Review Article

A COMPREHENSIVE SURVEY ON MASTITIS: DETECTION TECHNIQUES, INFRARED THERMOGRAPHY, AND STRATEGIES FOR SUBCLINICAL MASTITIS PREVENTION

M. Chengathir Selvi[1]*, M. Swarnaa[2], S.T. Veena[3], K. Kanagarajadurai[4]

Department of Computer Science and Engineering
Mepco Schlenk Engineering College
Sivakasi - 626 005

ABSTRACT

Mastitis, a prevalent inflammatory condition in the mammary gland of dairy cattle, is primarily caused by bacterial infections and results in reduced milk production and quality. There are two main types of mastitis: clinical and subclinical. Clinical mastitis is visible through symptoms such as swelling, redness, and abnormal milk secretion, while subclinical mastitis lacks visible signs but still impacts milk production and quality. The economic and health impacts of mastitis in cattle are profound, leading to reduced milk yield, increased veterinary costs, and potential culling of affected animals, contributing to substantial financial losses in the dairy industry. Traditionally, mastitis has been detected through clinical observation, somatic cell count (SCC) analysis, and microbiological tests. However, early detection, especially of subclinical cases, remains challenging. Infrared thermography (IRT) has emerged as a promising, non-invasive tool for early mastitis detection by capturing temperature variations in the udder caused by inflammation. IRT enables the identification of heat patterns associated with infections before clinical signs are visible. This study investigates the potential of IRT as a reliable and cost-effective method for early detection of mastitis in cattle, contributing to improved animal health and reduced economic losses for dairy farmers.

Keywords: Mastitis, Subclinical mastitis, Infrared thermography, Non-invasive, Somatic Cell Count, California Mastitis Test Kit.

Received : 30.09.2024 Revised : 23.12.2024 Accepted : 24.12.2024

INTRODUCTION

In India, where a significant proportion of the cattle population is dedicated to dairy farming, ensuring high productivity is crucial due to the country's dependence on dairy for nutrition and economic stability, underscoring the need for enhanced care and management to optimize yields and maintain animal health.

[1]Assistant Professor, Mepco Schlenk Engineering College.
* Corresponding Author Email Id: chengathir@mepcoenge.ac.in
[2]Junior Research Fellow, Mepco Schlenk Engineering College.
[3]Assistant Professor, Mepco Schlenk Engineering College.
[4]Assistant Professor, Veterinary University Training and Diagnosistic Centre, TANUAS, Madurai - 625 005

There are several significant threats that impact its efficiency and sustainability of dairy farming. Animal diseases such as mastitis and foot-and-mouth disease can drastically reduce milk production and increase veterinary costs. Climate change exacerbates these issues by stressing cattle through rising temperatures and extreme weather, while also affecting feed and water availability. Economic volatility, with fluctuating milk prices and global competition, challenges financial stability. Labor shortages strain farm management and animal care, and increasing environmental regulations on waste, emissions, and water usage add to operational costs .

Despite the above threats to dairy industry, the highest threat is the prevalence of mastitis in cattle. Bovine mastitis is an inflammatory response of the udder tissue in the mammary gland caused due to physical trauma or microbial infections Tommasoni *et al.* (2023). It is also caused due to bacteria or stress. It is associated with the swelling of the udder which is caused by various factors, such as contagious pathogens, poor nutrition, and ineffectual management conditions on the farm (Ajose *et al.* 2022). The principal organisms associated with mastitis are *Staphylococcus aureus, Streptococcus agalactiae, Streptococcus uberis, Escherichia coli* and *Micrococcus pyogenes* etc. These organisms usually cause a chronic mastitis and a loss in milk yield with or without the appearance of clinical symptoms (Plastridge, 1958). This leads to the infection of the udder tissue, causing a painful and inflamed udder. This not only causes animal distress but also leads to significant economic losses due to reduced milk yield, poor milk quality, increased veterinary costs, and the need for discarded milk during treatment.

This paper provides an insightful discussion on subclinical mastitis in dairy cattle. It begins with an introduction to mastitis followed by a classification of mastitis types. Detection methods are reviewed, with a focus on traditional techniques and advanced tools like infrared thermography. The paper highlights IRT as a promising, non-invasive method for early detection. Treatment approaches, including antibiotics and alternative therapies, are summarized, alongside practical prevention strategies emphasizing hygiene and management practices.

Mastitis, a complex disease affecting the mammary gland is categorized based several factors such as clinical symptoms, causative agent, duration of the disease (Cheng and Han 2020) which is shown in figure 1.

BASED ON CLINICAL SYMPTOMS

Clinical mastitis

Clinical mastitis in cattle is a significant and visible condition that severely impacts dairy operations (Cheng and Han 2020). It is characterized by a range of symptoms that affect both the udder and the quality of milk. In clinical mastitis, one or more quarters of the udder become visibly inflamed, which may present as swelling, redness, and warmth. The cow's milk also shows noticeable abnormalities, including changes in colour to yellowish or reddish hues, the presence of clots, pus, or blood, and a generally off-putting consistency that can range from watery to thick and lumpy. The cow often exhibits signs of pain and discomfort, particularly during milking or when the affected udder is touched. This discomfort is coupled with a significant decrease in milk production from the affected quarter(s), and in severe cases, from the entire cow (Plastridge 1958). Clinical mastitis can escalate to systemic symptoms such as fever, loss of appetite, dehydration, and a general decline in overall health, which can potentially lead to severe outcomes or even death if left untreated.

Subclinical Mastitis

Unlike clinical mastitis, subclinical mastitis does not show visible symptoms, making it more challenging to detect and manage clinical mastitis (Plastridge 1958). The infection is characterized based on the increase in somatic cell count (SCC) in the milk, which indicate the presence of subclinical mastitis despite the observable signs such as swelling in the udder, or abnormal milk conditions (Tommasoni *et al.* 2023). Cows with subclinical mastitis appear healthy and exhibit normal behaviour, which can make early detection difficult. However, the persistent presence of infection affects the cow's udder tissue, causing subtle damage that accumulates over time and can ultimately lead to chronic problems if not addressed.

Based on Duration of infection

Based on the number of days the infection persists in the cattle, the mastitis can be classified into 4 types as per-acute, acute, subacute and chronic mastitis (Cheng and Han 2020).

Per-acute Mastitis: This is the most severe and sudden onset form of mastitis. It develops rapidly, often within hours, and is accompanied by systemic symptoms such as high fever, rapid pulse, and significant pain. The udder is usually swollen, hot, and painful, and milk production from the affected quarter may cease completely. If untreated, per-acute mastitis can lead to death in severe cases.

Acute Mastitis: Acute mastitis develops quickly over a few days and is marked by inflammation of the udder, noticeable swelling, heat, and redness, along with abnormal milk that may contain clots or blood. Cows with acute mastitis may exhibit fever, lethargy, and a marked reduction in milk yield. Immediate treatment is required to prevent permanent damage to the udder and further complications.

Subacute Mastitis: This form of mastitis is milder than acute mastitis, with less pronounced symptoms. There may be some slight inflammation in the udder, and milk may show minor changes in consistency or colour. Although the cow's general health is not significantly affected, subacute mastitis still results in reduced milk quality and production.

Chronic Mastitis: Chronic mastitis persists over a long period, often resulting from untreated or inadequately treated infections. It is typically characterized by recurrent bouts of acute or subclinical mastitis, leading to progressive damage to the udder tissue. Over time, the cow's milk production declines, and affected quarters may become permanently damaged. Chronic mastitis can have a long-term economic impact on dairy operations due to ongoing losses in milk yield and quality. (Table 1) encapsulates the type of mastitis in cattle by symptom, causative agent (Ruegg 2017; Plastridge 1958; Cheng and Han, 2020), detection method.

Apart from pathogen that causes mastitis in cattle, figure 2, shows the several other risk factors that are associated with the incidence of mastitis namely host and environmental factors (Cheng and Han 2020; Mramba and Mohamed 2024). Type of breeding, structure of udder, age of the cattle (Haxhiaj et al., 2022), transition period and nutritional stress and immune system are few host factors that impose additional risk to cattle health when infected. High stocking density, contaminated floor, wet bedding, poor ventilation, and hot and humid climate can promote growth of mastitis pathogens and increased exposure of cows, resulting in higher occurrence of mastitis. The risk factors associated with subclinical mastitis include lactation stage, udder cleanliness, history of mastitis, teat drying/wiping after milking, pre-dipping with warm water, post dipping in iodine, housing cleanliness and also location (Khasanah *et al.* 2021),(Pakrashi *et al.* 2023).

Detecting subclinical mastitis is essential as it does not exhibit visible symptoms, unlike other forms of mastitis, which are more easily identified through noticeable signs such as udder inflammation or changes in milk appearance. While clinical mastitis and other forms can be diagnosed through observable symptoms, subclinical mastitis is more prevalent and often goes unnoticed, silently affecting milk quality and production. Thus, detecting subclinical mastitis at early is essential to prevent its spread and minimize damage.

Detection of Subclinical mastitis

Detecting subclinical mastitis is difficult because it shows no visible symptoms, making regular monitoring crucial. Various methods are available for detection, each with its own benefits in terms of simplicity, cost, and accuracy (Kour *et al.* 2023). Some of the subclinical mastitis detection methods include California Mastitis Test kit, Somatic Cell Count unit, and Electrical conductivity meter (Alhussien and Dang 2020).

Onsite detection

A simple and cost effective estimation of somatic cell count in milk is the use of California mastitis test kit (Rust *et al.,* (2023), George *et al.* (2008), Dingwell *et al.* (2003)). The process involves adding equal quantity of mastitis reagent called linear alkylbenzene sulphonate to milk sample. This causes the release of DNA from leukocytes that are present in the udder, and this DNA is then transformed into a gelatinous complex when combined with protein agents in the milk. The inference from the California mastitis test kit on milk sample is categorized in 4 stages (Leach *et al.* 2008) as shown in table 2.

Another mastitis detection method based on the quantitative analysis of somatic cell count in milk sample is the use of Somatic Cell Count unit. Lintner *et al.,* (1987), proposed a use of Somatic Cell Count Samples (SCCS) for Comparison of Milk Somatic Cell Counting Methods (Lintner *et al.* 1987). Milk SCC measures the number of cells in the milk. The higher the SCC, the greater the chance the quarter is infected. Pakrashi *et al.* (2023) imposed the SCC threshold for unhealthy cow based on parity. For a primarous cow, SCC of ≥150,000 cells/mL and for multiparous cow, SCC of ≥250,000cells/mL confirms SCM positive.

Laboratory testing

Norberg et al. (2004) stated the electrical conductivity of milk is an inverse indicator of the resistance of milk and basically depends on the strength of the vascular reaction. When the inflammatory process begins in the udder, the concentrations of sodium, potassium, calcium, magnesium, chlorine and other ions present in milk will change. Milk becomes more conductive to electricity. The electrical conductivity of healthy cow's milk is 4.0 – 5.5 mS/cm. The variation in electrical conductance of the milk is closely associated with the health condition of the cattle mostly in cases of mastitis infection compared to other health factors like foot and mouth disease, or lumpy disease. Galfi *et al.,* (2004) studied changes in electrical conductivity are also associated with genetic factors, lactation, changes in milk composition. With an increase in conductivity of more than 6.0 mS/cm, subclinical mastitis can be suspected.

Inflamed udders affected by subclinical mastitis exhibit higher temperatures than surrounding healthy tissue, making thermal imaging a promising tool for early detection. This section explores various thermographic methods for identifying mastitis.

Infrared thermography: A tool for subclinical mastitis detection

The survey by Sinha *et al.,* (2018) emphasizes the potential of non-invasive technologies like infrared thermography (IRT) as a promising tool for early detection of mastitis. IRT works by monitoring skin surface temperature, which increases due to infection-related inflammation. This method is particularly advantageous because it can detect subtle changes in udder temperature, making it suitable for early screening of subclinical and clinical mastitis. With the ability to monitor bio-physiological health, IRT provides dairy farmers a faster and more efficient method to identify udder infections before significant damage occurs.

Sathiyabarathi *et al.* (2016) aimed to evaluate the effectiveness of infrared thermography (IRT) for early mastitis detection in Holstein Friesian crossbred cows and its relationship with conventional mastitis indicators. The results prove that USST has a strong correlation with Electrical conductivity and Somatic Cell count. Berry *et al.* (2003) suggested a potential detection of mastitis in dairy cows by measuring the daily variation of udder temperature using infrared thermography. The daily variation in the udder skin temperature using FLIR Inframetrics 760 of 10 non-mastitis cattle was monitored over time and the variation in udder temperature in accordance with the environment is analysed when the reading is taken 10 minutes prior to milking at a distance of 2 – 2.5 m from the cattle which is then used for predicting variations in temperature when infected with mastitis. It was concluded that the use of Infrared thermography is a reliable mastitis detection method when cattle are monitored in accordance with environmental temperature.

Willits *et al.,* (2005) suggested the use infrared thermography as an effective tool for mastitis detection. A group of cattle during the drying off period is considered for the study where the mastitis prevalence is high, and no exterior history of cattle is considered for research. The temperature readings of cattle's udder above a threshold of 96º F is determined to be infected with mastitis. The prediction results are cross validated with the standard mastitis detection method, Somatic Cell count unit which proves infrared thermography is a more reliable mastitis detection method.

Can udder skin temperature alone serve as a reliable indicator for mastitis detection? To explore this hypothesis, Colak *et al.* (2008) conducted an experiment to evaluate the potential of infrared thermography as an early detection tool for mastitis, with results validated against the California Mastitis Test (CMT). Skin surface temperature (SST) and retinal temperature (RT) were measured in approximately 94 dairy cattle, aged between 4 and 8 years. The retinal temperature exhibited minimal variation in infected cattle, with fluctuations likely caused by external factors such as eye irritation or climatic changes. However, SST demonstrated significant temperature differences corresponding to various stages of mastitis. Healthy cattle showed an average SST of 33.19ºC, while cattle with subclinical and clinical mastitis exhibited average SSTs of 34.99ºC and 36.15ºC, respectively. These findings suggest that retinal temperature is not a reliable method for mastitis detection. In contrast, infrared thermography of udder skin surface temperature appears to be a promising tool for the early detection of mastitis in dairy cattle.

The application of infrared thermography for the early detection of subclinical mastitis in Gir cattle was evaluated using Somatic Cell Count (SCC) and microbiological culture tests. This study involved a group of 70 Gir cattle in their second or third lactation period, with milk samples collected twice a month over a six-month period. The results revealed no significant correlation between temperature changes and the specific type of microorganisms isolated from milk samples. While infrared thermography proved to be a viable method for measuring udder surface temperature, it was not found to be an effective approach for detecting subclinical mastitis in Gir cattle (Porcionato *et al.* 2009). Khakimov *et al.* (2022) proposed an infrared thermography-based cow udder status monitoring for subclinical mastitis prediction. He identified a healthy relationship between udder surface temperature and milk yield of mastitis affected cows whereas no such relation in case of a healthy cow.

Previous studies have indicated no significant correlation between retinal temperature changes and mastitis infection, which prompted the investigation of udder skin surface temperature (USST) as a potential diagnostic marker. To explore the relationship between udder skin temperature captured via infrared thermography (IRT) and other established mastitis indicators, Polat *et al.* (2010) aims to assess the reliability of IRT in detecting subclinical mastitis, in comparison with the California Mastitis Test (CMT) and Somatic Cell Count (SCC). The analysis revealed a positive correlation between CMT scores and udder surface temperature, provided that external factors influencing skin temperature variations were controlled. This suggests that elevated USST is indicative of mastitis infection, in line with CMT results. In conclusion, IRT proves to be a non-invasive and rapid screening method for subclinical mastitis detection by measuring USST. It demonstrates a high predictive diagnostic ability, comparable to CMT, making it a valuable tool for early detection in dairy cattle. Bortolami *et al.* (2015) proved the association between Somatic cell score and temperature measured using thermography images and suggested the IRT to be a significant tool for SCM detection. Moreover, the bacteriological culture cannot be efficient in comparing with IRT for SCM detection.

Velasco-Bolaños *et al.* (2021) evaluated the use of udder surface temperature (UST) measured by infrared thermography (IRT) as a diagnostic tool for subclinical mastitis (SCM) and intramammary infection (IMI) in dairy cows, particularly in high-altitude tropical regions. A total of 105 cows (397 quarters) from three dairy farms using both mechanical and manual milking methods were included. The results showed that UST was higher in quarters affected by SCM compared to healthy quarters. For hand-milked cows, optimal UST thresholds were 32.6°C for SCM and 34°C for IMI, while machine-milked cows showed slightly lower thresholds.

Zaninelli *et al.* (2018) evaluated infrared thermography (IRT) as a field-based tool for assessing cow udder health. Thermographic images from 310 udders across three farms were analysed to automatically calculate thermographic indices like maximum and minimum temperature. The results confirmed a significant positive correlation between udder surface temperature (UST) and somatic cell count (SCC). However, the number of cases predicted as mastitis using IRT was slightly higher than those confirmed by SCC. This suggests that refining the calculation of thermographic indices could improve the accuracy of IRT for the automatic and early detection of mastitis in commercial dairy farms.

Golzarian *et al,* (2017) examined the feasibility of using thermography for detecting bovine mastitis (BM) in Holstein dairy cattle, comparing results with somatic cell count (SCC) and the California Mastitis Test (CMT). Thermographic analysis revealed a temperature difference of 0.44°C between healthy and unhealthy tissues, with a detection accuracy of 57.3%. The study identified that factors such as non-uniform light, hair on the udder, and skin lesions affected the precision of thermal imaging.

The study highlights that temperature differences between healthy and infected cattle can vary significantly depending on several factors, including geographical region, breeding type, milking method, lactation stage, and climatic conditions. These variations suggest that the udder surface temperature (UST), as measured through infrared thermography (IRT), is influenced by both intrinsic and extrinsic factors. For example, cows in different regions may exhibit distinct temperature patterns due to environmental conditions such as altitude, humidity, and temperature. Additionally, hand-milking versus machine-milking methods can cause different thermal responses in the udder. The stage of lactation and breed composition also play a role in the animal's physiological response to infection. Given this complexity, it is crucial to consider all these variables when designing or implementing an IRT-based mastitis detection system. Ignoring such factors could lead to inaccurate diagnosis or inconsistent results, underscoring the need for a comprehensive approach that adapts the technology to specific farm conditions and animal characteristics. Oliveira et al. (2022) investigated the use of infrared thermigraphy (IRT) for early detection of subclinical mastitis in pasture-raised dairy cows. The study highlights the importance of understanding environmental and physiological factors in grazing systems to effectively manage and prevent mastitis.

Alsaaod *et al.* (2015) also recommended the use of infrared thermography as a non-invasive diagnostic tool for the detection of subclinical mastitis. The effective time to capture thermal images is about 10 minutes after cleaning the teats of cow. From a thermal image, the region red or white indicate the hot region and the black or blue coloration represent cold region or background. Infrared thermography can also be applied for the detection of various other animal diseases beyond mastitis.

Several studies on AI-driven approaches for mastitis detection using deep learning techniques, are explored and as discussed. Xudong *et al.* (2020) used EFMYOLOv3 (Enhanced Fusion Mobile Net V3 You Only Look Once v3) to detect dairy cow eyes and udders and is applied to the detection of mastitis in dairy cows based on thermal infrared images. This detection model makes use of bilateral filtering image enhancement algorithm based on gray histograms to enhance image details and YOLOv3 for disease detection which achieves an accuracy of 83.33%. Silva et al. (2021) evaluated the use of Infrared thermographic images captured for multiple views of cattle for detection of clinical mastitis. Where the region of interest (ROI) mask was generated, and the identification of cluster location. The analysis revealed that cluster regions are identified for mastitis infected cattle and not for healthy cattle.

Wang et al. (2022) suggested infrared thermal imaging - based mastitis detection using the ocular surface temperature and USST difference detection method. He made use of YOLO v5 deep learning model for obtaining retinal and udder surface temperature. The findings reveal a strong correlation between retinal and USST for determining prevalence of mastitis in cattle.

Table 3 summarizes the objectives, methodologies, key findings, and thermal imager from the surveys conducted by the authors, focusing on the use of thermography for mastitis detection.

Treatment for Subclinical Mastitis

Dego and Tareke, (2003) stated that any inflammatory infection in cows can progress to clinical or subclinical mastitis over time. Bradley, (2002) highlighted those factors related to the cow, management practices, antimicrobial use patterns, and pathogens significantly affect the treatment of subclinical mastitis (SCM). Seegers *et al.,* (2003) identified management factors such as sanitation, infection detection and diagnosis, timing of detection, and treatment availability as crucial in SCM treatment. While antimicrobial treatment is commonly used for clinical mastitis due to its visible symptoms, subclinical mastitis poses a greater challenge. Delays in diagnosing the infection in the udder can complicate antimicrobial treatment, as the bacterial load increases over the lactation period. Pyörälä (2009) noted that antimicrobial treatment for SCM in lactating cows is often costly and has a lower success rate. However, effective treatments exist for SCM caused by contagious pathogens such as Staphylococcus aureus or Streptococcus agalactiae. Alfonseca-Silva *et al.* (2021) identified the use of enrofloxacin hydrochloride-dihydrate (enro-C), followed by ceftiofur HCl, as an effective treatment for subclinical mastitis.

Preventive Measures from Subclinical Mastitis

Preventive measures for subclinical mastitis (SCM) revolves around the concept that proactive management can significantly reduce the incidence of disease, improve overall herd health, and decrease reliance on costly treatments like antimicrobials. Dego and Tareke, (2003) introduced a comprehensive, multi-step preventive method aimed at minimizing the occurrence of SCM as shown in figure 3. By reducing the incidence of SCM, the use of antimicrobials is minimized, which also aligns with the growing emphasis on reducing antibiotic resistance. Adaptation of these preventive strategies, dairy farmers can improve animal health, reduce costs, and ensure higher quality milk production.

Table 1 Causative agent, Severeness and detection method for Mastitis

S.No	Mastitis type	Pathogen involved	Detection method	Severeness of disease
1	Clinical	Staphylococcus aureus, Streptococcus agalactiae Escherichia coli, Klebsiella spp.	Visible to eyes (Change in milk color and udder inflammation)	Cattle suffers from severe pain
2	Subclinical	Staphylococcus aureus, Streptococcus agalactiae Streptococcus uberis,	CMT, SCC based detection	Can develop into clinical mastitis, which is more painful and costly to treat.
3	Contagious	Staphylococcus aureus, Streptococcus agalactiae Mycoplasma bovis	Visible to eyes	May affect the entire herd
4	Environmental	Escherichia coli, Streptococcus uberis, Klebsiella spp.	Visible to eyes	Poor hygiene

Table 2 California Mastitis Test inference

S.No.	Score	Description	Status
1.	0	No slime or gel form	No Mastitis
2.	1	Mixture becomes slimy or gel like.	Trace of mastitis
3.	2	Mixture distinctly forms a gel.	Mastitis **(Subclinical Stage)**
4.	3	Mixture thickens immediately, tends to form jelly	Mastitis **(Clinical Stage)**

Table - 3 Summary of Infrared thermography-based mastitis detection

S.No.	Authors	Methodology	Thermal Imager	Evaluation method
1	Pakrashi et al. (2023)	• Studied the effect of mastitis on cow milk yield, the effect of mastitis on udder surface skin temperature, and the dependence between severity of mastitis and udder temperature. • The experimentation reveals the temperature ranges of the udder surface of healthy cows [32–35.9 C] and mastitis [36.1–39 C] and also there is a correlation between the variation in udder temperature and milk yield.	Guide C400M infrared imager was used for acquisition of images. The udder was photographed from three angles to identify all quarters of the udder	SCC
2	Oliveira et al. (2022)	• This survey investigated the use of infrared thermography (IRT) for early detection of subclinical mastitis in pasture-raised dairy cows. • The California Mastitis Test (CMT) was applied as a diagnostic comparison, revealing a significant correlation between increased udder temperatures (38–40°C) and positive CMT results. • The study highlights the importance of understanding environmental and physiological factors in grazing systems to effectively manage and prevent mastitis.	FLIR E63900 T198547 infrared camera is used capture infrared images of cattle one meter from the right lateral view of the entire body, forehead, eye, and hind leg and 0.6 m from the udder both from the right and left antimere	CMT

S.No.	Authors	Methodology	Thermal Imager	Evaluation method
3	Velasco-Bolaños et al. (2021)	• Evaluated the use of infrared thermography as a tool for mastitis and intramammary infection in cattle where the statistical descriptors of infrared images are used for analysis. • The analysis reveal that the Udder surface temperature is 1.07º higher in quarters infected with Subclinical mastitis.	FLIR T450sc thermal camera is located 1 meter apart from the subject for image acquisition.	SCC
4	Silva et al. (2021)	• Evaluated the use of thermal imaging for detection of clinical mastitis, where the region of interest (ROI) mask was generated, and the cluster location are identified. • The finding reveals the subclinical mastitis infected udder has an average temperature of 2.38 ºC higher that healthy udder. The angle at which the images were captured also has an influence in enhancing the analysis performance	Infrared thermographic camera was used to capture left anterolateral, right anterolateral, posterior and inferior views, of cattle.	-
5	Xudong et al. (2020)	• EFMYOLOv3 (Enhanced Fusion MobileNetV3 You Only Look Once v3) is used to detect dairy cow eyes and udders and is applied to the detection of mastitis in dairy cows based on thermal infrared images. • This detection model makes use of bilateral filtering image enhancement algorithm based on gray histograms to enhance image details and YOLOv3 for disease detection which achieves an accuracy of 83.33%.	FLIR A615 thermal imager is used for capturing thermal image samples.	SCC

S.No.	Authors	Methodology	Thermal Imager	Evaluation method
6	Sathiyabarathi et al. (2016)	• Aimed to evaluate the effectiveness of infrared thermography (IRT) for early mastitis detection in Holstein Friesian crossbred cows and its relationship with conventional mastitis indicators. • Analysis showed that USST was 0.72°C higher in subclinical mastitis and 1.05°C higher in clinical mastitis quarters, while the mean body and USST of non-mastitis cows were similar.	(FLIR) i5 camera is used to capture thermographic image of eye and udder 1 meter from the target.	The results prove that USST has a strong correlation with Electrical Conductivity and Somatic Cell Count
7	Hovinen et al. (2008)	• A preliminary study to evaluate the temperature difference in udder infected by mastitis when indued in cattle using Escherichia coli lipopolysaccharide • The thermal camera was successful in detecting the 1 to 1.5°C temperature change on udder skin associated with clinical mastitis in cows because temperature of the udder skin of the experimental increased in line with the rectal temperature	-	The results are cross verified using conventional methods such as electrical conductivity meter and CMT kit
8	R. J. Berry et al, (2003)	• To determine the magnitude and pattern of udder temperature variation, daily fluctuations in udder temperature and the influence of environmental factors are considered. • The experiment shows significant difference in temperature between mastitis infected udder and healthy udder under regular monitoring. It fails to explore the variation in temperature due to environmental/ climatic changes.	FLIR Inframetrics 760 was used to capture images of the posterior surface of the left and right hind quarters of the udder.	SCC

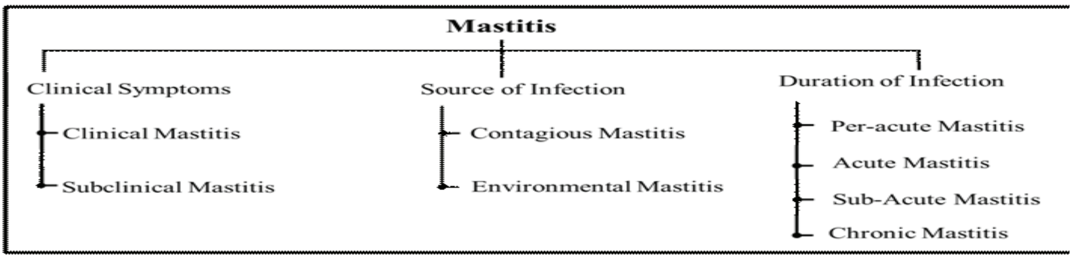

Fig.1 Classification of Mastitis in Cattle

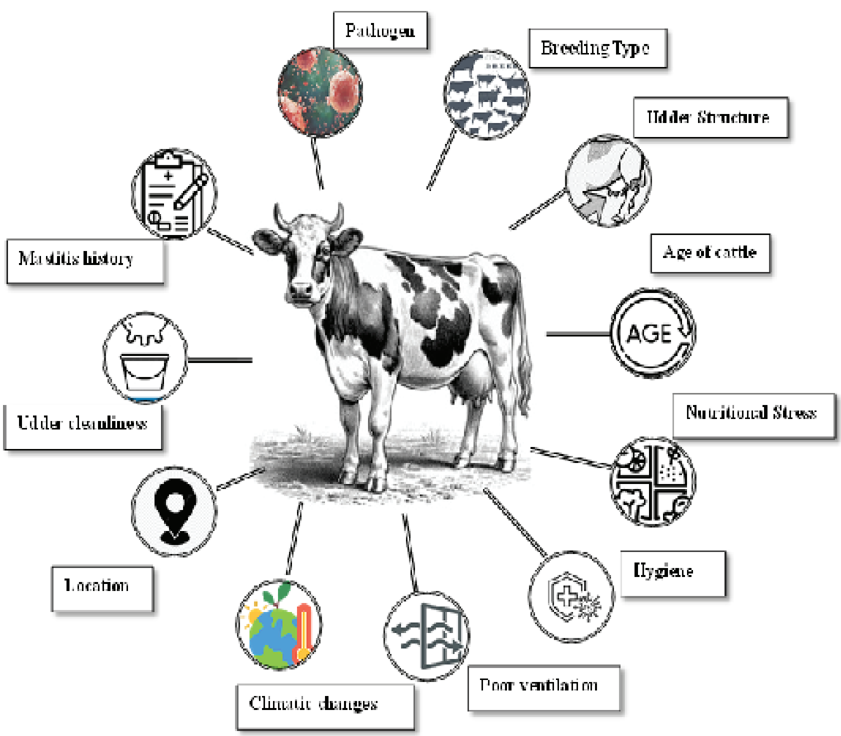

Fig. 2. Risk factors associated with mastitis

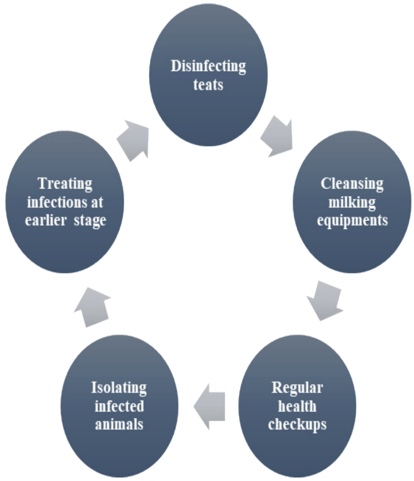

Fig.3. Five stages of Mastitis Prevention

CONCLUSION

Mastitis is a significant inflammatory condition in dairy cattle, driven primarily by bacterial infections and resulting in decreased milk production and quality. In this survey, the types of mastitis occurring in cattle are categorised based on the causative agent, source of infection and duration of infection are explained. The traditional detection methods such as clinical observation, somatic cell count (SCC) analysis, and microbiological tests are discussed. To detect mastitis at early stages, Infrared thermography (IRT) presents a promising solution by offering a non-invasive approach to detect mastitis through temperature variations in the udder caused by inflammation. This study highlighted the potential of IRT for early mastitis detection, which could enhance animal health management and mitigate economic losses in the dairy industry.

ACKNOWLEDGEMENTS

The authors are thankful to DST-TDT-TDP directorate, the Principal and the Management of Mepco Schlenk Engineering College, Sivakasi for their support and facilities provided to carry out this research work. The authors express their gratitude to the anonymous reviewers for their insightful comments and suggestions in improving the work.

FUNDING

The work presented in this paper was funded by Department of Science & Technology, Technology Development Transfer, Ministry of Science & Technology, New Delhi, India under Grant No. DST/TDT/TDP-33/2022.

REFERENCES

Ajose, D.J., Oluwarinde, B.O., Abolarinwa, T.O., Fri, J., Montso, K.P., Fayemi, O.E., Aremu, A.O. and Ateba, C.N. (2022). "Combating Bovine Mastitis in the Dairy Sector in an Era of Antimicrobial Resistance: Ethno-Veterinary Medicinal Option as a Viable Alternative Approach." *Frontiers in Veterinary Science,* **9** (April). https://doi.org/10.3389/fvets.2022.800322.

Alfonseca-Silva, E., Cruz-Villa, J.C., Gutiérrez, L. and Sumano, H. (2021). "Successful Treatment of Recurrent Subclinical Mastitis in Cows Caused by Enrofloxacin Resistant Bacteria by Means of the Sequential Intramammary Infusion of Enrofloxacin HCl-2H2O and Ceftiofur HCl: A Clinical Trial." *Journal of Veterinary Science,* **22** (6): e78. https://doi.org/10.4142/jvs.2021.22.e78.

Alhussien, M.N. and Ajay Kumar Dang. (2020). "Sensitive and Rapid Lateral-Flow Assay for Early Detection of Subclinical Mammary Infection in Dairy Cows." *Scientific Reports,* **10** (1): 11161. https://doi.org/10.1038/s41598-020-68174-0.

Alsaaod, M., Schaefer, A.L., Büscher, W. and Steiner, AWillits *et al.,* (2005) . (2015). "The Role of Infrared Thermography as a Non-Invasive Tool for the Detection of Lameness in Cattle." *Sensors,* **15** (6): 14513–14525. https://doi.org/10.3390/s150614513.

Berry, R. J., Kennedy, A.D., Scott, S.L., Kyle, B.L. and Schaefer, A.L.Willits *et al.,* (2005) (2003). "Daily Variation in the Udder Surface Temperature of Dairy Cows Measured by Infrared Thermography: Potential for Mastitis Detection." *Canadian Journal of Animal Science,* **83** (4): 687–693. https://doi.org/10.4141/A03-012.

Bortolami, A., Fiore, E., Gianesella, M., Corrò, M., Catania, S. and Morgante, M. (2015). "Evaluation of the Udder Health Status in Subclinical Mastitis Affected Dairy Cows through Bacteriological Culture, Somatic Cell Count and Thermographic Imaging." *Polish Journal of Veterinary Sciences,* **18** (4): 799–805. https://doi.org/10.1515/pjvs-2015-0104.

Bradley, A. J. (2002). "Bovine Mastitis: An Evolving Disease." *The Veterinary Journal,* **164** (2): 116–28. https://doi.org/10.1053/tvjl.2002.0724.

Cheng, W. N.Willits *et al.,* (2005) and Han, S.G. (2020). "Bovine Mastitis: Risk Factors, Therapeutic Strategies, and Alternative Treatments — A Review." *Asian-Australasian Journal of Animal Sciences,* **33** (11): 1699–1713. https://doi.org/10.5713/ajas.20.0156.

Colak, A., Polat, B., Okumus, Z., Kaya, M., Yanmaz, L.E. and Hayirli, A. (2008). "Short Communication: Early Detection of Mastitis Using Infrared Thermography in Dairy Cows." *Journal of Dairy Science,* **91** (11): 4244–48. https://doi.org/10.3168/jds.2008-1258.

Dego, O. K. and Tareke, F. (2003). "Bovine Mastitis in Selected Areas of Southern Ethiopia.", *Tropical Animal Health and Production*, **35** : 197-205

Dingwell, R.T., Leslie, K.E., Schukken, Y.H., Jan M. Sargeant, and Leo L. Timms. (2003). "Evaluation of the California Mastitis Test to Detect an Intramammary Infection with a Major Pathogen in Early Lactation Dairy Cows." *The Canadian Veterinary Journal*, **44** (5): 413–415.

Galfi, A., Radinović, M., Milanov, D., Boboš, S., Pajić, M., Savić, S. and Davidov, I. (2015), " Electrical Conductivity of Milk and Bacteriological findings in Cows with Subclinical Mastitis" *Biotechnology in Animal Husbandry,* **31** (4), p 533-541.

George, L.W., Divers, T.J., Norm D. and Frank L.W. (2008). "Chapter 8 - Diseases of the Teats and Udder." In Rebhun's Diseases of Dairy Cattle (Second Edition), edited by Thomas J. Divers and Simon F. Peek, 327–94. Saint Louis: W.B. Saunders. https://doi.org/10.1016/B978-141603137-6.50011-9.

Golzarian, M.R., Soltanali, H., Doosti Irani, O. and Ebrahimi, S.H. (2017). "Possibility of Early detection of bovine mastitis in dairy cows using thermal images processing". *Iranian Journal of Applied Animal Science*, **7**(4): 549 - 557.

Haxhiaj, K., Wishart, D.S. and Ametaj. B.N. (2022). "Mastitis: What It Is, Current Diagnostics, and the Potential of Metabolomics to Identify New Predictive Biomarkers." *Dairy,* **3**(4): 722–746. https://doi.org/10.3390/dairy3040050.

Hovinen, M., Siivonen, J., Taponen, S., Hänninen, L., Pastell, M., Aisla, A.M. and Pyörälä, S. (2008). "Detection of Clinical Mastitis with the Help of a Thermal Camera." *Journal of Dairy Science,* **91** (12): 4592–98. https://doi.org/10.3168/jds.2008-1218.

Khakimov, A.R., Pavkin, D.Y., Yurochka, S.S., Astashev, M.E. and Dovlatov, I.M. (2022). "Development of an Algorithm for Rapid Herd Evaluation and Predicting Milk Yield of Mastitis Cows Based on Infrared Thermography." *Applied Sciences,* **12**(13): 6621. https://doi.org/10.3390/app12136621.

Khasanah, H., Setyawan, H.B., Yulianto, R. and Widianingrum, D.C. (2021). "Subclinical Mastitis: Prevalence and Risk Factors in Dairy Cows in East Java, Indonesia." *Veterinary World,* **14**(8): 2102–8. https://doi.org/10.14202/vetworld.2021.2102-2108.

Kour, S., Sharma, N., Balaji N., Kumar, P., Soodan, J.S., Santos, M.V.D. and Son, Y.O. (2023). "Advances in Diagnostic Approaches and Therapeutic Management in Bovine

Mastitis." *Veterinary Sciences,* **10**(7): 449. https://doi.org/10.3390/vetsci10070449.

Leach, K. A., Green, M.J., Breen, J. E., Huxley, J.N., Macaulay, R., Newton, H.T. and Bradley, A.J. (2008). "Use of Domestic Detergents in the California Mastitis Test for High Somatic Cell Counts in Milk." *Veterinary Record,* **163**(19): 566–70. https://doi.org/10.1136/vr.163.19.566.

Lintner, T. J., Lange, A. L., Heald, C. W. and Eberhart, R. J. R. J. (1987). "Preparation and Use of Somatic Cell Count Samples (SCCS) for Comparison of Milk Somatic Cell Counting Methods." *Journal of Food Protection,* **50**(2): 132–35. https://doi.org/10.4315/0362-028X-50.2.132.

Mramba, R.P., and Mohamed, M.A. (2024). "The Prevalence and Factors Associated with Mastitis in Dairy Cows Kept by Small-Scale Farmers in Dodoma, Tanzania." *Heliyon,* **10**(13). https://doi.org/10.1016/j.heliyon.2024.e34122.

Norberg, E., Hogeveen, H., Korsgaard, I.R., Friggens, N.C., Sloth, K. H. M. N. and Løvendahl, P. (2004). "Electrical Conductivity of Milk: Ability to Predict Mastitis Status." *Journal of Dairy Science,* **87**(4): 1099–1107. https://doi.org/10.3168/jds.S0022-0302(04)73256-7.

Oliveira, A.V.D., Reis, E.M.B., Ferraz, P.F.P., Barbari, M., Santos, G.S., Cruz, M.V.R., Silva, G.F. and Silva, A.O.L. (2022). "Infrared Thermography as a Technique for Detecting Subclinical Bovine Mastitis." *Arquivo Brasileiro de Medicina Veterinária e Zootecnia,* **74** (6): 992–98. https://doi.org/10.1590/1678-4162-12834.

Pakrashi, A., Ryan, C., Guéret, C., Berry, D. P., Corcoran, M., Keane, M.T. and Mac Namee, B. (2023). "Early Detection of Subclinical Mastitis in Lactating Dairy Cows Using Cow-Level Features." *Journal of Dairy Science,* **106**(7): 4978–90. https://doi.org/10.3168/jds.2022-22803.

Plastridge, W. N. (1958). "Bovine Mastitis: A Review." J*ournal of Dairy Science,* **41**(9): 1141–1181. https://doi.org/10.3168/jds.S0022-0302(58)91071-3.

Polat, B., Colak, A., Cengiz, M., Yanmaz, L.E., Oral, H., Bastan, A., Kaya, S. and Hayirli, A. (2010). "Sensitivity and Specificity of Infrared Thermography in Detection of Subclinical Mastitis in Dairy Cows." *Journal of Dairy Science,* **93**(8): 3525–35L.E. 32. https://doi.org/10.3168/jds.2009-2807.

Porcionato, M.A.F., Canata, T.F., Oliveira, C.E.L.D. and Santos, M.V.D. (2009). "Udder Thermography of Gir Cows for Subclinical Mastitis Detection." *Revista Brasileira de Engenharia de Biossistemas,* **3**(3):

251–257. https://doi.org/10.18011/bioeng2009v3n3p251-257.

Pyörälä, S. (2009). "Treatment of Mastitis during Lactation." *Irish Veterinary Journal,* **62**(4): S40. https://doi.org/10.1186/2046-0481-62-S4-S40.

Ruegg, P.L. (2017a). "A 100-Year Review: Mastitis Detection, Management, and Prevention." J*ournal of Dairy Science,* **100**(12): 10381–10397. https://doi.org/10.3168/jds.2017-13023.

Rust, J.D., Christian, M.J., Vance, C.J., Bolajoko, M.B., Wong, J.T., Suarez-Martinez, J., Allan, F.K. and Peters, A.R. (2023). "A Study of the Effectiveness of a Detergent-Based California Mastitis Test (CMT), Using Ethiopian and Nigerian Domestic Detergents, for the Detection of High Somatic Cell Counts in Milk and Their Reliability Compared to the Commercial UK CMT." *Gates Open Research,* **5**:146. https://doi.org/10.12688/gatesopenres.13369.2.

Sathiyabarathi, M., Jeyakumar, S., Manimaran, A., Pushpadass, H.A., Sivaram, M., Ramesha, K.P., Das, D.N., Kataktalware, M.A., Jayaprakash, G. and Patbandha, T.K. (2016). "Investigation of Body and Udder Skin Surface Temperature Differentials as an Early Indicator of Mastitis in Holstein Friesian Crossbred Cows Using Digital Infrared Thermography Technique." *Veterinary World*, **9** (12): 1386–91. https://doi.org/10.14202/vetworld.2016.1386-1391.

Seegers, H., Fourichon, C. and Beaudeau, F. (2003). "Production Effects Related to Mastitis and Mastitis Economics in Dairy Cattle Herds." *Veterinary Research,* **34** (5): 475–91. https://doi.org/10.1051/vetres:2003027.

Silva, R.A.B.D., Stosic, B., Pandorfi, H., Gledson Luiz, P.D.A., Silva, M.V.D. and Batista, P.H.D. (2021). "Classification of Thermal Images of Bovine Mastitis by Computer Vision." *International Journal of Computer Applications,* **174** (31): 41–45. https://doi.org/10.5120/ijca2021921256.

Sinha, R., Bhakat, M., Mohanty, T.K., Ranjan, A., Kumar, R., Lone, S.A., Rahim, A., Paray, A.R., Khosla, K. and Danish, Z. (2018). "Infrared Thermography as Non-Invasive Technique for Early Detection of Mastitis in Dairy Animal: A Review." Agricultural Research Communication Centre - *Asian Journal of Dairy and Food Research*, **37**(1) : 1-6

Tommasoni, C., Fiore, E., Lisuzzo, A. and Gianesella, M. (2023). "Mastitis in Dairy Cattle: On-Farm Diagnostics and Future Perspectives." *Animals : An Open Access Journal from MDPI* **13**(15): 2538. https://doi.org/10.3390/ani13152538.

Velasco-Bolaños, J., Ceballes-Serrano, C.C., Velásquez-Mejía, D., Riaño-Rojas, J.D., Giraldo, C.E., Carmona, J.U. and Ceballos-Márquez, A. (2021). "Application of Udder Surface Temperature by Infrared Thermography for Diagnosis of Subclinical Mastitis in Holstein Cows Located in Tropical Highlands." *Journal of Dairy Science,* **104**(9): 10310–23. https://doi.org/10.3168/jds.2020-19894.

Wang, Y., Kang, X., He, Z., Feng, Y. and Liu, G. (2022). "Accurate Detection of Dairy Cow Mastitis with Deep Learning Technology: A New and Comprehensive Detection Method Based on Infrared Thermal Images." *Animal,* **16**(10): 100646. https://doi.org/10.1016/j.animal.2022.100646.

Willits, S. and Infrared, R. (2005). "Infrared thermography for screening and early detection of mastitis infections in working dairy herds. InfraMation proceedings.- *Agricultural and Food Science*, ITC 108 A.

Xudong, Z., Xi, K., Ningning, F. and Gang, L. (2020). "Automatic Recognition of Dairy Cow Mastitis from Thermal Images by a Deep Learning Detector." *Computers and Electronics in Agriculture,* **178** :105754. https://doi.org/10.1016/j.compag.2020.105754.

Zaninelli, M., Redaelli, V., Luzi, F., Bronzo, V., Mitchell, M., Dell'Orto, V., Bontempo, V., Cattaneo, D. and Savoini, G. (2018). "First Evaluation of Infrared Thermography as a Tool for the Monitoring of Udder Health Status in Farms of Dairy Cows." *Sensors,* **18**(3): 862. https://doi.org/10.3390/s18030862.