then held for 18 h at 22°C to allow further drainage. After this period, cheese samples were collected in sterile, airtight glass containers, weighed, and stored at 4°C for subsequent analyses.

### *Cheese yield and compositional analysis*

Cheese yield was calculated according to the following formula: Cheese yield (%) = (Weight of cheese / Weight of milk) × 100.

The chemical composition of the cheese, including pH, titratable acidity, fat, protein, total solids (TS) and ash content, was determined using standard methods as described by Feldsine *et al* (2002).

A representative cheese sample was taken, sliced and homogenised in accordance with the sampling protocol proposed by d'Ardö and Polychroniadou (1999). Fat content was determined using the Gerber method, protein content by the Kjeldahl method, while total solids and ash contents were quantified using gravimetric methods. All analyses, with the exception of protein determination, which was carried out on the following day, were performed within 24 h after completion of cheese drainage. Each measurement was conducted in triplicate.

### *Sensory analysis*

To evaluate the impact of milk powder enrichment on the sensory properties of the cheeses obtained, a delayed hedonic test was conducted by a trained panel of 10 assessors, including six assessors familiar with the consumption of camel milk cheese. In order to avoid any interference between the results of the different sensory evaluations, the tests were carried out on two separate days. Sensory assessment was performed 72 h after cheese manufacture.

Several sensory attributes were evaluated, including colour, appearance, aroma, taste and overall acceptability. Textural perception was not evaluated as a separate sensory attribute, however, its perception during mastication likely influenced taste and overall acceptability scores, as texture–flavour interactions are known to play a key role in consumer appreciation of fresh cheeses (Walstra *et al,* 2006). An additional criterion i.e., typicity of camel milk flavour, was introduced and clearly explained to the assessors to be taken into account during the overall evaluation. This criterion was used to assess the extent to which the addition of milk powders altered or preserved the distinctive sensory profile of camel milk cheese. Although, this parameter is not commonly reported in the literature, it is considered relevant in the context of valorising products with a strong identity, such as camel milk.

For each attribute, a 7-point hedonic scale was used, defined as follows: 1 = extreme dislike, 2 = moderate dislike, 3 = slight dislike, 4 = neither like nor dislike, 5 = slight like, 6 = moderate like, 7 = extreme like.

Samples were handonly coded and presented to the assessors at 3-min intervals. Tasting sessions were conducted in a sensory analysis laboratory equipped with individual booths, allowing easy sample handling by the operator and independent evaluation by each assessor, thereby avoiding interaction between panellists. Each booth was also equipped with an individual sink to allow mouth rinsing between samples.

### *Statistical analysis*

Results obtained from physicochemical analyses, cheese yield determination and consumer preference tests were analysed using analysis of variance (ANOVA) according to a completely randomised design with seven treatments. Treatment means were initially evaluated using the F-test at a significance level of $\alpha = 0.05$. When a significant treatment effect was observed ($p < 0.05$), mean comparisons were performed using Tukey's honestly significant difference (HSD) test for multiple comparisons.

## Results and Discussion

### *Monitoring of pH and titratable acidity of the samples*

The acidification kinetics of the milk, expressed in terms of pH and titratable acidity, until reaching a pH of approximately 5.9 and a titratable acidity of 24.7°D, are presented in tables 1 and 2.

The results showed that camel milk supplemented with cow milk powder, particularly at inclusion levels of 5% and 10%, exhibited a faster acidification rate, characterised by a more pronounced decrease in pH compared with samples fortified with camel milk powder and the control. In contrast, formulations containing camel milk powder displayed a slower development of titratable acidity, indicating a less intense acidification over time (Fig 1).

The differences observed in acidification profiles can be attributed to compositional variations induced by milk powder supplementation, particularly in terms of fermentable lactose, protein content and mineral composition. Cow milk powder, which is richer in caseins and readily available substrates for lactic acid bacteria, promotes faster lactic acid production and consequently a more rapid decrease in pH. Conversely, camel milk powder, characterised by a low κ-casein content and the presence of natural antimicrobial components, leads to a more gradual acidification process (Konuspayeva *et al,* 2009; Seifu, 2023).

Similar behaviour was reported by Desouky *et al* (2019), who observed consistently higher pH values in systems supplemented with camel milk powder compared with control samples, particularly at higher incorporation levels. The authors attributed these differences to compositional modifications, including changes in lactose content, soluble nitrogen fractions and salt balance, which collectively affect the acid–base equilibrium of cheese systems. Comparable effects of formulation on pH and acidity have also

**Table 1.** Evolution of milk pH following the addition of two types of milk powder at different inclusion levels.

| Time (min) | 2% CMP | 5% CMP | 10% CMP | 2% CWMP | 5% CWMP | 10% CWMP | Control | P-Value |
|---|---|---|---|---|---|---|---|---|
| 0 | $6.58±0.00^{a}$ | $6.57±0.01^{a}$ | $6.59±0.01^{a}$ | $6.51±0.02^{a}$ | $6.53±0.01^{a}$ | $6.47±0.00^{a}$ | $6.58±0.03^{a}$ | NS |
| 30 | $6.54±0.01^{a}$ | $6.53±0.00^{a}$ | $6.54±0.02^{a}$ | $6.49±0.02^{a}$ | $6.48±0.03^{a}$ | $6.39±0.01^{b}$ | $6.54±0.01^{a}$ | * |
| 60 | $6.48±0.00^{a}$ | $6.50±0.00^{a}$ | $6.51±0.00^{a}$ | $6.41±0.01^{b}$ | $6.38±0.00^{b}$ | $6.31±0.01^{b}$ | $6.49±0.01^{a}$ | ** |
| 90 | $6.45±0.01^{a}$ | $6.44±0.02^{a}$ | $6.36±0.00^{b}$ | $6.33±0.04^{b}$ | $6.27±0.01^{c}$ | $6.24±0.02^{c}$ | $6.48±0.01^{a}$ | ** |
| 120 | $6.32±0.01^{b}$ | $6.34±0.02^{ab}$ | $6.29±0.01^{c}$ | $6.22±0.03^{c}$ | $6.18±0.01^{d}$ | $6.16±0.00^{d}$ | $6.38±0.01^{a}$ | *** |
| 150 | $6.22±0.02^{b}$ | $6.29±0.02^{a}$ | $6.16±0.00^{c}$ | $6.15±0.03^{c}$ | $6.07±0.02^{d}$ | $6.04±0.00^{d}$ | $6.28±0.02^{a}$ | *** |
| 180 | $6.15±0.02^{a}$ | $6.12±0.02^{a}$ | $6.04±0.01^{b}$ | $6.03±0.02^{b}$ | $5.92±0.03^{c}$ | $5.88±0.03^{c}$ | $6.19±0.02^{a}$ | *** |

Values are expressed as mean±standard deviation (n = 2).

a–d: Means within the same row bearing different superscript letters differ significantly ($p < 0.05$). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

**Table 2.** Evolution of titratable acidity of milk supplemented with two types of milk powder at different inclusion levels.

| Time (min) | 2% CMP | 5% CMP | 10% CMP | 2% CWMP | 5% CWMP | 10% CWMP | Control | P-Value |
|---|---|---|---|---|---|---|---|---|
| 0 | $18.35±0.21^{a}$ | $18.50±0.42^{a}$ | $18.35±0.07^{a}$ | $18.85±0.49^{a}$ | $18.55±0.21^{a}$ | $19.40±0.28^{a}$ | $18.30±0.10^{a}$ | NS |
| 30 | $18.55±0.21^{b}$ | $18.50±0.00^{b}$ | $18.75±0.07^{b}$ | $19.20±0.71^{b}$ | $19.05±0.35^{b}$ | $20.70±0.00^{a}$ | $18.70±0.00^{b}$ | * |
| 60 | $19.60±0.14^{b}$ | $19.55±0.07^{b}$ | $20.45±0.07^{b}$ | $20.60±0.14^{b}$ | $21.10±0.42^{a}$ | $21.50±0.14^{a}$ | $19.60±0.26^{b}$ | ** |
| 90 | $20.45±0.21^{b}$ | $20.70±0.28^{b}$ | $21.70±0.28^{a}$ | $21.35±0.21^{a}$ | $22.30±0.57^{a}$ | $22.45±0.35^{a}$ | $20.50±0.20^{b}$ | ** |
| 120 | $21.45±0.64^{b}$ | $21.40±0.28^{b}$ | $22.45±0.07^{a}$ | $22.60±0.14^{a}$ | $23.00±0.28^{a}$ | $23.30±0.14^{a}$ | $20.93±0.46^{b}$ | *** |
| 150 | $21.70±0.14^{d}$ | $21.55±0.35^{d}$ | $22.70±0.28^{c}$ | $22.85±0.35^{c}$ | $23.80±0.14^{b}$ | $24.70±0.14^{a}$ | $21.50±0.26^{d}$ | * |

Values are expressed as mean±standard deviation (n = 2).

a–d: Means within the same row bearing different superscript letters differ significantly ($p < 0.05$). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

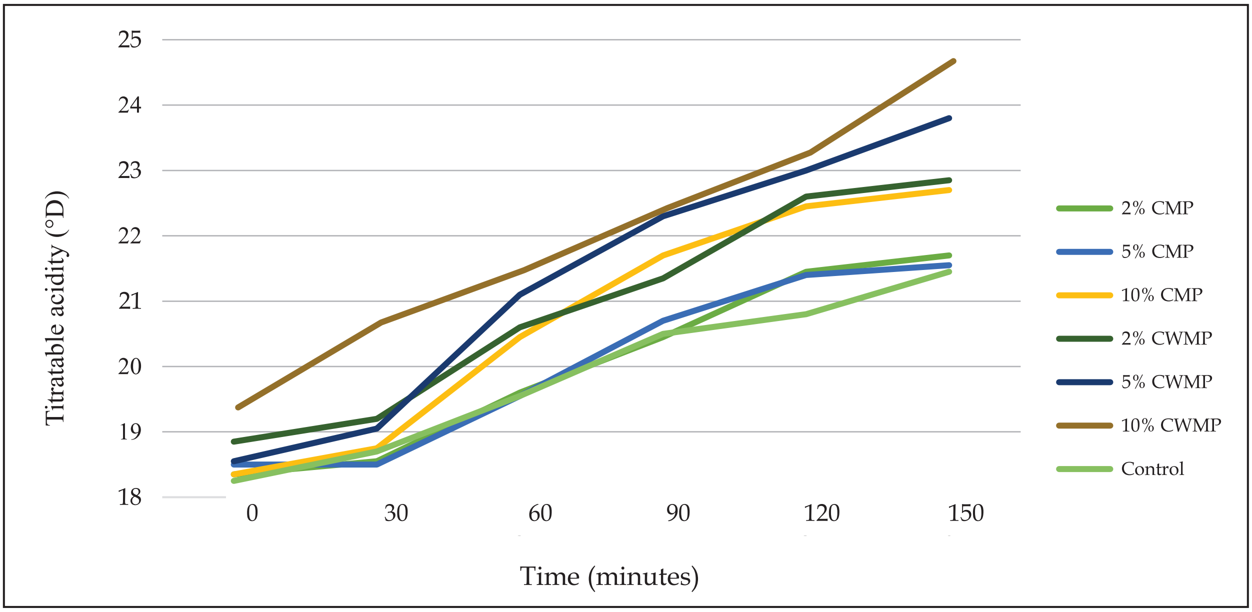


**Fig 1.** Evolution of milk titratable acidity following supplementation with two types of milk powder at different inclusion levels.

been described in dairy matrices by Aly *et al* (1995), Awad (2003) and Hassan *et al* (2007), emphasising the critical role of milk composition in regulating pH behaviour during cheese manufacture and storage.

These differences in acidification kinetics had a direct impact on coagulation properties. Formulations exhibiting a rapid pH decrease, particularly those enriched with cow milk powder, resulted in firmer and more cohesive curds, whereas samples with slower acidification produced weaker curds, accompanied by greater losses of fine particles into the whey. These observations confirm that, in cheese manufacture, the rate and intensity of acidification play a decisive role in gel structuring and curd quality, even when the same starter culture is used across treatments (Kongo, 2013).

### *Cheese analyses*

The cheeses were analysed for pH, titratable acidity, fat content, protein content, total solids (TS) and ash, with all determinations performed in duplicate.

The physicochemical and technological analyses of fresh cheese produced from camel milk supplemented with different milk powders revealed significant differences among formulation, reflecting the pronounced influence of milk composition on most key cheese-making parameters. Variations observed in pH and titratable acidity confirmed that the addition of cow milk powder promote more intense acidification compared with camel milk powder and the control non supplemented. Similar trends have been reported in several studies, indicating that milk acidification kinetics strongly depend on the nature of the substrates available to lactic acid bacteria and on the buffering capacity of the medium (Walstra *et al,* 2006; Fox and McSweeney, 2004).

Lower pH values and higher titratable acidity observed in cheese enriched with cow milk powder are consistent with previous findings showing that enrichment of dairy matrices with bovine components stimulates fermentative activity and accelerates lactic acid production (Ho *et al,* 2022; Abo-Amer, 2021). In contrast, cheese supplemented with camel milk powder exhibited a more moderate acidification profile, which is in line with the intrinsic characteristics of camel milk, notably its low κ-casein content and the presence of natural antimicrobial compounds that may partially inhibit the growth of lactic acid bacteria (Al Haj and Al Kanhal, 2010; Konuspayeva *et al,* 2009).

Cheese yield was significantly higher in formulations enriched with cow milk powder, particularly at higher inclusion levels. This increase in yield can be explained by improved curd formation and greater curd firmness, which limited the loss of fine protein and fat particles into the whey during drainage. Similar observations have been reported for fresh camel milk cheeses that were enriched or subjected to faster acidification, where effective acidification favoured the retention of solid

**Table 3.** Charactérisation of the cheese obtained.

| Parameter | 2% CMP | 5% CMP | 10% CMP | 2% CWMP | 5% CWMP | 10% CWMP | Control | P-Value |
|---|---|---|---|---|---|---|---|---|
| pH | 5,61±0,12$^{a}$ | 5,41±0,21$^{a}$ | 5,53±0,19$^{a}$ | 5,41±0,22$^{a}$ | 4,52±0,16$^{b}$ | 4,31±0,18$^{c}$ | 5,42±0,13$^{a}$ | *** |
| Titrable acidity (°D) | 75,2±0,8$^{c}$ | 86,0±1,5$^{b}$ | 86,5±2,0$^{b}$ | 97,6± 0,7$^{b}$ | 112,3±2,0$^{a}$ | 126,5±1,7$^{a}$ | 85,6±3,3$^{b}$ | *** |
| Fat (%) | 23,53 ±0,09$^{a}$ | 22,86±0,86$^{a}$ | 22,81±0,86$^{a}$ | 23,37±0,38$^{a}$ | 22,33±0,45$^{ab}$ | 20,24±0,27$^{b}$ | 22,67 ±0,31$^{a}$ | * |
| Ash (%) | 13,59±0,36$^{c}$ | 12,68±0,13$^{c}$ | 13,41±0,66$^{c}$ | 14,65±0,87$^{b}$ | 14,18±0,58$^{b}$ | 15,78 ±0,10$^{a}$ | 13,62±0,11$^{c}$ | * |
| Total Solids (%) | 44,01±2,09$^{a}$ | 39,65±2,64$^{b}$ | 43,47±0,63$^{a}$ | 39,08±0,91$^{b}$ | 39,99±1,72$^{b}$ | 41,85±0,91$^{ab}$ | 44,46±0,82$^{a}$ | ** |
| Protein (%) | 1,62±0,18$^{c}$ | 1,69±0,06$^{c}$ | 2,23±0,14$^{b}$ | 1,53±0,10$^{c}$ | 1,87±0,23$^{b}$ | 1,76±0,17$^{b}$ | 2,44±0,32$^{a}$ | *** |
| Yield (%) | 10,61±0,18$^{c}$ | 10,58±0,36$^{c}$ | 11,51±0,35$^{b}$ | 12,65±0,40$^{b}$ | 13,63±0,06$^{a}$ | 14,48±0,20$^{a}$ | 10,79±0,51$^{c}$ | ** |

Values are expressed as mean±standard deviation (n = 3).

a–d: Means within the same row bearing different superscript letters differ significantly ($p < 0.05$). *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

constituents within the curd (Siddig *et al,* 2016; Khan *et al,* 2004). Conversely, formulations associated with slower acidification resulted in lower yields, probably due to a more fragile gel structure and less controlled syneresis.

Variations in fat content among formulations can be related to the microstructural properties of the gels formed. Firmer and more cohesive gels, resulting from faster acidification, promote the retention of fat globules within the protein network, whereas weaker gels lead to increased fat losses into the whey (Castillo, 2006). The values obtained in the present study are comparable to those reported for fresh camel milk cheeses in some previous studies (Khan *et al,* 2004), but higher than those reported by Siddig *et al* (2016) and Mehaia (2006), highlighting the influence of formulation and processing conditions on lipid retention.

Protein content was also significantly affected by formulation, with cheese enriched with cow milk powder exhibiting higher values. This trend may be attributed to improved coagulation of bovine proteins and their greater ability to form dense protein networks, thereby enhancing their retention in the curd. Although, the protein contents measured were lower than those reported by Khan *et al* (2004), they remain comparable to values observed for fresh camel milk cheeses produced using similar processing approaches (Mehaia, 2006).

Total solids (TS) contents followed a trend consistent with that observed for yield and syneresis. Higher TS values were recorded in cheeses from formulations exhibiting faster acidification, confirming that acidification plays a key role in the solubilisation of colloidal minerals, gel contraction and whey expulsion (Lucey *et al,* 2003; Fox and McSweeney, 2004). The values obtained fall within the ranges reported for fresh camel milk cheeses at the end of drainage (Ramet, 2001; Hailu *et al,* 2014).

Finally, variations in ash content reflected differences in the mineral composition of the powders used and their impact on mineral retention in the curd. Higher ash contents were associated with formulations enriched with cow milk powder, in agreement with their higher calcium and phosphorus contents, whereas formulations characterised by slower acidification exhibited lower ash values. Comparable observations have been reported by Hailu *et al* (2014) and Siddig *et al* (2016), who emphasised the combined influence of milk composition, acidification mode and processing conditions on the mineral content of cheese.

## Sensory analysis

The sensory evaluation results of soft white cheese supplemented with different milk powders are presented in table 4 ????ed on 7-point hedonic scale:1 = extreme dislike, 2 = moderate dislike, 3 = slight dislike, 4 = neither like nor dislike, 5 = slight like, 6 = moderate like, 7 = extreme like.

Overall acceptance included the panelists' evaluation of the presence and perception of the typical camel milk flavour in the cheese as a positive criterion.

Highly significant differences ($p < 0.01$ to $p < 0.001$) were observed among formulations for all the sensory attributes evaluated, namely colour, appearance, aroma, taste and overall acceptability (Table 4). These results indicate that the nature of the milk powder added as well as its level of incorporation have a marked influence on the sensory perception of soft white cheese. Colour scores showed that cheeses enriched with 2% CWMP (6.75) and 5% CMP (6.50) obtained the highest values ($p < 0.001$), reflecting better visual appreciation by consumers.

**Table 4.** Sensory evaluation and consumer preference scores of soft white cheeses supplemented with milk powders.

| Parameter | 2% CMP | 5% CMP | 10% CMP | 2% CWMP | 5% CWMP | 10% CWMP | Non-supplemented control | P-Value |
|---|---|---|---|---|---|---|---|---|
| Colour | 4,50±0,58$^{bc}$ | 6,50±0,58$^{a}$ | 3,25±0,50$^{d}$ | 6,75 ±0,50$^{a}$ | 5,00±0,82$^{b}$ | 4,00±1,83$^{cd}$ | 4,00±0,82$^{cd}$ | *** |
| Appearance | 3,00±0,82$^{c}$ | 6,00 ±0,82$^{a}$ | 4,00±0,82$^{b}$ | 6,00±0,82$^{a}$ | 5,75±0,96$^{a}$ | 4,00±1,41$^{b}$ | 2,50±0,58$^{c}$ | *** |
| Aroma | 5,25±0,50$^{bc}$ | 6,50 ±0,58$^{a}$ | 4,00±0,82$^{d}$ | 6,00±0,82$^{ab}$ | 5,50±1,29$^{bc}$ | 3,75±1,26$^{d}$ | 5,00±0,82$^{c}$ | ** |
| Taste | 6,00± 0,00$^{ab}$ | 5,50±1,29$^{bc}$ | 4,25±0,96$^{cd}$ | 6,75± 0,50$^{a}$ | 5,50 ±0,58$^{bc}$ | 4,00±0,82$^{d}$ | 4,00±0,82$^{d}$ | *** |
| Overall acceptance | 5,50±0,58$^{bc}$ | 6,00 ±0,82$^{ab}$ | 2,75±0,96$^{d}$ | 6,75±0,50$^{a}$ | 6,00±1,15$^{ab}$ | 3,75±1,26$^{cd}$ | 5,75±0,50$^{b}$ | *** |

Values are expressed as mean±standard deviation.

a–d: Means within the same row bearing different superscript letters differ significantly ($p < 0.05$). **$p < 0.01$; ***$p < 0.001$.

In contrast, cheese enriched with 10% CMP (3.25) received the lowest colour score, suggesting a less favourable perception related to visual appearance. The control and the formulations 2% CMP and 10% CWMP showed intermediate scores, without reaching the level of acceptance of the highest-rated formulations.

Regarding appearance, highly significant differences ($p < 0.001$) were also observed. Cheeses enriched with 5% CMP (6.00) and 2% CWMP (6.00) obtained the highest scores, indicating a better perception of product structure and homogeneity. Conversely, the control (2.50) and cheese enriched with 2% CMP (3.00) showed the lowest scores, suggesting an appearance considered less attractive by consumers.

Aroma scores highlighted a significantly higher preference ($p < 0.01$) for cheeses enriched with 5% CMP (6.50) and 2% CWMP (6.00) compared with formulations containing 10% CMP (4.00) and 10% CWMP (3.75), which obtained the lowest scores. These results indicate that moderate enrichment levels favour the development of a more appreciated aromatic profile, whereas higher levels may lead to aroma notes perceived as less pleasant.

Concerning taste, the differences observed was highly significant ($p < 0.001$). Cheese enriched with 2% CWMP obtained the highest score (6.75), followed by 2% CMP (6.00) and 5% CMP (5.50). In contrast, cheese enriched with 10% CMP (4.25) and 10% CWMP (4.00) showed significantly lower taste scores, indicating reduced gustatory acceptability at higher enrichment levels.

Overall acceptability followed a similar trend, with significantly higher scores ($p < 0.001$) for cheeses enriched with 2% CWMP (6.75), 5% CWMP (6.00) and 5% CMP (6.00). Conversely, the 10% CMP formulation obtained the lowest overall acceptability score (2.75), suggesting that high levels of camel milk powder enrichment negatively affect the overall appreciation of the product. The control showed an intermediate score (5.75), indicating acceptable but lower consumer preference compared with some enriched formulations.

It should be noted that overall acceptability included the panellists' assessment of the presence and perception of the typical camel milk flavour, considered as a key identity attribute of camel milk cheese. In this context, moderate enrichment levels appeared to preserve this characteristic flavour while improving textural and visual attributes, whereas higher levels of camel milk powder tended to intensify intrinsic camel milk notes that were perceived as less pleasant by some consumers.

The variations observed in sensory scores can be attributed to changes in cheese composition and structure induced by milk powder supplementation. Moderate incorporation levels appear to promote a balance between texture, flavour and appearance, whereas high levels, particularly with camel milk powder, may intensify intrinsic sensory characteristics of camel milk that are perceived as less pleasant by consumers. Similar observations have been reported for fresh camel milk cheese, where sensory properties strongly depend on formulation and processing conditions (Bekele *et al,* 2019). Furthermore, differences in aroma and taste may be related to the formation of volatile compounds during fermentation, such as diacetyl, acetaldehyde and other aromatic metabolites produced by lactic acid bacteria. These compounds play a key role in the development of the aromatic profile of fresh cheeses, and their concentration depends on substrate composition and fermentative activity (Walstra *et al,* 2006; Papagianni, 2012). Overall, moderate enrichment of camel milk with milk powders, particularly cow milk powder, appears to create a more favourable environment for the development of sensory characteristics appreciated by consumers.

The present study demonstrated that the enrichment of camel milk with milk powders markedly influenced the acidification behaviour, coagulation properties, physicochemical composition, cheese yield and sensory quality of fresh soft white cheese. Significant differences was observed among formulations, highlighting the decisive role of milk composition in determining the technological performance and consumer acceptance of camel milk cheese.

Enrichment with cow milk powder, particularly at inclusion levels of 5% and 10%, resulted in a faster acidification rate, lower final pH values and improved curd firmness compared with camel milk powder supplementation and the control. These effects translated into higher cheese yields, greater retention of proteins and total solids, and more cohesive curd structures, thereby confirming the positive contribution of bovine milk components to the cheese making aptitude of camel milk. In contrast, formulations enriched with camel milk powder exhibited a slower acidification kinetics and weaker curd structure, reflecting the intrinsic compositional characteristics of camel milk, including its low κ-casein content and higher antimicrobial activity. From a sensory perspective, moderate levels of enrichment were found to be critical for balancing technological improvement and sensory quality. Cheese enriched with 2% cow milk powder and 5% cow milk powder achieved the highest scores for colour, appearance, taste and overall acceptability, while maintaining the typical camel milk flavour appreciated by the panellists. Conversely, higher incorporation levels, particularly 10% camel milk powder, negatively affected sensory perception, leading to lower consumer preference scores. These findings indicate that excessive enrichment may intensify certain intrinsic sensory attributes of camel milk that are perceived as less pleasant by consumers. Overall, the results suggest that moderate enrichment of camel milk with cow milk powder, especially at level of 5%, represents the most suitable compromise between technological performance and sensory acceptability. This formulation provided improved acidification, higher cheese yield, enhanced compositional quality and favourable consumer preference scores, while preserving the characteristic sensory identity of camel milk cheese. Controlled supplementation with cow milk powder constitutes a promising technological strategy for improving the manufacture of fresh soft white cheese from camel milk. Such an approach may contribute to the valorisation of camel milk in arid and semi-arid regions by enhancing processing efficiency and product quality without compromising consumer acceptance. Further studies could explore the combined use of different enrichment strategies or starter cultures to optimise both functional and sensory attributes of camel milk cheeses.

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## Seventh ISOCARD International Conference at Inner Mongolia, China

The 7$^{th}$ International conference of the International Society of Camelid Research and Development (ISOCARD) will be held from September 8 to 13, 2026, in Alxa League, Inner Mongolia, China with the theme "Belt and Road, Camel Science and Technology, Sustainable Development". The conference will conduct in-depth discussions focusing on six key areas: exploration and utilisation of camel genetic resources, production management and efficiency improvement, disease prevention and healthy breeding, innovative applications of nanobodies, development of high-value camel products, as well as camel culture and policy research. Through interdisciplinary and cross-regional exchange, the conference aims to inject new momentum into the high-quality development of the global camel industry. The conference calls for abstract submission. Interested scholars and postgraduate students from China and overseas.

Conference organisers are International Society of Camelid Research and Development (ISOCARD), Alxa League Committee of the Communist Party of China and Alxa League Administrative Office. The co-organisers are People's Government of Alxa Right Banner, Alxa League Bureau of Agriculture and Animal Husbandry, Alxa League Bureau of Science and Technology , Inner Mongolia China–Kazakhstan Camel Research Institute, Camel Branch of China Animal Agriculture Association, China-Mongolia Biomacromolecule Application "Belt and Road" Joint Laboratory, Inner Mongolia Agricultural University, Inner Mongolia Camel Conservation Society and Yak-Camel Foundation, Germany IV.

The conference dates are September 8–13, 2026. Venue will be Badain Jaran Town, Alxa Right Banner, Alxa League, Inner Mongolia, China.

(Contact Information Registration Website: http://www.isocard2026.com Email: isocard2026@163.com Contacts: Li Yi Tel: +86 18647977212 Taya Tang Tel: +86 13191404896 RenDalai Si Tel: +86 15034987337).

## MONITORING OF CAMEL HERDS BY AI-POWERED DRONES

Researchers at the King Abdullah University of Science and Technology (KAUST) have developed an artificial intelligence (AI)-powered drone system capable of autonomously tracking and monitoring camel herds across vast desert landscapes in real time. Unlike conventional livestock monitoring systems that depend on costly GPS collars attached to individual animals, the AI drone identifies and follows camels using advanced computer vision and deep learning algorithms. The technology enables continuous herd surveillance, behavioral monitoring, population counting, and movement analysis in remote desert environments while significantly reducing operational costs. This innovation has the potential to improve herd management, animal welfare, disease surveillance, and conservation efforts, particularly in extensive pastoral systems where manual monitoring is challenging.

Potential applications include real-time herd tracking without GPS collars, early detection of injured, sick, or isolated camels, monitoring grazing patterns and migration routes, improved livestock security and anti-theft surveillance, collection of data for precision camel farming and research and support for conservation of free-ranging camel populations. This AI-based drone technology represents an important step toward precision camel livestock management, combining unmanned aerial vehicles (UAVs), computer vision, and artificial intelligence to enhance efficiency while lowering monitoring costs in arid environments.

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# EFFECT OF SUPPLEMENTATION ON PRODUCTION AND QUALITY OF MILK IN CAMEL RAISED IN KUTCH REGION

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## ABSTRACT

Camels in Kutch region of India are raised on browse resources by the pastoralists. Availability of browse resources affects nutritional composition of milk from the species. Supplementation could be of advantage during pregnancy and during the lean season. An experiment was planned to monitor the animals under field conditions to study the preference of various species which contributed to the browse ingested, change in body condition score and quality of milk produced by camels raised on available browse with and without concentrate supplement. Pelleted feed concentrate was prepared with admixture of cotton seed extract, rapeseed extract, rice polish, deoiled rice bran, maize, di calcium phosphate, common salt and molasses. Body condition scores improved with the stage of pregnancy however differences with and without supplement were not observed. *Acacia nilotica* a tree species was the most preferred plant species followed by Zizyphus nummularia bush, Acacia tortalis tree, Leptidinia reticulata and Piper betle creepers were avidly consumed. Ruminations pattern was observed to be similar in animal's supplemented concentrate. Milk production increased from 3.68 to 4.05 kg/d and production of 4% FCM also improved from 2.43 to 2.66 kg/d which reflected improvement due to supplementation of concentrate feed. Observations suggest improvement in milk production and its fat content could be achieved in Kutchi camels raised under field conditions.

**Key words:** Browse resources, feed supplementation, Kutch region, milk production, plant species preferred

Kutchhi breed of Camel in the Kutch, Bhuj region of Gujarat state is dependent on plant species along the coastal line which provide important browse materials for survival in the area. Pastoralists in the Kutch region migrate with their herds within the taluka (90.54%) in search of food and water relying on the available range vegetation (Patel *et al*, 2008). Addressing energy and protein deficiencies through supplementation is crucial for boosting milk production. Increasing protein and energy level in the camel diet was associated with an improvement in milk yield and composition. Under field conditions, farmers provide supplements in the form of dry roughages during advance pregnancy to meet nutritional needs, only few provide concentrate supplements.

Inadequate feed resources in quantity and quality during dry season is the major factor affecting milk production in lactating dromedary camels (Lusala *et al,* 2025). Stabling camels had higher milk yield with more protein and less fat compared to grazing camels (Ayadi *et al,* 2019). Supplementing she camels fed on alfalfa with 4 kg/head of feed concentrate improved protein and mineral levels of milk (Abdelrahman *et al,* 2022). Lactation supplement containing 17% crude protein and 12% metabolism energy when fed at the rate of 2 kg/h/d improved milk by over 50% reflecting significant improvement in production of milk from camel (Hasan *et al,* 2023). Increasing the amount of concentrate feed given to grazing camels from 1kg/head/ day to 4 kg/head/day improved milk yield and composition (El Hatmi *et al,* 2004). Supplementation of concentrate diet at 1, 1.5, 2 kg/h/d to camels during dry season improved milk production, it improved protein and fat content of milk slightly (Lusla *et al,* 2025). Increase in energy content of the diet improved milk yield without affecting milk composition when TDN content was increased from 50% to 60% (Nagpal and Patil, 2012). Similar results were observed when dietary energy was increased on a low protein diet in camel (Al-Saiady *et al,* 2012). Thus improving energy availability is reflected in higher milk yield. Considering lower availability during the winter season, supplementation could be beneficial to mitigate lower nutrient availability to sustain milk production from the available browse in the field.

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However to economise, the present study on lactating camel was planned with the objective to evaluate effect of concentrate supplement on production and quality of milk, body condition score, organo-leptic assessment and aflatoxin residues in milk of kutchi breed camels from human health point of view as camels are raised on natural grazing/ browse resources under field conditions in kutch region.

## Materials and Methods

**Experimental design:** Data regarding number of pregnant animals, their milk production, and stage of pregnancy were collected from the herder. To conduct the experiment, 50 pregnant animals of Kutchi breed were selected from different herds and divided equally into 2 groups with similar production status. A colour band was put on their neck region at the start of experiment to identify animals during movement. Selected camels of both the groups (T1, T2) browsed for 12 hours (6 AM to 6 PM daily). Apart from daily browse, animals under T2 group received one kg pelleted concentrate/h/d during morning milking for a period of 6 weeks. Camel travelled nearly 8-10 kilometres daily ranging from plain to up hills to capture preferred plant species in Kutch region. The route was selected by the pastoralists which had a safe halting point to protect their animals from wild animals during night hours, the route also had a natural water resource to quench thirst of their animals and provide water for cooking which they do at the point of rest; after week to 10 days they shift to a newer place. Browsing behaviour of all the animals under experiment was recorded in which each animal was followed for 10 minutes to observe bites consumed from different plant species during the browse period of 12 hours for two consecutive days. A total of 8700 observations on preference of plant species were recorded to develop preference index of camels in the selected area. Rumination behaviour (bites per bout) was recorded from 10 consecutive observations while at rest in sternal recumbenc during early hours of winter months (November-December, between 5-7 AM) from 10 animals each in each group. Observations were recorded in near Ber Moti, Golay, Ganau villages of Mandvi tehsil of Bhuj. Browse materials of animals were collected, pooled, air dried for estimation of protein content (AOAC, 2016).

Flat and hard ground was preferred in the open enclosures/ fields for resting; adults took rest in sternal recumbence while calves were kept loose as they rest with adults during night hours. The animals were allowed to rest during mid day in the grazing land near water spot without tying for rest during day time.

**Evaluation of milk:** The animals were milked twice daily during early morning and evening to observe milk production status. Samples of milk were collected at weekly intervals to access compositional quality and analysed for Fat and SNF content with ISmart Milk Analyser. Organo-leptic attributes of milk were assessed to ascertain quality aspects before being pooled (morning and evening) for processing by using BIS Score card and judged by two judges to arrive at final score. The score card evaluated appearance (colour, consistency, freedom from foreign matter), body and texture (uniformity, smoothness, viscosity, absence of watery or curdy feel), flavour and taste (clean, fresh, pleasant, free from off-flavours (oxidised, rancid, sour, metallic etc.), odour (Smell) (Natural, fresh, free from feedy, cooked, or foreign odour), After taste / mouth feel (pleasant, no bitterness or astringency, balanced richness), overall acceptability (general impression considering harmony of all attributes) with maximum scores of 10, 20, 40, 10, 10, 10. Organo-leptic scores given by the judges were pooled over weeks to get final values for each treatment. Milk production data was converted to 4% FCM to observe change among un-supplemented and supplemented groups.

**Body condition scores:** Body condition scores were recorded to evaluate the amount of fat and muscle reserves on an animal's body which relied on visual observation and tactile palpation of rib, hump, pin, tail as key anatomical landmarks; at the start and end of experiment to observe change.

**Composition of feed pellets:** Pelleted feed concentrate was prepared at, Kutch's first fully automated, solar energy-operated cattle feed manufacturing unit located in Chandrani, with admixture of cotton seed extract, 5%; rapeseed extract, 30, rice polish, 6; deoiled rice bran, 24%; maize, 30%, di calcium phosphate, 2%; common salt, 1; and molasses 3% with protein content 16% and TDN 70.1% with the objective to provide 10% extra protein and energy to animals. Before initiation of experiment, pelleted feed prepared was assessed for presence of aflatoxin in the in-house facility of dairy unit. Milk samples were also assessed for presence of aflatoxin at the end of feeding period (pooled group wise).

**Analysis:** Browse materials were collected, Owen dried and analysed for protein content as per standard technique (AOAC, 2016). The data generated during the experiment was subjected to statistical analysis using by SPSS statistical software (2011) Version 20.0 and the data were statistically analysed using one-way and two-way ANOVA procedures for difference between treatments and periods.

## Results and Discussion

Grazing/browsing management is a common practice to raise camels in western arid region of India. Supplementation has been practiced as a beneficial strategy to enhance milk production and improve overall health of lactating and pregnant camels.

**Body condition score:** Five point scales was used to record body condition scores of animals before and after 6 weeks which revealed (Table 1) that the scores were similar among groups at both the stages.

**Table 1.** Body condition score of animals.

| Group | N | Start of experiment | After VI weeks |
|---|---|---|---|
| Grazing | 25 | 3.05 | 3.47 |
| Grazing+ Feed supplementation | 25 | 2.96 | 3.49 |
| SEM | | 0.004 | 0.005 |
| P value | | 0.136 | 0.799 |

**Browse preference:** Study of preference of different plants in the browse area revealed that *Acacia nilotica* a tree species was the most preferred plant (twigs along with pods) followed by *Zizyphus nummularia* bush, *Acacia tortalis* tree, *Leptidinia reticulata* and *Piper betle* creepers were avidly consumed. Other plants were also consumed but with lower preference; choice of different species was jotted to arrive at the preference index (Table 2). Camels usually take a variety of vegetation which presumably provides optimal nutrition. Camels moved from plant to plant and selected browse from different plants, the average bites consumed were 17.4 per minute. It is likely that biomass consumed for 10-12 hours from the available edible browse seemed to be adequate to meet their nutrient needs. Body condition scores in animals used to assess the nutritional status, fat reserves, and overall health of animals.

Milk production starts declining during the third quarter of pregnancy which coincides with the onset of lean season and winter. To meet emerging foetal nutrient requirements, need was felt to supplement she camels as they spend substantial time to select quality browse with more energy from the grazing area. Rumination behaviour in camels is a critical indicator of normal digestive function, good health, and a positive welfare state (Iqbal and Khan, 2001). Rumination behaviour signifies a state of health, comfort, and good welfare, an active, functioning digestive system. Camels chew their food efficiently to break down coarse desert forage, with peak activity occurring in the early morning and late evening. Ruminations pattern indicated in-significant decrease from 63.9 to 62.5 (chews/bolus) which could be due to supplementation of concentrate/ selection of less fibrous leafy vegetation as per choice of plant species available in the field (Table 3). Studies indicated that each bolus was chewed for an average of 45 s with 68 chews per min (Engelhardt *et al,* 2006) before being swallowed and re-fermented in camels fed hay-based diet. Difference in the numbers reflected fibrous nature of forage ingested as twigs of different plants available in the browse area also contained thorns.

**Table 2.** Preference index of plant species browsed by camels of Bhuj.

| S.No. | Plant name | Percent |
|---|---|---|
| 1 | *Acacia nilotica* | 26.1 |
| 2 | *Zizyphus nummularia* | 19.3 |
| 3 | *Acacia tortalis* | 12.9 |
| 4 | *Leptidinia reticulata* | 9.2 |
| 5 | *Piper betle* | 7.5 |
| 6 | *Pithecellobium dulce* | 4.5 |
| 7 | *Solanum xanthocarpum* | 4.0 |
| 8 | *Prosopis cineraria* | 3.7 |
| 9 | *Fagonia arabica* | 3.7 |
| 10 | *Abutilon indicum* | 3.3 |
| 11 | *Rivea hypocrateformis* | 1.9 |
| 12 | *Grewia tenax* | 1.4 |
| 13 | *Prosopis juliflora pod* | 1.1 |
| 14 | *Salvadora persica* | 0.9 |
| 15 | *Capparis decidua* | 0.3 |
| 16 | *Cordia myxa* | 0.2 |
| Total | | 100 |
| Bites consumed/ minute | | 17.4 |
| Bites consumed in 10 hrs of browse | | 10440 |
| Estimated DMI /bite | | 0.92g |
| DMI consumed/day for 600 Kg @1.6% BW | | 9.6 kg |

Aflatoxin content in the feed was observed to be within permissible limit of 15 ppb whereas no aflatoxin was observed in the milk of experimental groups reflecting safe for human use. Farmers were provided weekly quota of the feed to be supplemented. Thus the feed was safe from aflatoxin point of view. Milk production increased from 3.68 to 4.05 kg/d (Table 4) and production of FCM (4%) also improved from 2.43 to 2.66 kg/d which reflected improvement due to supplementation of concentrate feed (Fig 1). Improvement in milk production was observed in both the groups; however improvement was significant in the supplemented group ($T_2$) in which improvement in the yield of fat corrected milk was also observed which reflected usefulness for sustainability of production. The browse materials consumed were observed to contain 11.58% CP with an estimated TDN value of 54.75% reflecting energy to protein ration of nearly 4.7 which likely had beneficial nutrient proportion to produce quality milk with higher fat content even with available browse available. It is likely that higher proportion of *Acacia nilotica* in the browse supported better milk yield with higher fat content in the milk as it also contained *Acacia* pods which are a good source of protein, essential for growth, milk production, and overall animal health, especially during dry seasons when pasture quality is low, the pods contain tannins that have anthelmintic properties which help to reduce the parasitic load in grazing animals. Improvement in milk along with fat content could also be due to production of higher butyrate along with acetate in the rumen (Sawal and Kurar, 1998). Similar results have been observed by Lusala *et al* (2025) wherein supplementation of lactating camels with concentrate during the dry season increased milk production.

**Nutritional quality of milk:** Higher fat content improved organo-leptic score from 63.5 to 67.8 in the feed supplemented group reflecting preference for high fat milk. Though milk of camels raised on sole browse contained higher milk fat, further improvement in fat content and production was observed due to supplementation with feed containing higher energy: protein ratio. Since protein fraction in the biomass browsed by the animals seemed to be adequate due to preference of ingested plant material, however, it is likely the energy deficit was met either through consumption of pelleted feed with higher energy level or consumption of *Prosopis juliflora* pods which was an excellent source of energy (Sawal *et al*, 2004) available for grazing livestock in Kutch.

Under grazing conditions, animals prefer most digestible components as new sprouts, pods

**Table 3.** Rumination behaviour of camels (bites/bolus).

| Treatment | $T_1$ | $T_2$ | Mean | P value | | |
|---|---|---|---|---|---|---|
| | | | | Treatment | Observation | Treatment * Observation |
| Bites | 63.86 | 62.45 | 63.15 | 0.368 | 0.646 | 0.684 |

**Table 4.** Effect of concentrate supplementation on milk production and quality in camel under field conditions.

| Week | Morning | | | Evening | | | Total Milk (kg) | % FCM kg | | | Organo-leptic score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Milk (kg) | Fat | SNF | Milk (kg) | Fat | SNF | | M | E | T | |
| 0 | 1.79 | 2.84 | 6.72 | 1.64 | 3.09 | 6.79 | 3.43 | 1.14 | 1.12 | 2.26 | 61.3 |
| I | 1.79 | 2.82 | 6.74 | 1.61 | 3.13 | 6.81 | 3.40 | 1.14 | 1.11 | 2.25 | 62.8 |
| II | 1.87 | 3.53 | 6.60 | 1.83 | 4.18 | 7.09 | 3.70 | 1.27 | 1.35 | 2.62 | 61.2 |
| III | 1.94 | 2.39 | 6.78 | 1.76 | 3.39 | 6.93 | 3.70 | 1.14 | 1.21 | 2.35 | 62.7 |
| IV | 1.89 | 3.03 | 7.06 | 1.87 | 3.51 | 6.92 | 3.76 | 1.21 | 1.27 | 2.48 | 63.8 |
| V | 2.26 | 2.71 | 6.91 | 1.59 | 3.66 | 6.93 | 3.85 | 1.31 | 1.18 | 2.50 | 64.5 |
| VI | 2.07 | 2.91 | 6.87 | 1.83 | 3.66 | 6.95 | 3.90 | 1.26 | 1.28 | 2.54 | 68.2 |
| Week | Grazing+ feed supplemented group | | | | | | | | | | |
| 0 | 1.86 | 2.66 | 6.76 | 1.71 | 2.99 | 6.88 | 3.57 | 1.14 | 1.13 | 2.28 | 63.8 |
| I | 1.96 | 2.86 | 6.96 | 1.78 | 3.32 | 7.04 | 3.75 | 1.21 | 1.21 | 2.43 | 67.2 |
| II | 2.05 | 3.31 | 7.22 | 2.06 | 3.94 | 7.41 | 4.10 | 1.32 | 1.41 | 2.73 | 63.8 |
| III | 2.16 | 3.62 | 7.26 | 1.99 | 4.14 | 7.20 | 4.15 | 1.41 | 1.42 | 2.82 | 69.5 |
| IV | 2.14 | 3.18 | 7.02 | 1.97 | 3.72 | 6.96 | 4.11 | 1.33 | 1.34 | 2.68 | 66.6 |
| V | 2.22 | 3.00 | 7.01 | 2.09 | 4.46 | 7.32 | 4.31 | 1.34 | 1.50 | 2.84 | 71.0 |
| VI | 2.28 | 3.14 | 7.27 | 2.10 | 3.98 | 7.30 | 4.37 | 1.38 | 1.44 | 2.82 | 72.8 |
| SEM | 0.16 | 0.15 | 0.19 | 0.15 | 0.13 | 0.19 | 0.11 | 0.08 | 0.07 | 0.07 | 0.09 |
| P value | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

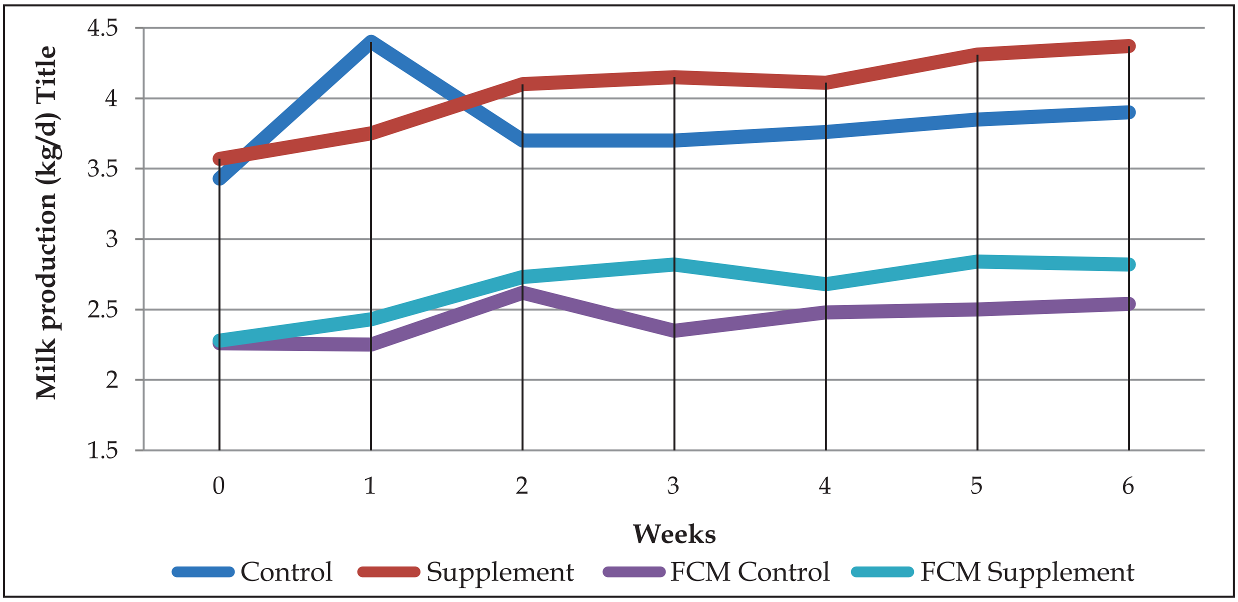


**Fig 1.** Effect of concentrate supplement on milk production in camel under field conditions.

of different browse species, which are relatively more nutritious. Under field conditions, it supports growth, pregnancy and milk production as well. However, nutrient availability reduces during autumn as pasture matures and senescence reduces availability of quality of biomass. In case of camel this coincides with last quarter of pregnancy as calving occurs usually during January-February. Seasonal fluctuations and poor nutrition during lean seasons reduced productivity which need to be addressed under field conditions to maintain quality of milk value chain. The study supports the view to supplement concentrate to improve nutrient availability and support better health of the camels raised under browsing management which also improved and improve milk production and its quality from value addition point of view which could be utilised for human health purpose.

Beyond developing targeted nutritional feed, this study also opens up possibilities for regular dietary supplementation during periods of feed scarcity or in regions where such shortages occur. This work can be extended to promote feed aimed at imparting specific nutritional and medicinal properties to the milk, such as benefits for diabetes and lactose intolerance, or enhanced protein and vitamin content, while simultaneously preserving and maintaining the organic qualities of camel milk.

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## Conflicts of Interest

The authors declare no conflict of interest.

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# INDIGENOUS KNOWLEDGE SYSTEMS (IKS) AND MATERIAL CULTURE OF CAMEL MEAT PRESERVATION: IMPLICATIONS FOR FOOD SECURITY IN BERHALE DISTRICT, ETHIOPIA

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## ABSTRACT

This research documents the indigenous knowledge and material culture used to preserve camel meat in Berhale district. In the lowlands of Ethiopia's Danakil Depression, the territory where extreme thermal stress makes modern refrigeration nonexistent, the dromedary camel (*Camelus dromedarius*) remains the primary safeguard against food insecurity for Afar pastoralist communities. Data were gathered from 90 households through multi-stage sampling, utilising structured interviews and focus group sessions to track how raw meat is converted into *Muqmad*, a long term protein reserve. The study found that Afar elders effectively utilise hurdle technology through a layered defense: solar drying, antimicrobial smoking and sealing the meat in rendered camel tallow. These cultural zero energy techniques keep the meat edible for up to a year, even when outside temperatures exceed 45°C. A critical component of this system is the *Xeedho*, a specialised wooden vessel that acts as an airtight storage unit to block oxygen and stop the fat from turning rancid. While these methods are essential for surviving seasonal hunger, the local industry is held back by informal trade routes and inconsistent quality measures. I argue for a scientific hybridity approach merging Afar expertise with modern food safety standards like Hazard Analysis and Critical Control Point (HACCP). By standardising these local methods, *Muqmad* can be transformed from a local survival food into a high value, clean label export, protecting both Afar heritage and regional food supplies in an increasingly volatile climate.

**Key words:** Camel meat preservation, climate resilience, danakil depression, hurdle technology, *Muqmad*, *Xeedho*

In Ethiopia, camel husbandry is a practice woven into the socio-economic and cultural fabric of the Somali and Afar regions. In these arid lowlands, the dromedary camel (*Camelus dromedarius*) is far more than a livestock asset; it is a fundamental survival mechanism. During protracted droughts, when cattle and small ruminants often face catastrophic losses, camels provide a resilient supply of milk and meat, sustaining both nomadic mobility and nutritional security (Yosef *et al,* 2013; Megersa, 2024). This adaptive capacity is supported by significant genomic diversity, allowing indigenous populations to remain productive under the extreme thermal stress of the Horn of Africa (Yakubu *et al,* 2022; Robert, 2018).

In the Berhale district, situated on the periphery of the Danakil Depression, the Afar people operate in one of the hottest environments on Earth. Here, the limited access of electrical infrastructure and modern refrigeration has forced a sophisticated evolution of indigenous technical resilience. Afar food preservation is not merely a survival tactic but a refined system of ethno-microbiology. For instance, medicinal flora are used to smoke wooden vessels to inhibit pathogens (Karssa *et al,* 2024) and botanical extracts serve as natural sanitizers to mitigate lipid oxidation (Seifu, 2007). Furthermore, specialised dehydration and deep frying processes allow meat to remain shelf stable for up to a year, providing a vital caloric reserve against climatic uncertainty (Dabasso *et al,* 2018).

The necessity for these methods is driven by the unique rhythms of pastoral life. Camel slaughter is rarely routine; it is typically reserved for major festivals, severe droughts, or emergency culling. This results in a sudden, substantial surplus of meat that must be stabilised immediately to prevent waste. Despite the camel's vital role in navigating Ethiopia's climatic shifts (Teku, 2025), the sector remains systemically underdeveloped. Regional agricultural research has historically exhibited a bovine bias, prioritising cattle while overlooking the adaptation strategies essential to the lowlands (Egeru *et al,* 2022).

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Moreover, camel meat presents specific biochemical challenges. Its high moisture content and elevated pH make it more susceptible to microbial spoilage than other red meats (Rezaei *et al,* 2026). While modern technologies like vacuum packaging offer potential solutions, there is a critical need to bridge the gap between industrial safety standards and traditional mastery.

This study addresses this gap by documenting the tools and indigenous techniques of the Afar in Berhale. By integrating field surveys and systematic photography with modern food science, this research seeks to document traditional preservation methods and their cultural equipment. Ultimately, empowering these eco-friendly, consumer accepted strategies can strengthen the camel value chain and secure the livelihoods of pastoralist communities in an increasingly volatile climate.

## Materials and Methods

### *Study Area and Environmental Context*

The fieldwork was centered in the Berhale district, a key pastoral corridor in Zone 2 of Ethiopia's Afar Regional State. Indeed, recent census data (Sintayehu *et al,* 2024) shows that camel density in Berhale far outstrips that of cattle or small ruminants. This makes the district a prime location for studying how indigenous knowledge maintains meat stability in temperatures that would otherwise cause rapid spoilage.

### *Sampling and Research Design*

The research used a multi-stage sampling approach to capture data from both pastoral and agro-pastoral households. First, five administrative units (kebeles) were purposively selected based on three factors: high camel populations, a continued reliance on traditional meat processing and accessibility. From these kebeles, 90 households were chosen through stratified random selection. To verify our findings, we triangulated data using three primary methods: Structured Surveys: To gather quantitative data on household preservation habits. Focus Group Discussions (FGDs): Sessions with community elders to record the ancestral logic and oral history behind preservation techniques. Field Observations: Direct verification of the processing steps, specifically the techniques used during dehydration and deep frying.

### *Documentation of Material Culture*

To record the Afar people's traditional preservation equipment, the study followed a specialised ethnographic protocol. We catalogued indigenous tools, including cutting implements and storage vessels. We recorded their local names, the specific woods or fibers used in their construction and their specific roles in the preservation cycle. Every stage of the process and each piece of equipment was documented with high resolution photography. This visual archive serves to validate household reports and creates a permanent record of Afar meat processing heritage.

### *Data Management*

Quantitative data were analysed using SPSS to produce descriptive statistics, such as frequencies and percentages of specific habits. Qualitative insights, including indigenous proverbs and survival logic shared by the elders, were analysed through thematic coding to better understand the cultural values supporting these traditional systems.

## Results and Discussion

### *Livestock Holding Patterns and Diversity*

Empirical evidence from Berhale indicates that 70% of pastoral households strategically maintain mixed species herds, predominantly integrating camels with goats (Table 1). This management paradigm facilitates stratified foraging, allowing livestock to exploit both browse and herbaceous biomass effectively. Such taxonomic diversification functions as a biological insurance policy, safeguarding communal livelihoods against species specific pathological outbreaks or abrupt thermal fluctuations (Egeru *et al,* 2022). Notably, the traditional reliance on massive, single species assemblages has diminished, with only 7.8% of modern herders maintaining camel exclusive

**Table 1.** Distribution of livestock species among surveyed households in Berhale district (n = 90).

| Herd Composition | Pastoral (n=76) | Agro-pastoral (n=14) | Combined (n=90) |
|---|---|---|---|
| Camels and Goats | 75.0% | 46.2% | 70.0% |
| Camels, Goats and Donkeys | 7.9% | 15.4% | 8.9% |
| Camels only | 7.9% | 7.7% | 7.8% |
| Goats only | 3.9% | 14.3% | 5.6% |
| Camels, Goats and Sheep | 2.6% | 7.7% | 3.3% |
| Camels, Goats, Donkeys and Sheep | 1.3% | 7.7% | 2.2% |
| Full Mixed Herd (all species) | 1.3% | 7.7% | 2.2% |

holdings. This transition signifies a calculated shift toward environmental flexibility, as Afar households prioritise resilience over herd size to navigate the increasingly volatile climate of the Depression (Demissie *et al,* 2024).

### *Livestock species distribution and tropical livestock units (TLU)*

The quantitative assessment in Berhale District demonstrates a definitive dominance of camels and goats within the household livestock portfolio (Table 2). Camels accounted for the highest mean Tropical Livestock Unit (TLU) at 4.6 per household, followed by goats at 2.2 TLU. In contrast, the contribution of cattle, sheep and donkeys to the total TLU was remarkably low; specifically, cattle were owned by only two surveyed households, with a mean TLU of 1.05. This distribution is fundamentally driven by the extreme environmental stressors characteristic of the Northern Afar lowlands. The hyper arid climate and proximity to the Danakil Depression impose severe physiological constraints on cattle and sheep, which exhibit lower thermo-tolerance and higher water requirements than the dromedary (Sintayehu *et al,* 2024). Extensive regional modeling confirms that a strategic shift from cattle to camel and goat farming in north sub Saharan Africa's dry lands can sustain milk and meat production with significantly lower resource inputs and lower environmental emissions (Rahimi *et al,* 2022).

Consequently, the livestock composition in Berhale represents a localised optimisation of this survival model. While other regions may still support bovine centric systems, the producers in this study area have de-stocked sensitive species in favor of the dromedary, which maintains higher productivity and lower mortality rates under the current trajectory of climate uncertainty (Teku, 2025). This transition ensures a steady supply of animal source proteins even during the prolonged dry spells characteristic of the Afar depression.

**Table 2.** Distribution and Tropical Livestock Units (TLU) of species owned per surveyed household in Berhale District.

| Livestock Species | N | Minimum | Maximum | Mean ± S.E | Mean TLU | TLU Range |
|---|---|---|---|---|---|---|
| Camels | 85 | 1.0 | 29.0 | 4.6 ±0.43 | 4.60 | 1.0 – 29.0 |
| Goats | 83 | 2.0 | 100.0 | 22.0 ±1.89 | 2.20 | 0.2 – 10.0 |
| Donkeys | 12 | 1.0 | 4.0 | 1.7 ±0.28 | 0.85 | 0.5 – 2.0 |
| Sheep | 6 | 1.0 | 5.0 | 3.2 ±0.65 | 0.32 | 0.1 – 0.5 |
| Cows | 2 | 1.0 | 2.0 | 1.5 ±0.50 | 1.05 | 0.7 – 1.4 |

Note: N = Number of households owning the species. TLU conversion factors used: Camel = 1.0, Cattle = 0.7, Donkey = 0.5, Goat/Sheep = 0.1. The total TLU is the sum of the means for all species recorded in the study area.

### *Comprehensive Camel Meat Production and Step by Step Indigenous Preservation of Camel Meat in Berhale*

In the Berhale district, the transformation of raw camel meat into a stable, yearlong food reserve follows a precise sequence of indigenous engineering steps. This process successfully manages the extreme 45°C ambient temperatures without any reliance on a cold chain.

#### *Phase 1: Strategic Selection and Cultural Slaughter*

Research in the Berhale district indicates a highly structured approach to camel slaughter, governed by both demographic and cultural priorities. The vast majority of households (83.3%) specifically select male camels for slaughter, while a smaller cohort (16.7%) utilises both adult males and females. A definitive age specific preference exists, with 91.1% of households slaughtering camels between 5 and 7 years of age. Only 8.9% of respondents reported slaughtering older camels, typically as a culling strategy when animals cease to be functional for transport or reproductive purposes. This specific window ensures the meat is mature enough for high protein yield while keeping the texture suitable for dehydration. Reproductive females are strictly excluded to maintain herd growth. These selection patterns align with established observations in the Horn of Africa, where adult males consistently represent the primary slaughtered stock to preserve the reproductive potential of the herd (Sintayehu *et al,* 2024; Kibebew *et al,* 2021).

The reluctance to slaughter young males is rooted in indigenous reproductive wisdom; local belief suggests that early slaughter of a male calf may negatively influence the dam's future conception of male offspring. Furthermore, female camels are strictly reserved for breeding and are only slaughtered upon confirmation of infertility. Due to the absence of formal abattoirs and the logistical challenge of processing large carcasses, 100% of slaughtering in Berhale occurs in open forest or stony areas. Traditional equipment, including the *Gile* (a specialised Afar cultural knife), axes and ropes, remain the primary tools for processing. Local producers estimate the edible meat yield of a single adult camel to be equivalent to that of 12 goats, underscoring the species' substantial role as a high volume protein source in the Afar food system.

Slaughter occurs in open, elevated stony areas. This choice of location is deliberate; the stones provide a clean surface and the elevation ensures high velocity airflow to begin cooling the carcass immediately. Using the *Gile* (Afar cultural knife), the carcass is segmented. Lean muscle is separated from the hump fat (tallow), which will later serve as the primary preservative medium.

***Phase 2: Precision Slicing, Indigenous Rack Drying and Medicinal Smoking***

The lean meat is carved into uniform, thin strips (Fig 1). This increases the surface-area-to-volume ratio, facilitating rapid moisture loss. Strips are draped over wooden racks or ropes. Intense solar radiation and dry winds reduce the water activity to a level where proteolytic bacteria cannot thrive. While drying, producers often ignite specific medicinal flora beneath the racks. The smoke deposits phenolic compounds on the meat, acting as a natural chemical shield against pathogens and insects (Karssa *et al,* 2024).

**Fig 1.** Indigenous meat preservation in Berhale Woreda, showing the lean meat is carved into uniform, thin strips for sun drying to achieve moisture reduction and long term protein stability.

***Phase 3: Dicing, Tallow Rendering and Deep Frying***

The brittle, sun dried strips are cut into small, uniform cubes. The saved hump fat is placed in a large pot and heated until it melts into a clear, boiling liquid. The meat cubes are submerged in the boiling fat. This step serves as a thermal hurdle, killing any surviving surface microbes and evaporating any remaining internal moisture (Fig 2).

**Fig 2.** The brittle, sun dried strips are cut into small, uniform cubes. Dehydrated, fire treated and cubed camel meat (*Muqmad*) prepared for long term storage.

***Phase 4: Bio-Preservation and Sealing***

During the final minutes of frying, a mixture of dates, cardamom and garlic is added. These are not merely flavorings; they are potent natural antioxidants that prevent the fat from turning rancid in the desert heat (Djenane *et al,* 2020). The meat is moved into traditional storage containers and completely covered with the hot rendered fat. As the fat cools and solidifies, it creates a physical airtight seal. This lipid barrier prevents oxidation and blocks secondary rehydration from the atmosphere. In the absence of cold chain infrastructure and under the 45°C ambient heat of Berhale, 86.7% of households utilise a meat preservation strategy centered on integrated sun drying and light fire smoking (Fig 3 and 4). This indigenous engineering model leverages natural high velocity airflow and intense solar radiation to rapidly reduce water activity in the meat, thereby inhibiting the proliferation of proteolytic and pathogenic bacteria. This method is scientifically recognized as one of the most effective low input stabilisation models for high protein assets in hyper arid landscapes (Sintayehu *et al,* 2024).

The primary output of this traditional engineering is *Muqmad*, produced through a rigorous three stage stabilisation process designed to achieve multi month shelf stability: **Dehydration Phase:** Lean muscle strips are hung on indigenous wooden racks for primary moisture reduction. **Thermal Stabilisation:** The dehydrated meat is cubed and deep fried in rendered camel tallow (hump fat). This

**Fig 3.** The leather wrapped exterior of the *Xeedho*, demonstrating the indigenous sealing mechanism that ensures an airtight environment for *Muqmad*. This specialised hardware is designed to withstand high impact transport and extreme thermal fluctuations, effectively acting as a portable, low entropy barrier against microbial contamination and environmental moisture.

**Fig 4.** The storage and transport of *Muqmad* rely on the *Xeedho*, a specialised, hand carved wooden bowl. The image displays the results of the final shelf stable product capable of resisting microbial spoilage for up to 12 months in the Afar climate.

step eliminates residual moisture and encapsulates the protein in a lipid barrier, preventing secondary rehydration and oxidation. **Bio-preservation Phase:** A final hurdle technology approach is applied by seasoning the meat with dates, cardamom and garlic. These spices are not merely flavorants; they function as natural antioxidants and antimicrobial agents that further suppress lipid oxidation and microbial growth (Dabasso *et al,* 2018; Djenane *et al,* 2020).

Data analysis reveals that 70.5% of households in Berhale achieve a shelf life of 6 to 8 months for *Muqmad*, with some respondents reporting product stability for up to a full year without refrigeration (Table 3). Consequently, this preserved meat serves as a critical food security buffer during protracted dry seasons and a vital nutrient source for women during postpartum recovery, demonstrating the profound socio-economic utility of Afar indigenous knowledge.

**Table 3.** Traditional meat processing (*Muqmad*) and storage in Berhale district.

| **Feature** | **Description / Finding** |
|---|---|
| Indigenous Name | *Muqmad* (also known as *Oodkac*) |
| Technical Steps | Sun-drying > Slicing > Deep-frying in tallow > Spicing |
| Natural Preservatives | Cardamom, garlic, camel tallow (ghee) and *Temir* (dates) |
| Household Adoption | 86.7% of surveyed households |
| Stability / Shelf Life | 6 to 8 months (up to 12 months in optimal conditions) |
| Cultural Hardware | *Xeedho* (Decorated, leather wrapped wooden bowl) |
| Dietary Role | Survival food |
| Relative Yield | 1 camel estimated at 12 goats in meat volume |

### *Indigenous Knowledge and Resilience Features*

The preservation systems in the study area are not merely traditional practices; they represent a sophisticated application of Climate Intelligence and Resource Engineering. Below is a breakdown of the core resilience features that define these indigenous systems.

### *Step 1: Application of the Multi Hurdle Strategy*

The pastoralists in the study area effectively apply what modern food science calls Hurdle Technology. By layering multiple preservation barriers, they ensure that if one hurdle fails, others are in place to prevent microbial growth. Heat (Boiling/ Frying): The first hurdle, which reduces the initial microbial load through thermal sterilisation. **Salt:** Acts as a solute to increase osmotic pressure, drawing moisture out of microbial cells. Drying: Lowers the water activity, making the environment too dry for bacteria to reproduce. Fat Encapsulation: The final hurdle, which creates a physical barrier against oxygen and moisture reentry.

### *Step 2: Resource Optimisation and Circularity*

The system is designed to be entirely self-sufficient, requiring zero external inputs or synthetic chemicals. Utilisation of Hump Fat: Instead of discarding the hump, its high quality tallow is used as the primary preservative and energy source for the meat. No External Preservatives: The process relies exclusively on local salt and botanical extracts (garlic, ginger, or medicinal smoke). Zero Waste: Every component of the carcass is utilised, ensuring high resource efficiency in a resource scarce environment.

*Step 3: Synchronisation with Climate Intelligence*

Indigenous techniques are strategically timed to align with environmental cycles, ensuring a high success rate. Seasonal Timing: Preservation is synchronised with the dry seasons when humidity is lowest and dehydration is most rapid. Solar Harnessing: Techniques leverage in Berhale district high solar radiation as a free, consistent energy source for moisture removal. Environmental Compatibility: Because the methods are built around the local climate (high heat and low humidity), they are more reliable than modern technologies like refrigeration, which often fail due to power instability.

*Step 4: Engineering for Mobility Compatibility*

For nomadic and transhumant communities, food must be as mobile as the herd. The preservation process transforms heavy, perishable raw meat into a transportable asset. Light weighting: By removing up to 70-80% of the meat's water content, the resulting product is significantly lighter and easier to carry. Non-Perishability: Products like *Muqmad* do not require specialised storage, allowing them to be packed in traditional leather bags or containers during long migrations. High Energy Density: The combination of protein and fat provides a concentrated nutrient source for herders traveling across vast distances.

*Storage Culture and Symbolic Materiality*

The storage and transport of *Muqmad* rely on the *Xeedho*, a specialised, hand carved wooden bowl (Fig 4). Observations in Berhale suggest that the *Xeedho* is not merely a functional container but a sophisticated cultural storage system. When the fried meat is submerged in dates within these airtight, leather wrapped vessels (Fig 5), it is shielded from oxidative rancidity and microbial contamination. Beyond its practical utility, the *Xeedho* frequently decorated with cowrie shells serves as a primary cultural signifier of household wealth and social status. This indigenous material culture enables the Afar of Berhale to maintain a stable, high protein food supply during long distance migrations. Such a resilient food engineering system represents a generational adaptation to the ecological pressures of the Danakil depression.

*Nutritional and Food Security Role*

In the Berhale district, preserved camel meat is not merely a food item; it is a vital nutritional insurance policy. Its role in local resilience is defined by key pillars: **Drought Proof Protein Reserves:** When environmental shocks deplete bovine populations, *Muqmad* provides a high protein, energy dense reserve that remains stable without refrigeration. **Year Round Availability:** Indigenous preservation transforms a seasonal surplus into a consistent, year round nutrient source, bridging the hunger gap during the long dry seasons. **Medicinal Perceptions:** Local Afar communities value camel meat for its perceived medicinal properties. Lean Composition: Its high protein-to-fat ratio and unique amino acid profile make it a preferred dietary staple.

**Fig 5.** A specialised, hand carved wooden bowl known as the *Xeedho*, used for the long term storage and transport of *Muqmad*. The image illustrates the leather wrapped, airtight construction and cultural ornamentation, which together function as a low entropy storage system to protect the preserved meat from oxidative rancidity during migration.

*Constraints and Risks*

While the indigenous systems are remarkably resilient, they face specific challenges that limit their potential for broader market integration: Processing Hygiene: 100% of slaughtering occurs in open air environments, which, despite the use of stony areas for cleanliness, exposes meat to environmental contaminants. Contamination Risks: Without controlled environments, meat is susceptible to dust, opportunistic insects and secondary microbial blooming if drying is interrupted by sudden humidity. Lack of Standardisation: Traditional methods rely on sensory cues (sight and touch) rather than standardised metrics, leading to inconsistent moisture content and varying shelf life between batches. Safety Awareness: There is a limited formal understanding of modern food safety protocols during the handling and dicing phases.

*Scope for Scientific Integration*

The future of the Ethiopian camel meat sector lies in the hybridity of traditional mastery and modern food technology. Integrating scientific standards can transform *Muqmad* from a local staple into a high value export product. Improved Dehydration: Implementing Solar Dryers can protect meat from dust and insects while maintaining the zero energy profile of the traditional process. Advanced Packaging: Utilising Vacuum Packaging for *Muqmad* could extend its shelf life even further and make it suitable for urban retail and international markets. Microbial Standardisation: Conducting systematic studies on the ethno-microbiology of Afar spices (garlic, dates and medicinal smoke) to identify and concentrate the most effective natural preservatives. Quality Frameworks: Applying HACCP (Hazard Analysis and Critical Control Points) to the indigenous workflow to ensure consistent safety and quality, facilitating certification for the global clean label market.

## Conclusion

The indigenous knowledge systems of the Berhale district represent a sophisticated, self-sustaining bio-preservation technology perfectly calibrated to the extreme thermal conditions of the Danakil Depression. This research demonstrates that Afar pastoralists have engineered effective strategies to mitigate meat spoilage in the total absence of modern cold chain infrastructure.

The production of *Muqmad* is, in essence, a master class in Hurdle Technology. By layering multiple microbial barriers, thermal sterilisation, solar dehydration, osmotic pressure (salt) and lipid encapsulation, the community achieves a zero-energy stabilisation model. This allows high-value protein assets to remain stable for up to 12 months in ambient temperatures exceeding 45°C.

By transforming seasonal livestock surpluses into long term nutritional reserves, the preservation process acts as a vital insurance policy against the cyclical droughts characteristic of the Ethiopian lowlands. The transition toward mixed species herds (camels and goats) signifies an adaptive shift toward environmental flexibility, prioritising survival and resource efficiency over raw herd size. The *Xeedho* is not merely a vessel; it is a specialised engineering tool designed to maintain a low entropy environment. Its ghee-sealed, airtight construction reflects a profound inherited understanding of anaerobic food chemistry.

Despite its success, the sector faces constraints from open air processing risks and a lack of metric standardisation. The path forward lies in Scientific Hybridity: integrating time-tested indigenous mastery with modern advancements. By strategically introducing solar dryers, vacuum packaging and HACCP based quality frameworks, the Afar community can bridge the gap between traditional survival and global safety standards. Such an evolution will not only bolster local food security but also position *Muqmad* as a premium, clean label export product, safeguarding the resilient cultural heritage of the Afar people against the shifting pressures of the twenty first century.

## Declarations

### Availability of Data and Materials

To maintain academic transparency and accountability, the primary datasets generated and analysed during this study are available from the corresponding author upon reasonable request.


### Funding

This research was entirely self-funded. The author received no specific grants or financial support from public, commercial, or non-profit funding agencies.


### Ethics Approval and Consent

This study was executed following the established ethical protocols for agricultural and social research. All participating pastoralist households provided informed verbal consent after being briefed on the study's purpose. Participants were assured of complete anonymity and the confidentiality of their responses prior to the data collection process.

### Manuscript Status and Originality

The author certifies that this manuscript is an original work that has not been published elsewhere, in part or in full and is not currently under consideration by any other journal.

### Conflict of Interest

The author declares no financial, professional, or personal affiliations that could represent a potential conflict of interest. No external influence or funding impacted the objectivity of the presented findings.

### Author's Contribution

The author was solely responsible for the end-to-end execution of the project, including the initial conceptualisation, study design and field data acquisition. Additionally, the author performed all statistical analyses, interpreted the results and was responsible for the drafting, critical revision and final approval of the manuscript.

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# NOVEL INSIGHTS INTO PRO-APOPTOTIC AND ANTI-PROLIFERATIVE ANTILARVAL ACTIONS OF IVERMECTIN ON CAMEL NASAL BOTS (*Cephalopina titillator*)

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## ABSTRACT

Camel nasal myiasis, caused by the larvae of *Cephalopina titillator*, poses significant health and economic burdens in tropical and subtropical regions. Ivermectin, a widely used antiparasitic, has shown promise, but its detailed tissue damaging effects and its mechanisms on this parasite remain underexplored. This study was aimed to elucidate the mechanism of action of Ivermectin against *C. titillator* larvae, the causative agent of camel nasal myiasis, by evaluating its histopathological and immunohistochemical effects on larval tissues, focusing on cellular structures, proliferative activity, and apoptosis. Larvae were collected from slaughtered camels in Al-Ahsa, Saudi Arabia, and exposed to Ivermectin (1 µg/ml) for 8 hours. Histopathological analysis assessed tissue damage in the cuticle, muscles, fat bodies, and gut. Immunohistochemistry was performed to detect Proliferating Cell Nuclear Antigen (PCNA) and caspase 3 expressions to evaluate cell proliferation and apoptosis, respectively. Control larvae received vehicle treatment. Ivermectin induced widespread damage across multiple larval strucutres. Structural barriers were compromised through cuticle thinning, locomotion was impaired by extensive muscle degeneration, and metabolic function was disrupted by fat body necrosis and lipid depletion. Digestive capacity was adversely affected by gut epithelial degeneration and brush border disruption. At the cellular level, ivermectin markedly suppressed PCNA expression in gut epithelium, indicating inhibition of tissue renewal, while strongly activating caspase-3-mediated apoptosis in the cuticle, fat body and gut. These combined effects suggest irreversible functional collapse rather than transient paralysis. Ivermectin impairs larval structural and cellular integrity, mobility, and metabolic functions while promoting apoptosis and inhibiting tissue repair. These findings clarify its larvicidal efficacy and support its use in managing *C. titillator* infestations in camels.

**Key words:** Antiparasitic, cephalopina, histopathology, immunohistochemistry, ivermectin

Camels are resilient creatures that can tolerate extreme temperatures and a lack of water (Bagiyal *et al,* 2024). However, they are susceptible to several diseases that might endanger their health (Khalafalla, 2023; Khalafalla and Hussein, 2021), such as “camel’s nasal myiasis,” which is caused by the larvae of the *C. titillator* fly, a member of the Oestridae family (Angulo-Valadez *et al,* 2010). *C. titillator* fly implants its larvae into the camel’s nostrils, where they remain for eleven months. Infected camels exhibit a range of respiratory symptoms, including mucous discharge, mucous membrane inflammation, irritation, widespread petechial haemorrhaging, respiratory issues, many localised granulomas, and tissue destruction (Zayed *et al,* 2008).

The presence of these larvae in camels causes enormous economic losses. While there are several approaches to managing this, one approach is medical treatment using drugs that activate or inhibit neural channels and receptors (Basu and Charles, 2019). Given the wide variety of anti-parasitic drugs on the market, it was recommended to conduct *in vitro* tests on the larvae to determine the most effective treatment. Furthermore, a side-by-side evaluation of Ivermectin’s larvicidal activities will be performed to determine its efficiency against the parasite (Aljasim *et al,* 2024; Subramanyam and Colecraft, 2015). Nasal bots are a major health concern in camels, hurting their overall well-being and productivity. This problem is especially prominent in places like Al-

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Ahsa, Saudi Arabia, where camel farming is not only a cultural tradition but also a vital part of the local economy (Fatani and Hilali, 1994).

The purpose of this study was to investigate the mechanism of action of Ivermectin on the larvae of *C. titillator*, the causative agent of camel nasal myiasis, by examining its histopathological and immunohistochemical effects. The study was aimed to determine how Ivermectin impacts larval tissues, including the cuticle, muscles, fat bodies, and gut, as well as its influence on cellular proliferation (PCNA) and apoptosis (caspase 3). By analysing these effects, the research sought to provide insights into Ivermectin's efficacy in disrupting larval integrity, mobility, and metabolic processes, ultimately contributing to a better understanding and management of nasal bot infestations in camels, which have significant economic and health implications.

## Materials and Methods

### *Animals and Collection of Larvae*

All procedures were conducted as previously described by Aljasim *et al* (2024). The study involved adult camels (aged ≥8 years) of a local Saudi breed, which were slaughtered at the Omran abattoir in Al-Ahsa, Eastern Province, approximately 328 km from Riyadh, Saudi Arabia, during 2022 and 2023.

Following slaughter, the nasal cavities of the camels were carefully examined for the presence of larvae. Detected larvae were collected using sterile techniques and placed into clean, sterile containers with tight-fitting lids to prevent contamination with blood or mucus. No more than five larvae were placed in each container. The collected specimens were then promptly transported to the laboratory for antiparasitic assays.

All procedures were approved by the King Faisal University ethics committee (approval number KFU-REC-2022-NOV-ETHICS308).

### *Antiparasitic assay*

During our previous research, the estimated IC50 of Ivermectin was estimated to be 0.0735 ± 0.016 µg/ml (Aljasim *et al,* 2024). During the current assay, the larvae were exposed to one µg/ml Ivermectin concentration, which is more than ten times higher than the estimated IC50 value. Larvae were placed in the culture media mixed with a drug to dwell in. All larvae were then placed in an incubator at 25°C for 8 hours. At the end of incubation, all dead larvae were collected for histopathology examination. A control group was kept in the same conditions without drug treatment. The control group received the same volume of the culture medium without drugs (Aljasim *et al,* 2024).

### *Histopathological examination*

Larvae specimens from both the treatment and control groups were collected for further study. After being collected, the specimens were rinsed with saline. The specimens were then put in a 10% neutral formalin solution, followed by rinsing overnight. The samples were then dehydrated using 70% ethyl alcohol and immersed in xylol. The clarified samples were then carefully placed in a covered jar containing a 50% combination of paraffin and xylol and heated to 37°C for three hours. Following the infiltration operation, the samples were immersed in molten paraffin at 48°C for another two hours. After that, the specimens were embedded in paraffin and stored in a cold environment to form a solid block that could be sectioned. Finally, 5 micron-thick sections were cut using a microtome, stained with Hematoxylin and Eosin (H & E), and mounted onto slides using DPX on a glass slide with a cover slip to be studied under a light microscope (Barbosa, 1975; Basu and Charles, 2019).

### *Immunohistochemistry examination*

The immunohistochemistry procedure was performed as previously described (Attia and Mahdy, 2022; Ibrahim *et al,* 2023). The tissue samples from the larvae were tested for PCNA and caspase 3, which are involved in cell cycle control and apoptosis, respectively.

## Results

The histological analysis of the larval body segment stained by H&E revealed the presence of significant anatomical features with an outer protective cuticle, highlighting its role in safeguarding the larva. Furthermore, well-developed striated muscles were identified, indicating the larva's capability for movement. Additionally, fat bodies, responsible for energy storage and metabolic processes, were detected. In addition, a food channel suggested its association with digestion and the absorption of nutrients within the larval body.

### *Cephalopina titillator cuticle*

The histological examination of the cuticle in the untreated larva (Fig 1A) reveals an undamaged cuticle with its epidermal layer intact. Additionally, the histological analysis of the cuticle in the

Ivermectin-treated larva at 8 hours post-treatment (Fig 1B) demonstrates mild degradation and a notable reduction in thickness.

### *Cephalopina titillator muscles*

The histological assessment of the muscular layer in an untreated larva (Fig 1C) demonstrates the presence of well-developed striated muscles with regular and dense patterns of staining by hematoxylin-eosin. Furthermore, the histological examination of the muscle in the Ivermectin-treated larva 8 hours after treatment reveals degeneration and fragmentation (Fig 1D).

### *Cephalopina titillator fat bodies*

The histological analysis of the fat body layer in untreated larvae revealed the presence of well-developed lipid droplets (Fig 1E). Moreover, the histological examination of the fat body in the Ivermectin-treated larvae 8 hours after treatment indicated evidence of necrosis and a reduction in the size of lipid droplets (Fig 1F).

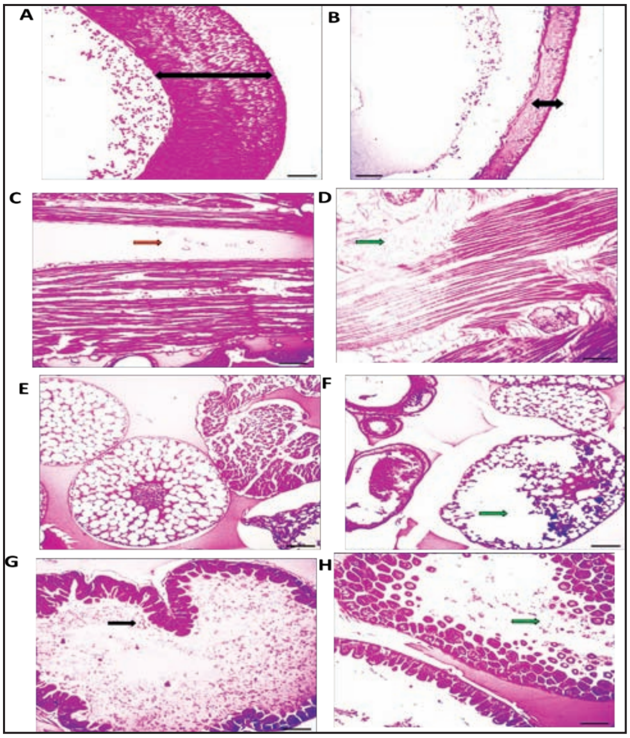


**Fig 1.** Histopathology by H&E (x400). A) *C. titillator* cuticle of untreated larva showing an undamaged cuticle with intact epidermal layer (black arrow). B) *C. titillator* cuticle of Ivermectin-treated larva showing mild degradation and reduction in thickness (black arrow). C) *C. titillator* muscle in an untreated larva showing well-developed striated muscles (red arrow). D) *C. titillator* muscle of Ivermectin-treated larva showing degeneration and fragmentation (green arrow). E) *C. titillator* fat bodies of untreated larva showing well-developed lipid droplets. F) *C. titillator* fat bodies of Ivermectin-treated larvae with necrosis and a reduction in the size of lipid droplets (green arrow). G) *C. titillator* gut of untreated group showing columnar cells with a large nucleus and a strong basophilic cytoplasm (black arrow). H) *C. titillator* gut of Ivermectin treatment with mild degeneration in the epithelial cells lining the food channel (green arrow).

### *Cephalopina titillator gut*

The gut tissue of the control showed the epithelium resting upon a basement membrane consisting of columnar cells with a relatively large nucleus and a strong basophilic cytoplasm. A detached sheath is known as a peritrophic membrane enclosing the lumen to shield the epithelium from food particles. The brush border present in the epithelial cells of the midgut exhibited a consistently tight and intact structure (Fig 1G). However, after Ivermectin treatment, mild degeneration was observed in the epithelial cells lining the food channel, characterised by the protrusion of cells and a thinning of the brush border (Fig 1H).

### *Immunohistochemical results*

### *PCNA*

The immunohistochemical analysis for PCNA in untreated larvae revealed positive nuclear staining in the gut epithelium (Fig 2A), indicating proliferative activity. In contrast, larvae treated with Ivermectin exhibited decreased PCNA immunostaining in the gut epithelium that indicate an decreased regenerative activity after Ivermectin induced insult (Fig 2B). For

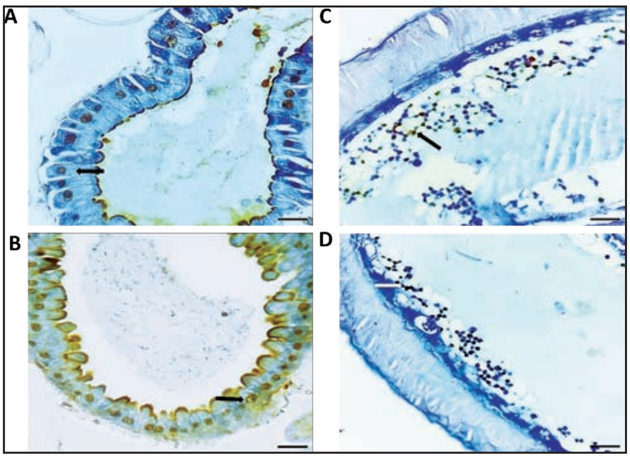


**Fig 2.** Comparative immunohistochemical analysis of PCNA expression in *C. titillator* larvae (x400). A) untreated larvae, showing positive nuclear PCNA staining in the gut epithelium (black arrow). B) larvae treated with Ivermectin revealed reduced PCNA staining in the gut epithelium (black arrow). C) untreated larvae, showing positive nuclear PCNA staining in the immune cells (white arrow). D) larvae treated with Ivermectin, revealing no change in PCNA staining in the immune cells (white arrow). Scale bar = 100 µm.

immune cells, no change in staining was detected between treated and untreated groups (Fig 2C and D).

### *Caspase 3*

The immunohistochemical examination for caspase 3 in the cuticle of untreated larvae showed no positive staining (Fig 3A). However, larvae treated with Ivermectin displayed positive caspase 3 immunoreactivity in the cuticle (Fig 3B)

The immunohistochemical examination for caspase 3 in fat body cells of *C. titillator* untreated larvae showed no positive caspase 3 staining (Fig 3C). While larvae treated with Ivermectin displayed positive caspase 3 immunoreactivity (Fig 3D).

The immunohistochemical examination for caspase 3 in Gut Cells of *C. titillator* untreated larvae showed no positive caspase 3 staining (Fig 3E). But, Gut cells of larvae treated with Ivermectin, displayed positive caspase 3 immunoreactivity, suggesting induced apoptosis in these regions (Fig 3F).

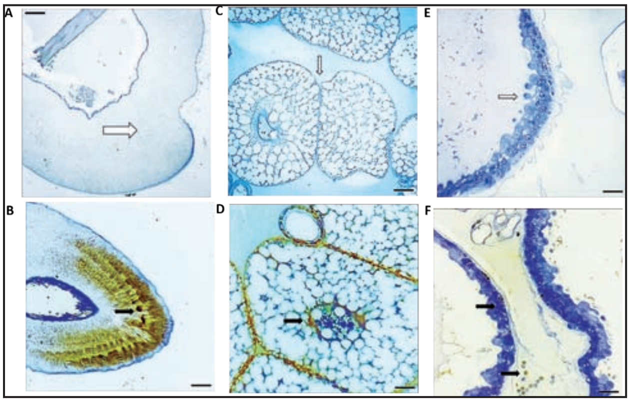


**Fig 3.** Immunohistochemical profiling of Caspase 3 expression (x400). A) Cuticle of *C. titillator* untreated larvae with no positive caspase 3 staining (white arrow). B) Cuticle of larvae treated with Ivermectin, displaying positive caspase 3 immunoreactivity (black arrow). C) fat body cells of *C. titillator* untreated larvae showing no positive caspase 3 staining (white arrow). D) fat body cells of larvae treated with Ivermectin, displaying positive caspase 3 immunoreactivity (black arrow). E) Gut Cells of *C. titillator* untreated larvae with no positive caspase 3 staining (white arrow). F) Gut cells of larvae treated with Ivermectin, displaying positive caspase 3 immunoreactivity, suggesting induced apoptosis in these regions (black arrow). Scale bar = 100 µm.

## Discussion

There have been reports of tropical botflies (*C. titillator*) infesting camels (*Camelus dromedarius*) in Iraq (Al-Ani *et al,* 1991), Libya (El-Rahman, 2010), Saudi Arabia (Banaja and Ghandour, 1994), Sudan, and Iran (Oryan *et al,* 2008). Many investigations on parasite infections in camels in Jordan have discovered infestations of *C. titillator* (Al-Ani *et al,* 1998).

Ivermectin binds to glutamate-activated chloride channels in nematode nerve and muscle cells with high specificity and affinity. This binding leads nerve or muscle cells to become hyperpolarised, increasing the chloride ion's permeability across the cell membrane. As a result, the larvae become immobile and eventually perish (Pemberton, 2001).

Ivermectin is hypothesized to be neurotoxic in larvae because it activates glutamate-gated chloride ion channels. Increased permeability to chloride ions and hyperpolarisation of nerve cells causes paralysis and death in the larvae. In addition to the enhanced activity of GABA-gated chloride channels. Because mammals lack GluCls channels and have a lower affinity for other mammalian chloride channels, they are frequently unaffected. These drugs do not alter GABA-gated channels in the mammalian CNS because they do not penetrate the blood-brain barrier (Salman *et al,* 2022).

Ivermectin showed a dose-dependent effect on *C. titillator* larvae, with higher concentrations producing more dead larvae (Aljasim *et al,* 2024). The histological investigation revealed modest degradation of the cuticle, degeneration of the muscle layer, necrosis and reduced lipid droplet size in the fat body layer, and mild epithelial cell degeneration and brush border thinning in the gut tissue. These data suggest that Ivermectin may impair larval integrity, mobility, energy storage, and food absorption, potentially leading to a general decline in larval health.

Proliferating cell nuclear antigen is a key component of nucleic acid metabolism that is involved in replication and repair. It is expressed in the nuclei of cells throughout the DNA synthesis phase of the cell cycle, as well as in the DNA damage tolerance pathway known as post-replication repair (Kelman, 1997). The immunohistochemical investigation shows a more ubiquitous PCNA staining, albeit with lower intensity staining, indicating reduction in both cell proliferation and tissue regeneration in the Ivermectin-treated group. The findings show a considerable reduction in PCNA staining, showing that cellular proliferation, which is required for tissue repair and regeneration, has been hindered. This restriction may provide long-term obstacles to larval growth and development because of a reduced ability to replace damaged or dead cells.

Caspases are cysteine-aspartic acid proteases and have recently received a lot of interest due to their critical involvement in tissue differentiation, regeneration, and neurological development. This enzyme is a critical zymogen in cell apoptosis and is not activated until it is cleaved by initiator caspases during the apoptotic process (Nadendla *et al,* 2025; Porter and Janicke, 1999; Snigdha *et al,* 2012). They are important regulators of programmed cell death. Among these, caspase-3 is a frequently activated death protease that catalyses the particular cleavage of numerous critical cellular proteins. An increase in caspase-3 immunoreactivity in Ivermectin-treated larvae suggests increased apoptotic activity, particularly in the cuticle, certain fat body cells, and basal gut epithelial cells. These findings highlight the ability of Ivermectin to cause cellular stress, impair normal cellular functioning, and promote apoptosis in treated larvae. Concurrently, caspase-3 staining increases, indicating increased apoptotic activity in a variety of larval organs, including the cuticle, fat body cells, and basal gut epithelial cells. Although apoptosis is a typical component of development and tissue maintenance, its excessive occurrence may cause tissue degeneration and reduced functionality (Shu *et al,* 2018).

Ivermectin may cause hyperpolarisation of fat body cell membranes, inhibiting the uptake of lipids, carbohydrates, and proteins, which results in smaller cytoplasmic inclusions. The presence of these small inclusions may also indicate stress in larvae exposed to ivermectin, suggesting the mobilisation of energy reserves for detoxification. This is consistent with previous findings that attribute insecticide resistance in some mosquito larvae to the action of detoxifying enzymes (Alves *et al,* 2004).

## Conclusions

This study provides novel insights into the antiparasitic action of Ivermectin on the larvae of *C. titillator*, the causative agent of camel nasal myiasis. Histopathological and immunohistochemical evaluations revealed significant structural alterations in treated larvae, including degeneration of epithelial and muscular tissues, vacuolisation, and cellular disintegration. These findings confirm that Ivermectin disrupts key biological systems within the parasite, ultimately leading to its death. These results confirm that Ivermectin exerts its larvicidal effects through multiple pathways—disrupting protective barriers, compromising mobility and energy storage, and inducing programmed cell death. The findings underscore Ivermectin's efficacy as an antiparasitic agent against *C. titillator* larvae infestations in camels.

## Authors' contributions

Conceptualisation: Y.A., A.A., M.A., S.A., I.A., A.An. and M.K.; methodology: Y.A., A.A., M.A. and M.K.; software: M.K.; formal analysis: M.A., and M.K.; resources: A.A., M.A. and M.K.; data curation: Y.A., A.A., M.A. and M.K., project administration: S.A., and I.A., writing original draft preparation: Y.A. and M.K.; writing, review and editing: Y.A., A.A., M.A., S.A., I.A. and A.An.


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## Declarations

There is no conflict of interest.

## Ethics approval

KFU-REC-2022-NOV-ETHICS308.

## Consent for publication

Not applicable.

## Data availability and sharing policy

Data can be requested from the corresponding author upon reasonable request.

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# THREE DECADES OF CHANGE: CORRELATION BETWEEN DROUGHT SEVERITY AND CAMEL POPULATION TRAJECTORIES IN ETHIOPIA (1995/96–2021/22 G.C.)

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## ABSTRACT

This study investigates the intersection of dromedary population dynamics and drought intensity in Ethiopia across a 27-year longitudinal timeframe (1995/96–2021/22). By aggregating longitudinal data from the Central Statistical Agency (CSA) and various secondary academic sources, we analysed the correlation between herd fluctuations and historical moisture stress cycles. The findings indicate an unprecedented 700% increase of the national camel herd, which grew from a baseline of 1 million to 8.12 million animals. Although brief population dips were noted in 2009 and 2013, the species demonstrated rapid geometric recovery. A significant demographic skew was observed, with females comprising the majority of the population a result of the selective market off-take of males for the meat trade. Analysis confirms a robust positive correlation between drought severity and population growth. While ruminants suffered 40–60% mortality during extreme shocks (e.g., 2011/12), dromedary populations remained stable. This shift, termed camelisation, represents a deliberate adaptation by herders to utilise the camel as a climate resilient insurance asset. To maximise this strategic resource, we propose a four pillar framework that prioritises technological integration through solar powered cold chain systems for milk value chains, alongside a shift toward veterinary specialisation focused on dromedary specific pathologies. Furthermore, this approach advocates for enhanced financial support by providing credit facilities for species-based herd diversification and emphasises robust environmental governance to protect traditional migratory grazing corridors through formal land use planning.

**Key words:** Camelisation, climate resilience, drought severity, Ethiopia, livestock dynamics, pastoralism, sustainable production

The dromedary (*Camelus dromedarius*) possesses unique physiological adaptations that enable it to thrive in environments characterised by severe heat, high salinity and scarce nutritional resources. These biological advantages allow the species to withstand intense thermal stress and irregular foraging conditions, establishing the camel as a foundational element of pastoral economies. Beyond providing nutrition and transport, camels represent a form of mobile capital for desert dwelling communities (Zeleke and Bekele, 2001). While dromedary production spans 46 countries, the majority are concentrated in 26 African nations (Faye, 2020). The East African corridor encompassing Somalia, Sudan, Kenya and Ethiopia serves as the global hub for the species, hosting approximately 60% of the world's 38.5 million dromedaries (Faye, 2015; FAOSTAT, 2020).

Within Ethiopia, the camel is vital to the endurance of lowland populations. In contrast to the mixed-crop focus of the highlands, the eastern arid zones rely on the camel's inherent durability against environmental shocks (Bekele *et al,* 2002; Mirkena *et al,* 2018). Recent shifts in the livestock sector reveal a significant geographic expansion; camel rearing has moved into areas like the Borana zone, where numbers have surged by an estimated 200% (Coppock, 2013; Yosef *et al,* 2013). This camelisation phenomenon indicates a strategic adaptation by herders to the increasing volatility of the regional climate.

Despite their economic weight, camels have historically lacked the research attention given to other livestock. To address this data deficit, the present study reviews the 27 year population trajectory (1995/96 to 2021/22) against patterns of drought. Evidence synthesised from the Central Statistical Agency (CSA) and related literature confirms a massive 700% growth in the national herd,

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rising from 1 million to 8.12 million head over the study period (CSA, 2022).

This rapid population growth aligns closely with cycles of moisture deficit. During the extreme droughts of 1999/00, 2011/12 and 2015/16, while cattle and sheep populations faced devastating losses of 40% to 60%, camel numbers remained remarkably resilient or even increased (Shapiro *et al,* 2017). Consequently, camels function as a climate insurance mechanism for high risk households (Yosef *et al,* 2013). Transitioning this sector toward an evidence-based economy-requires modernising veterinary infrastructure, implementing solar-powered cold chains and establishing land policies that protect traditional migratory corridors.

## Materials and Methods

### *Spatial and Ecological Scope*

This investigation was bounded by the national borders of Ethiopia, prioritising the Arid and Semi-Arid Lowlands (ASALs). The geographical focus centered on the Somali and Afar regional states, along with the southern Oromia pastoral corridors (Guji and Borana zones). These areas serve as the definitive ecological habitats for the dromedary (*Camelus dromedarius*) and represent the territories most frequently impacted by high-intensity drought cycles.

### *Data Acquisition Strategy*

A 27-year retrospective longitudinal analysis was conducted, covering the period from 1995/96 to 2021/22 G.C. (equivalent to 1988–2014 E.C.). Information was synthesised from the following distinct channels:

- National Statistics: Primary longitudinal datasets were extracted from 14 official Livestock Sample Survey reports published by the Central Statistical Agency (CSA). These reports facilitated the assessment of demographic shifts and sex disaggregated population trends.
- International Databases: Validation of national trajectories was performed by cross-referencing figs with FAOSTAT livestock records.
- Climatological Records: To identify periods of catastrophic moisture stress (notably 1999/00, 2011/12 and 2015/16), we utilised the Standardised Precipitation Index (SPI) and historical meteorological archives.
- Academic Synthesis: A systematic review of peer-reviewed journals and gray literature provided the qualitative context for camelisation behaviours and pastoralist economic motivations.

### *Analytical Framework*

Statistical analysis was performed using IBM SPSS statistics (version 16.0). The analytical approach involved:

- Growth Metrics: Cumulative and annual expansion rates were determined using the 1995/96 population (approximately 1 million head) as the fixed baseline.
- Trend Modeling: We applied regression and trend analysis to distinguish between linear growth and the geometric surges observed during the final 2021/22 reporting cycle.
- Resilience Comparison: A comparative mortality assessment was conducted to measure camel herd stability against the survivability of traditional ruminants (cattle, goats and sheep) during major drought events.
- Demographic Ratios: Sex-disaggregated data were utilised to establish male-to-female ratios, allowing for an evaluation of meat-oriented off-take versus the retention of reproductive assets

## Results and Discussion

### *Camel Demographic Evolution and Sectoral Shift in Ethiopia (1995/96–2021/22 G.C)*

The 27 year trajectory of Ethiopia's dromedary population reflects a fundamental restructuring of the national livestock landscape, transitioning from marginal growth into a high-velocity expansion phase. From a mid-1990s baseline of roughly one million head, the national herd surged to 8.12 million by 2021/22 (CSA, 2022). This demographic climb was characterised by distinct volatility; the industry navigated notable contractions in 2009 and 2013, briefly falling back to the one-million mark. However, a significant turning point occurred after 2017/18, where the population moved from a steady 1.42 million into the current geometric growth cycle. This camelisation phenomenon is defined not just by volume, but by a radical geographicss reorientation. While historical dromedary hubs such as Gode, Shinille and Jijiga recorded incremental growth between 10% and 25%, the Borana pastoral corridor witnessed an extraordinary 200% population spike (Yosef *et al,* 2013). This suggests that dromedaries are no longer localised assets but are being integrated into diverse ecosystems across the country (Mirkena *et al,* 2018). The unprecedented data from the 2021/22 cycle indicates that this trend is a deliberate, adaptive response by pastoralists to replace climate-sensitive ruminants with species that offer superior survival under extreme moisture stress (Coppock, 2013; CSA, 2022).

As evidenced by the trends in figs 1 and 2, the 1995/96 period marks the lowest population density recorded in this nearly three-decade analysis. While the national herd experienced brief downturns during the mid-to-late 2000s and again in 2013 timeframes that align with intense climatic pressure the overall demographic momentum has remained overwhelmingly positive. This growth cycle reached its zenith in the most recent 2021/22 assessment, which revealed a massive expansion to over 8.1 million head (CSA, 2022). The fact that these populations continued to climb despite recurring environmental shocks reinforces the conclusion that camels are being systematically prioritised over more fragile livestock types in Ethiopia's eastern and southern peripheries (Mirkena *et al,* 2018; Yosef *et al,* 2013). This transition suggests a deliberate, strategic realignment of pastoral wealth toward species capable of surviving extreme moisture deficits.

***Longitudinal Resilience and Demographic Strategy***

While Ethiopia has a deep-rooted history of dromedary husbandry, the national herd has undergone a fundamental structural shift over the last three decades. Growth has been characterised by high-velocity expansion interrupted by periodic negative growth phases during acute moisture stress events specifically in the mid-2000s and again in 2013 and 2017 (CSA, 2022). Despite these climatic setbacks, the species' inherent durability has enabled rapid post-drought rebounds, leading to the current peak of more than 8.1 million head (Mirkena *et al,* 2018; Yosef *et al,* 2013).

***Gender-Skewed Demographics***

A longitudinal review of herd composition from 1995/96 to 2021/22 highlights a widening gap between male and female populations. Current data reveals that females now comprise approximately four fifths of the national herd, a trend driven by two distinct economic pressures (CSA, 2022). In the milk based economy, reproductive females are retained as critical biological capital to secure household nutrition and drive the birth pulse recovery following droughts (Tadele *et al,* 2018). Conversely, the meat economy targets males for domestic and international trade, leading to a high extraction rates, which suppresses their standing numbers in the census (Mirkena *et al,* 2018). These local trends align with global observations by Faye and Bonnet (2012), who noted that the rise in global camelid productivity is a result of accelerated slaughtering cycles rather than increased individual growth. While the world camel population expanded at roughly 1.5% annually over the last half century, the rate of slaughtering grew twice as fast. In Ethiopia's arid rangelands, this translates to a dual purpose strategy: the long term preservation of females for dairy and resilience and a high turnover market for males to satisfy meat demand and regional commerce.

***Long-term Population Dynamics (1995/96–2021/22)***

The 27-year retrospective analysis reveals a profound and systemic transformation in Ethiopia's livestock landscape. In 1995/96, the national camel herd was a secondary asset, estimated at approximately 1 million heads. By the 2021/22 census, this figure reached 8.12 million, representing an extraordinary 700% increase in the standing population (CSA, 2022). While the early decades of the study (1995–2013) were characterised by minor fluctuations and periodic declines most notably dipping below the 1 million mark during the drought cycles of 2009 and 2013. The post 2013 era marked a pivotal turning point. Following the 2013 recovery, the population entered a consistent upward trajectory that transitioned into a geometric increment by 2021/22. This surge moved the camel from a marginalised species to a cornerstone of the national livestock economy. This sustained expansion, occurring in direct correlation with increased drought severity, generalises a broader ecological shift known as camelisation. As traditional ruminants (cattle and sheep) succumb to the dwindling herbaceous cover and rising temperatures, pastoralists have systematically restructured their herds. The 8.12 million figure is not merely a numerical increase but an indicator of a structural adaptation strategy where the dromedary serves as a high value, climate-resilient insurance asset (Mirkena *et al,* 2018; CSA, 2022). Ultimately, the data suggests that in the face of escalating aridification, the camel has emerged as the most successful biological and economic response to climate change in the Ethiopian lowlands.

***Correlation Analysis: Drought Severity and Camel Population Trends***

The 27-year dataset demonstrates a statistically significant positive correlation between drought severity and camel population growth ($r = +0.345$, $P < 0.001$) (Fig 5 and 6). This creates a unique species

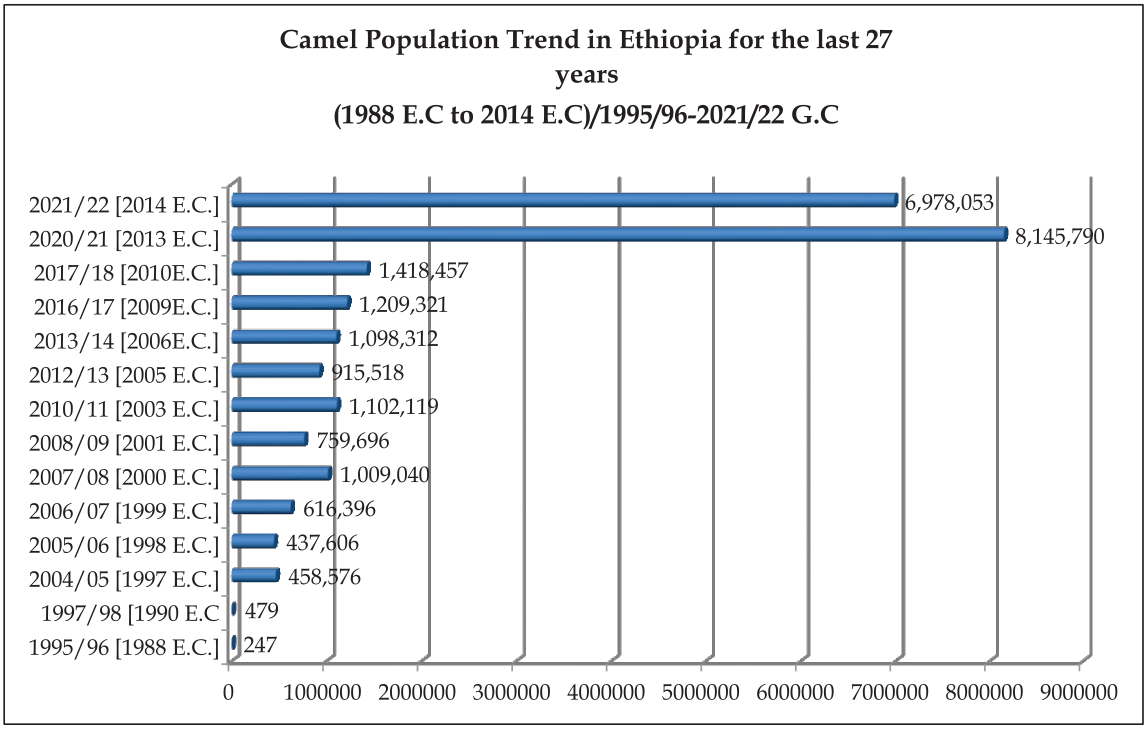


**Fig 1.** Overall camel population trend in Ethiopia for the last 27 years. Sources: CSA (author computation)

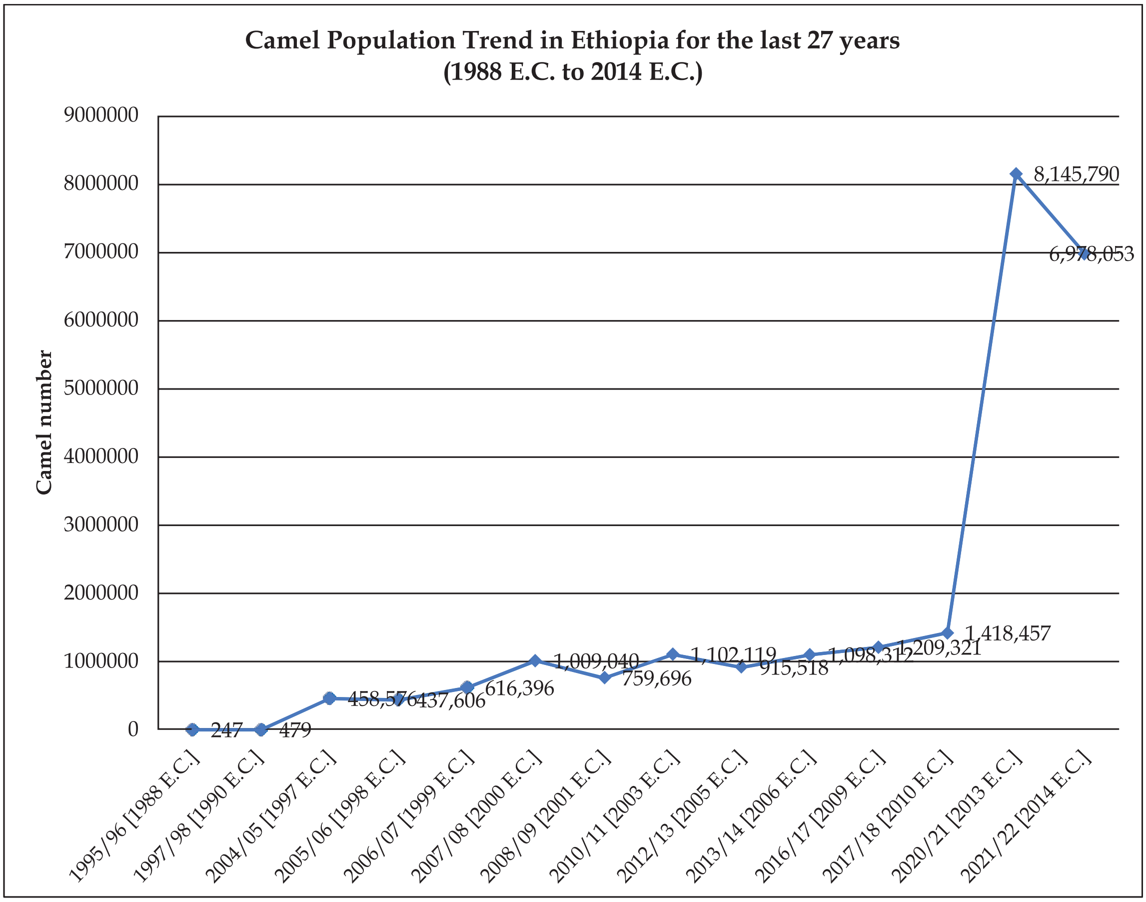


**Fig 2.** Camel population growth trend in Ethiopia. Sources: CSA (author computation).

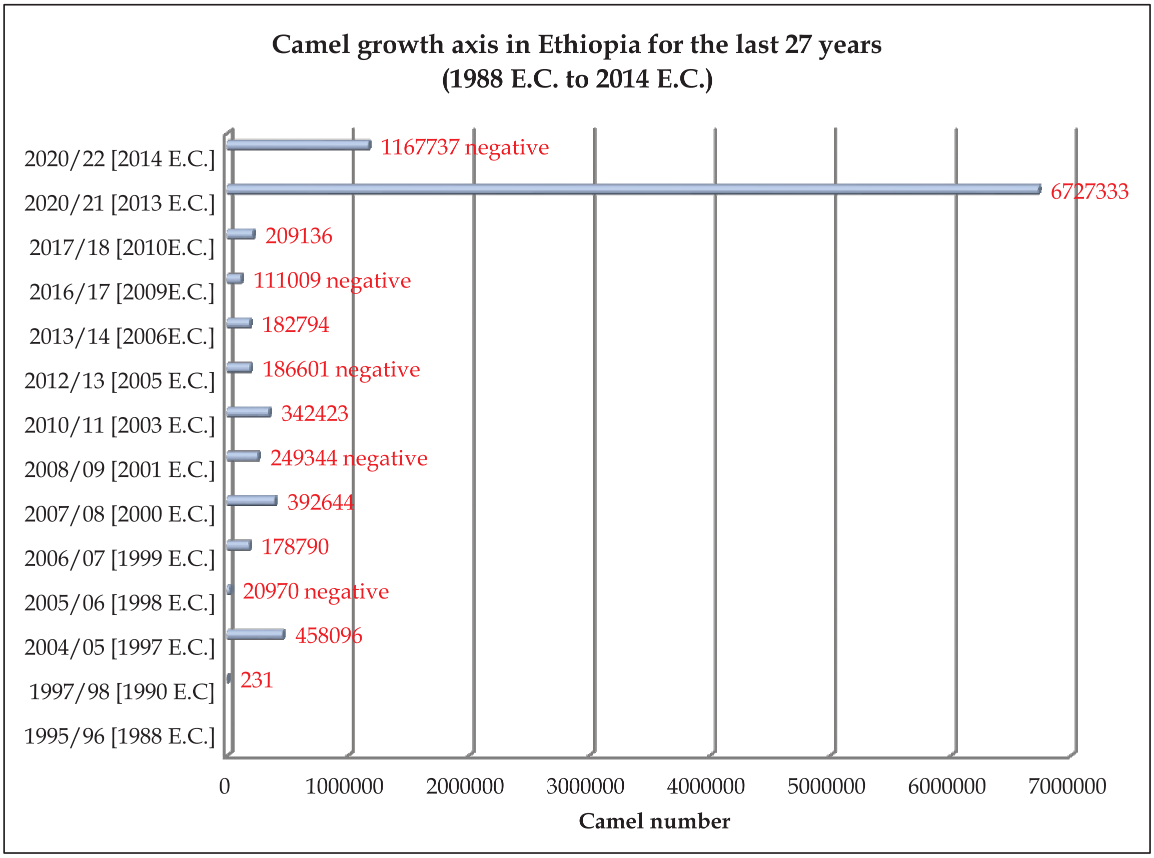


**Fig 3.** Camel population growth trend in Ethiopia. Sources: CSA (author computation).

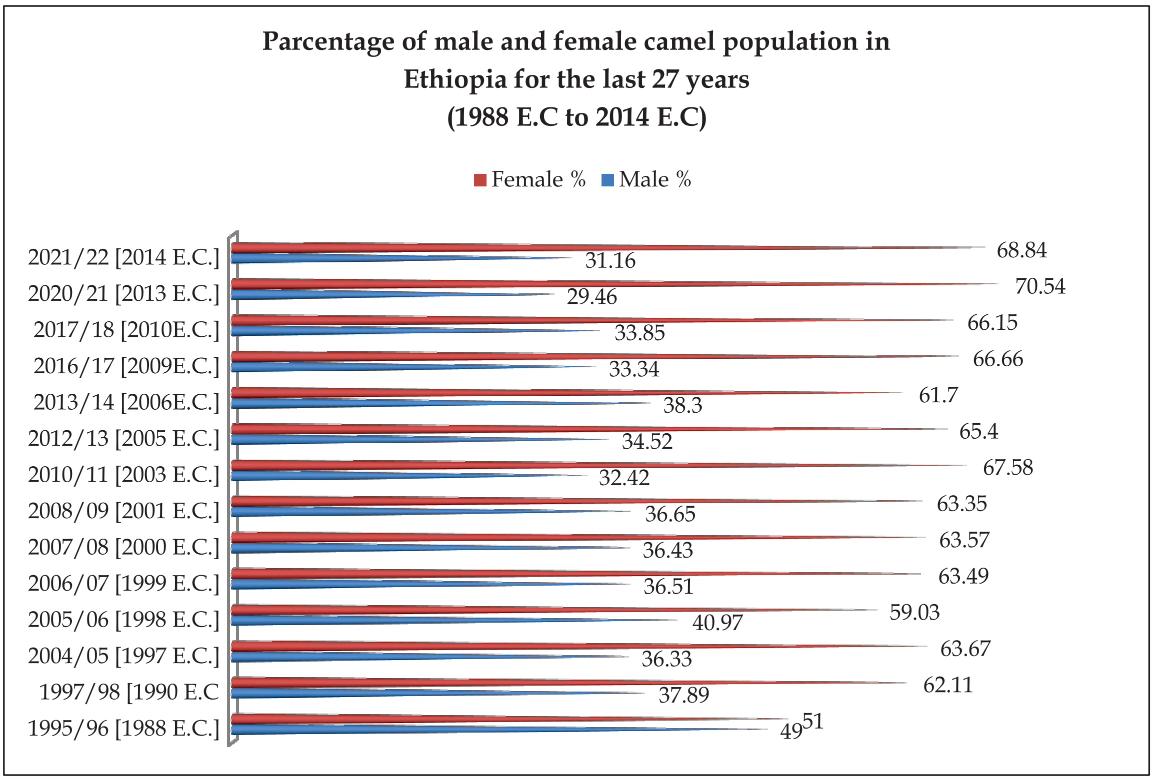


**Fig 4.** Total number of female and male camel population in Ethiopia from 1995/96 to 2021/22.

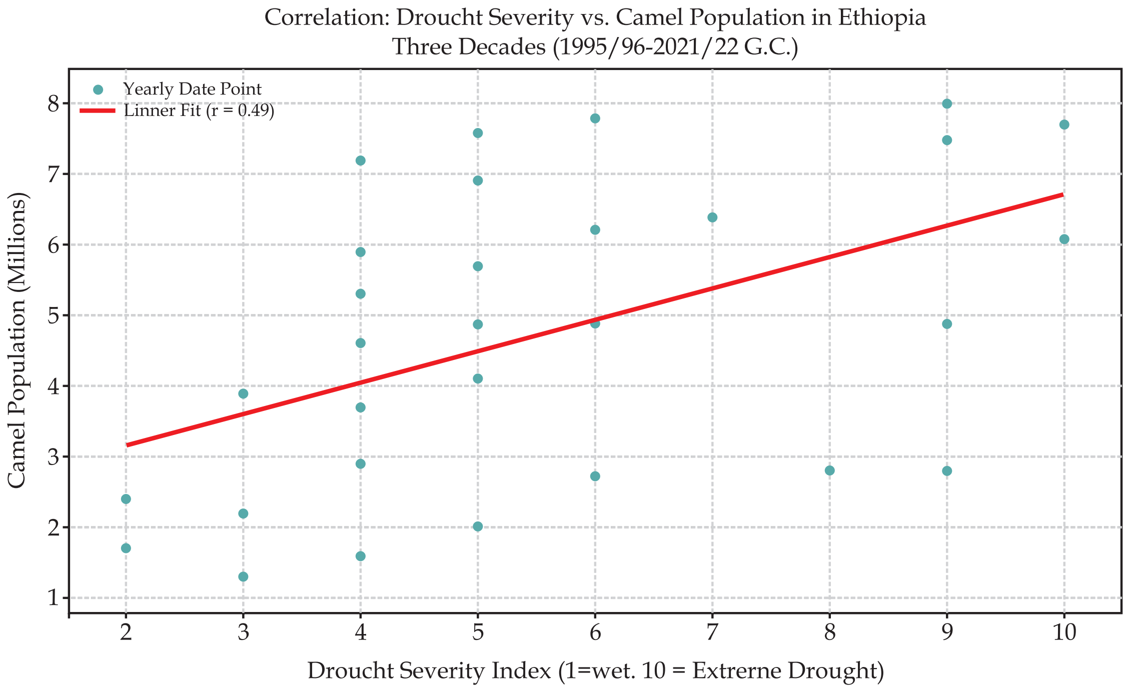


**Fig 5.** Correlation Analysis of Drought Severity and Camel Population Trends in Ethiopia.

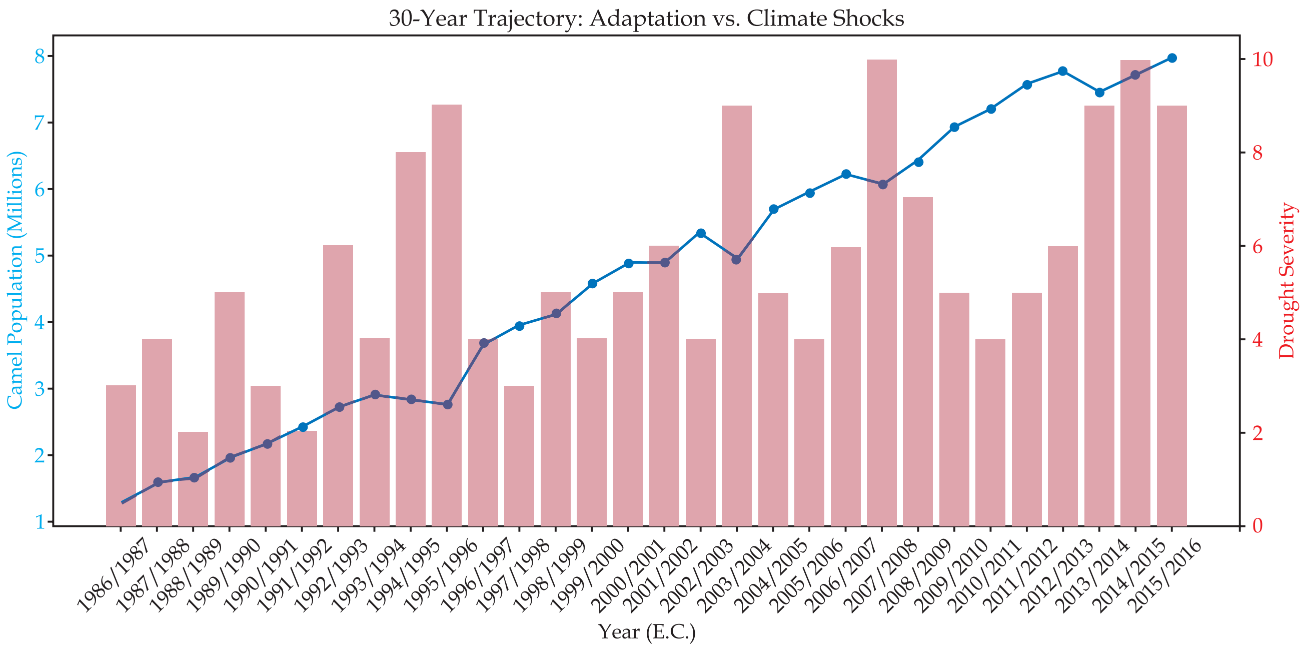


**Fig 6.** Camel adaptation and climatic shocks in Ethiopia.

decoupling effect where camels thrive during the same climatic shocks that cause catastrophic declines in traditional livestock. In Ethiopia's Arid and Semi-Arid Lowlands (ASALs), the historical drought cycle has accelerated from a decadal occurrence to a recurring stressor every two to three years. This is most acute in three primary corridors: The Somali Region: Facing extreme drought ratings, this region experienced four consecutive failed rainy seasons between 2021 and 2022 the most severe in 40 years yet remains the nation's primary camel hub (NDRMC, 2023). The Borena Zone (Oromia): Traditionally cattle-centric, Borena has transitioned toward Camelisation as a survival mechanism. Following the 2021/22 drought, which saw over 2.3 million cattle perish, camel mortality remained statistically insignificant (Tamene *et al,* 2025). The Afar Region resilience is maintained despite extreme ambient temperatures exceeding 40°C and the depletion of the Awash River tributaries (CSA, 2022).

### *Correlation between Temperature and Population Trends*

The relationship between these two variables is characterised by an adaptive shift: as temperatures rise, the population of traditional livestock (cattle) decreases while camel populations increase (Table 1).

**Table 1.** Correlation between temperature and population trends.

| Factor | Trend (Last 27 Years) | Observation |
|---|---|---|
| Global Temperature | Increasing | Mean annual temperatures in arid regions have risen by up to 3°C in specific zones (Wako *et al,* 2017). |
| Camel Population | Increasing | The global population grew from ~25 million in the late 1990s to over 35.5 million by the early 2020s (Machan *et al,* 2022; Faye, 2020). |
| Correlation | Positive | High temperatures and frequent droughts trigger a shift from cattle-based to camel-based pastoralism (Yosef *et al,* 2013). |

The correlation between rising temperatures and increasing camel populations is driven by a combination of physiological resilience, strategic pastoral adaptation and shifting ecological landscapes. Camels possess extraordinary thermo-tolerance, utilising advanced water conservation mechanisms such as the ability to withstand a body temperature increase of up to 6°C and expressing high levels of heat shock protein, which allows them to maintain productivity under thermal stress that would be fatal to other ruminants (Alkali *et al,* 2017). Consequently, pastoralists in regions like Southern Ethiopia have intentionally shifted toward camel husbandry to mitigate the high mortality rates (45–70%) seen in cattle during droughts, viewed as a vital adaptation strategy against frequent environmental shocks (Wako *et al,* 2017; Yosef *et al,* 2013). This transition is further supported by "bush encroachment," where rising temperatures and declining rainfall cause grasslands to be replaced by shrubs; as browsers, camels thrive on this shifting vegetation, ensuring a more stable food source than traditional grazing livestock (Yosef *et al,* 2013). While the camel is often viewed as the ultimate biological insurance policy against climate change, recent evidence (2021–2023) indicates that even their legendary endurance has a breaking point. The prolonged, multi-season droughts recently observed in East Africa have begun to exceed the species' physiological and reproductive thresholds. Specifically, in the Borana zone of Ethiopia, the combination of unprecedented heat and total rainfall failure has compromised the health of camel herds, leading to diminished milk production, lower calving rates and, in extreme cases, increased mortality (Machan *et al,* 2022). This suggests that the positive correlation between rising temperatures and camel population growth is not infinite; rather, it is subject to a critical threshold. If global warming continues to accelerate toward more extreme scenarios, the safety net provided by camel husbandry may fail, indicating an upper limit to how much pastoralist communities can rely on biological adaptation alone to survive a collapsing climate.

### *Regression Analysis: Rainfall Deficit vs. Species Resilience*

Regression models indicate that while cattle (r = -0.512) and sheep (r = -0.535) are highly sensitive to rainfall variability, the camel population is positively influenced by aridification trends (Table 2).

**Table 2.** Regression Analysis: Rainfall Deficit vs. Species Resilience.

| Metric | Regression Correlation (r) | Impact on Population | Reference |
|---|---|---|---|
| Rainfall Deficit vs. Cattle | -0.512 | Negative: High mortality/low birth rates | Kefyalew *et al* (2016) |
| Rainfall Deficit vs. Sheep | -0.535 | Negative: High vulnerability to water shortage | Kefyalew *et al* (2016) |
| Rainfall Deficit vs. Camel | +0.345 | Positive: Increased herd share as coping strategy | Yosef *et al* (2013) |

The paradoxical growth of camels during periods of extreme moisture stress is driven by three distinct mechanisms: Biological Decoupling: Camels can lose up to 30% of their body weight in water without fatality and forage up to 50 km away from water points. This allows them to maintain reproductive cycles while cattle populations collapse (Tamene *et al,* 2025). **Ecological Niche (Browse vs. Grass)**: Droughts trigger a crash in herbaceous biomass (grass) but often promote deep-rooted woody plants. Camels, as browsers, utilise this stable feed source that is inaccessible to cattle (Amejo *et al,* 2018). **Climate Insurance Strategy**: There is a threshold effect where every 10% decrease in annual rainfall increases the probability of a household transitioning from cattle to camels by 15–18%.

Pastoralists deliberately reinvest in camels as a high-value insurance asset to protect against future losses (Tamene *et al,* 2025). While the camel has emerged as an expanding resource, the transition from subsistence to a market-oriented sector remains hindered by infrastructure deficits. **Capitalising on this 700% growth requires**: Cold chain technology which is essential for stabilising the burgeoning camel milk market. **Specialised Veterinary Care**: Moving beyond traditional bovine medicine to address camel-specific pathologies and respiratory infections (Faye, 2020).

## Conclusion

The 27-year retrospective review of Ethiopia's livestock dynamics (1995/96–2021/22) confirms a paradigm shift in the rangeland ecosystem. The camel population has demonstrated a remarkable 700% increase, surging from approximately 1 million to a record 8.12 million head (CSA, 2022). This growth is not an isolated biological event but is positively correlated with the increasing frequency and severity of drought cycles ($r = +0.345$, $P < 0.001$).

While traditional livestock species, such as cattle and sheep, suffer catastrophic mortality rates (40–60%) during extreme moisture stress, the camel's physiological and behavioural resilience allows it to remain an expanding resource. This Camelisation of the Ethiopian lowlands most notably in the Somali, Afar and Borena regions represents a deliberate climate-adaptation strategy by pastoralists who now view the camel as a critical climate insurance asset. However, the current demographic disparity, characterised by a herd composition dominated by females (75–82%), suggests a sector still largely driven by subsistence needs and informal markets. While the camel has emerged as a cornerstone of the national economy and a biological indicator of aridification, it's full economic potential remains untapped due to infrastructure deficits and a lack of specialised documentation. To transition from spontaneous adaptation to a structured, sustainable and economically vibrant camel industry, the following interventions are recommended:

- **Investment in Value Chain Infrastructure:** The government and private sector should prioritise establishing Specialised processing units and solar powered cold chain technology. This is essential for the White Gold (milk) market to reach high value urban and international consumers while reducing postharvest losses in high-heat zones.
- **Institutionalisation of Specialised Veterinary Services:** Veterinary frameworks must evolve beyond bovine centric models. Specialised mobile clinics and research into camel specific pathologies, such as Trypanosomiasis and respiratory complexes, are required to ensure herd stability during extreme droughts.
- **Climate-Smart Financial and Policy Integration:** Financial institutions should promote Index Based Livestock Insurance (IBLI) and credit facilities specifically for camel acquisition. This enables pastoralists to divest from climate vulnerable cattle early and reinvest in resilient camel herds before the peak of drought cycles.
- **Sustainable Rangeland and Water Management:** Policy makers must protect migratory corridors and manage invasive woody species (e.g., *Prosopis juliflora*). Rather than treating bush encroachment solely as degradation, it should be managed as a vital, high-protein browse resource for camels during herbaceous collapses.
- **Enhanced Scientific and Genetic Research:** There is an urgent need for multidisciplinary research into the camel's total contribution to the National GDP. Future studies should focus on genetic improvement and optimised breeding strategies to balance sex-ratio disparities and improve individual productivity. Generally, the data proves that the pastoralist community has already identified the camel as the most viable solution to climate change. Policy must now catch up to practice. By shifting national investment from climate vulnerable cattle systems to climate-resilient camel systems, Ethiopia can secure its position as a global leader in arid-land food production and ensure the livelihood security of millions of pastoralists.

## Declarations

Availability of Data and Materials: The datasets analysed during this study were sourced from the Central Statistical Agency (CSA) of Ethiopia and published academic literature. All data sources used are fully listed and acknowledged in the reference list.

## Funding

This research received no specific grant from any funding agency in the public, commercial, or not for profit sectors.

## Ethics Approval

Not applicable. This study is a retrospective review and analysis of secondary data; it does not involve direct experimental procedures on live animals or human subjects.

## Manuscript Status and Originality

The authors confirm that this manuscript is original, has not been published previously and is not currently under consideration for publication elsewhere.

## Conflict of Interest

The authors declare that they have no competing interests or financial conflicts that could influence the findings of this study.

## Author's Contribution

KA: Conceptualisation, data acquisition, statistical analysis and drafting the manuscript. HL: Manuscript review, technical improvement and editorial coordination. Both authors have read and approved the final version.

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# THE PROXIMATE ANALYSIS OF RANGELAND PLANTS GRAZED BY CAMELS IN THE BUTANA PLAIN, GADARIF STATE, SUDAN

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## ABSTRACT

Butana plain, Gadarif State is a very important camel grazing area, but there is no available information on rangeland characteristics and plants nutritive value in the area. Consequently, a study was conducted to furnish this information using 1x1m iron quadrate and the standard methods. Plants samples were collected, stored and used for proximate analysis. Data was statistically analysed according to the completely randomised design and Duncan's Multiple Range Test was used for means separation. Rangeland plants proximate analysis varied highly among sampling sites, areas and month. Ether extract was very low in all plants. Forbs generally had good CP (>6.5%) in all month.

**Key words:** Butana plain, camel, Gadarif state, proximate analysis, rangeland plants

Camels are important in Gadarif State, Sudan and are mainly reared in traditional systems based on rangeland plants (Darosa, 2005). However, camels' contribution to meat and dairy production in national economy is lower than expected due to many constraints. Poor nutrition is major concern for camel production due to rangeland deterioration (Mohamed, 2019; Abusuwar and Darag, 2002) and seasonal variations in feed quantity and quality (Mohamed, 2013). This situation affects animal health and performance, especially in the dry season. Information on rangeland characteristics and plants nutritive value is vital to improve rangeland conservation and exploitation (Elimam *et al,* 2026). It is well documented that these parameters are affected by rainfall (Abusuwar and Yahia, 2010; Abusuwar *et al,* 2011; Mohamed, 2013), soil (Fdial, 2013; Elimam *et al*, 2024), and site (Abusuwar and Yahia, 2010; Mohamed, 2013; Elimam, 2026). These are also affected by month (Mohamed, 2013) and seasons and years (Abusuwar and Yahia, 2010).

Rangeland plants proximate analysis is an important parameter affecting plants nutritive value. Information on rangeland plants proximate analysis in the Butana plain is limited in the Gezira State (Mohamed, 2013) and are not available in Gadarif State. Consequently, this study was conducted to furnish the proximate analysis of rangeland plants and their nutritional value to improve camel nutrition and production in the Butana plain, Gadarif State.

## Materials and Methods

### *Study area*

The study was conducted in the southern and northern areas in Butana plain, Gadarif State, Sudan. There are two climatic belts in the Butana plain, Gadarif State (Farouk and Mohamed, 1982). The first one is semi-arid in the north and northwest with summer seasonal rains from July to October with a peak in August. Average rainfall is 345-385 mm. The second belt has a wet climate in the eastern and southern parts of the state with 500 - 900 mm average rainfall and maximum mean temperature is 47°C. The northern area is in Elbutana locality in the north of Gadarif State. The Locality is bordered by central gadarif locality in the south, River Nile state in the north, Khartoum State from the west, Kassala State from the east and Gezira State from the southwest. The locality is about 30000 km$^2$ in area and livestock rearing and agriculture are the main occupations. Sampling sites in the northern area were Elekharesh, Um Ruwashid, Elhagar and Shemal Khat Elamara (North pasture area). The southern area sampling sites were Wadi Abuganafid, Wadi Abugrad, Elaadeed, Altakoon, south- east Elsaada and Wadi Abumatarig. The survey was conducted from August to October

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as the area was bare after that due to extensive overgrazing.

### *Rangeland characteristics*

An iron quadrate (1×1m) was used to determine rangeland herbs (grasses and forbs) characteristics. The quadrate was thrown four times on different sampling sites. Plants in the quadrat were identified, counted, weighed and stored in paper bags. Shrubs and trees samples were collected and stored in paper bags. Plant samples were air dried in the laboratory, grinded using a laboratory grinder (1 mm screen) and stored in polyethene bags for laboratory analysis.

### *Laboratory analysis*

Plants samples were used for proximate analysis according to AOAC (1990). Nitrogen free extract (NFE) was calculated by subtracting the sum of CP, CF, EE and ash from 100. Organic matter (OM) was calculated by subtracting ash from 100.

### *Statistical analysis*

Data was statistically analysed according to the completely randomised design using the general linear model procedure (SPSS, version 20). Duncan's Multiple Range Test was used for means separation.

## Results and Discussion

Rangeland plants proximate analysis varied highly among sampling sites and areas. It also varied between month (August and September). Ether extract was very low in grasses and forbs. Ash and NFE varied highly among plants in September and October.

Table 1 shows that grasses and forbs proximate analysis varied highly in the southern area in August. Ether extract was very low in grasses, forbs, shrubs and trees in the two areas.

Grasses and forbs proximate analysis varied highly and significantly ($P<0.05$) among plants, except for CP in grasses in the southern area in August. In grasses CP, NFE and ash were higher in Donbolab and least in Asslug. Ether extract and CF were higher in Asslug and least in Donbolab. Asslug had the highest CF, EE and least CP, NFE and ash. Crude protein was >6.25% in all forbs and was highest in Bassal elkilab and least in Hantout. Ether extract was highest in Eiffian and least in Bassal elkilab and CF was highest in Eiffian and least in Turba. Ash was highest in Hantout and least in Eiffian and NFE was highest in Turba and least in Bassal elkilab. Bassal elkilab had the highest CP and least EE and NFE and Eiffian had the highest EE and CF and least ash.

Table 2 shows rangeland plants proximate analysis in August in the northern area of the Butana plain, Gadarif State. Forbs proximate analysis varied highly among plants. Crude protein was >6.25% in about half of the plants and was highest in Sikaryan and least in Khudra and Sanamaka. Crude fibre was

**Table 1.** Rangeland plants proximate analysis in August in the southern area of the Butana plain, Gadarif State, Sudan

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Grasses: Asslug | $95.37\pm0.25^{bc}$ | $4.53\pm0.91^{e}$ | $7.06\pm0.41^{b}$ | $1.18\pm0.62^{bc}$ | $16.78\pm0.39^{b}$ | $66.20\pm2.38^{c}$ |
| Donbolab | $96.5\pm0.04^{a}$ | $5.17\pm0.25^{e}$ | $4.71\pm0.93^{c}$ | $0.82\pm0.63^{cd}$ | $17.75\pm0.68^{a}$ | $71.10\pm1.59^{a}$ |
| Forbs: Bassal elkilab | $95.32\pm0.29^{c}$ | $12.20\pm0.26^{a}$ | $10.72\pm0.35^{a}$ | $0.09\pm0.01^{d}$ | $12.23\pm3.58^{c}$ | $59.99\pm3.83^{e}$ |
| Hantout | $95.55\pm0.04^{c}$ | $6.57\pm0.25^{d}$ | $9.17\pm0.14^{b}$ | $1.82\pm0.65^{ab}$ | $17.72\pm0.52^{a}$ | $60.25\pm0.92^{e}$ |
| Turba | $96.25\pm0.03^{b}$ | $7.4\pm0.10^{c}$ | $3.49\pm0.10^{d}$ | $0.62\pm0.09^{cd}$ | $12.57\pm0.59^{c}$ | $72.17\pm0.63^{b}$ |
| Eiffian | $94.57\pm0.07^{d}$ | $9.37\pm0.31^{b}$ | $11.10\pm0.50^{a}$ | $2.60\pm0.00^{a}$ | $9.51\pm1.03^{d}$ | $62.03\pm1.03^{d}$ |
| Overall mean | $95.60\pm0.68$ | $7.54\pm2.70$ | $7.71\pm3.00$ | $1.19\pm0.93$ | $14.59\pm15.13$ | $65.29\pm11.44$ |

Means followed by different letters were significantly different at $P<0.05$.

**Table 2.** The proximate analysis of rangeland plants in August in the northern area of the Butana plain, Gadarif States, Sudan.

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Forbs: Hantout | $94.76\pm0.07^{d}$ | $8.40\pm0.30^{b}$ | $12.55\pm3.74^{d}$ | $0.01\pm0.01^{d}$ | $6.90\pm1.63^{d}$ | $66.49\pm5.06^{b}$ |
| Sharaya | $94.11\pm0.02^{f}$ | $10.73\pm2.11^{a}$ | $11.66\pm0.89^{d}$ | $0.77\pm0.01^{d}$ | $12.39\pm2.13^{b}$ | $58.55\pm0.96^{d}$ |
| Sanamaka | $94.55\pm0.01^{e}$ | $3.60\pm0.56^{c}$ | $21.56\pm2.31^{c}$ | $1.41\pm0.13^{c}$ | $6.88\pm1.13^{e}$ | $61.09\pm1.25^{c}$ |
| Khudra | $95.42\pm0.08^{b}$ | $3.60\pm0.17^{c}$ | $13.80\pm1.07^{d}$ | $1.68\pm0.57^{c}$ | $9.20\pm0.67^{c}$ | $67.13\pm0.12^{a}$ |
| Sikayran | $96.19\pm0.12^{a}$ | $10.96\pm1.12^{a}$ | $12.89\pm5.71^{d}$ | $0.45\pm0.01^{d}$ | $12.53\pm0.03^{a}$ | $62.50\pm0.81^{c}$ |
| Shrubs and trees: Seyal | $93.84\pm0.04^{g}$ | $7.47\pm1.08^{b}$ | $26.73\pm0.96^{b}$ | $3.38\pm0.15^{b}$ | $4.220.04^{f}$ | $52.04\pm1.143^{e}$ |
| Kitir | $94.57\pm0.05^{a}$ | $3.60\pm0.17^{c}$ | $37.62\pm0.90^{a}$ | $1.17\pm0.39^{c}$ | $5.79\pm0.44^{f}$ | $45.81\pm1.18^{f}$ |
| Overall mean | $94.82\pm0.72$ | $6.48\pm3.26$ | $18.44\pm9.39$ | $1.40\pm0.29$ | $8.27\pm18.15$ | $59.09\pm10.03$ |

Means followed by different letters were significantly different at $P<0.05$.

highest in Sanamaka and least in Sharaya and EE was highest in Khudra and least in Hantout. Ash was highest in Sikaryan and least in Sanamaka and NFE was highest in Khudra and least in Sharaya. Sanamaka had the highest CF and least CP and ash and Sikayran had the highest CP and ash. Forbs overall mean CP, EE and NFE were higher in the southern area than in the northern one, but overall mean CF and ash were higher in the northern area than in the southern one. Trees and shrubs CP was higher in Seyal and lower in Kitir and CF was higher in Kitir and lower in Seyal. Ether extract was higher in seyal and lower in Kitir and ash was higher in Kitir and lower in Seyal. Nitrogen free extract was higher in Seyal and lower in Kitir. Seyal had the higher CP, EE and NFE and lower CF and ash. Kitir had the higher CF and ash and lower CP, EE and NFE.

Table 3 shows that rangeland plants proximate analysis varied highly and significantly ($P<0.05$) among grasses, forbs, shrubs and trees in September in the southern area of the Butana plain, Gadarif State.

Grasses CP was highest in Abolisag and least in Muhutriba and CF was highest in Tuffa and least in Muhutriba in the southern area. Ether extract was highest in Abolisag and least in Tuffa and ash was highest in Muhutriba and least in Abolisag. Nitrogen free extract was highest in Muhutriba and least in Tuffa. Abolisag had the highest CP and EE and least ash and Tuffa had the highest CF and least EE and NFE. Muhutriba had highest ash and NFE and least CP and CF. Forbs CP was highest in Safari and least in Eiffian and CF was highest in Hantout and least in Lablab ahmar. Ether extract was highest in Sureeb and least in Gubbain and Tabar. Ash was highest in Gubbain and least in Umlibaina and NFC was highest in Umlibaina and least in Fagus. Gubbain had highest ash and least EE. Shrubs and trees CP was highest in Sonut and least in Laout and CF was highest in Kitir and least in Sonut. Ether extract was highest in Laout and least in Ghabash and ash was highest in Ghabash and least in Sonut. Nitrogen free extract was highest in Sonut and least Ghabash. Sonut had the highest CP and NFE and least CF and ash and Laout had the highest EE and least CP. Ghabash had the highest ash and least EE and NFE.

Table 4 shows that the proximate analysis of September rangeland plants varied significantly ($P<0.05$) in the northern area of the Butana plain, Gadarif State.

Forbs CP was >6.25% in most plants and was highest in Sharaya and least in Umglagila. Crude fibre was highest in Hantout and least in Khudra and EE was highest in Umlibaina and least in Rabaa. Ash was highest in Tabar and least in Gubbain and NFE was highest in Umglagila and least in Tabar. Sharaya had the highest CP and Umlibaina had the highest EE. Tabar had the highest ash and least NFE

**Table 3.** Rangeland plants proximate analysis in September in the southern area of the Butana plain, Gadarif State, Sudan.

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Forbs: Turba | 92.90±0.23$^{f}$ | 5.13±0.20$^{i}$ | 13.210.33$^{kl}$ | 1.91±0.11$^{d}$ | 15.25±0.71$^{e}$ | 57.34±0.77$^{b}$ |
| Hantout | 93.44±0.06$^{cdef}$ | 5.95±0.60$^{h}$ | 28.60±0.02$^{b}$ | 0.19±0.01$^{l}$ | 14.08±0.08$^{h}$ | 44.62±0.11$^{hi}$ |
| Lablabahmar | 95.32±0.05$^{a}$ | 10.50±0.00$^{d}$ | 13.04±0.25$^{l}$ | 1.15±0.01$^{g}$ | 13.16±0.01$^{i}$ | 57.33±0.15$^{c}$ |
| Sanamaka | 94.78±1.05$^{ab}$ | 7.00±0.60$^{efg}$ | 27.17±0.02$^{c}$ | 1.02±0.02$^{i}$ | 11.73±0.22$^{l}$ | 47.73±1.03$^{gh}$ |
| Khudra | 93.67±0.02$^{cdef}$ | 7.23±0.40 | 12.27±0.03$^{m}$ | 1.08±0.01$^{h}$ | 17.76±0.23$^{b}$ | 55.28±0.54$^{f}$ |
| Gubbain | 94.19±0.17$^{bcd}$ | 10.38±0.20$^{d}$ | 21.52±0.02$^{e}$ | 1.85±0.01$^{e}$ | 9.57±0.02$^{m}$ | 50.87±0.38$^{j}$ |
| Sharaya | 92.97±0.22$^{f}$ | 13.88±0.20$^{b}$ | 15.52±0.02$^{g}$ | 2.13±0.03$^{b}$ | 15.83±0.02$^{d}$ | 45.60±0.31$^{gh}$ |
| Sikiran | 94.26±0.10$^{bc}$ | 7.12±0.53$^{ef}$ | 14.56±0.01$^{j}$ | 2.18±0.00$^{b}$ | 16.17±0.58$^{c}$ | 54.24±0.83$^{l}$ |
| Lablab | 95.44±0.02$^{e}$ | 6.30±0.35$^{gh}$ | 13.08±0.01$^{l}$ | 1.26±0.01$^{f}$ | 19.70±0.18$^{b}$ | 54.90±0.50$^{g}$ |
| Umlibaina | 93.05±0.11$^{f}$ | 11.65±0.51$^{c}$ | 15.27±0.01$^{h}$ | 2.43±0.06$^{a}$ | 138. 3±0.12$^{l}$ | 49.97±0.28$^{gh}$ |
| Tabar | 93.51±0.37$^{cdef}$ | 13.42±0.20$^{b}$ | 24.16±0.01$^{dd}$ | 0.60±0.0$^{k}$ | 21.87±0.06$^{a}$ | 33.46±0.48$^{l}$ |
| Raba | 93.24±0.15$^{ef}$ | 10.97±0.81$^{cd}$ | 13.29±0.01$^{k}$ | 0.15±0.00$^{l}$ | 14.79±0.02$^{f}$ | 54.04±0.83$^{h}$ |
| Umglagila | 94.70±1.45$^{ab}$ | 3.27±0.20$^{j}$ | 14.70±0.01$^{j}$ | 1.16±0.01$^{g}$ | 12.72±0.19$^{k}$ | 62.86±1.64$^{a}$ |
| Deraisa | 93.94±0.01$^{bcde}$ | 7.47±0.40$^{e}$ | 14.86±0.01$^{ij}$ | 0.99±0.01$^{i}$ | 14.08±0.07$^{h}$ | 56.54±0.36$^{e}$ |
| Shrubs and Trees: Kitir | 93.36±0.07$^{def}$ | 5.97±0.35$^{h}$ | 30.26±0.06$^{a}$ | 0.83±0.03$^{j}$ | 8.08±0.08$^{n}$ | 48.21±0.40$^{gh}$ |
| Laout | 93.05±0.09$^{f}$ | 16.45±0.35$^{a}$ | 24.16±0.02$^{d}$ | 1.84±0.03$^{e}$ | 14.29±0.01$^{g}$ | 36.21±2.27$^{fg}$ |
| Seyal | 92.91±0.29$^{f}$ | 6.42±1.01fg$^{h}$ | 20.70±0.01$^{f}$ | 2.02±0.01$^{c}$ | 6.57±0.06$^{o}$ | 57.21±1.32$^{d}$ |
| Overall mean | 93.81±0.91 | 8.77±3.54 | 18.61±6.04 | 1.34±0.68 | 14. 09±11.07 | 50.96±1.23 |

Means followed by different letters were significantly different at P<05.

and Umglagila had the highest NFE and least CP. In shrubs and trees CP was highest in Laout and least in Kitir. Crude fibre was highest in Kitir and least in Seyal and EE was highest in Seyal and least in Kitir. Ash was highest in Laout and least in Seyal and NFE was highest in Seyal and least in Laout. Laout had the highest CP and ash and least NFE. Kitir had the highest CF and least CP and EE and Seyal had the highest EE and NFE and least CF and ash.

Table 5 shows high variations in proximate analysis among rangeland plants in October in the southern area of the Butana plain, Gadarif State.

Forbs CP was >6.25% in all plants and was highest in Umglagila and least in Sanamaka. Crude fibre was highest in Safari and least in Sanamaka and EE was highest in Sanamaka and least in Sikayran. Ash was highest in Umglagila and least in Sanamaka and NFE was highest in Sikaryan and least in Safari. Sanamaka had the highest EE and least CP, CF and ash. Sikiran had the highest NFE and least EE and Umglagila had the highest CP and ash. Safari had the highest CF and least NFE. Shrubs and trees CP, EE and ash were highest in Laout and least in Kitir. Crude fibre and NFE were highest in Kitir and least

**Table 4.** The proximate analysis of September rangeland plants in the northern area of the Butana plain, Gadarif State, Sudan

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Forbs: Turba | 92.90±0.23$^{f}$ | 5.13±0.20$^{i}$ | 13.210.33$^{kl}$ | 1.91±0.11$^{d}$ | 15.25±0.71$^{e}$ | 57.34±0.77$^{b}$ |
| Hantout | 93.44±0.06$^{cdef}$ | 5.95±0.60$^{h}$ | 28.60±0.02$^{b}$ | 0.19±0.01$^{l}$ | 14.08±0.08$^{h}$ | 44.62±0.11h$^{i}$ |
| Lablabahmar | 95.32±0.05$^{a}$ | 10.50±0.00$^{d}$ | 13.04±0.25$^{l}$ | 1.15±0.01$^{g}$ | 13.16±0.01$^{i}$ | 57.33±0.15$^{c}$ |
| Sanamaka | 94.78±1.05$^{ab}$ | 7.00±0.60$^{efg}$ | 27.17±0.02$^{c}$ | 1.02±0.02$^{i}$ | 11.73±0.22$^{l}$ | 47.73±1.03$^{gh}$ |
| Khudra | 93.67±0.02$^{cdef}$ | 7.23±0.40 | 12.27±0.03$^{m}$ | 1.08±0.01$^{h}$ | 17.76±0.23$^{b}$ | 55.28±0.54$^{f}$ |
| Gubbain | 94.19±0.17$^{bcd}$ | 10.38±0.20$^{d}$ | 21.52±0.02$^{e}$ | 1.85±0.01$^{e}$ | 9.57±0.02$^{m}$ | 50.87±0.38$^{j}$ |
| Sharaya | 92.97±0.22$^{f}$ | 13.88±0.20$^{b}$ | 15.52±0.02$^{g}$ | 2.13±0.03$^{b}$ | 15.83±0.02$^{d}$ | 45.60±0.31$^{gh}$ |
| Sikiran | 94.26±0.10$^{bc}$ | 7.12±0.53$^{ef}$ | 14.56±0.01$^{j}$ | 2.18±0.00$^{b}$ | 16.17±0.58$^{c}$ | 54.24±0.83$^{l}$ |
| Lablab | 95.44±0.02$^{e}$ | 6.30±0.35$^{gh}$ | 13.08±0.01$^{l}$ | 1.26±0.01$^{f}$ | 19.70±0.18$^{b}$ | 54.90±0.50$^{g}$ |
| Umlibaina | 93.05±0.11$^{f}$ | 11.65±0.51$^{c}$ | 15.27±0.01$^{h}$ | 2.43±0.06$^{a}$ | 138. 3±0.12$^{l}$ | 49.97±0.28$^{gh}$ |
| Tabar | 93.51±0.37$^{cdef}$ | 13.42±0.20$^{b}$ | 24.16±0.01$^{dd}$ | 0.60±0.0$^{k}$ | 21.87±0.06$^{a}$ | 33.46±0.48$^{l}$ |
| Raba | 93.24±0.15$^{ef}$ | 10.97±0.81$^{cd}$ | 13.29±0.01$^{k}$ | 0.15±0.00$^{l}$ | 14.79±0.02$^{f}$ | 54.04±0.83$^{h}$ |
| Umglagila | 94.70±1.45$^{ab}$ | 3.27±0.20$^{j}$ | 14.70±0.01$^{j}$ | 1.16±0.01$^{g}$ | 12.72±0.19$^{k}$ | 62.86±1.64$^{a}$ |
| Deraisa | 93.94±0.01$^{bcde}$ | 7.47±0.40$^{e}$ | 14.86±0.01$^{ij}$ | 0.99±0.01$^{i}$ | 14.08±0.07$^{h}$ | 56.54±0.36$^{e}$ |
| Shrubs and Trees: Kitir | 93.36±0.07$^{def}$ | 5.97±0.35$^{h}$ | 30.26±0.06$^{a}$ | 0.83±0.03$^{j}$ | 8.08±0.08$^{n}$ | 48.21±0.40$^{gh}$ |
| Laout | 93.05±0.09$^{f}$ | 16.45±0.35$^{a}$ | 24.16±0.02$^{d}$ | 1.84±0.03$^{e}$ | 14.29±0.01$^{g}$ | 36.21±2.27$^{fg}$ |
| Seyal | 92.91±0.29$^{f}$ | 6.42±1.01$^{fgh}$ | 20.70±0.01$^{f}$ | 2.02±0.01$^{c}$ | 6.57±0.06$^{o}$ | 57.21±1.32$^{d}$ |
| Overall mean | 93.81±0.91 | 8.77±3.54 | 18.61±6.04 | 1.34±0.68 | 14. 09±11.07 | 50.96±1.23 |

Means followed by different letters were significantly different at P<0.05.

**Table 5.** Proximate analysis of rangeland plants in October in the southern area of the Butana plain, Gadarif States, Sudan

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Grasses: Taffa | 94.59±0.31$^{b}$ | 8.69±0.27$^{e}$ | 17.40±0.02$^{de}$ | 7.11±0.30$^{ab}$ | 16.81±1.04$^{a}$ | 44.57±1.42$^{b}$ |
| Forbs: Eifain | 92.70±0.09$^{e}$ | 17.10±0.26$^{b}$ | 32.32±0.67$^{b}$ | 2.62±0.51$^{de}$ | 13.42+0.47$^{d}$ | 27.24±1.01$^{c}$ |
| Sanamaka | 93.34±0.61$^{d}$ | 6.40±0.27$^{c}$ | 17.26±0.35$^{de}$ | 8.71±0.05$^{a}$ | 10.91±0.45$^{e}$ | 40.06±0.39$^{b}$ |
| Sikayran | 94.43±0.02$^{b}$ | 10.56±0.27$^{d}$ | 25.65±1.74$^{c}$ | 2.46±0.23$^{e}$ | 13.86±1.18$^{c}$ | 41.90±0.97$^{b}$ |
| Safari | 95.28±0.05$^{a}$ | 10.62±0.53$^{d}$ | 41.33±3.18$^{a}$ | 4.67±3.05$^{cd}$ | 11.69±0.44$^{e}$ | 25.31±3.47$^{d}$ |
| Umglagila | 92.59±0.16$^{e}$ | 20.30±0.35$^{a}$ | 25.62±0.97$^{c}$ | 3.78±0.17$^{de}$ | 16.60±0.86$^{b}$ | 26.26±2.10$^{d}$ |
| Shrubs and Trees: Laout | 94.66±0.15$^{b}$ | 20.58±0.26$^{a}$ | 15.49±0.45$^{e}$ | 6.06±0.1$^{bc}$ | 12.05±0.61$^{e}$ | 40.33±0.70$^{b}$ |
| Kitir | 93.79±0.04$^{c}$ | 8.69±0.27$^{e}$ | 18.79±1.81$^{d}$ | 3.54±0.22$^{de}$ | 8.67±0.28$^{f}$ | 53.99±1.80$^{a}$ |
| Overall mean | 93.92±0.96 | 14.12±4.82 | 24.24±1.77 | 4.87±2.33 | 13. 00±6.17 | 37.46±11.22 |

Means followed by different letters were significantly different (P<0.05).

in Laout. Kitir had the highest CF and NFE and least CP, EE and ash and Laout had the highest CP, EE and ash and least CF and NFE.

Table 6 shows high variations in proximate analysis of rangeland plants in October in the northern area of the Butana plain, Gadarif State.

Forbs CP was >6.25% in all plants in the northern area in October and was highest in Eifain and least in Rabaa. Crude fibre was highest in Sanamaka and least in Eifain and EE was highest in Sanamaka and least in Eifain. Ash was highest in Eifain and least in Sanamaka and NFE was highest in Rabaa and least in Eifain. Sanamaka had the highest CF and EE and least ash. It had the highest EE in the northern and southern areas. Eifain had the highest CP and ash and least CF, EE and NFE. Shrubs and trees CP was highest in Laout and least in Seyal. Crude fibre was highest in Kitir and least in Seyal and EE was highest in Laout and least in Kitir. Ash was highest in Laout and least in Kitir and NFE was highest in Seyal and least in Kitir. Laout had the highest CP, EE and ash and kitir had the highest CF and least EE, ash and NFE. Seyal had the highest NFE and least CP and CF.

High variations in rangeland plants proximate analysis among areas and month in the Butana plain were also reported by many workers in Butana plain (Elsadig *et al,* 2008; Elimam *et al,* 2013; Mohamed, 2013) and in different parts of the Sudan (Ahmed, 1999; Abusuwar and Yahia, 2010; Elimam *et al,* 2024). The variations among areas in proximate analysis were mainly due to variations in soil, stages of plants growth and grazing intensity. Monthly variations in proximate analysis between the southern and northern areas were mainly due to variations in rainfall, grazing intensity and stages of plants growth. The low EE in all plants (grasses, forbs and shrubs and trees) was also found in many studies (Elimam *et al*, 2013; Mohamed, 2013, Elimam *et al,* 2026) and is good for camels due to absence of gallbladder.

In August Donbolab highest CP and least CF among plants in the southern area suggested high nutritive value, but it differed from that reported by many workers (Mohamed, 2013; Elimam *et al,* 2026). It had lower CP, CF, EE and NFE than that reported by Mohamed (2013). Asslug high CF and least CP indicated inferior nutritive value and it also had high tannins and alkaloids that may depress nutritive value (Elimam, M. E., personal communication). Forbs higher CP (>6.25%) in all plants suggested good nutritive value and better microbial fermentation and protein synthesis as it is above the minimum CP required for microbial fermentation (Orskov, 1982). Bassal elkilab high CP and low CF suggested good nutritive value and Turba higher NFE and low CF suggested it had relatively better nutritive value than that in the Butana plain, Gezira State (Mohamed, 2013). Forbs higher overall mean CP in the southern area than in the northern one was mainly due to higher plants diversity in the former. Sikaryan highest CP and relatively low CF and Sanamaka highest CF and least CP among forbs suggested high and inferior nutritive value, respectively. Khudra proximate analysis differed from that Observed by Mohamed (2019) and Yousif and Babiker, 1989. Seyal high CP and low CF suggested good nutritive value and Kitir low CP and high CF suggested low nutritive value. Kitir proximate analysis differed from that recorded by many authors (Elimam *et al,* 2013; Elimam *et al,* 2024).

The high variations in grasses, forbs and shrubs and trees proximate analysis in September in the southern and northern areas in the Butana Plain, Gadarif State were also found in August and were mainly due to variations in rainfall. Abolisag highest CP, EE and NFE and low CF suggested good nutritive value. Low grasses EE in September was also found in August. Taffa proximate analysis in September differed from that in Butana plain, Gezira State (Mohamed, 2013) and that found by Yousif

**Table 6.** Proximate analysis of October rangeland plants in the northern area of the Butana plain, Gadarif State, Sudan.

| Plants | DM | CP | CF | EE | Ash | NFE |
|---|---|---|---|---|---|---|
| Forbs: Eifain | 93.03±0.01$^{a}$ | 16.88±0.24$^{a}$ | 16.92±2.73$^{d}$ | 0.30±0.17$^{bc}$ | 16.62±0.04$^{a}$ | 43.49±3.34$^{d}$ |
| Raba | 93.36±0.36$^{a}$ | 8.33±1.16$^{d}$ | 19.53±0.82$^{d}$ | 0.39±0.20$^{bc}$ | 15.40±0.31$^{b}$ | 50.03±1.90$^{b}$ |
| Sanamaka | 92.87±0.17$^{ab}$ | 9.75±0.87$^{c}$ | 27.52±0.51$^{b}$ | 2.45±0.47$^{a}$ | 6.57±0.69$^{d}$ | 46.60±1.12$^{c}$ |
| Shrubs and trees: Seyal | 92.95±0.70$^{ab}$ | 4.85±0.28$^{e}$ | 23.55±0.09$^{c}$ | 0.38±0.05$^{bc}$ | 7.13±0.49$^{d}$ | 57.04±1.34$^{a}$ |
| Laout | 93.55±0.30$^{a}$ | 11.03±0.47$^{b}$ | 25.32±0.25$^{bc}$ | 0.96±0.71$^{b}$ | 8.30±0.23$^{c}$ | 48.26±1.52$^{c}$ |
| Kitir | 92.35±0.07$^{b}$ | 10.09±0.27$^{bc}$ | 35.99±4.04$^{a}$ | 0.19±0.01$^{c}$ | 7.02±0.18$^{d}$ | 39.10±3.90$^{e}$ |
| Overall mean | 93.02±0.49 | 10.16±3.74 | 24.80±6.52 | 0.78±0.87 | 10.17±9.13 | 47.42±8.07 |

Means followed by different letters were significantly different at P<0.05.

and Babikes, 1989. Eiffian low CP and moderate CF in September in the northern area suggested low nutritive value and it is also unpalatable. Tabar proximate analysis differed from that Butana plain (Elimam *et al*, 2013; Mohamed, 2013, Ibrahim *et al*. 2016) and other parts of the Sudan (Mohamed, 2019; Yousif and Babiker, 1989; Elimam *et al*, 2026). Fakha proximate analysis varied from that in Butana plain, Gezira State (Mohamed, 2013). Sonut highest CP and NFE and least CF highlighted good nutritive value and Laout high CF and least CP indicated low nutritive value and it is not preferred by ruminants. Gubeish proximate analysis varied from that reported by many workers (Ali, 2015: Mohamed, 2019; Yousif and Babiker, 1989. Kitir proximate analysis differed from that found by Mohamed (2019).

Forbs CP >6.25% in most plants in the northern area in September showed the importance of high plants diversity and it was sufficient for the least rumen fermentation and microbial protein synthesis and feed intake (Orskov, 1982). Sikayran highest CP among forbs and moderate CF suggested good nutritive value, but it is unpalatable and may be due to anti-nutritional factors. However, Hantout highest CF and low CP suggested low nutritive value. Sanamaka and Gubbain proximate analysis differed from that in the Butana plain, Gezira State (Mohamed, 2013). Laout had very high CP in September in the northern area than in the southern one and could be mainly due to variations in rainfall and leaves growth stage.

The variations in forbs proximate analysis in October in the southern area were also found in August and September and were mainly due to variations in rainfall and grazing intensity. The good CP (>6.25%) in all forbs in September and October indicated good nutritive value and was generally found in all month in the two study areas. Laout high CP and low CF were found in September. Forbs good CP (above 6.25%) in all plants in October was also found in the southern area in October and in September in the two parts of the Butana plain, Gadarif State. Eifain high CP and low CF suggested high nutritive value, but it is unpalatable and may be due to anti-nutritional factors. It had higher tannins and alkaloids (Elimam, M.E., personal communication). Laout high CP was also found in September and October, except in September in the southern area. This highlighted the importance of studying Laout as ruminants feed.

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## News

### COMMERCIAL HONEY-INFUSED CAMEL MILK


A dairy product innovation is done by Camelicious, a leading camel dairy company based in Dubai, which has expanded its portfolio of value-added dairy products by introducing the UAE's first commercial honey-infused camel milk. This product combines the nutritional benefits of camel milk with the natural antioxidant and antimicrobial properties of honey, targeting the growing consumer demand for functional and health-promoting foods. The innovation reflects the increasing diversification of camel dairy products beyond traditional fresh milk and includes flavored milk, fermented beverages, probiotic products, cheeses, chocolates, ice creams, and nutraceutical formulations. Such product diversification enhances market competitiveness, adds value to the camel dairy industry, and supports the commercialisation of camel milk in both regional and international markets.

This development illustrates the growing emphasis on functional foods and value-added processing in the global camel dairy industry, aligning with increasing consumer demand for nutritious and innovative dairy products.

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# MY JOURNEY TO CAMEL SCIENCE: FROM MOROCCO TO TUNISIE

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## ABSTRACT

This autobiographical account chronicles my professional journey in camel science, from my early inspiration in Morocco to my international engagement through the Food and Agriculture Organisation of the United Nations (FAO) in Tunisia. Growing up in a country where camels are central to the livelihoods and cultural heritage of arid and semi-arid regions, I developed a lasting interest in understanding the remarkable biological adaptations of these animals. My academic and research career at the Agronomic and Veterinary Institute Hassan II initially focused on animal physiology and health but gradually evolved toward camel physiology, clinical biochemistry, mineral metabolism, nutrition, dehydration, stress physiology, and adaptation to desert environments. Over the years, my work expanded to encompass camel health, reproduction, disease management, milk quality, and sustainable production systems through multidisciplinary research and international collaborations. Participation in FAO-led programmes provided opportunities to promote camel development through research, technical cooperation, capacity building, policy dialogue, and scientific networking across Africa and the Middle East. This journey also reflects the remarkable evolution of camel science from a relatively neglected discipline to a rapidly advancing field driven by innovations in genomics, precision livestock management, nutrition, health, and value addition of camel products. Beyond scientific achievements, the article highlights the vital role of camels in enhancing food security, climate resilience, and sustainable pastoral livelihoods in dryland ecosystems. It concludes by emphasising the importance of continued investment in research, innovation, and international collaboration to fully harness the potential of camels as strategic livestock species capable of addressing emerging global challenges related to climate change, sustainable agriculture, and rural development.

**Key words:** Camel science; *Camelus dromedarius*; camel physiology; clinical biochemistry; dehydration physiology; mineral metabolism; desert adaptation; food security; climate resilience; sustainable livestock systems; FAO; pastoral development; camel research; Morocco; Tunisia

My journey into camel science began with a profound fascination for the remarkable adaptation of camels to some of the world's harshest environments. Growing up in Morocco, where camels have always been an integral part of the cultural heritage and pastoral economy of arid and desert regions, I became increasingly aware of their unique biological characteristics and their crucial role in the livelihoods of millions of people.

As a veterinarian and researcher at the Agronomic and Veterinary Institute Hassan II, my early scientific interests focused on animal physiology and health. However, I soon realised that while considerable scientific attention had been devoted to conventional livestock species, camels remained relatively understudied despite their extraordinary capacity to thrive under challenging environmental conditions. This realisation inspired me to dedicate

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an important part of my professional life to understanding these exceptional animals.

Over the years, I pursued research aimed at uncovering the physiological and biochemical mechanisms that allow camels to withstand extreme heat, dehydration, and nutritional stress. Their unique adaptation strategies represented not only a fascinating scientific challenge but also a source of valuable knowledge for addressing the growing impacts of climate change on livestock production systems worldwide.

My work gradually expanded beyond basic research into broader issues related to camel health, production, and sustainable development. I became involved in multidisciplinary studies exploring camel nutrition, metabolism, reproductive performance, disease management, and the quality and safety of camel-derived products. Throughout this journey, I had the privilege of collaborating with scientists, veterinarians, and development specialists from different countries, all united by a common interest in advancing camel research and supporting pastoral communities.

One of the most rewarding aspects of my career has been contributing to the growing recognition of camels as strategic livestock species for food security and resilience in arid and semi-arid regions. As environmental pressures and climate variability continue to affect traditional agricultural systems, camels are increasingly acknowledged for their ability to provide milk, meat, transport, and income under conditions where other livestock species may struggle to survive.

My engagement with international organisations, particularly the Food and Agriculture Organisation of the United Nations (FAO), has provided opportunities to promote camel development at regional and global levels. Through technical cooperation projects, capacity-building initiatives, policy dialogue, and scientific networking, I have worked to strengthen the role of camels in sustainable livestock systems and to support countries seeking to enhance the productivity and resilience of their camel sectors.

Throughout my professional journey, I have witnessed a remarkable transformation in the field of camel science. What was once a relatively niche area of research has evolved into a dynamic and rapidly growing discipline attracting increasing scientific interest worldwide. Advances in genetics, genomics, animal health, nutrition, precision livestock management, and camel product valorization are opening new horizons for research and development.

Yet, beyond the scientific discoveries, camels and camel pastoralist continue to teach us valuable lessons about resilience, adaptation, and coexistence with fragile ecosystems. They remind us that sustainable livestock production is not merely a technological challenge but also a matter of understanding and respecting the biological wisdom that nature has developed over centuries.

Today, my passion for camel science remains as strong as ever. I continue to advocate for greater investment in research, innovation, and knowledge sharing to unlock the full potential of camel production systems. I firmly believe that camels will play an increasingly important role in addressing future challenges related to food security, climate change adaptation, and sustainable rural development.

Looking back, my journey into camel science has been both a professional endeavor and a personal commitment. It has allowed me to contribute to a field that combines scientific excellence, practical relevance, and meaningful impact on the lives of pastoral communities. It is a journey that continues, driven by curiosity, innovation, and an enduring respect for one of nature's most extraordinary animals.

Prof. Mohammed Bengoumi (Morocco/FAO) is internationally recognised as one of the leading camel physiologists and clinical biochemists. His research has focused primarily on camel clinical biochemistry, mineral and trace element metabolism, nutrition, stress physiology, dehydration, and metabolic adaptation to desert environments. He has authored or co-authored more than 100 scientific publications, many in collaboration with Dr. Bernard Faye and other leading camel scientists.

## Important Publications

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# MY JOURNEY TO CAMEL SCIENCE: AYRES ROCK TO ABU DHABI

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## ABSTRACT

An obsession with unusual animals led me to pursue a veterinary career as a Zoovet only to end up in specialising in one "exotic" species, the camel. This interest led me to initially be involved with chasing wild Australian camels in the Australian desert and then being employed to manage the world's longest animal endurance race in 1988. As a result of this I was offered the opportunity to go to Abu Dhabi where I could truly "specialise "in many aspects of veterinary medicine with this incredible animal.

**Key words:** Camels, cloning, embryo transfer, racing

I didn't find camels, they found me. My dream job out of Melbourne University in 1977 was to be a "Zoovet" having been obsessed with snakes, lizards, frogs and our Australian marsupials as a teenager. My heroes were Gerald Durrell and zoovet David Taylor so I found myself extremely lucky to apprentice at both Taronga and Melbourne Zoo under the watchful eyes of Dr Ted Finnie and Dr Ray Butler in my last two years of my Veterinary Science degree at Melbourne University. Imagine my delight to get my first job out of University in late 1977 in nearby Bacchus Marsh, splitting my time between being a mixed practice veterinary assistant at the Bacchus Marsh Vet Clinic and the Bacchus Marsh Lion Safari as their first ever veterinarian. The name itself was misleading as the establishment, set on about 200 acres of land not far from Melbourne, boasted not only lions, but a menagerie of creatures including tigers, buffalo, many species of monkeys, various gazelle, crocodiles, marsupials and of course a good number of dromedary camels.

### Australia and my "Early Camels Days"

Nothing could have prepared me for the "Lion Park" despite it being my dream. When things went wrong at the park it was always on an epic scale. The gate between the Tiger and Lion enclosures being left open, escaping baboons, not to mention the Himalayan Tahr and Barbary Sheep jumping the fences to escape to the Australian Bush. Looking back the camels were the "easy" animal in some ways. I do remember however, my first camel anaesthetic, having called Dr Ray Butler and being told he'd never had to do one on a camel, I experimented with my Tiger/Lion combination only to watch the camel stagger around in circles for 5 minutes before rolling 40 metres down an incline. I learnt one thing quickly, they were tough! Fast forward two years later and I had left Bacchus Marsh and had set up practice on the Southern Gold Coast at Tweed heads with friend and colleague Dr Doug Cluer. Truth be known we chose the location because the surfing was great, but also there was a large private zoo nearby at Coolangatta which certainly provided a lot of challenges for me, even if they didn't have any camels. But the Gold Coast and Northern NSW environs had several camel owners and word got around that I had some experience. A camel character called Paddy McHugh sought my advice and treatment on several occasions and soon I discovered there was a big event being planned for the 1988 Bicentennial of Australia. The world's longest Animal Endurance event, a 3,250 km Camel race from Ayres Rock to the Gold Coast with $100,000 prize money and a documentary film crew to boot, showing off the adventure and dramas while trying to turn us into "movie stars".

So, I took the risk and signed up to be Head Veterinarian and part time Race Director, dragging my wife Patti and two young daughters away from home for 5 months to prepare for and then supervise 69 camels and 170 odd people in the most insane adventure of our lives. Paddy and I embarked on a few trips to the wilds of Central Australia with the purpose of catching wild camels and training them and looking at their physiology regarding training

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for a long-distance race. I had to come up with a set of racing rules like that of endurance racehorses, that would protect the animal's welfare. The race would be broken into stages with separate prizes plus a major cash prize for the overall winner. We all survived the ordeal and so did the camels and the race was documented in a film unsurprisingly called "The Great Australian Camel Race". However, it was that during the ordeal a famous horse trainer and movie identity, Mr Heath Harris appeared out of the Australian Desert Sands to change my life forever and to offer me a job in Abu Dhabi helping to set up a Camel Hospital and Research Institute working for then the Crown Prince, H.H. Sheikh Khalifa Bin Zayed Al Nahyan. Obviously, I had to finish the race first, but having done that we jumped at the chance for an adventure overseas, even if we weren't quite sure where Abu Dhabi was!

**Abu Dhabi and "Real " Racing Camels**

I arrived in Abu Dhabi with Doug Cluer and Heath Harris in September 1988 thinking I knew something about camels. It was made clear very early that our job was to make His Highness's camels the fastest on the Arabian Peninsula. However, it was clear the athletic ability of a 700 kg Australian Camel walking and trotting over hundreds of kilometres at a time was very different to a 350 kg Arabian Racing Camel racing over eight kilometres. We were comparing pickup trucks to a Ferrari. We needed a plan and so started my scientific journey into the world of elite ''Arabian Racing Camels" (Saltin and Rose, 1994)

We developed a two-pronged approach. Our main competition had faster camels and more of them. So, we needed to "Breed Better" and "Race Better". Before we knew it we were working with world famous horse and human exercise physiologists, Professor's Reuben Rose, David Evans and Bengt Saltin. We had camels running on treadmills on 3 degree inclines at 30 km an hour. I'm not sure who was more nervous, Doug and I or the camels. At the same time we started our pioneering work in assisted reproduction with world expert and friend Dr Angus Mckinnon, we were busy that's for sure.

Things moved very swiftly particularly with our reproductive achievements. First we managed the world's first birth of a camel calf from embryo transfer in January 1991, followed by first multiple E.T. calves born from champion female Sumha, six calves born in April 1991 (McKinnon *et al,* 1994). Frozen Embryos resulted in a first E.T. birth of two camel calves on 13$^{th}$ of February 1995 and then in March 2001 we produced identical twins (Fig 3) from splitting a single hatched blastocyst (Tinson *et al,* 2001).

Further advances occurred with our general facilities and in 2008 we built a purpose-built surgical facility (Fig 4) which allowed us to deal with various racing injuries and reproductive challenges (Tinson *et al,* 2014). We continued with more work in artificial insemination (A.I.) and reported a few births from frozen semen using A.I. (Tinson, 2013). Interestingly the surgical facilities became central in our cloning research that started in 2019 in collaboration with our Korean colleagues led by Professor Hwang Woo Suk. We were using laparotomy techniques to collect ooytes and surgically transfer cloned embryos. This work is now being taken on as a "commercial" project producing up to 300 cloned pregnancies a season. The "resurrection of Mabrokan" was probably our "crowning" achievement resulting in the birth of 11 cloned camel calves from a famous male beauty camel "Mabrokan" that had died in 2010, and subsequently cloned embryos were created from stored skin fibroblast DNA (Hossein *et al,* 2021) (Fig 5 and 6). In terms of my scientific journey, it is hard to compare any of it to the first moment I held the first born Mabrokan calf in my arms knowing he had died 10 years earlier and yet here he was "Back in Black" (as the A/C song goes!).

My last five years has seen me step away from racing to a certain extent and concentrate more on our commercial E.T. and Cloning projects which keep Dr Rajesh and myself extremely busy 6 days and week 6 months of the year. But the good news for our bosses and us is that the "Breed Better and Race Better" strategy we started 38 years ago has definitely born fruit as one can see from Fig 7 which shows our trophies from the 2024/2025 racing season.

**Publications**

Clearly a big part of the scientific journey has been also documenting our work and trying to contribute to information on this incredible animal. Our first contribution was courtesy of being invited to present at the World's First Camel Conference in Dubai in 1992 (McKinnon and Tinson, 1992). My colleague Geoff Manefield and I wrote "Camels A Comphendium" with Sydney University in 1997 and more recently writing "The Camel, The Animal of the 21$^{st}$ Century'' in 2017. Speaking at numerous conferences around the world has been central to the journey, sharing information and making new friends in the camel community. A visit to Iran to lecture at

**Fig 1.** Start of Camel Race 1988- 3,250 km.

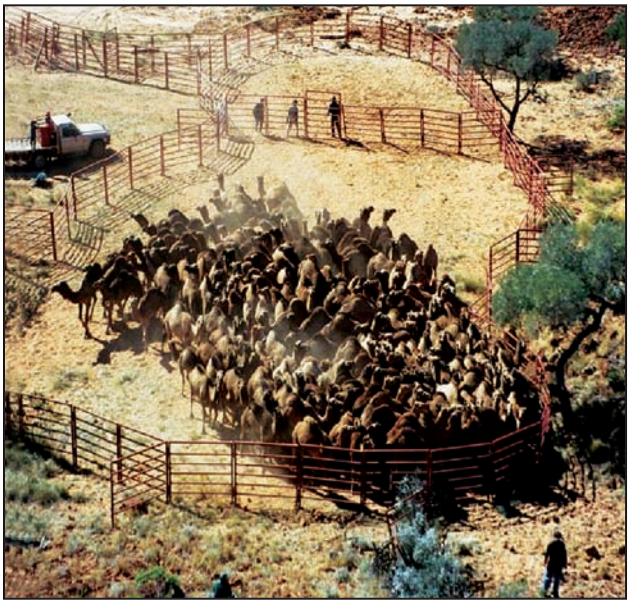

**Fig 2.** Camel Catching Central Australia 1988.

**Fig 3.** Twins at Hilli 2001.

**Fig 4.** Hilli Surgical Facilities.

**Fig 5.** Dr Rajesh, late Dr Kuhad, myself and Amit Kumar with 5 Mabrokan calves "brought back from the dead".

Tehran and Shiraz Universities in 2002 (Courtesy: Professor Amir Niasari-Naslaji) was a highlight and other excellent conference organised at Bikaner (Courtesy: Dr. T.K. Gahlot). On a tangent to my writing interests, I have also managed to write a series of children's books about "Harry the Camel", but I guess they remain more of a mental health diversion than a scientific one.

**HEFFoundation and Overseas camel interests**

Through my interest in camels, I undertook setting up a foundation to sponsor camel projects in other countries. Hef foundation (Harry's Endangered Friends Foundation) was set up in the mid 90's and managed to play a role in some environmental projects such as working with Mr John Hare and the Wild Camel Foundation in Mongolia along with

**Fig 6.** Mabrokan and me in his prime prior to his death in 2010.

**Fig 7.** His Highness the President Sheikh Mohammed bin Zayed Al Nahyan, Sheikh Mansoor Bin Zayed al Nahyan, Sheikh Sultan Bin Hamdan al Nahyan camel trainers and the rest of the "Higgin Al Riasa" racing team with trophies from 2024-25 Season.

**Fig 8.** Riding a pure white Bactrian camel gifted to me on my first visit in 2002.

**Fig 9.** Large group of curious Bactrain camels near Bulgansomme in Gobi desert.

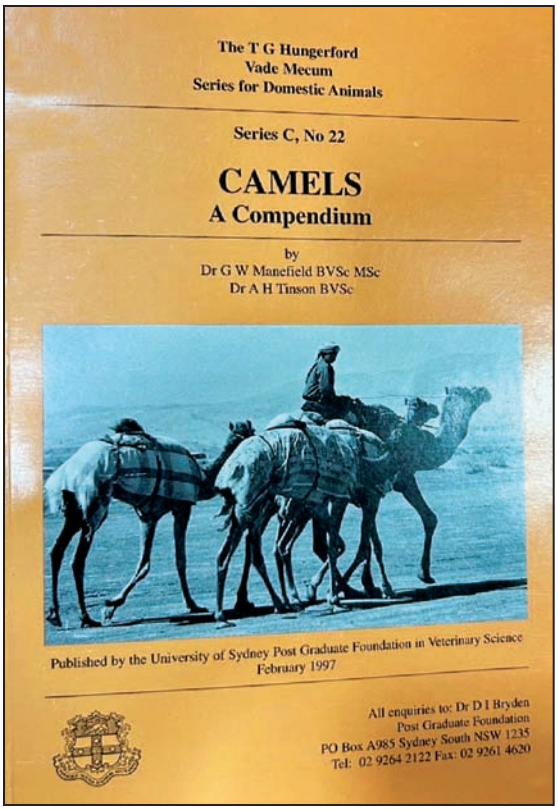


**Fig 10.** First Camel Text 1997.

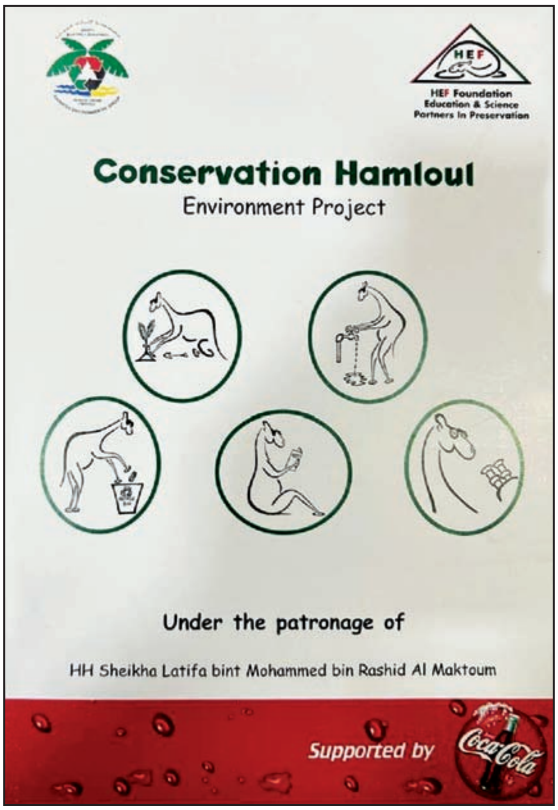


**Fig 11.** Schools HEF Project U.A.E. 2001.

Mr Batsuuri Lhagva from Ulanbataar Agricultural University. I was lucky enough to have several trips there to see the endangered Bactrian Camel project and experience the amazing people and geography before it became popular as a tourist destination. We also managed some interesting trips to India with late Dr Kuhad including visiting Nubra Valley in Indian Kashmir to see the Bactrian camels living there since the closure of the silk road during the 1960's.

Thirty-Eight Years later I am still there working with camels. I have been lucky enough to work on many pioneering projects from exercise physiology to race management and assisted reproduction including embryo transfer and cloning. I have been involved in a Camel Safari business with Doug Cluer, imported camels from Australia to the U.A.E. and even written children's books about camels. So, camels have truly taken over most aspects of my life. My oldest daughter Katya married her childhood sweetheart Khaled who is Emirati and I have four Emirati grand children, amongst my total of 10 grand children. I'm still living in the same house I arrived at in Al Ain in 1988 and still loving "the Camel Life "challenges and have somehow managed to document it all in my book "The Desert Vet.

## Acknowledgements

Besides the noble camel I would like to acknowledge chronologically the role of numerous individuals who helped and encouraged me along the journey. Mr Paddy McHugh who pushed me to spend more time working with camels. Heath Harris who relentlessly pursued me in the Australian desert to offer me the job in the Abu Dhabi, along with Dr Doug Cluer and Geoff Manefield who completed our team in the U.A.E. adventure. Dr Angus McKinnon who supported our early efforts to pioneer assisted reproduction in the dromedary camel and most importantly the Al Nahyan Royal Family who supported and encouraged all our work no matter how unusual and crazy some of our requests must have sounded at the time.

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## GENOMICS AND CAMEL HEALTH TO STRENGTHEN REGIONAL BIOSECURITY

The Abu Dhabi Agriculture and Food Safety Authority (ADAFSA), through its Camel Middle East Network (CAMENET) and WOAH Collaborating Centre for Camel Diseases, has strengthened regional biosecurity by promoting collaborative surveillance, epidemiological monitoring, laboratory standardisation, and information sharing among Middle Eastern camel-rearing countries. CAMENET enhances early detection and control of transboundary camel diseases while supporting capacity building and harmonised diagnostic protocols across the region. Concurrently, advances in camel genomics, including whole-genome sequencing and genome-wide association studies (GWAS), have enabled the identification of genetic markers associated with economically important traits such as milk yield, meat production, disease resistance, and environmental adaptation. These genomic discoveries are expected to accelerate marker-assisted selection and genomic breeding programs, thereby improving the productivity, health, and sustainability of camel populations.

(Source: Abu Dhabi Media Office, Wiley Online Library)

## DIGITAL CAMEL PASSPORTS AND TRACEABILITY


Saudi Arabia has introduced a mandatory digital Camel Passport system in which every registered camel is identified by a unique microchip linked to a centralised electronic database. The digital passport records essential information, including animal identification, ownership, pedigree (lineage), health status, vaccination history, movement records, and breeding information. Covering approximately 2.2 million camels, the system enhances livestock traceability, strengthens disease surveillance and biosecurity, facilitates rapid outbreak response, prevents livestock theft and ownership disputes, and supports genetic improvement and breeding programs. The initiative represents a major advancement in the digital transformation of camel husbandry and aligns with Saudi Arabia's broader strategy for modernising livestock management and promoting sustainable camel production.

Significance of digital camel passports for camel production is individual animal identification through RFID microchips, comprehensive digital health and vaccination records, accurate pedigree and breeding management, improved disease surveillance and outbreak control, enhanced traceability for domestic and international trade, support for genomic selection and precision livestock management and better protection against theft and fraudulent ownership claims.

This digital identification system is regarded as one of the largest national camel traceability programs worldwide and serves as a model for integrating electronic identification (EID), animal health management, and precision camel farming.

(Source of Picture: The Times of India)

# INSTRUCTIONS TO CONTRIBUTORS

**(For the year 2025 to 2027)**

**(Journal of Camel Practice and Research - triannual -April, August and December issues every year)**

The Journal of Camel Practice and Research (JCPR) is a triannual journal (April, August and December issues) published in the English language by the Camel Publishing House, 67, Gandhi Nagar West, Near Lalgarh Palace, Bikaner, 334 001 (India). It is in offset print size of 20.5x27.5 cm in two columns with a print area of 17x22 cm. It will be known as **Journal of Camel Practice and Research** with **Volume number** on yearly basis and **Number** on issues per volume basis (in exceptional cases there can be more than three issues in a volume). The editorial policies of JCPR are established by the editor-in-chief and is detailed in this section. Views expressed in papers published in JCPR represent the opinions of the author(s) and do not necessarily reflect the official policy of the author's affiliated institution, or the editor-in-chief.

**Nature of coverage:** This journal is dedicated to disseminate scientific information about new and old world camelids in form of **Original research** articles in camel science, health, husbandry, pastoralism, sports, specific behaviour, history and socio-economics. **Reports** on unusual clinical case(s) or unreported management of clinical case(s) are also published. Review articles will be accepted on invitation only. Book review directly or indirectly related to camels will be reviewed by subject-matter specialists and included if sent to the journal for this purpose. The Journal of Camel Practice and Research will occasionally contain an invited editorial commenting on the current research and papers in the issue.

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- Manuscript should have been read and approved by all the authors. All the authors mentioned in the manuscript should have agreed for authorship and it's order. An author consent letter, duly signed should accompany the manuscript as per the given format (Author in correspondence can do it). (The authorship criteria should be based on the ICMJE guidelines.)
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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).
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- Data availability

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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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Wilson R Trevor. The one-humped camel in Eritrea and Ethiopia: a critical review of the literature and a bibliography. Journal of Camel Practice and Research. 2020; 27(3):229-262.

**For edited symposium/congress/proceedings:** Abdalla HS. Camel trypanosomiasis in the Sudan. Proceedings of the First International Camel Conference, Dubai (UAE). February 2-6, 1992; pp 401-403.

**Books (Personal authors):** Faye B and Bengoumi M. Camel Clinical Biochemistry and Haematology: Springer International Publishing. 2018; pp 275-286.

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**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.

**Personal communication:** Hall LW. Reader in Comparative Anaesthesia, Department of Clinical Veterinary Medicine, Madingley Road, University of Cambridge, Cambridge, CB3 0ES, England. 1995.

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