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Review on Subclinical Mastitis in Dairy Camels

Khaled Djeddi[1], Hind Houssou[1], Siham Rabah[2], Dounia Ouchtati[1], Amira Djeddoubenabid[1] Miloudi Abdellatif[3] and Tarek Khenenou[1]

[1]Institute of Agronomic and Veterinary Sciences, Laboratory of Sciences and Techniques of the Living, Souk-Ahras University, Algeria
[2]Ministry of the Interior and the Local Governments, Tebessa Provence, Birelater, Algeria
[3]Agricultural Services department of Oued Souf Provence, Oued, Algeria
***Corresponding Author:** Khaled Djeddi, **E-Mail:** k.djeddi@univ-soukahras.dz

ABSTRACT

Camels play a crucial role as multipurpose animals, providing milk and meat and serving as a means of transportation. They serve as a financial reserve for pastoralists and hold significant cultural and social value. Camel milk, known for its exceptional nutritional properties, is considered a valuable substitute for human milk. However, udder infections, particularly mastitis, pose significant challenges to camel farming. Mastitis, especially the subclinical form, is a persistent and prevalent condition affecting milk hygiene and quality in dairy camels. This review offers insights into the prevalence, risk factors, and bacterial pathogens associated with subclinical mastitis in camels, noting its prevalence ranging from 9.28% to 87.78%. Pathogens identified include *Staphylococcus aureus*, Coagulase-negative Staphylococcus, *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, *Escherichia coli*, *Micrococcus* spp., *Pasteurella haemolytica*, and *Corynebacterium* spp. The study outlines key risk factors contributing to camel mastitis, emphasizing severe tick infestation, age, lactation stage, parity, body condition score, skin lesions on the teats or udders, anti-suckling devices, udder history, conformation, breed, unhygienic milking practices, and production system, amongst others, that have been reported to be important in the prevalence of subclinical mastitis. The findings underscore the importance of holistic management practices, emphasizing hygiene, health monitoring, and targeted interventions to ensure camel well-being and productivity in various agro-pastoral contexts.

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INTRODUCTION

In arid, semiarid, and desert areas, camel (Camelus dromedarius) livestock plays an essential role in the lives of local populations; it provides milk, meat, hair products, transportation, racing, and tourism. Thus, these activities participate in the circular local economy and offer camel herders a fair and stable income **(Alary *et al.*, 2021)**.

Camel milk holds significant dietary importance in the arid and semiarid regions of African and Asian countries. Camel pastoralists favor camel milk over other types of milk because it is highly nutritious, refreshing, easily digestible, and possesses excellent preservability **(El-Agamy, 2006)**. Like other dairy animals, dromedary camels could be affected by mastitis, a complex disease occurring worldwide among dairy animals, with heavy economic losses largely due to mastitis **(Matofari *et al.*, 2003)**.

According to the pathological signs, the inflammatory reaction in the parenchymal tissue of the mammary gland is mainly divided into clinical and subclinical forms **(Constable *et al.*, 2017)**, the latter requiring indirect means of diagnosis (Matofari ***et al.*, 2003)**. The sub-clinical mastitis in she camels is considered the most prevalent type **(Alamin *et al.*, 2013),** and it is characterized by no visible signs of inflammation or pain in the udder, no changes in milk appearance or texture, an increase in somatic cell count (SCC) in milk samples, and a potential decrease in milk production **(Archana *et al.*, 2014; Jilo *et al.*, 2017).**

The prevalence of subclinical mastitis in dairy camels varies across different regions and is influenced by various risk factors such as the number of parities, lactation stage, and production system **(Ahmad *et al.*, 2012; Aljumaah *et al.*, 2020).** According to a review study, during the last decades, cases of mastitis in dromedary camels have been reported from many of the camel-rearing countries of Africa and Asia, such as Kenya, Somalia, Sudan, Egypt, Saudi Arabia, Iraq and UAE **(Abdelgadir, 2014)**.

Bacterial infections are the primary causes of mastitis in domestic animals **(Gutiérrez *et al.*, 2004)**. For this reason, many different bacteria have been isolated from the mastitic mammary glands of she-camels. The major pathogens of mastitis in she-camels are *Staphylococcus aureus*, *Streptococcus agalactiae*, *Bacillus cereus*, *Actinomyces pyogenes*, *Escherichia coli*, *Micrococcus* spp., and *Corynebacterium bovis* **(Abdelgadir, 2014)**, in addition to *Streptococcus dysgalactiae* **(Husein *et al.*, 2013)** coagulase-negative staphylococci **(Wanjohi *et al.*, 2013)** *Pasteurella* spp., and *Pseudomonas aeruginosa* **(Al-Juboori *et al.*, 2013)**.

The mastitis following a teat or udder injury could be attributed to environmental bacteria and the normal flora of the skin and teat canal **(Wubishet *et al.*, 2016)**. Overall, these findings underscore the need for comprehensive monitoring and management practices to control subclinical mastitis in lactating dairy camel herds. Bacterial pathogens play a significant role in the etiology of subclinical mastitis, emphasizing the importance of effective diagnostic and management strategies to control this condition in dairy camel herds **(Geresu *et al.*, 2021).** Understanding the epidemiology and risk factors of the disease, as well as establishing methods for accurate detection of mastitis, are fundamental to improving udder health in camels **(Seligsohn, 2021).**

Definition and impact

Mastitis is an important disease in camels, affecting the livelihood of pastoralists **(Megersa, 2010; Wubishet *et al.*, 2016)**. The word mastitis stands for breast inflammation (mast=breast, it is=inflammation). It can be defined as inflammation of the mammary gland or the udder of dairy animals such as cows, camels, etc., regardless of the cause **(Mohamed *et al.*, 2016)** and is characterized by physical, chemical, and usually bacteriological changes in the milk **(Archana *et al.*, 2014)**. Clinical and subclinical mastitis can lead to substantial economic losses **(Toroitich *et al.*, 2017; Gramay and Ftiwi, 2018; Ali *et al.*, 2019).**

Mastitis, especially the subclinical form, is a persistent and prevalent condition affecting milk hygiene and quality in dairy camels **(Younan *et al.*, 2000; Husein *et al.*, 2013; Hadef *et al.*, 2017).** Furthermore, camel milk poses a public health concern for consumers. **(Geresu *et al.*, 2021)**. Subclinical mastitis in dairy camels is a significant concern due to its impact on milk production and animal health. In addition, the presence of subclinical mastitis has been associated with changes in milk immune cell composition and milk yield **(Aljumaah *et al.*, 2011; Al-Dughaym and Fadlelmula, 2015; Hadef *et al.*, 2020).** It has been estimated to affect more than 40% of the lactating she-camels **(Regassa *et al.*, 2013).**

Prevalence of subclinical mastitis

The prevalence of subclinical camel mastitis has been studied in various regions where camel farming is prevalent. Research conducted in countries such as Kenya, Ethiopia, Somalia, Saudi Arabia, Egypt, and the United Arab Emirates has reported varying prevalence rates **(Table 1)**. Studies in Garissa and Wajir districts of north-eastern Kenya found a prevalence of 46% to 61.2% for subclinical mastitis in camels. These findings are in accordance with an earlier published report from dromedary she-camels in Jordan **(Hawari and Hassawi, 2010)**, while another study in Somalia reported a prevalence of 9.85%.

Table 1: Positive prevalence of subclinical mastitis in some countries in dromedary camels.

Prevalence %	Country	References
87.78	Egypt	(Asfour and Anwer, 2015)
46.20	Eastern Ethiopia	(Abdelgadir *et al.*, 2005)
37.10	Southern Ethiopia	(Abdelgadir *et al.*, 2005)
45.4	Northeastern Ethiopia	(Abdelgadir *et al.*, 2005)
11.67	Abu Dhabi, United Arab Emirates	(Al-Juboori *et al.*, 2013)
44.4	Saudi Arabia	(Al-Dughaym and Fadlelmula, 2015)
9.85	Benadir Region of Somalia	(Mohamud *et al.*, 2020)
46	Isiolo County, central Kenya	(Seligsohn *et al.*, 2020)
61.2	North-Eastern Province, Kenya	(Wanjohi *et al.*, 2013)

According to **(Mohamud *et al.*, 2020)**, the prevalence of subclinical mastitis in camel herds (animal level) in the Deyniile district of Benadir Region, Somalia, at 9.85%, is lower than the prevalence reported in Abu Dhabi, United Arab Emirates (11.67% by **(Al-Juboori *et al.*, 2013)**, and 24.7% by **(Mehamud *et al.*, 2017)** and **(Megersa, 2010)** respectively , 18.1% in the Gomole District of Borena Zone, Southern Ethiopia **(Geresu *et al.*, 2021)**, 25.3% in Jijiga town of eastern

Ethiopia **(Husein *et al.*, 2013)**, 39.4% in Yabello district of Borena Zone Southern Ethiopia **(Regassa *et al.*, 2013)**, 22.2% in Borena zone of Oromia Regional State, Southern Ethiopia **(Wubishet *et al.*, 2016)**, and 24.7% in Gursum district of Hararghe Zone **(Megersa, 2010).** 47.5% in South Sinai, Egypt (**Abo Hashem *et al.*, 2020).**

The prevalence of subclinical mastitis reported in the study by **Geresu *et al.*, (2021)** at 24.7% contrasts with findings by **Megersa (2010)**, who documented a prevalence ranging from 28.6% to 37.6% in Borana areas of southern Ethiopia. This discrepancy underscores subclinical mastitis as a significant health issue in dairy camels. Variations in management systems likely contribute to the higher prevalence observed in these studies **(Mohamoud *et al.*, 2024)**. Unlike clinical mastitis, which is easily detectable and treatable in camels, subclinical mastitis often goes unnoticed by owners and facilitates infection spread within herds **(Alebie *et al.*, 2021)**, and none of the farmers routinely screen their camels for subclinical mastitis using methods like the California Mastitis Test (CMT) or others **(Imane *et al.*, 2023)**.

Earlier research **(Abdurahman *et al.*, 1995)** highlighted camels' susceptibility to mastitis, particularly in areas with poor hygiene practices and inadequate treatment protocols **(Mohamoud *et al.*, 2024)**. It is recommended to focus on various aspects to address camel mastitis. These include conducting further research, utilizing traditional knowledge, increasing the availability of alternative drugs, providing comprehensive training, and implementing improved management practices. These measures aim to reduce the prevalence and transmission of the disease. To reduce the prevalence of SCM, it will be especially important to study the effective implementation of possible interventions under pastoralist herd management and milking conditions **(Seligsohn *et al.*, 2020); Mwangi *et al.*, (2022)** recommend that the extension packages used for training camel keepers on mastitis control highlight the importance of both management and camel-level factors.

A reduced occurrence of subclinical mastitis may stem from differences in the effectiveness of diagnostic methods like the CMT, seasonal fluctuations during the study period, and the absence of bush clearing that limits tick habitat. Conversely, increased infection risks in hind quarters compared to front quarters might be linked to poor hygiene conditions and heightened exposure to dung and urine. Moreover, the shorter length of hind teats and their corresponding teat canals may diminish the defense mechanisms against pathogens in the hind quarters. **(Mogeh *et al.*, 2019)**.

According to a study by **Radhwane Saidi *et al.*, (2021), there** were 62 camels, all from an indigenous race, mainly the Sahrawi population, on seven farms in the Laghouat and Djelfa regions of southern Algeria. Breeding management followed an extensive and sometimes intensive mode, and milking was performed manually. The herd in the area of Bellil (Laghouat region) did not present any clinical or sub-clinical mastitis, which can be explained by the natural diet, where camels graze only the pastures rich in plants of medicinal interest without ever receiving supplementation.

The worldwide average camel mastitis calculated from different studies presented 45.66% of camel population suffering from subclinical mastitis starting from the lowest of 9.85% in Somalia **(Mohamud *et al.*, 2020)** to the highest of 87.78% in Egypt **(Asfour and Anwer, 2015)** on an individual study basis. Global trends of camel mastitis are noteworthy here because prevalence studies need to be revised based on the inclusion of a larger sample size **(Aqib *et al.*, 2022).**

Diagnostic of subclinical mastitis “field- lab.” Somatic Cell Count

Regarding the emerging challenges of camel mastitis, there is a significant lack of knowledge about commonly used tests for detecting subclinical mastitis in dromedary camels **(Mohamud *et al.*, 2020)**. Monitoring somatic cell count (SCC) concentration in milk is the most commonly implemented indicator for detecting mastitis, especially in its subclinical form **(Addis *et al.*, 2016)**. However, there are notable issues with current screening techniques, such as the lack of a defined SCC threshold and the presence of cell fragments, which can lead to false enumeration of SCC **(Aqib *et al.*, 2022)**.

Under normal health conditions, the somatic cells in the mammary gland are primarily macrophages, comprising 66–68% of detected cells. Other somatic cells include neutrophils, mononuclear cells, and epithelial cells. As intramammary infection (IMI) progresses, the local concentration of neutrophils increases. High SCCs, indicative of mastitis, are characterized by a significant presence of leukocytes, specifically high numbers of neutrophils, which are seen in almost 90% of subclinical mastitis (SCM) cases **(Pilla *et al.*, 2012)**. The normal levels of somatic cells, their physiological variations, and the lack of standardized SCC thresholds in Camelidae pose difficulties in both somatic cell counting and mastitis diagnosis. However, a study provided SCC readings in camels using a cut-off Log10 SCC value of 5.67 (SCC = 472.50×10^3 cells/ml) **(Aljumaah *et al.*, 2019).**

The study by **Niasari-Naslaji *et al.*, (2016)** offers valuable insights into using SCC as a gold standard for detecting subclinical mastitis in dromedary camels, facilitating early diagnosis and management. It identifies SCC levels exceeding 306,000 cells/mL as reliable indicators of subclinical mastitis in these animals. This research underscores the importance of SCC thresholds in efficiently identifying and addressing mastitis in dromedary camels.

Bacterial culturing

The gold standard for identifying mastitis pathogens is culture-based techniques. These methods involve incubating a known volume of milk on culture plates for at least 18 hours at specific temperatures to promote bacterial growth. After the incubation period, colony-forming units (CFU) are counted, and an analysis of the colony phenotype is performed to identify the pathogen. Additional biochemical tests may be conducted if necessary. Most pathogens grow readily on a variety of available culture media, either aerobically (the great majority) or anaerobically (e.g., Mycoplasma sp.). Culture plates are commercially available and relatively inexpensive, and specific media can be used to promote the growth of particular microorganisms **(Martins *et al.*, 2019).** When taking milk samples for culture, it is crucial to avoid contamination. Factors such as a dirty stall, a contaminated environment, poor udder preparation, or incorrect sampling procedures can lead to milk contamination, resulting in a high number of bacteria on the plate and false-positive results **(Ashraf and Imran, 2018; Constable *et al.*, 2017)**.

After confirming contamination, the causative agent should be identified for treatment purposes and to implement good management practices. However, bacterial culturing is expensive, time-consuming, and often impractical in pastoral settings. Therefore, investigating other indirect methods to determine the presence of intramammary infection (IMI) is essential (**Seligsohn *et al.*, 2021).**

Polymerase Chain Reaction (PCR)-based Methods

The high frequency of false negatives using culture-based methods has driven the development of molecular diagnostic tests, which offer high sensitivity and specificity and can detect growth-inhibited and non-viable bacteria. Polymerase chain reaction (PCR) is known for its high sensitivity and specificity in detecting mastitis pathogens, providing accurate pathogen identification, including those that do not grow using conventional culturing techniques **(Martins *et al.*, 2019)**.

Different types of PCR are used to identify the genomic structures of pathogens causing mastitis: conventional PCR for DNA fragment amplification, reverse transcription PCR (RT-PCR) for the detection and quantification of one pathogen, and multiplex PCR for detecting and quantifying various pathogens in the same sample. Many methods exist for detecting Staphylococcus aureus, including classical methods that take about 24 hours to yield results. In contrast, PCR is faster and more accurate, requiring about 4 hours to identify S. aureus isolates **(Izadpanah *et al.*, 2018)**.

According to **Sheet *et al.*, (2021)**, PCR is one of the best techniques for identifying *Staphylococcus aureus* isolated from camel milk by detecting the nuc gene, which is specific to *S. aureus*. The first study in Iraq by **Al-Alim *et al.*, (2023)** used PCR as the primary diagnostic molecular tool to detect *Mycoplasma*, particularly *M. bovis*, as a cause of subclinical mastitis in camels. The study concluded that *Mycoplasma*, especially *M. bovis*, is a significant causative agent of subclinical mastitis in camels, highlighting PCR as a rapid, simple, and current technique for detecting these bacteria.

Additionally, a study by **Sheet *et al.*, (2024)** employed conventional isolation and PCR methods to isolate *E. coli* from camel milk and detect virulence factors such as Stx2 and Stx1. The study concluded that the isolation of *E. coli* harboring various virulence genes, with a higher prevalence of Stx1 than Stx2, poses a public health concern.

Modern techniques of diagnosis of subclinical mastitis

1. Pen-side test

1.1. California Mastitis Test

The CMT test is rapid, inexpensive, and simple, making it one of the most common techniques for indirectly counting somatic cells in milk samples **(Schukken *et al.*, 2003)**. Its value as a screening test for early detection of subclinical mastitis in camels is widely validated through microbiological testing **(Abdelgadir *et al.*, 2005; Abdelgadir, 2014; Asi *et al.*, 2021**), making it an ideal tool for important farm management decisions. However, this method has several drawbacks: it can be slow and costly due to the chemical-reactive process, relies heavily on an expert's trained eye, and can be imprecise **(Ramirez-Morales *et al.*, 2021)**. Additionally, handling reagents on the farm poses a challenge for small farmers **(Viguier *et al.*, 2009).**

1.2. Electrical conductivity test

Ali *et al.*, (2016) reported that subclinical mastitis alters the composition of camel milk by decreasing protein, fat, and lactose content, increasing enzymatic activity, and raising electrical conductivity. They found that the electrical conductivity of mastitic milk was significantly higher than that of milk from healthy animals, attributing this to the increased somatic cell count in the milk. The increased electrical conductivity is due to the leakage of various ions and salts resulting from the heightened permeability of vascular membranes during inflammatory reactions.

However, **Hadef *et al.*, (2020) and Younan *et al.*, (2001)** noted that electrical conductivity readings were non-diagnostic in camels, and **Aljumaah *et al.*, (2019)** found the reliability of the EC test to be unsatisfactory. Additionally, **Eberlein, (2007)** suggested that while electrical conductivity values sometimes correlated with a positive CMT reaction in some camels, there was no consistent correlation with CMT, total bacterial counts, or pathogenic bacteria in other camels or even the same camels on different days. These inconsistent results regarding the variation of electrical conductivity in relation to subclinical mastitis may be influenced by factors such as breed differences, feeding, stage of lactation, parity number, and season. Furthermore, during mastitis, cell membrane permeability is altered, leading to increased leakage of blood components into the udder and changing the milk composition **(Sharif and Muhammad, 2008).**

1.3. Power of hydrogen test

pH is considered a useful indicator for detecting mastitis in camels, as it is less time-consuming, economical, and can be performed directly in the field **(Dande and Sahani, 2001)**. A recent study by **Ndirangu *et al.*, (2019)** developed and validated a novel pH-based pen-side test for detecting subclinical mastitis (SCM) in cattle and camels. The findings indicate that this method is reliable, rapid, and cost-effective at the farm level. Accelerating the registration and commercialization of this test kit, along with implementing appropriate mastitis control measures, could significantly reduce the prevalence of mastitis in the study areas in Kenya. However, according to **Hadef *et al.*, (2017, 2020)**, determining the pH of camel milk is not a suitable method for detecting subclinical mastitis in camels. They argue that milk pH can be influenced by various factors such as milk yield, lactation stage, milk composition, and the nature of fodder.

2. On-Farm Culture

2.1. Lateral flow assay

In the last decade, lateral flow assay (LFA) has gained popularity and is widely used in various biological fields due to its simplicity, rapidity, cost-effectiveness, and suitability for field deployment **(Sajid *et al.*, 2015).** This technique relies on biochemical interactions, such as antigen-antibody reactions or probe DNA-target DNA hybridization **(Bahadır and Sezgintürk, 2016)**. Lateral flow assays have been successfully developed for detecting mastitis in dairy cows, demonstrating high sensitivity and accuracy **(Alhussien and Dang, 2020)**.

These assays target specific biomarkers like myeloperoxidase (MPO) in milk neutrophils, enabling the early detection of subclinical mastitis (SCM) and clinical mastitis in cows. Additionally, lateral flow assay systems can incorporate incubators and readers for continuous monitoring and test result generation, enhancing the efficiency of mastitis diagnosis in dairy animals **(Markovsky *et al.*, 2014)**. Overall, lateral flow assays offer a promising approach for the quick and reliable detection of mastitis in dairy camels, contributing to improved milk quality and animal welfare. However, no studies specifically address the use of lateral flow assays for subclinical mastitis in dairy camels.

2.2. Chip test

Microarray technology has become an essential method for evaluating the expression of thousands of genes in tissues, aiding in understanding the biological roles of encoded proteins and protein interaction systems in gene expression patterns. This technology relies on hybridizing different types of target genes loaded onto microarray chips and visualizing them after exposure to complementary DNA (cDNA) probes bound with fluorescent stains **(Lin, 2009).**

Vidic *et al.*, (2017) reported that more than seven mastitis-causing pathogens could be detected in a single reaction using multiplex biochips. Additionally, a study by **Phiphattanaphiphop *et al.*, (2023)** designed and fabricated analytical microfluidic chips that utilize a mini-spectrometer to detect high somatic cell counts in milk. The experimental results of the microfluidic device were consistent with those of the standard Fossomatic device, achieving up to 95% precision. This suggests that the microfluidic device can detect mastitis trends in cows comparable to the Fossomatic device. These results could be used to conduct similar studies for detecting mastitis in dairy camels using the latest chip test technology.

On the other hand, microfluidic chip-based sensors offer a promising solution for continuous, non-invasive analysis of biomarkers predictive of disease. When integrated into wearable or ingestible formats, these microfluidic sensors enable mobile, animal-centric monitoring, promoting early disease detection, supporting treatment decisions, and providing insights into individual animal variations **(Zhang and Hua, 2023)**.

2.3. Milk scan

The numerous factors influencing the composition of milk make it a very complex product, complicating its analysis. Many techniques are currently implemented for milk analysis, including spectroscopic techniques such as dielectric, Raman, MIR, NIR, and Vis-NIR spectroscopy, as well as capillary electrophoresis with UV detection. However, these methods have certain drawbacks. For instance, the infrared absorption of milk components can be affected by interferences caused by light scattering of milk fat globules **(Cattaneo *et al.,* 2009)**. Various physical and chemical factors of milk, such as structure, ions, water, fat, and protein, also influence the prediction of its main components in dielectric spectroscopy.

Another widely used technique is chromatography, which is extensively utilized to separate components like fat, proteins, lactose, minerals, and vitamins in milk. Liquid chromatography (LC), in particular, has become an indispensable tool in milk analysis due to its outstanding advantages of flexibility, sensitivity, and specificity **(Imperiale *et al.,* 2023).** Milk scanning with different techniques should be investigated in dairy camels across different regions and breeds to determine the most important and effective diagnostic methods.

Bacterial causative agents of subclinical mastitis

Many infective agents have been implicated as causes of mastitis in camels, with bacterial infection being the most common. Cultures from camel mammary glands have unearthed bacteria such as *Streptococcus agalactiae*, *Staphylococcus aureus*, and various coagulase-negative *staphylococci*, alongside *Streptococcus bovis*, *uberis*, and *dysgalactiae*, echoing findings from earlier studies **(Faye and Saleh, 2011).** In Pakistan, the prominent bacterial causes of camel mastitis include *Staphylococcus aureus* (*S. aureus*), *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, and *E. coli*. **(Aqib *et al.,* 2017). Ali *et al.,* (2019)** identified a high occurrence of subclinical mastitis in camels, predominantly caused by *Staphylococcus aureus*, with isolation rates between 48.02% and 57.84%. **Al-Juboori *et al.,* (2013)** reported that *staphylococci*, particularly in their role as a primary etiological agent for both clinical and subclinical mastitis in camels, were predominant at a rate of 41.67%. This was followed by *Streptococcus* spp. (21.67%), *Enterobacter* spp. (15.00%), and *C. pyogenes* (10.00%), with these findings being consistent with other studies conducted across a range of countries, including Iraq, Saudi Arabia, Egypt, the UAE, Sudan, and India **(Table 2; Table 3).**

In a study by **Bekele *et al.,* (2011)** in northeastern Ethiopia, researchers identified several pathogens responsible for mastitis in camels. These included *Staphylococcus aureus*, *Streptococcus dysgalactiae*, *Streptococcus agalactiae*, coagulase-negative staphylococci, assorted species of *Streptococci*, *Pasteurella haemolytica*, and *Escherichia coli*. **Husein *et al.,* (2013)** identified coagulase-negative staphylococci as the leading cause of camel mastitis in their research area. Furthermore, *Streptococcus agalactiae* and *S. aureus* were reported to be the most common causes of camel mastitis in Kenya **(Younan *et al.,* 2000**) and in Eastern Sudan **(Obied *et al.,* 1996).**

The study by **Hadef *et al.,* (2017)** in southeastern Algeria revealed that the etiological agents responsible for subclinical mastitis in camels included *Staphylococcus aureus*, *Staphylococcus hyicus*, *Staphylococcus intermedius*, *Staphylococcus arlettae, Staphylococcus muscae*, *Micrococcus* spp., and *Streptococcus* spp., with prevalence rates of 7.14%, 7.14%, 3.57%, 9.53%, 11.91%, 4.14%, and 2.38%, respectively.

In Jordan, **Hawari and Hassawi, (2010)** indicated that the most predominant bacterial isolates were *Micrococcus* spp., *Staphylococcus aureus*, *Streptococcus* spp., and *Corynebacterium* spp., and this is in agreement with that of **Wubit *et al.,* (2001)**. Researchers have also identified other pathogens, such as *Staphylococcus auricularis*, *Staphylococcus cohnii* spp., *Staphylococcus pettenkoferi, Staphylococcus equorum* **(Kirkan *et al.,* 2021)**, *Staphylococcus epidermidis* **(Al-Juboori *et al.,* 2013; Abdelgadir, 2014; Mohamud *et al.,* 2020),** *Staphylococcus simulans* **(Mohamed et al., 2016)**, *Klebsiella* **(Alebie *et al.,* 2021; Archana *et al.,* 2014)**, *Pasteurella haemolytica* **(Archana *et al.,* 2014)**, *Pasteurella multocida* **(Husein *et al.,* 2013)**, *Pseudomonas aeruginosa, and Providencia* spp **(Hadef *et al.,* 2017),** which can contribute to subclinical mastitis in camels.

The prevalence of *E. coli* has been reported in those studies **(Table 3)** to range between 6.3% and 17.4%. Therefore, the prevalence of *E. coli* in the study of **Toroitich *et al.,* (2017)** is higher than what has been reported earlier in other studies. The low rate of *E. coli* isolates might be partially attributed to effective udder washing and drying, post-milking teat dipping, and maintaining clean washing towels (**Wanjohi *et al.,* 2013)**. Coliforms can serve as indicators of poor hygiene conditions and, to a lesser extent, fecal contamination. Consequently, their prevalence can vary significantly depending on the hygiene standards in place **(Geresu *et al.,* 2021).** But camel feces are typically dry and do not commonly contaminate the udder skin **(Eberlein, 2007)**. However, their presence in milk cannot be entirely eliminated but can be significantly minimized through effective management and hygienic milking practices **(Hadef *et al.*, 2018)**. According to **Alebie *et al.*, (2021)**, *Bacillus* spp. were found in 19.57% of the total isolates, which is higher than the percentages reported by other studies **(Ahmad *et al.*, 2012; Archana *et al.*, 2014; El Tigani-Asil *et al.*, 2020; Geresu *et al.*, 2021; Hadef *et al.*, 2017; Husein *et al.*, 2013; Mengistu *et al.*, 2010; Woubit *et al.*, 2001)** reported 4.3%, 10.82%, 3.57%, 3.7%, 3.48%, 9.1%, and 7.6%, respectively. The higher prevalence of *Bacillus* spp. reported in the study of **Alebie *et al.*, (2021)** could be attributed to poor milking hygiene and contamination from soil **(Table 3).**

Table 2: Coagulase positive *staphylococci* (CPS) species isolated causing the subclinical mastitis in she camels.

Country Authors	Number of animals	samples	*Staphylococcus aureus* %	*Staphylococcus hyicus* %	*S.intermedius* %
Algeria (Hadef et al., 2017)	70	153	7.14	7.14	3.57
Ethiopia (Geresu et al., 2021)	348	1392	11.9		
Sudan (Mohamed et al., 2016)		337	58.07	2.61	
Ethiopia (Abdelgadir et al., 2005)	253	956	24.7	9.6	0.9
Ethiopia (Husein et al., 2013)	384	174	4.2		
United Arab Emirates (Al-Juboori et al., 2013)	162	630	32.26		
Ethiopia (Alebie et al., 2021)	96	384	8.7	6.52	6.52
Pakistan (Ahmad et al., 2012)	150	596	26.56		
Saudi Arabia (Saleh and Faye, 2011)	30	120	16.6		
Iraq (Al-Rammahi et al., 2018)	82		10.2		
Turkey (Kirkan et al., 2021)	20	40	12.5		

Table 3: Coagulase negative staphylococci CNS species and authors Gram - species isolated causing the subclinical mastitis in she camels.

Country / Authers	Bacterial pathogens	Prevalence %
Algeria (Hadef *et al.*, 2017)	*Staphylococcus arlettae Staphylococcus muscae* *E.coli* *Bacillus sp* *????????*	9.53 11.91 10.72 3.57
Ethiopia (Geresu *et al.*, 2021)	*E.coli* *Bacillus sp*	10.5 3.7
Sudan (Mohamed *et al.*, 2016)	*Staphylococcus epidermidis Staphylococcus simulans Bacillus sp*	1.74 0.87 3.48
Ethiopia (Husein *et al.*, 2013)	*E.coli* *Bacillus sp* *Corynebacterium sp*	6.3 7.6 9
United Arab Emirates (Al-Juboori *et al.*, 2013)	*Staphylococcus epidermidis* *Corynebacterium sp*	3.23 9.67
Ethiopia (Alebie *et al.*, 2021)	*E.coli* *Bacillus sp* *Klebsilla*	6.52 19.57 4.35
Iraq (Al-Rammahi *et al.*, 2018)	*E.coli*	8.16
Turkey (Kirkan *et al.*, 2021)	*Staphylococcus auricularis* *Staphylococcus cohnii spp*	12.5 6.25 12.5

Risk factors of subclinical mastitis

The prevalence of subclinical camel mastitis varies across different regions and is influenced by various risk factors such as age, stage of lactation, parity, tick infestation, skin lesions on the teats or udders, and unhygienic milking practices, amongst others. These factors have been reported to be important in the prevalence of subclinical mastitis **(Table 4 & 5).**

Table 4: Positive correlation between occurrence of camel mastitis and risk factors.

Factors	References
Age	(Ahmad et al., 2012; Aqib et al., 2017; Geresu et al., 2021; Seligsohn et al., 2020)
Parity	(Ahmad et al., 2012; Aljumaah et al., 2011; Aqib et al., 2017; Seligsohn et al., 2020; Wubishet et al., 2016)
Stage of lactation	(Ahmad et al., 2012; Aljumaah et al., 2011; Aqib et al., 2017; Geresu et al., 2021; Seligsohn et al., 2020)
Body condition score	(Ali et al., 2019; Aqib et al., 2017; Geresu et al., 2021)
Breed	(Ahmad et al., 2012; Aljumaah et al., 2011)
Tick infestation	(Abdurahman et al., 1995; Ahmad et al., 2012; Bekele et al., 2011; Obied et al., 1996; Wubishet et al., 2016)
Anti-suckling devices	(Abdelgadir et al., 2005; Abdurahman et al., 1995; Ahmad et al., 2012; Obied et al., 1996; Wubishet et al., 2016)
Previous history of the udder	(Seligsohn et al., 2020)
unhygienic milking practices	(Wubishet et al., 2016)
Skin lesion on the teats or udders	(Ahmad et al., 2012; Regassa et al., 2013; Seligsohn et al., 2020)
Production system	(Wubishet et al., 2016)

Table 5: Negative correlation between occurrence of camel mastitis and risk factors.

Factors	References
Tick infestation	(Abdelgadir et al., 2005; Seligsohn et al., 2020)
Skin lesion on the teats or udders	(Abdelgadir et al., 2005; Wubishet et al., 2016)
Previous history of the udder	(Abdelgadir et al., 2005)
Conformation of the udder	(Abdelgadir et al., 2005)

1. Age and Anti-suckling devices

The lowest prevalence (33.33%; 15 of 45) of mastitis in she-camels was observed between 5 and 7 years of age, while the highest (80%; 12 of 15) was observed in animals aged between 14 and 16 years **(Ahmad *et al.*, 2012).** Regarding the effect of age on camel mastitis, studies such as those by **Bouchoucha *et al.*, (2023) and Faye and Saleh, (2011)** have reported varying frequencies of subclinical mastitis depending on age classifications (e.g., 60%, 67%, and 80% in different age groups). The observation that mastitis rates increase with years of camel husbandry can be attributed to several factors. Firstly, experienced farmers often manage larger herds, which require intensive management practices, including high standards of milking hygiene. This can be challenging in pastoral areas due to limited access to clean water, potentially leading to higher infection rates. Secondly, older farmers may adhere to traditional management practices such as teat tying, which can predispose camels to mastitis **(Mwangi *et al.*, 2022)**.

Furthermore, older camels may have a reduced physiological immune response in their mammary glands, making them more susceptible to bacterial penetration and subsequent mastitis development **(Abdurahman, 2006)**. However, **Regassa *et al.*, (2013)** found no significant effect of age on camel mastitis in Ethiopia, suggesting variability across different studies and regions.

Additionally, lactoferrin levels in camel milk have been noted to vary with age, with higher concentrations found in younger animals (3–4 years). Older camels may also experience teat dilation due to repeated lactations over the years, which can lead to a partially open teat canal, providing opportunities for environmental and opportunistic skin bacteria to enter **(Shittu *et al.*, 2012).** These factors collectively highlight the complex interplay between age, management practices, and physiological factors in influencing camel mastitis rates (**Schroeder, 2012)**. Furthermore, the use of anti-suckling devices was a contributing factor to camel mastitis **(Abdurahman *et***

***al*., 1995; Obied *et al*., 1996; Abdelgadir *et al*., 2005; Ahmad *et al*., 2012; Wubishet *et al*., 2016).** However, in contrast, **Seligsohn *et al*., (2020)** noted that the incidence of anti-suckling device observations was notably lower than reported in other regional studies **(Fig. 1).**

Fig. 1: Anti-sucking device **(Abdelgadir, 2014).**

2. Tick infestation and skin lesion on the teats or udders

The study conducted by **Seifu and Tafesse, (2010)** indicates that a higher prevalence of subclinical mastitis is associated with tick infestation, with nearly 98.3% of quarters infected, according to the California Mastitis Test (CMT) screening used in their research. Tick infestation serves as a predisposing factor by creating a suitable environment for microbial invasion, thereby increasing bacterial pathogenicity in the udder. This suggests that controlling tick infestations may play a crucial role in reducing the incidence of mastitis in camels (**Obied *et al*., 1996).** Ticks biting the mammary gland can initiate bacterial infections, causing skin irritation and localized inflammatory responses **(Mengistu *et al*., 2010).** This is further supported by **Amenu *et al*., (2017)**, who observed that tick bites can directly damage the skin of the teat or udder **(Fig. 2),** thereby facilitating bacterial entry and heightening the risk of mastitis. Multiple studies, including **Abera *et al*., (2010); Husein *et al*., (2013); Hadef *et al*., (2020) and Geresu *et al*., (2021)** reinforce this connection.

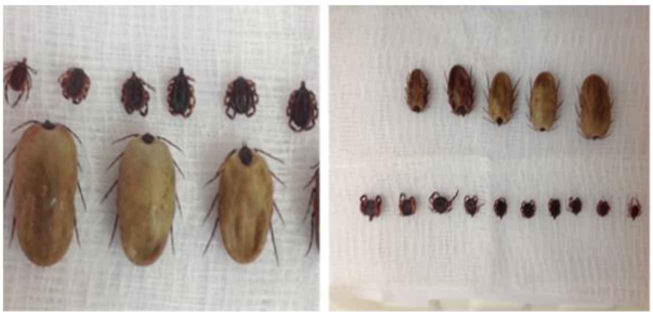

Fig. 2: Shows the infested ticks (larvae, nymph and adult stages) **(Karima *et al*., 2018).**

The skin lesions that appeared on the tick-infested camels were classified as mild, moderate, and severe lesions, depending on the degree of damage in the infested area. Moreover, the majority of the examined animals expressed severe lesions particularly on the udder **(Karima *et al*., 2018).** Skin lesions on the teats or udder in camels have been observed to be associated with subclinical mastitis, as reported by **Bekele *et al*., (2011); Ahmad *et al*., (2012); Regassa *et al*., (2013) and Seligsohn *et al*., (2020).** However, **Abdelgadir *et al*., (2005)** present contrasting findings regarding the relationship between tick infestation and teat lesions. This discrepancy might be attributed to the examination of a larger population of camels with tick infestations, in comparison to a smaller group exhibiting tick lesions (**Fig. 3).**

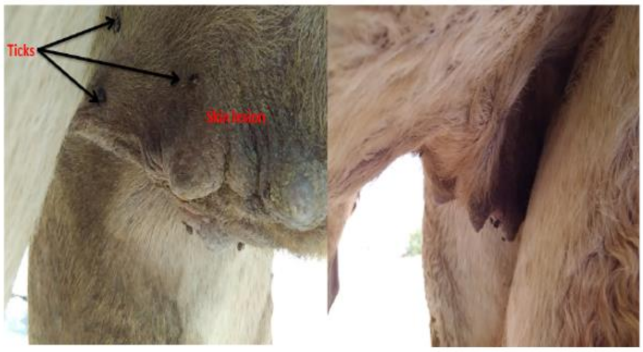

Fig. 3: Shows the severe udder lesions due to ticks infestation **(Karima *et al*., 2018).**

3. Stage of lactation and parity

The prevalence of subclinical mastitis varies across lactation stages, with higher rates in early lactation (23.33%) and mid-lactation (27.42%) but lower in the final stage, as reported by **Alebie *et al*., (2021)** and supported by **Mengistu *et al*., (2010) and Regassa *et al*., (2013).** This pattern may be influenced by traditional practices like not milking she-camels for the initial weeks post-birth, thereby reducing udder contamination **(Alebie *et al*., 2021).** The study by **Hadef *et al*., (2018)** concluded that the proportion of subclinical mastitis cases in camels did not vary significantly with different lactation stages. This finding suggests that subclinical mastitis in camels may not be strongly influenced by the specific stage of lactation, contrasting with findings in other livestock species where mastitis prevalence often varies depending on lactation phases.

However**, Suheir (S004)** observed a different trend, with mastitis cases increasing progressively from the first stage (25%) to the last stage (45%) of lactation. This variation could be attributed to other factors that were important for predisposing mastitis in she-camels, such as the hygienic milking process **(Ahmad *et al*., 2012)**. According to a study by **Ahmad *et al*., (2012),** younger camels and those in the early lactation stages are more susceptible to subclinical mastitis. Regarding the prevalence of subclinical mastitis in relation to the number of parities, **Mengistu *et al.*, (2010) and Alebie *et al.*, (2021)** found it more common in she-camels with three or more parities. This finding contrasts with **Suheir, (2004)** who noted a prevalence of 25% during the first three calvings, rising to 43.8% at the fourth and fifth calvings, before decreasing to 16.7% in later calvings. The increase in mastitis with parity might be due to diminished immune defense, altered udder morphology, and increased trauma with each parity **(Faye and Saleh, 2011).**

4. Unhygienic milking practices, conformation, and previous history of the udder

The lack of acceptable hygiene standards for milking provides a possible explanation for the spread and circulation of *Strep. agalactiae* within camel herds **(Seligsohn *et al.*, 2020).** Risk factors for *Strep. agalactiae*, such as a previous history of clinical mastitis, clinical findings of induration of udder tissue, and blind teats, all indicate that *Strep. agalactiae*-derived intramammary infections (IMI) are likely to develop into a chronic condition **(Seligsohn *et al.*, 2020).** In Oued Souf province of Algeria, **Boudalia *et al.*, (2023)** recorded that hygienic conditions throughout manual milking in the open air were poor in the transhumant system, Additionally, environmental conditions in the Sahara, such as sand storms, strong dust, and water shortages, aggravate hygienic conditions. **(Alebie *et al.*, 2021)** reported that in camel udders, the highest prevalence of subclinical mastitis was found in the right front quarter (14.6%), followed by the left front quarter (7.3%), and then the right hind and left hind quarters (both at 7.3% and 6.3%, respectively). This distribution is thought to be influenced by the camel's anatomical structure, where the narrower basin might offer better protection to the hind quarters. Additionally, the common practice of starting milking from the right front quarter could increase the risk of microbial contamination **(Alebie *et al.*, 2021).** However, in the study of **Abdelgadir *et al.*, (2005)**, there was no significance between the occurrence of mastitis and various risk factors such as the conformation of the udder and the previous history of mastitis.

Economic importance of camel subclinical mastitis

Understanding the economic impact of mastitis and the cost-effectiveness of management measures is crucial for decision-making in mastitis management. The term 'economic cost' has been proposed to replace 'economic losses,' encompassing all economic effects—including both losses and expenditures—resulting from the disease's occurrence **(Ranjan *et al.*, 2021)**. Subclinical mastitis, despite lacking clinical signs, significantly impacts the dairy industry. It leads to reduced milk production, deterioration in milk quality due to unfavorable properties, lower milk prices due to high somatic cell counts, loss of milk due to antibiotic treatment, increased costs of animal care, reduced productive life of animals, and annual losses due to decreased overall dairy production needed to meet national demands. **(Huijps, 2009)**. Additionally, consumption of contaminated milk poses a greater risk to public health and becomes a source of milk-borne diseases in humans **(Aqib *et al.*, 2022).**

Subclinical mastitis has been found to result in significant financial implications, as highlighted by various studies **(Gramay and Ftiwi, 2018; Ali *et al.*, 2019)**. Furthermore, subclinical mastitis has a greater impact on the productivity of lactating animals compared to sporadic clinical cases **(Jilo *et al.*, 2017).** The reduction in milk yield is linked to mastitis, which causes damage to mammary tissue and decreases the number and function of epithelial cells, thereby leading to reduced milk production **(Zhao and Lacasse, 2008).** There are no published reports detailing the economic impact of subclinical mastitis in dromedary camels on a daily, annual, or per-animal basis. In Algerian pastoral settings, obtaining cooperation from camel breeders is particularly challenging **(Boudalia *et al.*, 2023)**. The conditions of nomadism, remote pastures, and extensive mobility without a reliable system for identification and traceability further complicate efforts in this regard **(Gherissi *et al.*, 2020)**.

CONCLUSION

This comprehensive overview provides valuable insights into the multifaceted aspects of subclinical mastitis in camels, encompassing prevalent bacterial pathogens and diverse risk factors. Few available pieces of literature indicate that *Staphylococcus aureus*, *Streptococcus* spp., *Micrococcus* spp., *Streptococcus agalactiae*, coagulase-negative staphylococci, *Escherichia coli*, *Pasteurella haemolytica*, *Escherichia coli*, *Corynebacterium* spp., and other bacteria have been implicated as causes of mastitis in camels.

Subclinical mastitis poses a significant threat to camels, which are vital animals. Proper management of lactating camels and maintaining adequate hygienic conditions in their environment are essential to minimizing the occurrence of mastitis in the studied areas. More efforts are needed to enhance overall udder health to prevent and control subclinical mastitis in camels and to ensure the well-being and productivity of camels in various agro-pastoral contexts. Further epidemiological studies on camel mastitis are needed to gather solid scientific data on disease transmission, pathogen characterization, other possible risk factors, diagnostic methods, and the impact of the disease on public health. Proper control strategies should be adopted through early diagnosis, veterinary treatment, and the avoidance of potential risk factors to ensure good quality milk from camels. Educating camel owners about the importance of hygienic milking practices would minimize the adverse effects of mastitis on the yield and quality of camel milk. Additionally, it would be beneficial to adopt and employ advanced diagnostic methods, such as advanced molecular tests and emerging technologies. The government should build additional national laboratories and research centers to provide mastitis tests for farmers, serving as valuable tools for mastitis diagnosis and management.

Conflict of interest

No competing interests to declare regarding the research tools and data used.

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