REVIEW

Sokoto Journal of Veterinary Sciences

(P-ISSN 1595-093X: E-ISSN 2315-6201)

http://dx.doi.org/10.4314/sokjvs.v24i3.1

Shittu *et al.*/*Sokoto Journal of Veterinary Sciences*, **24**(3): 175 - 200.

Subclinical mastitis, cow welfare, and dairy sustainability: Insights from Nigeria for developing economies

A Shittu[1]*, AI Daneji[2], UM Chafe[2], MB Abubakar[3], FO Fasina[4], J Onyango[5], B Amato[6], AH Jibril[7], I Idris[1], I Ibrahim[1], N Lawal[3], A Jibril[1], HU Mungadi[2] & YS Baraya[8]

1. *Quantitative Epidemiology and Animal Health Research Group, Department of Theriogenology and Animal Production, Faculty of Veterinary Medicine, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria*
2. *Department of Veterinary Medicine, Faculty of Veterinary Medicine, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria*
3. *Department of Veterinary Microbiology, Faculty of Veterinary Medicine, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria*
4. *Department of Veterinary Tropical Diseases, University of Pretoria, Onderstepoort, South Africa*
5. *The Harper and Keele Veterinary School, Harper Adams University, Edgmond, Newport TF10 8NB and Keele University, Keele, Stafford, ST5 5BG, UK*
6. *Department of Veterinary Pathology, Bristol Veterinary School, University of Bristol, Bristol, United Kingdom*
7. *Department of Veterinary Public Health and Preventive Medicine, Faculty of Veterinary Medicine, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria*
8. *Department of Veterinary Pathology, Faculty of Veterinary Medicine, Usmanu Danfodiyo University, Sokoto, Sokoto State, Nigeria*

*Correspondence: Tel.: +2348065489917; E-mail: shittuaminu38@gmail.com

Copyright: © 2026 Shittu *et al.* This is an open-access article published under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Udder health and subclinical mastitis (SCM) are important determinants of dairy productivity, milk quality, and animal welfare, particularly in low- and middle-income countries (LMICs). Despite the economic and nutritional importance of dairy production, comprehensive information on bovine udder health remains limited in Nigeria. This review examines key aspects of udder health, with emphasis on SCM detection, associated risk factors, histopathological changes, and microbiological investigations, drawing primarily on evidence relevant to Nigerian dairy systems. Three commonly used diagnostic techniques – the California Mastitis Test (CMT), White Side Test (WST), and Draminski Mastitis Detector (DMD) – are discussed in relation to their operational principles and applicability for detecting asymptomatic intramammary infections. Although a detailed comparative evaluation of their diagnostic accuracy, feasibility, and cost-effectiveness is beyond the scope of this review, these aspects warrant further field-based investigation under local production conditions. The review also highlights the importance of histopathological examination in identifying microscopic mammary tissue alterations and microbiological techniques in detecting mastitis-associated

bacterial pathogens. Particular attention is drawn to existing knowledge gaps, including limited region-specific epidemiological data, inadequate pathogen characterisation, and insufficient understanding of the relationship between bacterial infections and corresponding mammary lesions in indigenous cattle breeds. Integrating epidemiological, diagnostic, microbiological, and histopathological approaches could provide a more comprehensive understanding of bovine udder health and support the development of context-specific disease prevention and control strategies. Furthermore, improved surveillance, early detection, appropriate management practices, and targeted research are essential for reducing mastitis-associated economic losses and enhancing dairy cow welfare. This review provides insights relevant to farmers, veterinarians, researchers, and policymakers, while identifying priority areas for future investigations aimed at improving udder health, milk production efficiency, and the sustainability of dairy systems in Nigeria and comparable production environments.

Publication History:
Received: 11-01-2025
Revised: 02-03-2026
Accepted: 10-05-2026

Keywords: Cow welfare, Dairy industry, Mastitis detection, Subclinical mastitis, Udder health

Introduction

Background

The welfare and health of cows are critical to the productivity and sustainability of the dairy industry (Arnott *et al.,* 2017; EFSA, 2023). Cow welfare encompasses various aspects, including nutrition, housing, health care, and overall management practices that impact both the physical and psychological well-being of the animals (Ventura *et al.,* 2021). Inadequate welfare can lead to stress and disease, ultimately affecting milk production and quality (Abeni & Bertoni, 2009; EFSA, 2023). Udder health, particularly the incidence of mastitis, is a significant concern, as it directly influences the quality and quantity of milk produced (Neculai-Valeanu & Ariton, 2022).

Global importance of the dairy sector and knowledge gaps

Globally, the dairy sector is an integral part of the agricultural economy, providing essential income for farmers and nutritious products for consumers (Brown *et al.,* 2022; Shamsuddoha *et al.,* 2023). The sector contributes significantly to food security and rural development, with dairy products being a crucial source of protein and other nutrients (FAO, 2013). Despite its importance, there has been limited research on the welfare and health of dairy cows in Nigeria. Most studies focus on production metrics rather than the conditions affecting cow welfare and udder health (Gonçalves *et al.,* 2018; Zachut *et al*., 2020; Themistokleous *et al.,* 2023).

Subclinical mastitis: a hidden burden

Subclinical mastitis (SCM) – a non-symptomatic inflammation of the mammary gland – is among the most widespread and economically damaging conditions affecting dairy cows globally, impacting 20–50% of cows within a given herd (Forsbäck *et al.,* 2009; Morales-Ubaldo *et al.,* 2023). The typical pathogens isolated from mastitis and SCM include but are not limited to Streptococci organisms, *S. aureus*, coagulase-positive *Staphylococci*, coagulase-negative *Staphylococci*, and *E. coli* (Botrel *et al.,* 2010; Hedge *et al.,* 2013). SCM can significantly reduce milk yield and alter milk composition (Pakrashi *et al.,* 2023).

Nigerian context and breeds in focus

In Nigeria, dairy cows, including the Sokoto Gudali and White Fulani breeds (Plate I), are primarily raised on farms and in households (Shittu *et al*., 2008; Shittu *et al.,* 2012). These settings offer varying levels of resources and management practices, which can impact cow welfare and udder health in different ways.

Economically significant breeds, such as the Sokoto Gudali and White Fulani, along with Red Bororo and other less common breeds (Plates I, II, and III), are frequently used in dairy production. While these breeds are well-adapted to the local climate (Rege & Tawah, 1999; Adeyeye *et al.,* 2020; Nosike *et al.,* 2020), they are often raised in suboptimal conditions that can negatively impact their welfare and health. The particular factors influencing their welfare and udder health have not been thoroughly studied, hindering the development of specific interventions.

There is limited data on cow welfare and udder health in Nigeria, particularly across different settings such as farms, households, markets, and slaughterhouses. This lack of information hinders the development of effective management practices to improve cow

a)

b)

Plate I: (a) Sokoto Gudali and (b) White Fulani breeds of cow, both commonly used in dairy production in Nigeria. The Sokoto Gudali, or Bokolo, is known for its large frame, short horns, and predominantly white or light-colored coat with black patches. The White Fulani, or Bunaji, features a more slender build, long curved horns, and a white or light grey coat, often with dark spots. Both breeds are valued for milk and meat production in Nigeria

a)

b)

Plate II: Photographs depicting two Nigerian cattle breeds: (a) Red Bororo, also known as Rahaji, characterized by its distinctive reddish coat and long, curved horns, known for its hardiness in arid regions; (b) Adamawa Gudali, a breed with a more robust build and shorter horns, typically found in the savanna regions, valued for both milk and meat production

a)

b)

Plate III: Photographs showcasing crossbreeds of Sokoto Gudali cattle: (a) Guernsey-Sokoto Gudali, a hybrid exhibiting the Guernsey's distinctive colouring and dairy traits combined with the hardiness of the Sokoto Gudali; (b) Friesian-Sokoto Gudali crossbreed, merging the high milk yield capacity of the Friesian with the adaptability and resilience of the Sokoto Gudali, suited to diverse environmental conditions

welfare and milk production. Without a clear understanding of the current state of cow welfare and udder health, it is challenging to identify risk factors, develop preventive strategies, and enhance overall productivity in the dairy industry. Addressing this gap is essential for improving the health and productivity of dairy cows, ensuring high-quality milk production, and sustaining the economic viability of the dairy sector in Nigeria.

Rationale and objectives of the review

Despite its insidious nature and economic burden, SCM remains underreported and poorly understood in many low- and middle-income countries (LMICs), including Nigeria. This review aims to evaluate the impact of subclinical mastitis (SCM) on cow welfare and milk productivity in low- and middle-income countries (LMICs), with a particular focus on Nigeria's dairy industry. It seeks to synthesize existing knowledge on diagnostic methods, risk factors, and the interplay between animal welfare and udder health across various management systems and cattle breeds. By critically examining both microbiological and histopathological aspects of udder health, the review highlights key challenges and opportunities for early detection and effective control of SCM. The overarching goal is to inform regionally relevant, evidence-based interventions that can guide farmers, veterinarians, and policymakers in improving animal health, milk quality, and dairy sustainability. Addressing this knowledge gap is especially vital in Nigeria, where rapid urbanization and growing demand for animal-source foods place increasing pressure on traditional and emerging dairy systems.

Udder Health

Impact on milk production and quality

Udder health is a pivotal factor in maintaining high standards of milk production and quality (Neculai-Valeanu & Ariton, 2022; Zapata-Salas *et al.,* 2022; Böker *et al.,* 2023). Mastitis, particularly in its subclinical form, poses a significant challenge to dairy operations by negatively affecting both milk yield and milk composition (Azooz *et al.,* 2020; Abed *et al.,* 2021; Goncalves *et al.,* 2023). Understanding these impacts is crucial for effective management and improvement of dairy farm profitability and product quality.

Decrease in milk yield

This decrease is primarily due to the inflammatory response triggered by the infection, which disrupts the normal functioning of the mammary gland (Ezzat Alnakip *et al.,* 2014; Blum *et al.,* 2020). Research has demonstrated that cows with SCM can experience up to a 20% reduction in milk yield compared to healthy cows (Goncalves *et al.,* 2023). The milk losses ranged from 0.07 to 1.4 Kg/quarter milking according to the pathogen causing SCM (Goncalves *et al.,* 2018). The inflammation affects the milk-secreting cells, leading to a lower volume of milk produced per milking (Ezzat Alnakip *et al.,* 2014). This reduction in yield not only impacts the daily output of milk but also has cumulative effects over time, contributing to significant economic losses for dairy producers. For SCM, there is a significant increase in somatic cells in the milk, leading to changed milk composition, enzymatic activity, increased matrix metalloproteinases (MMPs) and Lipopolysaccharide (LPS), with implications for milk stasis, infection, and micronutrient deficiency (Plummer & Plummer, 2012).

Alterations in milk composition and quality

In addition to reducing milk yield, SCM can alter the composition of the milk. Key components affected are discussed below.

Elevated milk leucocytes or Somatic Cell Count (SCC), a primary indicator of mastitis and reflects the immune response to infection. Normal milk SCC levels are typically below 200,000 cells/mL, but in cases of SCM, SCC can rise significantly, often exceeding 500,000 cells/mL (Olde Riekerink *et al.,* 2007; Sharma *et al.,* 2011; Rainard *et al.,* 2018; Sumon *et al.,* 2020; van den Crommenacker-Konings *et al.,* 2021; Taponen *et al.,* 2022; Williamson *et al.,* 2022; Fadillah *et al.,* 2023). High SCC can affect milk quality and processing characteristics, leading to potential rejection by dairy processors or lower prices for milk (Nightingale *et al*., 2008; Le Maréchal *et al.,* 2011; Dejyong *et al*., 2022; Carmo *et al.,* 2024).

Subclinical mastitis (SCM) can lead to a decrease in milk fat content. Studies have shown that milk from cows with high SCC often has lower fat percentages, which can affect the taste, texture, and quality of dairy products such as cheese and butter (Le Maréchal *et al.,* 2011; Malek dos Reis *et al.,* 2013; Gonçalves *et al.,* 2020; Harjanti & Sambodho, 2020; Youssif *et al.,* 2020; Bentayeb *et al.,* 2023; Bochniarz *et al.,* 2023). Lower fat content can reduce the yield of dairy products and affect their market value.

Similar to milk fat, milk protein levels can also be impacted by SCM, e.g. lower milk fat content and altered composition can affect the texture and taste of butter and yogurt. Milk from infected cows with

altered protein composition affects the functional properties of milk in dairy products (Batavani *et al.,* 2007; Le Maréchal *et al.,* 2011; Martins *et al.,* 2020; Saleem *et al.,* 2021; Bochniarz *et al*., 2023).

Subclinical mastitis (SCM) can cause a reduction in lactose levels in milk. Lactose is crucial for the sweetness and texture of dairy products. Reduced lactose content can lead to a decrease in the overall quality and consumer acceptance of dairy products (Le Maréchal *et al*., 2011; Antanaitis *et al.,* 2021; Portnoy & Barbano, 2021; Bochniarz *et al.,* 2023).

Altered milk composition can result in defects in texture, flavor, and overall quality of cheese (Maristela *et al.,* 2015; Bobbo *et al.,* 2017; *Olives et al.,* 2020; Bezerra *et al.,* 2021; Ivanova *et al.,* 2021; Moradi *et al.,* 2021). The consistency and quality of these products are influenced by the composition of the milk, and SCM can lead to inferior products that may not meet consumer or processor expectations (Le Maréchal *et al.,* 2011; Youssif *et al.,* 2020; Bentayeb *et al.,* 2023).

Economic Implications

The economic impact of SCM extends beyond direct reductions in milk yield and alterations in milk composition.

Lower milk yields and altered milk composition can lead to reduced profitability for dairy producers (FAO, 2014; Silva-Villacorta *et al.,* 2016). The financial loss from decreased milk production and potential penalties for poor milk quality can be substantial. In some cases, the cumulative effect of reduced milk yield and altered milk quality can significantly impact the overall financial stability of dairy operations.

The costs associated with managing SCM include veterinary expenses, labor for monitoring and treating affected cows, and potential costs related to culling animals with persistent issues. These additional costs further impact the economic viability of dairy farms (Sinha *et al.,* 2014; Aghamohammadi *et al.,* 2018; Moru *et al.,* 2018; Azooz *et al.,* 2020; Richardet *et al.,* 2023).

Dairy processors may impose penalties for milk with high SCC or altered composition, which can affect the revenue received by dairy producers. The quality of milk is crucial for meeting industry standards and consumer expectations, and any deviations can lead to financial repercussions (Busanello *et al.,* 2017; Dejyong *et al.,* 2022). Specifically, the costs can be apportioned into the following:

Direct costs

Direct costs associated with mastitis encompass the immediate expenses incurred in the diagnosis, treatment, and management of the disease.

The costs for veterinary consultations, diagnostic tests (such as SCC measurements and culture tests), and therapeutic interventions (e.g., antibiotics and anti-inflammatory drugs) are significant. These costs can vary depending on the severity of the mastitis, the frequency of veterinary visits, and the specific treatments required (Senturk, 2014; Aghamohammadi *et al.,* 2018; Wilm *et al.,* 2021; de Jong *et al.,* 2024).

The use of antibiotics and other medications to treat mastitis incurs additional costs. In some cases, prolonged or repeated treatments may be necessary, leading to higher expenses. The cost of medication can also be influenced by factors such as drug resistance and the need for more expensive or specialized treatments (Bar *et al.,* 2008; Rollin *et al.,* 2015; van Soest *et al.,* 2016; Bonestroo *et al.,* 2023; de Jong *et al.,* 2023; Leite *et al.,* 2023).

Managing mastitis cases requires labor for various tasks, including monitoring cows, administering treatments, and maintaining hygiene standards to prevent further infections. The increased labor demands can lead to higher operational costs and may require additional staffing or overtime for existing workers (Blowey & Edmondson, 2010; Aghamohammadi *et al.,* 2018; Bonestroo *et al.,* 2023).

Indirect costs

Indirect costs associated with mastitis are less immediate but can have significant long-term effects on the profitability of dairy operations.

Cows with mastitis, especially subclinical mastitis (SCM), often experience reduced milk production. The decrease in milk yield can be substantial, with affected cows producing less milk over both short and extended periods. This reduction in yield directly impacts the revenue from milk sales and overall farm income (Moru *et al.,* 2018; Martins *et al.,* 2020).

During the treatment of mastitis, milk from affected cows may need to be discarded or withheld from the market due to the presence of antibiotics or other residues. This results in a loss of potential revenue and increases the cost of production per unit of milk. The financial impact of discarded milk can be significant, particularly in large-scale operations (Janzen, 1970; Geary *et al.,* 2011; Guimarães *et al*., 2017; Sachi *et al.,* 2019; Azooz *et al.,* 2020; He *et al.,* 2020; Singh *et al.,* 2021; Kebede & Tilahun, 2023).

In severe cases of mastitis or when cows do not respond to treatment, culling may be necessary. The decision to cull can result in the loss of valuable animals and the associated costs of replacement, including purchasing new cows and integrating them into the herd. Additionally, the culling of high-yielding cows can further impact milk production and farm profitability (Bascom & Young, 1998; Seegers *et al.,* 1998; Seegers *et al.,* 2003; Olechnowicz & Jaskowski, 2011; Pinedo *et al.,* 2014; Rilanto *et al.,* 2020; Cockram, 2021; Yanga & Jaja, 2022; Kulkarni *et al.,* 2023).

The effects of mastitis can have long-term consequences on overall herd productivity. Chronic mastitis cases can lead to prolonged reductions in milk yield, persistent alterations in milk composition, and increased vulnerability to other diseases. These long-term impacts can compound the economic losses associated with mastitis (Seegers *et al.,* 2003; Dubuc *et al.,* 2011; De Vliegher *et al.,* 2012; FAO, 2014; Carvalho *et al.,* 2019; Haxhiaj *et al.,* 2022; Miyata *et al.,* 2024).

Economic Estimates and Industry Impact

Estimates of the economic impact of mastitis suggest that it costs dairy producers billions of dollars annually (Guimarães *et al.,* 2017; Rasmussen *et al.,* 2024). According to recent studies, the total costs associated with mastitis can account for up to 10-20% of a dairy farm's operating expenses. The high economic burden highlights the need for effective mastitis management strategies and preventative measures to reduce the incidence and severity of the disease (Morales-Ubaldo *et al.,* 2023; Nakada *et al.,* 2023).

Efforts to mitigate the economic impact of mastitis and SCM include implementing comprehensive management practices to reduce incidences and prevalence of pathogens, improving housing and milking procedures, and investing in early detection and treatment technologies. By addressing these factors, dairy producers can reduce the economic burden of mastitis and enhance the overall profitability and sustainability of their operations.

Welfare Considerations

Mastitis and SCM has significant welfare implications for dairy cows, impacting their physical health, emotional well-being, and overall quality of life. Addressing udder health effectively is crucial not only for optimizing milk production but also for ensuring humane treatment and meeting ethical standards in dairy farming.

Physical discomfort and pain

Mastitis, particularly when acute or severe, can cause considerable pain and discomfort in dairy cows. The infection leads to inflammation of the udder tissues, which can result in swelling, redness, and tenderness. Affected cows may exhibit signs of distress, such as reluctance to be milked, altered posture, and decreased activity levels (Cheng & Han, 2020; Mainau *et al.,* 2022). Chronic mastitis can lead to persistent discomfort and reduced quality of life for the affected animals.

Severe cases of mastitis can also impact a cow's mobility. Painful udders may make it difficult for cows to walk or lie down comfortably, which can contribute to lameness and further exacerbate their discomfort. Mobility issues can affect a cow's ability to access feed, water, and shelter, thereby influencing overall health and welfare (Cheng & Han, 2020; Mainau *et al.,* 2022).

Mastitis can compromise the immune system, making cows more susceptible to secondary infections and other health issues. For example, cows with mastitis may be more prone to developing hoof problems or respiratory infections due to weakened immune defenses and the stress associated with the disease (Cheng & Han, 2020; Morales-Ubaldo *et al.,* 2023).

Emotional and behavioral changes

The pain and discomfort associated with mastitis can lead to increased stress and anxiety in cows. Stressful conditions can be exacerbated by factors such as poor housing, inadequate milking practices, and high milk production demands. Chronic stress can have detrimental effects on overall health and behavior, including reduced social interactions and abnormal behaviors (Mainau *et al.,* 2022; Ataallahi *et al.,* 2023; Jurkovich *et al.,* 2024).

Cows suffering from mastitis may display changes in behavior that indicate distress. These changes can include reduced activity levels, altered feeding patterns, and increased aggression or withdrawal from herd mates. Behavioral changes can reflect the cow's discomfort and the challenges in managing mastitis effectively (Siivonen *et al.,* 2011; de Boyer des Roches *et al.,* 2017; Dittrich *et al.,* 2019; Mainau *et al.,* 2022).

Quality of life and ethical considerations

Chronic or severe mastitis can significantly diminish a cow's quality of life. Prolonged pain, discomfort, and decreased ability to perform natural behaviors can lead to a poor overall welfare state. Ensuring that cows receive prompt and effective treatment is

essential for improving their quality of life and maintaining ethical standards in dairy farming (McLennan, 2018; Cheng & Han, 2020; EFSA, 2023).

Meeting ethical standards in dairy farming involves not only managing production efficiently but also providing humane care for animals. This includes implementing practices that prevent mastitis, promptly addressing any cases that arise, and ensuring that animals are not subjected to unnecessary suffering. Ethical considerations also extend to the use of antibiotics and other treatments, ensuring that they are used judiciously and in accordance with welfare standards (von Keyserlingk & Weary, 2017; Temple & Manteca, 2020; Ventura *et al.,* 2021; Hernandez *et al.,* 2022).

Effective mastitis management includes preventive measures that aim to reduce the incidence and severity of the disease. This involves maintaining high standards of udder hygiene, optimizing milking practices, and ensuring that cows have access to comfortable and clean housing. Regular monitoring and early detection of mastitis can also help mitigate welfare concerns and enhance the overall well-being of dairy cows (De Vliegher *et al.,* 2012; Cheng & Han, 2020; Zigo *et al.,* 2021).

Prevalence of Mastitis

Global and regional prevalence

Mastitis is a pervasive and significant issue in dairy farming, impacting dairy herds worldwide. The prevalence of mastitis varies considerably across different regions and farming systems due to a range of factors, including climate, housing systems, and management practices.

Global prevalence

Mastitis is a prevalent disease among dairy cattle worldwide. Research indicates a wide variation in its occurrence (Figures 1 to 5), with estimates suggesting that the global prevalence of subclinical mastitis (SCM) is around 42%, while clinical mastitis (CM) affects about 15% of dairy cows (Krishnamoorthy *et al.,* 2021a; Çelik Gürbulak & Akçay, 2024). These high rates highlight the ongoing difficulties dairy farmers encounter in controlling and preventing the disease.

Regional variations

In many Western countries, mastitis control programs have been implemented for decades, leading to a decline in cases of *Streptococcus agalactiae* and *Staphylococcus aureus* mastitis, while *Streptococcus uberis* and *Escherichia coli* have become more prominent. In some regions, *Klebsiella* spp. and *Streptococcus dysgalactiae* are emerging as significant mastitis pathogens. Variations in national legislation, veterinary services, laboratory facilities, and farmers' management practices influence the distribution and impact of these pathogens (Zadoks & Fitzpatrick, 2009).

In Europe, the prevalence of mastitis varies by country and region. For instance, studies from the Netherlands and Denmark report lower mastitis prevalence due to stringent animal welfare regulations and advanced management practices (Miltenburg *et al.,* 1996; Norberg *et al.,* 2004; Sampimon *et al.,* 2009; Borne *et al.,* 2010). In contrast, regions with less stringent regulations or more intensive production systems may experience higher rates of mastitis (Valde *et al.,* 2004; Hiitiö *et al.,* 2017; Krishnamoorthy *et al.,* 2021a; Krishnamoorthy *et al.,* 2021b). The variation in prevalence can be attributed to differences in housing conditions, milking practices, and climate.

In North America, mastitis prevalence is influenced by factors such as large-scale dairy operations and the use of automated milking systems. Studies in the United States and Canada indicate that while prevalence rates can be high, advancements in milking technology and management practices have to mitigate some of the impacts of mastitis (Jacobs & Siegford, 2012; Barkema *et al.,* 2015). However, variations in prevalence exist between different states and provinces, often reflecting differences in climate, farm size, and management practices (Olde Riekerink *et al.,* 2008).

In developing countries, the prevalence of mastitis, particularly subclinical mastitis (SCM), is often significantly higher than in high-income settings due to structural and systemic limitations (Figure 6). These include poor access to veterinary services,

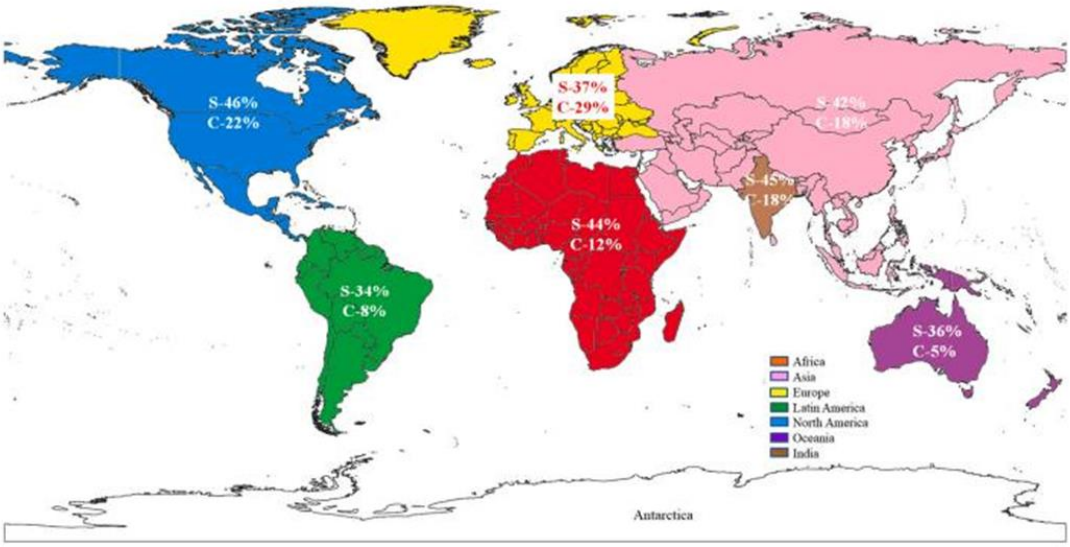

Figure 1: World map showing prevalence estimates for Subclinical (S) and Clinical (C) mastitis in dairy cattle and buffaloes (Krishnamoorthy *et al.,* 2021a).

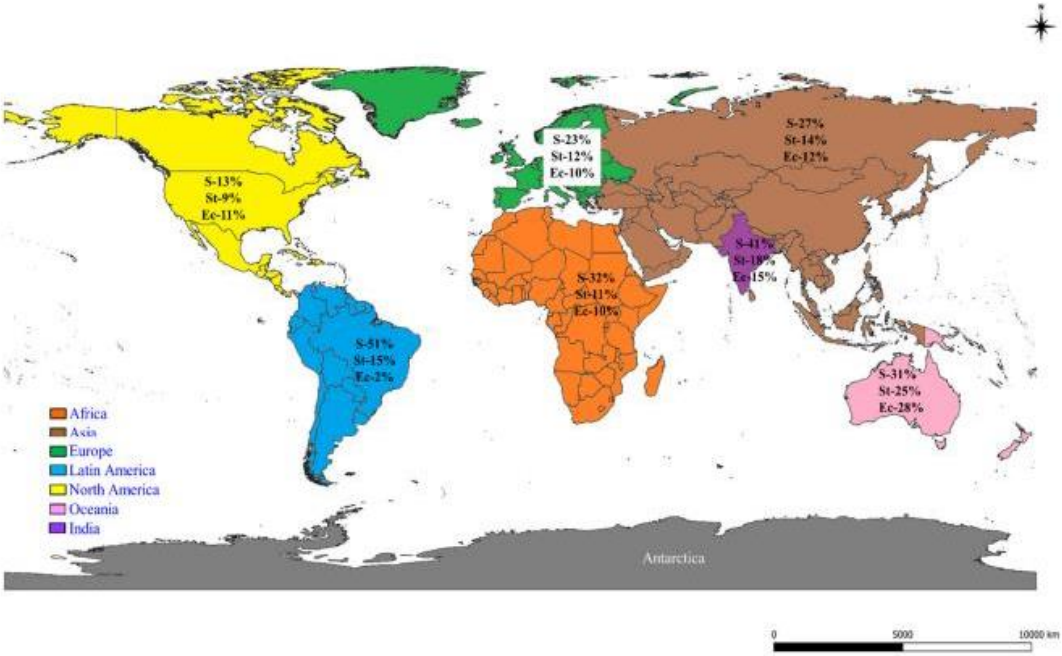

Figure 2: World map showing the continent-wise prevalence of *Staphylococcus* species (S), *Streptococcus* species (St), and *Escherichia coli* (Ec) (Krishnamoorthy *et al.,* 2021b).

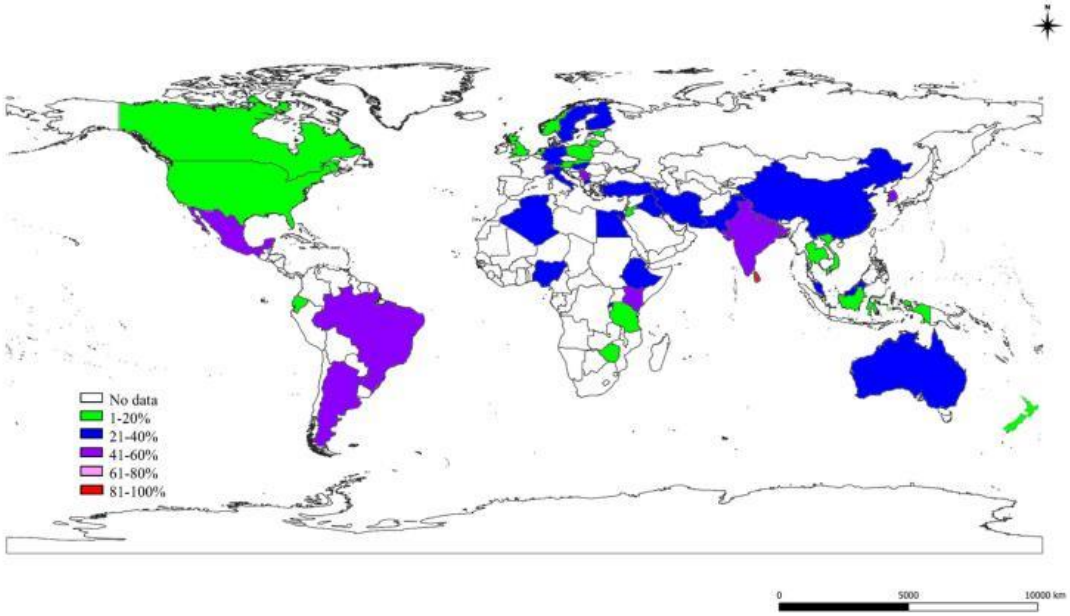

Figure 3: World map showing the prevalence estimates of *Staphylococcus* species in different countries (Krishnamoorthy *et al.,* 2021b).

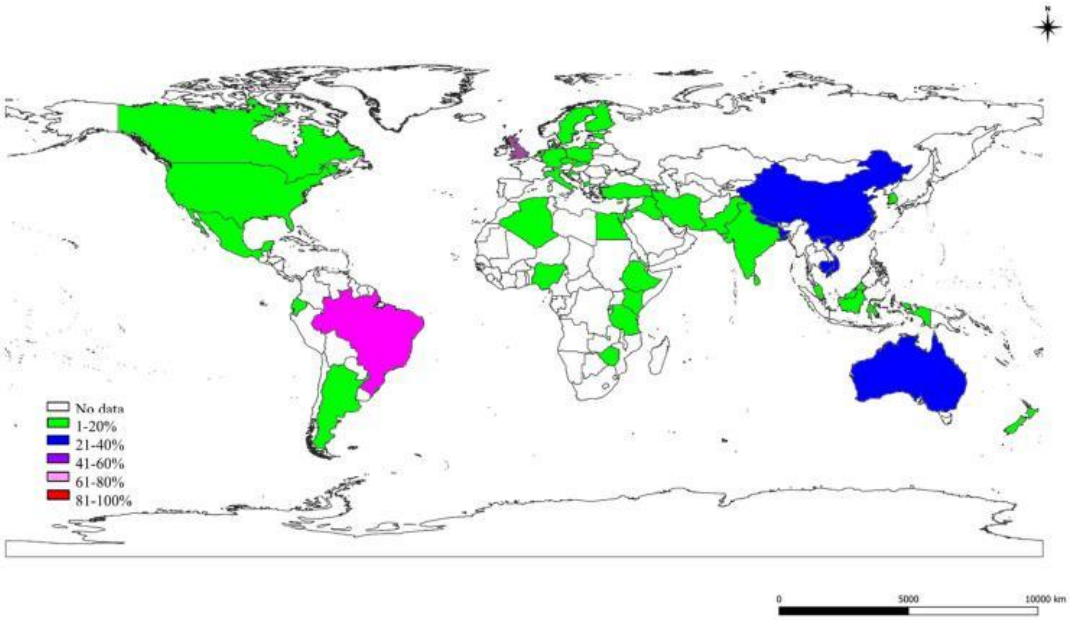

Figure 4: World map showing the prevalence estimates of Streptococcus species in different countries (Krishnamoorthy *et al.,* 2021b).

suboptimal housing, hygiene, and feeding conditions, and a general lack of awareness or training in early disease detection and prevention strategies (Mungube *et al.,* 2005; FAO, 2014; Abebe *et al.,* 2016; Khasapane *et al.,* 2023; Iraguha, 2024).

For example, in sub-Saharan Africa, several studies have reported SCM prevalence rates ranging from 40% to over 60%, especially among smallholder and pastoral herds where hand-milking, poor udder hygiene, and inadequate sanitation are common (Karimuribo *et al.,* 2008; Shittu *et al.,* 2012; Blignaut *et al.,* 2018).

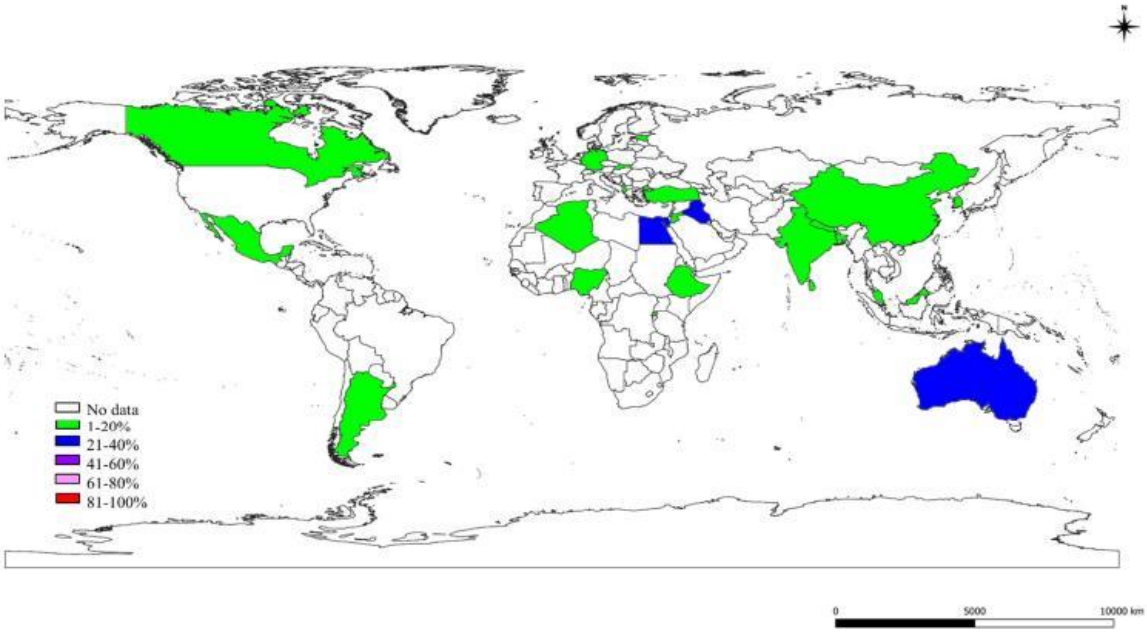

Figure 5: World map showing the prevalence estimates of Escherichia coli in different countries (Krishnamoorthy *et al.,* 2021b)

In Nigeria, mastitis prevalence mirrors these high levels, with multiple reports indicating SCM rates well above 50% in smallholder dairy systems (Shittu *et al.,* 2012; Adamu *et al.,* 2020; Yunusa *et al.,* 2025). Comparatively, countries like Ethiopia and Kenya also face similar challenges, but targeted interventions such as farmer training on clean milking practices and use of CMT for routine screening have demonstrated measurable reductions in mastitis burden (Birhanu *et al.,* 2017; Zeryehun & Abera, 2017; Mbindyo *et al.,* 2020). In South Asia, particularly India and Pakistan, dairy production is likewise dominated by smallholder systems. However, more structured extension services, national disease control programs, and widespread adoption of low-cost diagnostics have contributed to better management of udder health (Ghafar *et al.,* 2020; Bari *et al.,* 2022).

Figure 6: A map showing prevalence estimates for subclinical mastitis among dairy cattle in Africa (Khasapane *et al.,* 2023).

Additionally, genetic differences in dairy breeds, coupled with region-specific environmental stressors (e.g., heat, drought, and parasite burden), also influence susceptibility to mastitis across LMICs (Detilleux, 2009; Das *et al*., 2016; Cheng & Han, 2020). In most cases, local breeds such as Nigeria's Sokoto Gudali and White Fulani, or Ethiopia's Boran cattle, may exhibit greater disease resilience but lower productivity compared to high-yielding exotic breeds

that are more mastitis-prone under local management conditions.

By contextualizing Nigeria's situation within this broader LMIC framework, it becomes evident that while the challenges are shared, solutions must be tailored. Lessons from successful regional strategies – such as mobile veterinary outreach in Uganda or community-level milk quality control in Bangladesh – can be adapted to Nigeria's dairy landscape. Hence, this review emphasizes the necessity for regionally informed and socioeconomically appropriate approaches to mastitis control and cow welfare improvement across LMICs. In Australia and New Zealand, mastitis prevalence is influenced by pasture-based systems and climatic conditions. Research indicates that while pasture-based systems can offer benefits, such as improved cow comfort, they can also pose challenges, including increased exposure to environmental pathogens. As a result, mastitis prevalence can vary depending on local conditions and management practices (McDougall, 1999; Plozza *et al.,* 2011; Chung *et al*., 2021; Moscovici Joubran *et al.,* 2021).

Influencing Factors

Climate plays a crucial role in the prevalence of mastitis. Warm and humid conditions can promote the growth of pathogens, increasing the risk of mastitis. Conversely, cold and dry climates may reduce the prevalence of certain pathogens but can introduce other challenges such as frostbite or winter-related injuries (Morse *et al.,* 1988; Vitali *et al.,* 2016; Jamali *et al.,* 2018).

Housing systems significantly impact mastitis prevalence. Systems with inadequate ventilation, poor bedding, or overcrowding can increase the risk of mastitis. Conversely, well-maintained housing with proper ventilation and hygiene practices can help reduce mastitis incidence (Hogan & Smith, 2012; FAO, 2014; Witkowska & Ponieważ, 2022; Freu *et al.,* 2023; Meçaj *et al.,* 2023).

Effective management practices, including regular milking equipment maintenance, proper udder hygiene, and timely veterinary interventions, are critical in controlling mastitis. Variations in management practices can lead to significant differences in mastitis prevalence across regions and farms (LeBlanc *et al.,* 2006; Shittu *et al.,* 2012; Farag *et al.,* 2023).

Genetic factors also influence mastitis susceptibility. Certain breeds or genetic lines may be more resistant or susceptible to mastitis, and selective breeding programs can help manage this aspect of mastitis control (Shook & Schutz, 1994; Rupp & Boichard, 2003; Berry *et al.,* 2011; Shittu *et al.,* 2012; Weigel & Shook, 2018; Brajnik & Ogorevc, 2023; Narayana *et al.*, 2023).

Factors Influencing Prevalence

The prevalence of mastitis is influenced by a range of factors, each contributing to the likelihood of infection in dairy cattle (Figure 7). Understanding these factors is crucial for developing effective management strategies to control and prevent mastitis. The main factors influencing mastitis prevalence include management practices, environmental conditions, and genetics.

Management practices

Poor hygiene is a significant risk factor for mastitis. Dirty environments, including contaminated bedding and milking equipment, can harbor pathogens that cause mastitis. Inadequate cleaning protocols for milking equipment and udder hygiene can increase the incidence of both clinical and subclinical mastitis (Shittu *et al.,* 2012; Abebe *et al.,* 2016). Ensuring that milking equipment is properly sanitized and that cows' udders are clean before milking are essential practices to reduce mastitis risk.

Incorrect milking procedures, such as improper milking machine settings or failure to detect early signs of mastitis, can contribute to increased mastitis prevalence. Overmilking or under-milking can also damage teat tissues and create an environment conducive to infection (Abebe *et al.,* 2016; Zigo *et al.,* 2021). Regular maintenance and calibration of milking machines, along with training personnel in proper milking techniques, are critical for minimizing mastitis risk.

Overcrowding in housing systems can lead to increased transmission of mastitis-causing pathogens. High stocking densities can result in higher rates of udder contact and increased stress on animals, which may compromise their immune response and make them more susceptible to infection (Arnott *et al.,* 2017; Neculai-Valeanu & Ariton, 2022). Proper housing design that allows for adequate space per cow and facilitates good ventilation can help reduce mastitis risk.

Environmental conditions

Environmental conditions, particularly the quality of bedding, play a crucial role in mastitis prevalence. Damp, soiled, or inadequately managed bedding can create a favorable environment for pathogens such as Streptococcus and Staphylococcus species to thrive.

Studies have shown that bedding material that remains wet or soiled can lead to higher rates of mastitis (Fávero *et al*., 2015; Patel *et al.,* 2019; Alanis *et al.,* 2021; Freu *et al.,* 2023; Nogara *et al.,* 2023). Regular replacement and proper management of bedding materials are essential to maintaining a dry and clean environment.

Climatic conditions also impact mastitis prevalence. In regions with high humidity or frequent rainfall, the risk of mastitis can increase due to the higher likelihood of wet and dirty bedding. Conversely, extreme cold can lead to issues such as frostbite or teat injuries, which can predispose cows to mastitis (Morse *et al.,* 1988; Biffa *et al.,* 2005; Jingar *et al.,* 2014; Assatbayeva *et al.,* 2022). Effective climate control and environmental management practices are necessary to mitigate these risks.

The design and maintenance of housing facilities can influence mastitis risk. Poorly designed facilities that do not allow for proper drainage, ventilation, or hygiene can exacerbate mastitis problems. Adequate drainage systems to remove waste and prevent the accumulation of moisture are important for reducing mastitis risk (Abebe *et al.,* 2016; Leso *et al.,* 2020; Zigo *et al.,* 2021).

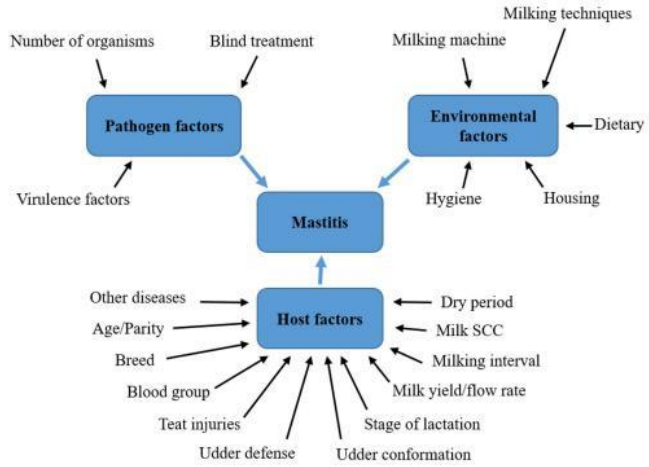

Figure 7: Factors influencing the development of mastitis in dairy cows (Abebe *et al.,* 2016)

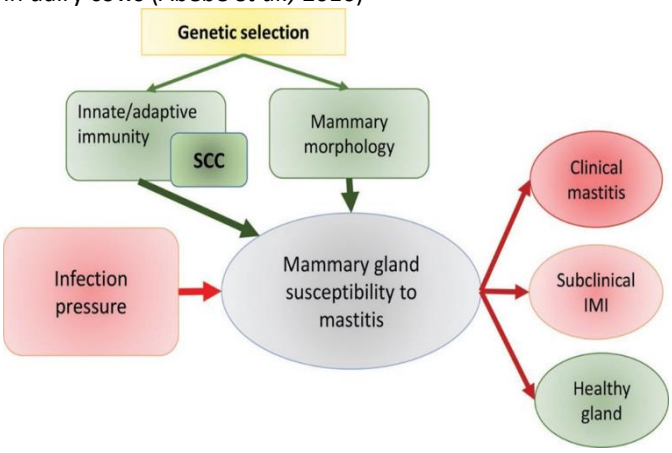

Figure 8: Relationship between some major determinants of the mammary gland health status (Rainard *et al.,* 2018)

Genetics

Genetic factors play a role in mastitis susceptibility. Certain breeds or genetic lines of dairy cattle may be more predisposed to mastitis than others. For example, studies have shown that some dairy breeds, such as Holsteins, may have a higher prevalence of mastitis compared to others due to differences in udder anatomy or immune response (Harmon, 1994; Rupp & Boichard, 2003; Berry *et al.,* 2011; Sender *et al.,* 2013; Abebe *et al.,* 2016; Rainard *et al.,* 2018; Zemanova *et al.,* 2022; Brajnik & Ogorevc, 2023). Selective breeding programs can help identify and promote traits that are associated with increased resistance to mastitis.

Genetic selection for traits associated with mastitis resistance can be an effective strategy for reducing prevalence in dairy herds (Figure 8). This includes selecting animals with lower susceptibility to infection and better udder health characteristics. Research has shown that breeding for improved udder conformation and immune response can lead to reduced mastitis incidence (Rainard *et al.,* 2018; Brajnik & Ogorevc, 2023; Gutiérrez-Reinoso *et al*., 2023; Narayana *et al.,* 2023). Implementing genetic selection programs requires careful consideration of breeding objectives and monitoring of mastitis incidence over time.

Subclinical Mastitis

Subclinical mastitis (SCM) is a prevalent form of mastitis that poses a significant challenge to dairy farming due to its often-inconspicuous nature. Unlike clinical mastitis (CM), which presents with obvious symptoms such as swelling, redness, and changes in milk appearance (e.g., clots or a decrease in milk yield), SCM does not exhibit visible signs. This section elaborates on the characteristics, impact, and detection of SCM, emphasizing its importance in maintaining udder health and optimizing dairy production.

Characteristics of subclinical mastitis

Subclinical mastitis (SCM) is defined by an increase in somatic cell count (SCC) in the milk without any visible clinical signs of infection. The

SCC is a measure of the number of white blood cells present in milk, which typically increases in response to an infection or inflammation within the mammary gland. In SCM, the SCC can be elevated to levels that indicate an underlying infection, even though the udder and milk may appear normal (Sumon *et al.,* 2020; Dejyong *et al.,* 2022; Williamson *et al.,* 2022). Research indicates that SCM is responsible for a significant proportion of mastitis cases in dairy herds (Figure 9). Studies have shown that up to 70% of mastitis cases can be classified as subclinical (Shittu *et al.,* 2012; Khasapane *et al.,* 2023; Tommasoni *et al.,* 2023). Despite the lack of visible symptoms, SCM can have considerable effects on milk production and quality. Elevated SCC associated with subclinical mastitis can lead to reduced milk yield and altered milk composition, which may negatively impact dairy product quality and farm profitability (Malek dos Reis *et al.,* 2013; FAO, 2014; Fernandes *et al.,* 2021).

The economic impact of subclinical mastitis is substantial. The increased SCC resulting from subclinical infections can lead to milk that is less suitable for processing and sale, affecting both the quality and quantity of milk produced. Additionally, the cost of managing subclinical mastitis includes not only the potential loss in milk production but also the costs associated with testing and monitoring SCC levels, as well as any necessary treatments (Geary *et al.,* 2011; FAO, 2014; Dejyong *et al.,* 2022).

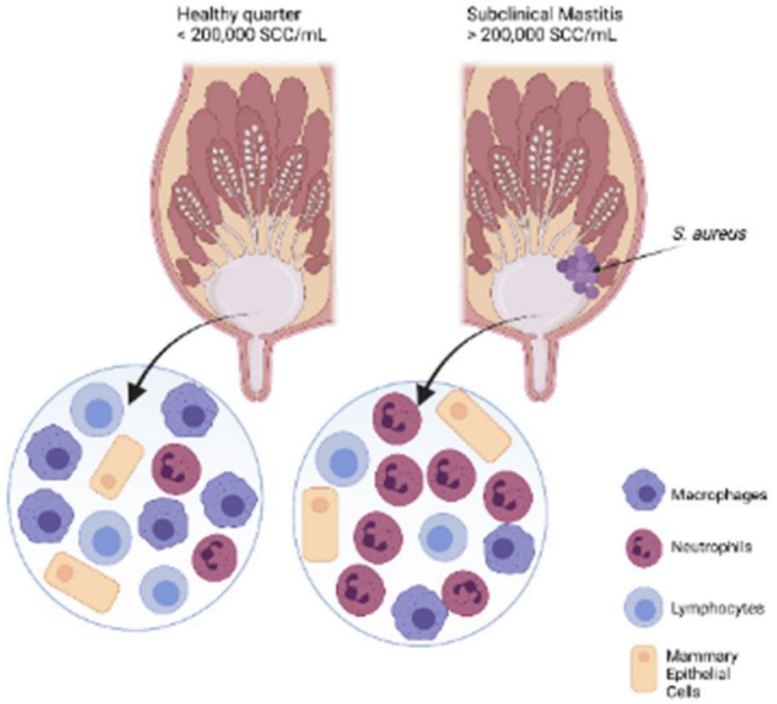

Figure 9: Somatic cell composition in healthy versus infected cow udder quarters. In milk from a healthy udder quarter, macrophages are most prevalent, with smaller proportions of lymphocytes, neutrophils, and epithelial cells. In contrast, milk from an infected quarter, whether with clinical or subclinical mastitis, shows a high concentration of neutrophils along with fewer macrophages, lymphocytes, and epithelial cells (Haxhiaj *et al.,* 2022).

Detection and Diagnosis

The detection of subclinical mastitis (SCM) requires specific testing methods, as the condition is not visible through standard visual inspection. Several tests are commonly used to identify elevated SCC and diagnose SCM.

The California Mastitis Test (CMT) is a widely used, rapid, and cost-effective test that measures the SCC in milk. The test principle involves mixing equal volume of CMT reagent (alkyl aryl sulphonate) with milk samples and observing the reaction, which forms a gel-like substance if the SCC is elevated. The CMT reagent interacts with the DNA of the somatic cells in mastitis udder to form gel. The CMT provides a qualitative measure of SCC and helps in identifying cows with subclinical mastitis (Rice, 1981; Chakraborty *et al.,* 2019; Menzies, 2021; Huang & Kusaba, 2022; Rust *et al.,* 2023).

Similar to the CMT, the White Side Test (WST) is used to assess SCC by mixing milk with a reagent on a white surface. The resulting reaction indicates the level of SCC, with higher levels suggesting the presence of subclinical mastitis. This test is also useful for initial screening of udder health (Badiuzzaman *et al.,* 2015; Iraguha *et al.,* 2017; Chakraborty *et al.,* 2019; Tanni *et al.,* 2021).

The Draminski Mastitis Detector (DMD) is an electronic device used for detecting mastitis. It measures electrical conductivity in milk, which increases with elevated SCC. The device provides a quantitative measure of mastitis and is useful for monitoring udder health on a larger scale (Sheldrake & Hoare, 1981; Iraguha *et al.,* 2017; Chakraborty *et al.,* 2019; Draminski, 2024).

One of the main challenges with subclinical mastitis (SCM) is its asymptomatic nature, which often delays detection and intervention. Timely and regular testing is therefore essential to identify SCM early, manage it effectively, and prevent its

Table 1: Prevalence of mastitis in livestock across the states and zones in Nigeria (adopted from Adamu *et al.*, 2020)

Zone	Location	Number examined	Prevalence (%)	Method	Livestock type	Reference
North-West	Kaduna	147	19.7	PEM, CMT	Cattle	(Makolo *et al.,* 2019)
	Kaduna	360	26.9	CMT	Cattle	(Umaru *et al.,* 2017)
	Kaduna	386	60.1	CMT	Goat	(Udoh *et al.,* 2019)
	Kaduna	147	8.1	CM/PCR	Cattle	(Makolo *et al.,* 2020)
	Kaduna	300	29.7	CMT	Cattle	(Mbuk *et al.,* 2016)
	Kaduna	42	31	CMT	Cattle	Umoh *et al.,* 1990)
	Kaduna	390	7.17	LAT	Cattle	Akange *et al.,* 2013)
	Kaduna, Kano, Kastina	900	10.2	PEM	Goat	(Ameh *et al.,* 1993)
	Sokoto	88	10.23	PEM	Cattle, Sheep, Goat	(Umaru *et al.,* 2009)
	Sokoto	300	85.33	CMT	Cattle	(Shittu *et al.,* 2012)
	Sokoto	100	52	CM	Cattle	(Junaidu *et al.,* 2011)
	Zamfara	263	21.6	RFCT	Goat	(Tanimomo *et al.,* 2012)
North-East	Bauchi	122	47.5	PEM, CMT	Goat	(Danmallam & Pimenov, 2019)
	Bauchi	348	28.1	PEM, CMT	Sheep, Goat	(Danmallam *et al.*, 2018)
	Borno	300	17	PEM	Goat	(Ameh & Tari, 2000)
	Borno	81	70.3	PEM	Goat	(Egwu *et al.,* 1999)
	Borno	5000	2.1	PEM	Cattle	(Ameh *et al.,* 1999)
	Borno	206	50	PEM	Goat	(Egwu *et al.,* 1994)
North-Central	Plateau	51	63.7	PEM	Cattle	(Ebojei *et al.,* 2010)
	Plateau	85	30.5	CMT	Cattle	(Suleiman *et al.,* 2012)
	Plateau	16	43.7	PEM, CM	Cattle	(Anueyiagu & Isiyaku, 2015)
	Plateau	65	36.9	PEM, CMT	Goat	(Danmallam *et al.*, 2018)
South-East	Enugu	58	67.24	CMT	Goat	(Ugochukwu *et al.,* 2017)
	Imo	8615	9.7	PEM	Cattle, Sheep, Goat	(Okoli *et al.,* 2006a)
	Imo	327000	3.3	PEM	Cattle, Sheep, Goat	(Okoli *et al.,* 2006b)
South-South	Edo	63	30.2	PEM, CMT	Goat	(Danmallam *et al.*, 2018)
South-West	Oyo	411	26	CMT	Cattle	(Olufemi *et al.,* 2018)
	Ogun, Lagos	641224	0.22	CCF	Cattle	(Cadmus & Adesokan, 2009)

PEM = Physical Examination Method; CMT = California Mastitis Test; PCR = Polymerase Chain Reaction; LAT = Latex Agglutination Test; RFCT = Rapid Field Catalase Test.

progression to clinical mastitis (CM), thereby preserving udder health and ensuring milk quality (Abed *et al.,* 2021; Neculai-Valeanu & Ariton, 2022; Tommasoni *et al.,* 2023). While numerous global studies have documented SCM prevalence and risk factors, region-specific data, particularly from Nigeria, remain limited. To address this gap, we have included Table 1 from Adamu *et al. (*2020), which

synthesizes existing findings from within the country. This inclusion provides valuable local context to complement the global prevalence data previously referenced (Krishnamoorthy *et al.,* 2021a; Krishnamoorthy *et al.,* 2021b), thereby enriching the comparative framework of this review.

Conclusion

This review underscores the pivotal role of cow welfare and udder health – especially the control of subclinical mastitis (SCM) – in ensuring the sustainability and productivity of Nigeria's dairy industry. The asymptomatic nature of SCM and its negative effects on milk quality and yield necessitate early detection and continuous monitoring using affordable and cow-side diagnostic tools such as the California Mastitis Test (CMT), White Side Test (WST), and Draminski Mastitis Detector (DMD).

Future research should prioritize large-scale epidemiological investigations that map regional variations in SCM prevalence, assess risk factors across diverse production systems, and identify herd-level management challenges. In addition, exploring the genetic resistance of indigenous breeds to mastitis can contribute to more resilient, locally adapted dairy systems.

To translate evidence into practice, the following policy recommendations are proposed:

- National mastitis control programs should be developed and integrated into broader animal health initiatives under the Federal Ministry of Livestock Development, focusing on training, surveillance, and control.
- Incentivized farmer education programs, delivered through state Agricultural Development Programmes (ADPs) or veterinary extension services, should promote best practices in hygiene, milking protocols, housing, and nutrition.
- Subsidies for affordable diagnostic kits like CMT and DMD should be implemented to encourage widespread SCM screening at the farm and household levels.
- Promotion of welfare-friendly housing systems, especially for peri-urban and semi-intensive systems, should be supported through extension messaging and pilot demonstration farms.
- Strengthening veterinary-livestock market-slaughterhouse linkages to integrate welfare assessment, antimicrobial stewardship, and early detection of mastitis at critical points along the value chain.

Furthermore, interdisciplinary collaborations that incorporate veterinary medicine, animal behavior, environmental science, and socioeconomics are needed to develop holistic, evidence-based strategies that enhance cow welfare and udder health. A national policy framework that embeds animal welfare and udder health as strategic pillars of dairy development will not only improve productivity but also safeguard public health and rural livelihoods.

Funding

No funding was received.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

Abebe R, Hatiya H, Abera M, Megersa B & Asmare K (2016). Bovine mastitis: Prevalence, risk factors and isolation of *Staphylococcus aureus* in dairy herds at Hawassa milk shed, South Ethiopia. *BMC Veterinary Research,* doi.10.1186/s12917-016-0905-3.

Abed AH, Menshawy AMS, Zeinhom MMA, Hossain D, Khalifa E, Wareth G & Awad MF (2021). Subclinical mastitis in selected bovine dairy herds in north upper Egypt: Assessment of prevalence, causative bacterial pathogens, antimicrobial resistance and virulence-associated genes. *Microorganisms*, doi. 10.3390/microorganisms9061175.

Abeni F & Bertoni G (2009). Main causes of poor welfare in intensively reared dairy cows. *Italian Journal of Animal Science,* doi.10.4081/ijas.2009.s1.45.

Adamu HO, Hussaini RO, Obasuyi C, Anagha LI & Okoduwa GO (2020). Prevalence of mastitis in Nigerian livestock: a Review. *Open Veterinary Science,* **1**(1): 20-29.

Adeyeye AA, Muhammad BI & Adamu U (2020). Reproductive Performance and its associated factors in cows raised in Sokoto, Nigeria. *Journal of Agriculture and Environment,* **16**(2): 35-42.

Aghamohammadi M, Haine D, Kelton DF, Barkema HW, Hogeveen H, Keefe GP & Dufour S (2018). Herd-level mastitis associated costs on Canadian dairy farms. *Frontiers in Veterinary Science,* 5:100. doi. 10.3389/fvets.2018.00100.

Akange EN, Kwanashie CN, Bisalla M, Useh NM & Ngbede EO (2013). Evidence of

cryptococcosis in cattle in Zaria, Kaduna State, Nigeria. *Veterinary World,* **6**(2):64.

Alanis VM, Zurakowski M, Pawloski D, Tomazi T, Nydam DV & Ospina PA (2021). Description of the Characteristics of five bedding materials and association with bulk tank milk quality on five New York dairy herds. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2021.636833.

Ameh JA, Addo PB, Adekeye JO & Gyang EO (1993). Prevalence of clinical mastitis and of intramammary infections in Nigerian goats. *Preventive Veterinary Medicine*, **17**(1-2):41-6.

Ameh JA, Edegbe NT & Zaria LT (1999). Prevalence of bovine mastitis in Maiduguri, Borno State, Nigeria. *Veterinarski Arhiv*, **69**(2): 87–95.

Ameh JA & Tari IS (2000). Observation on the prevalence of caprine mastitis in relation to predisposing factors in Maiduguri. *Small Ruminant Research,* **35**(1): 1–5.

Antanaitis R, Juozaitienė V, Jonike V, Baumgartner W & Paulauskas A (2021). Milk lactose as a biomarker of subclinical mastitis in Dairy Cows. *Animals (Basel),* doi. 10.3390/ani11061736.

Anueyiagu KN & Isiyaku AW (2015). Isolation, identification of *Staphylococcus aureu*s from bovine milk and its antibiotics susceptibility. *International Journal of Livestock Production,* **6**(6):74–77.

Arnott G, Ferris CP & O'Connell NE (2017). Review: welfare of dairy cows in continuously housed and pasture-based production systems. *Animal*, **11**(2): 261-273.

Assatbayeva G, Issabekova S, Uskenov R, Karymsakov T & Abdrakhmanov T (2022). Influence of microclimate on ketosis, mastitis and diseases of cow reproductive organs. *Journal of Animal Behaviour and Biometeorology*, doi.10.31893/jabb.22030J.

Ataallahi M, Cheon SN, Park GW, Nugrahaeningtyas E, Jeon JH & Park KH (2023). Assessment of stress levels in lactating cattle: Analyzing cortisol residues in commercial milk products in relation to the temperature-humidity index. *Animals (Basel),* doi. 10.3390/ani13152407.

Azooz MF, El-Wakeel SA & Yousef HM (2020). Financial and economic analyses of the impact of cattle mastitis on the profitability of Egyptian dairy farms. *Veterinary World,* **13**(9): 1750-1759.

Badiuzzaman M, Samad MA, Siddiki SHMF, Islam MT & Saha S (2015). Subclinical mastitis in lactating cows: Comparison of four screening tests and effect of animal factors on its occurrence. *Bangladesh Journal of Veterinary Medicine,* **13**(2): 41-50.

Bar D, Tauer LW, Bennett G, González RN, Hertl JA, Schukken YH, Schulte HF, Welcome FL & Gröhn YT (2008). The cost of generic clinical mastitis in dairy cows as estimated by using dynamic programming. *Journal of Dairy Science,* **91**(6): 2205-2214.

Bari MS, Rahman MM, Persson Y, Derks M, Sayeed MA, Hossain D, Singha S, Hoque MA, Sivaraman S, Fernando P, Ahmad I, Samad A & Koop G (2022). Subclinical mastitis in dairy cows in south-Asian countries: a review of risk factors and etiology to prioritize control measures. *Veterinary Research Communications*;**46**(3): 621-640.

Barkema HW, von Keyserlingk MA, Kastelic JP, Lam TJ, Luby C, Roy JP, LeBlanc SJ, Keefe GP & Kelton DF (2015). Invited review: Changes in the dairy industry affecting dairy cattle health and welfare. *Journal of Dairy Science,* **98**(11): 7426-45.

Bascom SS & Young AJ (1998). A summary of the reasons why farmers cull cows. *Journal of Dairy Science,* **81**(8): 2299-305.

Batavani RA, Asri S & Naebzadeh H (2007). The effect of subclinical mastitis on milk composition in dairy cows. *Iranian Journal of Veterinary Research, University of Shiraz*, **8**(3) Ser. No. 20.

Bentayeb L, Akkou M, Zennia SS-I, Titouche Y, Doumandji A & Megateli S (2023). Impacts of subclinical mastitis on milk quality, clotting ability and microbial resistance of the causative Staphylococci. *Large Animal Review,* **29**(3): 105-111.

Berry DP, Bermingham ML, Good M & More SJ (2011). Genetics of animal health and disease in cattle. *Irish Veterinary Journal,* doi.10.1186/2046-0481-64-5.

Bezerra JS, Sales DC, Oliveira JPF, Silva YMO, Urbano SA, Lima Junior DM, Borba LHF, Macedo CS, Anaya K & Rangel AHN (2021). Effect of high somatic cell counts on the sensory acceptance and consumption intent of pasteurized milk and coalho cheese*. Journal of Food Science and Technology, Campinas*, doi.10.1590/fst.21620.

Biffa D, Debela E & Beyene F (2005). Prevalence and risk factors of mastitis in lactating dairy cows in Southern Ethiopia. *The International Journal of Applied Research in Veterinary Medicine,* **3**(3): 189-198.

Birhanu M, Leta S, Mamo G & Tesfaye S (2017). Prevalence of bovine subclinical mastitis and isolation of its major causes in Bishoftu Town, Ethiopia. *BMC Res Note*. doi. 10.1186/s13104-017-3100-0.

Blignaut D, Thompson P & Petzer IM (2018). Prevalence of mastitis pathogens in South African pasture-based and total mixed ration-based dairies during 2008 and 2013. *Onderstepoort Journal of Veterinary Research,* **85**(1): e1-e7.

Blowey RW & Edmondson P (2010). Mastitis Control in Dairy Herds, (second edition). CABI. Pp 1-266.

Blum SE, Heller DE, Jacoby S, Krifuks O, Merin U, Silanikove N, Lavon Y, Edery N & Leitner G (2020). Physiological response of mammary glands to *Escherichia coli* infection: A conflict between glucose need for milk production and immune response. *Scientific Reports,* doi.10.1038/s41598-020-66612-7.

Bobbo T, Ruegg PL, Stocco G, Fiore E, Gianesella M, Morgante M, Pasotto D, Bittante G & Cecchinato A (2017). Associations between pathogen-specific cases of subclinical mastitis and milk yield, quality, protein composition, and cheese-making traits in dairy cows. *Journal of Dairy Science,* **100**(6): 4868-4883.

Bochniarz M, Błaszczyk P, Szczubiał M, Vasiu I, Adaszek Ł, Michalak K, Pietras-Ożga D, Wochnik M & Dąbrowski R (2023). Comparative analysis of total protein, casein, lactose, and fat content in milk of cows suffering from subclinical and clinical mastitis caused by *Streptococcus* spp. *Journal of Veterinary Research,* **67**(2): 251-257.

Böker AR, Bartel A, Do Duc P, Hentzsch A, Reichmann F, Merle R, Arndt H, Dachrodt L, Woudstra S & Hoedemaker M (2023). Status of udder health performance indicators and implementation of on-farm monitoring on German dairy cow farms: Results from a large scale cross-sectional study. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2023.1193301.

Bonestroo J, Fall N, Hogeveen H, Emanuelson U, Klaas IC & van der Voort M (2023). The costs of chronic mastitis: A simulation study of an automatic milking system farm. *Preventive Veterinary Medicine,* doi. 10.1016/j.prevetmed.2022.105799.

Borne BH, Schaik G, Lam TJ & Nielen M (2010). Variation in herd-level mastitis indicators between primi and multiparae in Dutch dairy herds. *Preventive Veterinary Medicine,* **96**(1-2): 49–55.

Brajnik Z & Ogorevc J (2023). Candidate genes for mastitis resistance in dairy cattle: A data integration approach. *Journal of Animal Science and Biotechnology,* doi. 10.1186/s40104-022-00821-0.

Brown KA, Venkateshmurthy NS, Potubariki G, Sharma P, Cardwell JM, Prabhakaran D, Knai C & Mohan S (2022). The role of dairy in healthy and sustainable food systems: community voices from India. *BMC Public Health,* doi. 10.1186/s12889-022-13194-w.

Botrel MA, Haenni M, Morignat E, Sulpice P, Madec JY & Calavas D (2010). Distribution and antimicrobial resistance of clinical and subclinical mastitis pathogens in dairy cows in Rhône-Alpes, France. *Foodborne Pathogens and Disease,* **7**(5): 479-487.

Busanello M, de Freitas LN, Winckler JPP, Farias HP, Dos Santos Dias CT, Cassoli LD & Machado PF (2017). Month-wise variation and prediction of bulk tank somatic cell count in Brazilian dairy herds and its impact on payment based on milk quality. *Irish Veterinary Journal,* doi. 10.1186/s13620-017-0103-z.

Cadmus SI & Adesokan HK (2009). Causes and implications of bovine organs/offal condemnations in some abattoirs in Western Nigeria. *Tropical Animal Health and Production*. **41**(7): 1455–1463.

Carmo RMd, Nascimento LECd, Leão PVT, de Paula GH, Dias MBdC, Fernandes, PB, Mesquita AA, Nicolau ES, Rezende MMR, Sousa WAd, Silva ECNMd & Silva MAPd (2024). Influence of somatic cell removal on milk quality and yield. *Beverages*, doi.10.3390/beverages10010005.

Carvalho MR, Peñagaricano F, Santos JEP, DeVries TJ, McBride BW & Ribeiro ES (2019). Long-term effects of postpartum clinical disease on milk production, reproduction, and culling of dairy cows. *Journal of Dairy Science,* doi.10.3168/jds.2019-17025.

Çelik Gürbulak E & Akçay A (2024). Meta analysis of the prevalence of subclinical mastitis in dairy cattle. *Journal of the Hellenic Veterinary Medical Society,* **74**(4): 6649–6662.

Chakraborty S, Dhama K, Tiwari R, Iqbal Yatoo M, Khurana SK, Khandia R, Munjal A, Munuswamy P, Kumar MA, Singh M, Singh R, Gupta VK & Chaicumpa W (2019). Technological interventions and advances in the diagnosis of intramammary infections in animals with emphasis on bovine population-a review. *Veterinary Quarterly,* **39**(1): 76-94.

Cheng WN & Han SG (2020). Bovine mastitis: risk factors, therapeutic strategies, and alternative treatments - A review. *Asian-Australasian Journal of Animal Sciences,* **33**(11): 1699-1713.

Chung LK, Sahibzada S, Annandale HC, Robertson ID, Waichigo FW, Tufail MS & Aleri JA (2021). Bacterial pathogens associated with clinical and subclinical mastitis in a Mediterranean pasture-based dairy production system of Australia. *Research in Veterinary Science,* doi. 10.1016/j.rvsc.2021.10.005.

Cockram MS (2021). Invited Review: The welfare of cull dairy cows. *Applied Animal Science,* **37**(3): 334–352.

Danmallam FA, Pimenov NV, Ngulukun SS & Mwankon SE (2018). Prevalence and bacterial etiology of mastitis in small ruminants in Toro local government area, Bauchi State, Nigeria. *Russian Journal of Agricultural and Socio-Economic Sciences,* **7**(7):341–345.

Danmallam FA & Pimenov NV (2019). Study on prevalence, clinical presentation, and associated bacterial pathogens of goat mastitis in Bauchi, Plateau, and Edo states, Nigeria. *Veterinary World,* **12**(5): 638–645.

Das R, Sailo L, Verma N, Bharti P, Saikia J, Imtiwati & Kumar R (2016). Impact of heat stress on health and performance of dairy animals: A review. *Veterinary World,* **9**(3): 260-268.

de Boyer des Roches A, Faure M, Lussert A, Herry V, Rainard P, Durand D & Foucras G (2017). Behavioral and patho-physiological response as possible signs of pain in dairy cows during Escherichia coli mastitis: A pilot study. *Journal of Dairy Science,* **100**(10): 8385-8397.

de Jong E, McCubbin KD, Speksnijder D, Dufour S, Middleton JR, Ruegg PL, Lam TJGM, Kelton DF, McDougall S, Godden SM, Lago A, Rajala-Schultz PJ, Orsel K, De Vliegher S, Krömker V, Nobrega DB, Kastelic JP & Barkema HW (2023). Invited review: Selective treatment of clinical mastitis in dairy cattle. *Journal of Dairy Science,* **106**(6): 3761-3778.

de Jong E, van der Velden I, Smid A-MC, Ida JA, Reyher KK, Kelton DF & Barkema HW (2024). Dairy farmers' considerations for antimicrobial treatment of clinical mastitis in British Columbia and Alberta, Canada. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2024.1417958.

Dejyong T, Chanachai K, Immak N, Prarakamawongsa T, Rukkwamsuk T, Tago Pacheco D & Phimpraphai W (2022). An economic analysis of high milk somatic cell counts in dairy cattle in Chiang Mai, Thailand. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2022.958163.

Detilleux JC (2009). Genetic factors affecting susceptibility to udder pathogens. *Veterinary Microbiology,* **134**(1-2): 157-164.

De Vliegher S, Fox LK, Piepers S, McDougall S & Barkema HW (2012). Mastitis in dairy heifers: nature of the disease, potential impact, prevention, and control. *Journal of Dairy Science,* **95**(3):1025-1040.

Dittrich I, Gertz M & Krieter J (2019). Alterations in sick dairy cows' daily behavioural patterns. *Heliyon,* doi.10.1016/j.heliyon.2019.e02902.

Draminski. DRAMINSKI 4QMAST Mastitis Detector for 4 Quarters. https://bestharveststore.com/files/Mastitis%20Detector%20Instruction%20Manual.pdf , retrieved 10-09-2024.

Dubuc J, Duffield TF, Leslie KE, Walton JS & Leblanc SJ (2011). Effects of postpartum uterine diseases on milk production and culling in dairy cows. *Journal of Dairy Science,* **94**(3): 1339-1346.

Ebojei CO, Davou GC, Salman BS & Mosimabale VO (2010). Prevalence of mastitis among dairy cattle in Kanam Local Government Area of Plateau State, Nigeria. *Human and Veterinary Medicine,* doi.10.51791/njap.vi.4509.

EFSA Panel on Animal Health and Animal Welfare (AHAW); Nielsen SS, Alvarez J, Bicout DJ, Calistri P, Canali E, Drewe JA, Garin-Bastuji B, Gonzales Rojas JL, Gortázar Schmidt C, Herskin M, Michel V, Miranda Chueca MÁ, Padalino B, Roberts HC, Spoolder H, Stahl K,

Velarde A, Viltrop A, De Boyer des Roches A, Jensen MB, Mee J, Green M, Thulke HH, Bailly-Caumette E, Candiani D, Lima E, Van der Stede Y & Winckler C (2023). Welfare of dairy cows. *European Food Safety Authority Journal,* doi. 10.2903/j.efsa.2023.7993.

Egwu GO, Zaria LT, Onyeyili PA, Ambali AG, Adamu SS & Birdling M (1994). Studies on the microbiological flora of caprine mastitis and antibiotic inhibitory concentrations in Nigeria. *Small Ruminant Research,* **14**(3): 233–239.

Egwu GO, Ameh MM & Aliyu FD (1999). Caprine mycoplasmal mastitis in Nigeria. *Veterinarski Arhiv,* **69**(5): 241–50.

Ezzat Alnakip M, Quintela-Baluja M, Böhme K, Fernández-No I, Caamaño-Antelo S, Calo-Mata P & Barros-Velázquez J (2014). The immunology of mammary gland of dairy ruminants between healthy and inflammatory conditions. *Journal of Veterinary Medicine,* doi. 10.1155/2014/659801.

Fadillah A, van den Borne BHP, Poetri ON, Hogeveen H, Slijper T, Pisestyani H & Schukken YH (2023). Evaluation of factors associated with bulk milk somatic cell count and total plate count in Indonesian smallholder dairy farms. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2023.1280264.

FAO (2013). Milk and dairy products in human nutrition. Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/4/i3396e/i3396e.pdf., retrieved 22-04-2026.

FAO (2014). Impact of Mastitis in Small-Scale Dairy Production Systems. Animal Production and Health Working Paper. No. 13, Rome. Pp 14,15,21.

Farag HS, Aly SS, Fahim KM, Fayed AA, Abdelfattah EM, El-Sayed SM, Hegazy YM & ElAshmawy WR (2023). Management practices of bovine mastitis and milk quality on Egyptian Dairies. *Veterinary Sciences,* doi.10.3390/vetsci10100629.

Fávero S, Portilho FVR, Oliveira ACR, Langoni H & Pantoja JCF (2015). Factors associated with mastitis epidemiologic indexes, animal hygiene, and bulk milk bacterial concentrations in dairy herds housed on compost bedding, *Livestock Science*, doi.10.1016/j.livsci.2015.09.002

Fernandes JN, Hemsworth PH, Coleman GJ & Tilbrook AJ (2021). Costs and Benefits of Improving Farm Animal Welfare. *Agriculture,* doi.10.3390/agriculture11020104.

Forsbäck L, Lindmark-Månsson H, Andrén A, Åkerstedt M & Svennersten-Sjaunja K (2009). Udder quarter milk composition at different levels of somatic cell count in cow composite milk. *Animal,* **3**(5): 710-717.

Freu G, Garcia BLN, Tomazi T, Di Leo GS, Gheller LS, Bronzo V, Moroni P & Dos Santos MV (2023). Association between mastitis occurrence in dairy cows and bedding characteristics of compost-bedded pack barns. *Pathogens,* doi.10.3390/pathogens12040583.

Geary U, Begley N, McCoy F, O'Brien B, O'Grady L & Shalloo L (2011). Estimating the impact of mastitis on the profitability of Irish dairy farms. In: *Udder Health and Communication* (H Hogeveen, TJGM Lam, eeditors). Wageningen Academic Publishers, Wageningen. doi.10.3920/978-90-8686-742-4_36.

Ghafar A, McGill D, Stevenson MA, Badar M, Kumbher A, Warriach HM, Gasser RB & Jabbar A (2020). A participatory investigation of bovine health and production issues in Pakistan. *Frontiers in Veterinary Science,* doi.10.3389/fvets.2020.00248.

Gonçalves JL, Kamphuis C, Martins CM, Barreiro JR, Tomazi T, Gameiro AH, Hogeveen H & Dos Santos MV (2018). Bovine subclinical mastitis reduces milk yield and economic return. *Livestock Science,* doi.10.1016/j.livsci.2018.01.016.

Gonçalves JL, Kamphuis C, Vernooij H, Araújo JP Jr, Grenfell RC, Juliano L, Anderson KL, Hogeveen H & Dos Santos MV (2020). Pathogen effects on milk yield and composition in chronic subclinical mastitis in dairy cows. *Veterinary Journal,* doi. 10.1016/j.tvjl.2020.105473.

Goncalves JL, Freu G, Garcia BLN, Barcelos MM, Alves B G, de Freitas Leite R, Pedrosa Monteiro C, Martins M, Tomazi T, Hogeveen H & Veiga dos Santos M (2023). Effect of bovine subclinical mastitis on milk production and economic performance of Brazilian dairy farms. *Brazilian Journal of Veterinary Research and Animal Science,* doi.10.11606/issn.1678-4456.bjvras.2023.208514.

Guimarães JLB, Brito MAVP, Lange CC, Silva MR, Ribeiro JB, Mendonça LC, Mendonça JFM & Souza GN (2017). Estimate of the economic impact of mastitis: A case study in a Holstein dairy herd under tropical conditions. *Preventive Veterinary Medicine,* doi. 10.1016/j.prevetmed.

Gutiérrez-Reinoso MA, Aponte PM & García-Herreros M (2023). Genomic and phenotypic udder evaluation for dairy cattle selection: A review. *Animals (Basel)*. doi. 10.3390/ani13101588.

Harjanti DW & Sambodho P (2020). Effects of mastitis on milk production and composition in dairy cows. IOP Conference Series: *Earth and Environmental Science*, doi. 10.1088/1755-1315/518/1/012032.

Harmon RJ (1994). Physiology of mastitis and factors affecting somatic cell counts. *Journal of Dairy Science,* **77**(7): 2103-2112.

Haxhiaj K, Wishart DS & Ametaj BN (2022). Mastitis: What it is, current diagnostics, and the potential of metabolomics to identify new predictive biomarkers. *Dairy*, **3**(4): 722-746.

He W, Ma S, Lei L, He J, Li X, Tao J, Wang X, Song S, Wang Y, Wang Y, Shen J, Cai C & Wu C (2020). Prevalence, etiology, and economic impact of clinical mastitis on large dairy farms in China. *Veterinary Microbiology,* doi. 10.1016/j.vetmic.2019.108570.

Hegde R, Isloor S, Prabhu KN, Shome BR, Rathnamma D, Suryanarayana VV, Yatiraj S, Prasad CR, Krishnaveni N, Sundareshan S & Akhila DS (2013). Incidence of subclinical mastitis and prevalence of major mastitis pathogens in organized farms and unorganized sectors. *Indian Journal of Microbiology,* **53**(3): 315-20.

Hernandez E, Llonch P & Turner PV (2022). Applied animal ethics in industrial food animal production: exploring the role of the Veterinarian. *Animals (Basel)*. doi. 10.3390/ani12060678.

Hiitiö H, Vakkamäki J, Simojoki H, Autio T, Junnila J, Pelkonen S & Pyörälä S (2017). Prevalence of subclinical mastitis in Finnish dairy cows: changes during recent decades and impact of cow and herd factors. *Acta Veterinaria Scandinavica,* doi.10.1186/s13028-017-0288-x.

Hogan J & Smith KL (2012). Managing environmental mastitis. *Veterinary Clinics of North America: Food Animal Practice,* **28**(2): 217-224.

Huang CH & Kusaba N (2022). Association between differential somatic cell count and California mastitis test results in holstein cattle. *Journal of Dairy Science Communication*s; **3**(6):441-445.

Iraguha B, Hamudikuwanda H, Mushonga B, Kandiwa E & Mpatswenumugabo JP (2017). Comparison of cow-side diagnostic tests for subclinical mastitis of dairy cows in Musanze district, Rwanda. *Journal of the South African Veterinary Association,* doi. 10.4102/jsava.v88i0.1464.

Iraguha B (2024). Bovine Mastitis Control Strategies with Emphasis on Developing Countries. *Veterinary Medicine and Science, IntechOpen*, doi.10.5772/intechopen.112348.

Ivanova I, Ivanova M, Ivanov G & Bilgucu E (2021). Effect of somatic cells count in cow milk on the formation of biogenic amines in cheese. *Journal of Food Science and Technology*, **58**(9): 3409-3416.

Jacobs JA & Siegford JM (2012). Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science,* **95**(5): 2227-2247.

Jamali H, Barkema HW, Jacques M, Lavallée-Bourget EM, Malouin F, Saini V, Stryhn H & Dufour S (2018). Invited review: Incidence, risk factors, and effects of clinical mastitis recurrence in dairy cows. *Journal of Dairy Science,* **101**(6): 4729-4746.

Janzen JJ (1970). Economic losses resulting from mastitis. A review. *Journal of Dairy Science,* 53(9): 1151-1160.

Jingar SC, Mehla RK & Singh M (2014). Climatic effects on occurrence of cloinical mastitis in different breeds of cows and buffaloes. *Archivos de Zootecnia,* **63**(243): 473-482.

Junaidu AU, Salihu MD, Tambuwal FM, Magaji AA & Jaafaru S (2011). Prevalence of mastitis in lactating cows in some selected commercial dairy farms in Sokoto metropolis. *Advances in Applied Science Research,* **2**(2): 290-294.

Jurkovich V, Hejel P & Kovács L (2024). A review of the effects of stress on dairy cattle behaviour. *Animals,* doi.10.3390/ani14142038.

Karimuribo ED, Fitzpatrick JL, Swai ES, Bell C, Bryant MJ, Ogden NH, Kambarage DM & French NP (2008). Prevalence of subclinical mastitis and associated risk factors in smallholder dairy

cows in Tanzania. *Veterinary Record,* **163**(1): 16-21.

Kebede N & Tilahun A (2023). Review on dairy cow mastitis and its economic impact. *International Journal of Advanced Research in Biological Sciences,* 10(2): 109-125.

Khasapane NG, Byaruhanga C, Thekisoe O, Nkhebenyane SJ & Khumalo ZTH (2023). Prevalence of subclinical mastitis, its associated bacterial isolates and risk factors among cattle in Africa: A systematic review and meta-analysis. *BMC Veterinary Research,* doi.10.1186/s12917-023-03673-6.

Krishnamoorthy P, Goudar AL, Suresh KP & Roy P (2021a). Global and countrywide prevalence of subclinical and clinical mastitis in dairy cattle and buffaloes by systematic review and meta-analysis. *Research in Veterinary Science,* **136**: 561-586.

Krishnamoorthy P, Suresh KP, Jayamma KS, Shome BR, Patil SS & Amachawadi RG (2021b). An understanding of the global status of major bacterial pathogens of milk concerning bovine mastitis: A systematic review and meta-analysis (Scientometrics). *Pathogens*, doi.10.3390/pathogens10050545.

Kulkarni PS, Mourits MCM, Slob J, Veldhuis AMB, Nielen M, Hogeveen H, Schaik GV & Steeneveld W (2023). Dutch dairy farmers' perspectives on culling reasons and strategies. *Preventive Veterinary Medicine*, doi.10.1016/j.prevetmed.2023.105997.

Le Maréchal C, Thiéry R, Vautor E & Le Loir Y (2011). Mastitis impact on technological properties of milk and quality of milk products—a review. *Dairy Science and Technology,* doi.10.1007/s13594-011-0009-6.

LeBlanc SJ, Lissemore KD, Kelton DF, Duffield TF & Leslie KE (2006). Major advances in disease prevention in dairy cattle. *Journal of Dairy Science,* **89**(4): 1267-79.

Leite de Campos J, Gonçalves JL, Kates A, Steinberger A, Sethi A, Suen G, Shutske J, Safdar N, Goldberg T & Ruegg PL (2023). Variation in partial direct costs of treating clinical mastitis among 37 Wisconsin dairy farms. *Journal of Dairy Science,* **106**(12): 9276-9286.

Leso L, Barbari M, Lopes MA, Damasceno FA, Galama P, Taraba JL & Kuipers A (2020). Invited review: Compost-bedded pack barns for dairy cows. *Journal of Dairy Science,* **103**(2): 1072-1099.

Mainau E, Llonch P, Temple D, Goby L & Manteca X (2022). Alteration in activity patterns of cows as a result of pain due to health conditions. *Animals (Basel),* doi. 10.3390/ani12020176.

Makolo D, Suleiman AB, Olonitola OS, Bello M, Ahmadu I, Awulu FO, Aliyu Y, Hammuel C, Enenye RP & Itua MP (2019). Prevalence of mastitis in lactating bovines and associated coliforms among selected pastoral herds in parts of Kaduna State, Nigeria. *Academic Journal of Life Sciences,* **5**(51): 1–9.

Makolo D, Suleiman AB, Olonitola OS, Bello M & Ahmadu I (2020). Genotypic identification of coliforms isolated from cases of subclinical mastitis among pastoral herds in parts of Kaduna State, Nigeria. *African Journal of Clinical and Experimental Microbiology,* **21**(2): 114-122.

Malek dos Reis CB, Barreiro JR, Mestieri L, Porcionato MA & dos Santos MV (2013). Effect of somatic cell count and mastitis pathogens on milk composition in Gyr cows. *BMC Veterinary Research,* doi.10.1186/1746-6148-9-67.

Maristela R, Natalia R, Gerardo C, Jordi S & Gabriel L (2015). Effect of subclinical intrammamay infection on milk quality in dairy sheep: I. Fresh-soft cheese produced from milk of uninfected and infected glands and from their blends. *Small Ruminant Research,* doi.10.1016/j.smallrumres.2015.02.019.

Martins L, Barcelos MM, Cue RI, Anderson KL, Santos MV dos & Gonçalves JL (2020). Chronic subclinical mastitis reduces milk and components yield at the cow level. *Journal of Dairy Research,* **87**(3): 298-305.

Mbindyo CM, Gitao GC & Mulei CM (2020). Prevalence, etiology, and risk factors of mastitis in dairy cattle in Embu and Kajiado Counties, Kenya. *Veterinary Medicine International,* doi. 10.1155/2020/8831172.

Mbuk EU, Kwaga JK, Bale JO, Boro LA & Umoh JU (2016). Coliform organisms associated with milk of cows with mastitis and their sensitivity to commonly available antibiotics in Kaduna State, Nigeria. *Journal of Veterinary Medicine and Animal Health,* **8**(12): 228-236.

McDougall S (1999). Prevalence of clinical mastitis in 38 Waikato dairy herds in early lactation. *New Zealand Veterinary Journal,* **47**(4): 143-149.

McLennan KM (2018). Why pain is still a welfare issue for farm animals, and how facial expression could be the answer. *Agriculture,* doi.10.3390/agriculture8080127.

Meçaj R, Muça G, Koleci X, Sulçe M, Turmalaj L, Zalla P, Koni A & Tafaj M (2023). Bovine environmental mastitis and their control: an overview. *International Journal of Agriculture and Biosciences*, **12**(4): 216-221.

Menzies P (2021). Udder health for dairy goats. *Veterinary Clinics of North America: Food Animal Practice,* **37**(1): 149-174.

Miltenburg JD, De Lange D, Crauwels APP, Bongers JH, Tielen MJM, Schukken YH & Elbers ARW (1996). Incidence of clinical mastitis in a random sample of dairy herds in the southern Netherlands. *Veterinary Record,* **139**(9):204-207.

Miyata S, Fan L, Kambe J, Qasimi MI, Takemoto S, Ito M, Li C, Yamamoto Y & Nagaoka K (2024). Influence of repeated mastitis on the milk production and metabolic status in the subsequent lactation period of dairy cattle. *Heliyon,* doi. 10.1016/j.heliyon.2024.e29789.

Moradi M, Omer AK, Razavi R, Valipour S & Guimarães JT (2021). The relationship between milk somatic cell count and cheese production, quality and safety: A review. *International Dairy Journal,* doi.10.1016/j.idairyj.2020.104884.

Morales-Ubaldo AL, Rivero-Perez N, Valladares-Carranza B, Velázquez-Ordoñez V, Delgadillo-Ruiz L & Zaragoza-Bastida A (2023). Bovine mastitis, a worldwide impact disease: Prevalence, antimicrobial resistance, and viable alternative approaches. *Veterinary and Animal Science,* doi.10.1016/j.vas.2023.100306.

Morse D, DeLorenzo MA, Wilcox CJ, Collier RJ, Natzke RP & Bray DR (1988). Climatic effects on occurrence of clinical mastitis. *Journal of Dairy Science,* **71**(3): 848-853.

Moru NH, Umoh JU, Maikai BV, Barje PP & Amuta P (2018). Milk yield losses and cost of clinical mastitis in Friesian × Bunaji crossbred dairy cows in Zaria, Nigeria. *Sokoto Journal of Veterinary Sciences,* doi.10.4314/sokjvs.v16i2.4.

Moscovici Joubran A, Pierce KM, Garvey N, Shalloo L & O'Callaghan TF (2021). Invited review: A 2020 perspective on pasture-based dairy systems and products. *Journal of Dairy Science,* **104**(7): 7364-7382.

Mungube EO, Tenhagen BA, Regassa F, Kyule MN, Shiferaw Y, Kassa T & Baumann MP (2005). Reduced milk production in udder quarters with subclinical mastitis and associated economic losses in crossbred dairy cows in Ethiopia. *Tropical Animal Health and Production,* **37**(6): 503-512.

Nakada S, Fujimoto Y, Kohara J & Makita K (2023). Economic losses associated with mastitis due to bovine leukemia virus infection. *Journal of Dairy Science,* **106**(1): 576-588.

Narayana SG, de Jong E, Schenkel FS, Fonseca PAS, Chud TCS, Powell D, Wachoski-Dark G, Ronksley PE, Miglior F, Orsel K & Barkema HW (2023). Underlying genetic architecture of resistance to mastitis in dairy cattle: A systematic review and gene prioritization analysis of genome-wide association studies. *Journal of Dairy Science,* **106**(1): 323-351.

Neculai-Valeanu AS & Ariton AM (2022). Udder health monitoring for prevention of bovine mastitis and improvement of milk quality. *Bioengineering (Basel),* doi. 10.3390/bioengineering9110608.

Nightingale C, Dhuyvetter K, Mitchell R & Schukken Y (2008). Influence of variable milk quality premiums on observed milk quality. *Journal of Dairy Science,* **91**(3): 1236-44.

Nogara KF, Busanello M, Tavares QG, De Assis JA, Freu G, Dos Santos MV, Vieira FMC & Zopollatto M (2023). Factors influencing milk quality and subclinical mastitis in dairy herds housed in compost-bedded pack barn system. *Animals,* doi.10.3390/ani13233638.

Norberg E, Hogeveen H, Korsgaard IR, Friggens NC, Sloth KH & Løvendahl P (2004). Electrical conductivity of milk: Ability to predict mastitis status. *Journal of Dairy Science,* **87**(4): 1099-107.

Nosike RJ, Nwakpu OF, Isaac UC, Akinsola KL, Nwose RN & Onunkwo DN (2020). Characterization of indigenous cattle genotypes based on linear body traits in the humid tropics. *Nigerian Journal of Animal Production,* **47**(1): 41 – 46.

Okoli IC, Opara MN, Iheukwumere E & Herbert U (2006a). Analysis of abattoir records for Imo State, Nigeria from 1995-1999 IV: Incidence of mastitis among cattle, sheep and goats. *Journal of Agriculture and Social Research,* **6**(2): 66–72.

Okoli CG, Okoli IC, Okorondu UV & Opara MN (2006b). Environmental and public health issues of animal food products delivery system in Imo State, Nigeria. *Online Journal of Health & Allied Sciences,* **5**(2): 1–11.

Olde Riekerink RG, Barkema HW, Veenstra W, Berg FE, Stryhn H & Zadoks RN (2007). Somatic cell count during and between milkings. *Journal of Dairy Science,* **90**(8): 3733-3741.

Olde Riekerink RG, Barkema HW, Kelton DF & Scholl DT (2008). Incidence rate of clinical mastitis on Canadian dairy farms. *Journal of Dairy Science,* **91**(4): 1366-1377.

Olechnowicz J & Jaskowski JM (2011). Reasons for culling, culling due to lameness, and economic losses in dairy cows. *Medycyna Weterynaryjna*, **6** (9): 618-621.

Olives AM-De, Peris C & Molina MP (2020). Effect of subclinical mastitis on the yield and cheese-making properties of ewe's milk. *Small Ruminant Research,* doi.10.1016/j.smallrumres.2019.106044.

Olufemi O, Adesola A, Uzo O & Yemi O (2018). Bulk tank somatic cell count and associated microbial quality of milk from selected dairy cattle herds in Oyo State, Nigeria. *Italian Journal of Food,* **7**(2): 95–100.

Pakrashi A, Ryan C, Guéret C, Berry DP, Corcoran M, Keane MT & Mac Namee B (2023). Early detection of subclinical mastitis in lactating dairy cows using cow-level features. *Journal of Dairy Science,* **106**(7): 4978-4990.

Patel K, Godden SM, Royster E, Crooker BA, Timmerman J & Fox L (2019). Relationships among bedding materials, bedding bacteria counts, udder hygiene, milk quality, and udder health in US dairy herds. *Journal of Dairy Science,* **102**(11): 10213-10234.

Pinedo PJ, Daniels A, Shumaker J & De Vries A (2014). Dynamics of culling for Jersey, Holstein, and Jersey × Holstein crossbred cows in large multibreed dairy herds. *Journal of Dairy Science,* doi.10.3168/jds.2013-7685.

Plozza K, Lievaart JJ, Potts G & Barkema HW (2011). Subclinical mastitis and associated risk factors on dairy farms in New South Wales. *Australian Veterinary Journal,* **89**(1-2): 41-46.

Plummer PJ & Plummer C (2012). Chapter 15 - Diseases of the Mammary Gland. In: *Sheep and Goat Medicine* (Second Edition). Pp 442-465. doi.10.1016/B978-1-4377-2353-3.10015-0.

Portnoy M & Barbano DM (2021). Lactose: Use, measurement, and expression of results. *Journal of Dairy Science,* **104**(7): 8314-8325.

Rainard P, Foucras G, Boichard D & Rupp R (2018). Invited review: Low milk somatic cell count and susceptibility to mastitis. *Journal of Dairy Science,* **101**(8): 6703-6714.

Rasmussen P, Barkema HW, Osei PP, Taylor J, Shaw AP, Conrady B, Chaters G, Muñoz V, Hall DC, Apenteng OO, Rushton J & Torgerson PR (2024). Global losses due to dairy cattle diseases: A comorbidity-adjusted economic analysis. *Journal of Dairy Science,* **107**(9): 6945-6970.

Rege JEO & Tawah CL (1999). The state of African cattle genetic resources II. Geographical distribution, characteristics and uses of present-day breeds and strains. *Animal Genetic Resources Information Bulletin,* https://hdl.handle.net/10568/7045, retrieved 23-04-2026.

Rice DN (1981). G81-556 Using the California Mastitis Test (CMT) to Detect Subclinical Mastitis". Historical Materials from University of Nebraska-Lincoln Extension. 483. https://digitalcommons.unl.edu/extensionhist/483., retrieved 12-04-2026.

Richardet M, Solari HG, Cabrera VE, Vissio C, Agüero D, Bartolomé JA, Bó GA, Bogni CI & Larriestra AJ (2023). The Economic Evaluation of Mastitis Control Strategies in Holstein-Friesian Dairy Herds. *Animals (Basel),* 13(10):1701. doi. 10.3390/ani13101701.

Rilanto T, Reimus K, Orro T, Emanuelson U, Viltrop A & Mõtus K (2020). Culling reasons and risk factors in Estonian dairy cows. *BMC Veterinary Research,* doi.10.1186/s12917-020-02384-6.

Rollin E, Dhuyvetter KC & Overton MW (2015). The cost of clinical mastitis in the first 30 days of lactation: An economic modeling tool. *Preventive Veterinary Medicine*, **122**(3): 257-264.

Rupp R & Boichard D (2003). Genetics of resistance to mastitis in dairy cattle. *Veterinary Research*, **34**(5): 671-688.

Rust JD, Christian MJ, Vance CJ, Bolajoko MB, Wong JT, Suarez-Martinez J, Allan FK & Peters AR (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,* doi. 10.12688/gatesopenres.13369.2.

Sachi S, Ferdous J, Sikder MH & Azizul Karim Hussani SM (2019). Antibiotic residues in milk: Past, present, and future. *Journal of Advanced Veterinary and Animal Research,* **6**(3): 315-332.

Saleem HD, Razooqi MA & Gharban HAJ (2021). Cumulative Effect of Subclinical Mastitis on Immunological and Biochemical Parameters in Cow Milk. *Archives of Razi Institute,* **76**(6): 1629-1638.

Sampimon OC, Barkema HW, Berends IM, Sol J & Lam TJ (2009). Prevalence and herd-level risk factors for intra mammary infection with coagulase-negative *StaphIylococci* in Dutch dairy herds. *Veterinary Microbiology*,**134**(1-2): 37–44.

Seegers H, Beaudeau F, Fourichon C & Bareille N (1998). Reasons for culling in French Holstein cows. *Preventive Veterinary Medicine,* **36**(4): 257-271.

Seegers H, Fourichon C & Beaudeau F (2003). Production effects related to mastitis and mastitis economics in dairy cattle herds. *Veterinary Research*, **34**(5): 475-491.

Sender G, Korwin-Kossakowska A, Pawlik A, Abdel Hameed KG & Oprządek J (2013). Genetic basis of mastitis resistance in dairy cattle – a review. *Annals of Animal Science,* **13**(4): 663– 673.

Senturk B (2014). Evaluation of the costs of clinical mastitis treatment in dairy farming. *World's Veterinary Journal,* **4**(1): 11-14.

Shamsuddoha M, Nasir T & Hossain NUI (2023). A sustainable supply chain framework for dairy farming operations: A system dynamics approach. *Sustainability,* doi.10.3390/su15108417.

Sharma N, Singh NK & Bhadwal1 MS (2011). Relationship of somatic cell count and mastitis: An overview. *Asian-Australasian Journal of Animal Sciences,* **24**(3): 429 – 438.

Sheldrake RF & Hoare RJ (1981). The detection of mastitis in individual quarters using electrical conductivity or somatic cell concentration. *New Zealand Veterinary Journal,* **29**(11): 211-213.

Shittu A, Junaidu AU, Chafe UM, Magaji AA, Faleke OO, Salihu MD, Jibril A. & Mahmud M.A (2008). A survey on current milk production and pricing in Sokoto State, Nigeria. *Sokoto Journal of Veterinary Sciences,* **7**(1): 53-58.

Shittu A, Abdullahi J, Jibril A, Mohammed AA & Fasina FO (2012). Sub-clinical mastitis and associated risk factors on lactating cows in the Savannah Region of Nigeria. *BMC Veterinary Research,* doi. 10.1186/1746-6148-8-134.

Shook GE & Schutz MM (1994). Selection on somatic cell score to improve resistance to mastitis in the United States. *Journal of Dairy Science,* **77**(2): 648-58.

Silva-Villacorta D., Lopez-Villalobos N, Blair HT, Hickson RE & MacGibbon AK (2016). Production and profitability of dairy farms producing milk with different concentrations of unsaturated fatty acids: A simulation study. *New Zealand Journal of Agricultural Research,* **60**(1): 32–44.

Siivonen J, Taponen SS, Hovinen M, Pastell M, Lensink J, Pyörälä S & Hänninen L (2011). Impact of clinical acute mastitis on cow behaviour. *Applied Animal Behaviour Science,* **132**(3-4): 101-106.

Singh SV, Singh JP, Ramakant DN, Kumar YD, Rakesh G & Maurya SK (2021). Analysis of economic losses due to mastitis in cattle of Uttar Pradesh, India. *International Journal of Current Microbiology and Applied Sciences,* **10**(03): 1571-1576.

Sinha MK, Thombare NN & Mondal B (2014). Subclinical mastitis in dairy animals: incidence, economics, and predisposing factors. *Scientific World Journal,* doi. 10.1155/2014/523984.

Suleiman AB, Kwaga JK, Umoh VJ, Okolocha EC, Muhammed M, Lammler C, Shaibu SJ, Akineden O & Weiss R (2012). Macro-restriction analysis of *Staphylococcus aureus* isolated from subclinical bovine mastitis in Nigeria. *African Journal of Microbiology Research,* **6**(33):6270-6274.

Sumon SMMR, Parvin MS, Ehsan MA & Islam MT (2020). Relationship between somatic cell counts and subclinical mastitis in lactating dairy cows. *Veterinary World,* **13**(8): 1709-1713.

Tanimomo BK, Hena SA, Ngbede EO, Tarhyel R, Owoleke OE (2012). Prevalence of mastitis in goat herds in some northwestern villages in Nigeria. *Scientific Journal of Veterinary Advances,* **1**(2): 52–56.

Tanni NS, Islam MS, Kabir M, Parvin MS, Ehsan MA & Islam MT (2021). Evaluation of sodium lauryl sulfate for the development of cow-side mastitis screening test. *Veterinary World,* **14**(8): 2290-2295.

Taponen S, Myllys V & Pyörälä S (2022). Somatic cell count in bovine quarter milk samples culture positive for various Staphylococcus species. *Acta Veterinaria Scandinavica,* doi.10.1186/s13028-022-00649-8.

Temple D & Manteca X (2020). Animal welfare in extensive production systems is still an area of concern. *Frontiers in Sustainable Food Systems,* doi. 10.3389/fsufs.2020.545902.

Themistokleous KS, Papadopoulos I, Panousis N, Zdragas A, Arsenos G & Kiossis E (2023). Udder ultrasonography of dairy cows: investigating the relationship between echotexture, blood flow, somatic cell count and milk yield during dry period and lactation. *Animals*, doi.10.3390/ani13111779.

Tommasoni C, Fiore E, Lisuzzo A & Gianesella M (2023). Mastitis in dairy cattle: On-farm diagnostics and future perspectives. *Animals (Basel),* doi. 10.3390/ani13152538.

Udoh EK, Kwaga JK, Umoh JU & Raji MA (2019). Occurrence of mastitis and methicillin resistant *Staphylococcus aureus* in goats in Zaria, Kaduna State, Nigeria. *Nigerian Veterinary Journal,* **40**(2): 164-177.

Ugochukwu IC, Anyaoha CO, Aneke CI, Idoko SI, Ugwu JU, Ughamba KT, Edeh ER & Ugochukwu EI (2017). Aerobic bacteria pathogens associated with caprine mastitis in Nsukka Area of Enugu State. *Bio-Research,* **15**(1): 980–987.

Umaru MA, Adeyeye AA, Abubakar A & Garba HS (2009). Retrospective analysis of disease conditions among reproductive domestic ruminants in Sokoto, Nigeria. *Animal Research International,* **6**(1):946–948.

Umaru GA, Kwaga JKP, Bello M, Raji MA & Maitala YS (2017). Occurrence of bovine mastitis and isolation of *Staphyloccocus* species from fresh cow milk in settled Fulani herds in Kaduna State, Nigeria. *Bayero Journal of Pure and Applied Sciences,* **10**(1): 259-263.

Umoh VJ, Adesiyun AA & Comwalk NE (1990). Enterotoxigenicity of *staphylococci* isolated from raw milk obtained from settled and nomadic herds around Zaria, Nigeria. *Revue d'élevage et de médecine vétérinaire des pays tropicaux;* **43**(1): 43-47.

Valde JP, Lawson LG, Lindberg A, Agger JF, Saloniemi H & Osterås O (2004). Cumulative risk of bovine mastitis treatments in Denmark, Finland, Norway and Sweden. *Acta Veterinaria Scandinavica,* **45**(3-4): 201-110.

van den Crommenacker-Konings LWJH, van Dam P, Everts R, Shittu A, Nielen M, Lam TJGM & Koop G (2021). Dynamics of intramammary infections in suckler ewes during early lactation. *Journal of Dairy Science,* **104**(5): 5979-5987.

van Soest FJS, Santman-Berends IMGA, Lam TJGM & Hogeveen H (2016). Failure and preventive costs of mastitis on Dutch dairy farms. *Journal of Dairy Science,* **99**(10): 8365-8374.

Ventura G, Lorenzi V, Mazza F, Clemente GA, Iacomino C, Bertocchi L & Fusi F (2021). Best Farming Practices for the Welfare of Dairy Cows, Heifers and Calves. *Animals (Basel),* doi. 10.3390/ani11092645.

Vitali A, Bernabucci U, Nardone A & Lacetera N (2016). Effect of season, month and temperature humidity index on the occurrence of clinical mastitis in dairy heifers. *Advances in Animal Biosciences,* **7**(03), 250–252.

von Keyserlingk MAG & Weary DM (2017). A 100-Year Review: Animal welfare in the Journal of Dairy Science-The first 100 years. *Journal of Dairy Science,* **100**(12): 10432-10444.

Weigel KA & Shook GE (2018). Genetic selection for mastitis resistance. *Veterinary Clinics of North America: Food Animal Practice*, **34**(3): 457-472.

Williamson J, Callaway T, Rollin E & Ryman V (2022). Association of milk somatic cell count with bacteriological cure of intramammary infection—A review. *Agriculture,* 10.3390/agriculture12091437

Wilm J, Svennesen L, Østergaard Eriksen E, Halasa T & Krömker V (2021). Veterinary treatment approach and antibiotic usage for clinical mastitis in Danish dairy herds. *Antibiotics (Basel),* doi. 10.3390/antibiotics10020189..

Witkowska D & Ponieważ A (2022). The effect of housing system on disease prevalence and productive lifespan of dairy herds-a case study. *Animals (Basel)*, doi. 10.3390/ani12131610.

Yanga DS & Jaja IF (2022). Culling and mortality of dairy cows: why it happens and how it can be

mitigated. *F1000Res.,* doi. 10.12688/f1000research.55519.2.

Youssif NH, NM Hafiz, MA Halawa, HM Aziz & MF Saad (2020). Impact of subclinical mastitis on milk quality in different seasons.*International Journal of Veterinary Science,* **9**(2): 313-316.

Yunusa AA, Mai HM & Abubaar M (2025). Determination of mastitis prevalence using California Mastitis Test (CMT) Paddle on Two Breeds of Dairy Cattle. *Nigerian Journal of Agriculture and Agricultural Technology,* **5**(1A):200-205.

Zachut M, Šperanda M, De Almeida AM, Gabai G, Mobasheri A & Hernández-Castellano LE (2020). Biomarkers of fitness and welfare in dairy cattle: healthy productivity. *Journal of Dairy Research*, **87**(1):4-13.

Zadoks R & Fitzpatrick J (2009). Changing trends in mastitis. *Irish Veterinary Journal*, doi.10.1186/2046-0481-62-S4-S59.

Zapata-Salas R, Guarín JF & Ríos-Osorio LA (2022). Udder health, conceptual construct, and uses of the term: A systematic review from 1962 to 2019. *Veterinary World*, **15**(4):855-869.

Zemanova M, Langova L, Novotná I, Dvorakova P, Vrtkova I & Havlicek Z (2022). Immune mechanisms, resistance genes, and their roles in the prevention of mastitis in dairy cows. *Archives Animal Breeding,* **65**(4):371-384.

Zeryehun T & Abera G (2017). Prevalence and Bacterial Isolates of Mastitis in Dairy Farms in Selected Districts of Eastern Harrarghe Zone, Eastern Ethiopia. *Journal of Veterinary Medicine,* doi. 10.1155/2017/6498618.

Zigo F, Vasil' M, Ondrašovičová S, Výrostková J, Bujok J & Pecka-Kielb E (2021). Maintaining optimal mammary gland health and prevention of mastitis. *Frontiers in Veterinary Science,* doi. 10.3389/fvets.2021.607311.