How Important is Mastitis Really?

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%	Percent / Percentage
≈	Approximately
<	Less than
>	Greater than
=	Equal to
&	And
AMR	Antimicrobial Resistance
BDCT	Blanket Dry Cow Therapy
CIP	Cleaning-in-Place
CMT	California Mastitis Test
IgA	Immunoglobulin A
IgG	Immunoglobulin G
IgG1 / IgG2	Immunoglobulin G1 / G2
IMIs	Intramammary infections
PCR	Polymerase Chain Reaction
PMN	Polymorphonuclear Neutrophil
SCC	Somatic Cell Count
SCS	Somatic Cell Score
SDCT	Selective Dry-Cow Therapy
E. coli	*Escherichia coli*
M. bovis	*Mycoplasma bovis*
Prototheca spp.	Prototheca species

Preface

Mastitis is one of the leading causes of both economic losses and reduced animal welfare in dairy cattle farming. This disease not only decreases milk yield and quality but also leads to serious financial consequences such as higher treatment costs, milk losses, and premature culling of affected cows.

This book addresses mastitis in a comprehensive manner, covering its etiology, epidemiology, immunological mechanisms, its relationship with milk quality and milking systems, as well as key strategies for prevention and treatment. The goal is to provide veterinarians working in the field and researchers with evidence-based, up-to-date, and practical information.

Successful farm management depends not only on correct treatment but also on the combined application of proper hygiene, housing conditions, nutrition, milking hygiene, herd management, biosecurity, and alternative control methods. In the present era, where antimicrobial resistance has become an increasing global concern, the importance of innovative approaches such as selective dry-cow therapy, probiotics, phytotherapy, and nanotechnology has grown even further.

This volume has been prepared as both a scientific reference and a practical guide. The content is based on current research findings and supported by reliable academic studies. In this way, it aims to provide readers with accurate and up-to-date perspectives on the most effective methods for combating mastitis.

We believe that this book will serve as a valuable resource for all readers seeking to develop scientifically grounded and practically applicable solutions for mastitis control.

Respectfully,

Editors

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Chapter 1.

INTRODUCTION

Mastitis is a common disease in dairy farming. It causes serious economic losses and negatively affects animal welfare.Mastitis is defined as an inflammation of the udder, most often caused by bacterial infections. Less frequently, fungi, mycoplasmas, or viruses are involved (Philpot and Nickerson, 2000). The disease is characterized by physical, chemical, and bacteriological changes in milk. It is also associated with pathological alterations in mammary tissue (Wellenberg et al., 2002).

Mastitis occurs in two main forms: clinical and subclinical. Clinical mastitis presents with swelling, redness, and pain in the udder. It also causes visible changes in milk, such as clots, blood, or abnormal odor. Subclinical cases show no visible signs. They are usually detected by an increase in somatic cell count and are the most common form found in dairy herds (Bradley, 2002; Seeger et al., 2003; Halasa et al., 2007; Ruegg, 2017).

Subclinical mastitis is more widespread than the clinical form and serves as a reservoir for infection in the herd. It is also important for public health because milk from affected cows may contain antibiotic residues and pathogens that pose risks to consumers (Oliver and Murinda, 2012; Ruegg, 2017).

For many years, mastitis in heifers was underestimated. It was often assumed that heifers were not at risk before their first lactation. However, research has shown that intramammary infections can occur, especially in late pregnancy when mammary tissue develops (Trinidad et al., 1990; Fox, 2009; Oliver et al., 2003). Reported prevalence ranges from 35% to 100%, causing significant losses in animal welfare and future milk production (Jordan et al., 2002; Malinowski et al., 2003).

Effective control of mastitis depends on several factors: milking hygiene, proper housing, rational use of antibiotics, vaccination, and advanced milking technologies. Mistakes during milking allow bacteria to enter the udder through the teat canal (Schukken et al., 2011; Ruegg, 2017). Modern systems, including robotic milking, provide new opportunities for prevention (Hogeveen and Ouweltjes, 2003).

The economic burden of mastitis remains high. Around 60–70% of costs are due to reduced milk yield. Other losses arise from discarded milk, treatment, culling, mortality, and labor (Halasa et al., 2007; Seegers et al., 2003). Hidden losses from subclinical cases also reduce herd profitability and often remain undetected (Hogeveen et al., 2011).

Monitoring somatic cell count (SCC) is now an essential part of mastitis control programs. High SCC reduces milk quality, shortens shelf life, and impairs processing properties (Ruegg, 2017; Hissira et al., 2023).

For these reasons, mastitis control requires a multidisciplinary approach. Success depends on close cooperation among veterinarians, farmers, herd managers, and researchers.

The aim of this book is to present the classification of mastitis, the udder's defense mechanisms, and the relationship between milking systems and mastitis. It highlights the importance of somatic cell count, identifies the major causes, and examines the economic consequences of the disease. It also introduces the emerging role of the udder microbiota, showing how microbial balance can influence susceptibility to mastitis and guide future prevention strategies. Finally, it offers evidence-based guidance on prevention and treatment.

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Chapter 2.
DEFINITION, CLASSIFICATION, AND ETIOLOGY OF MASTITIS

Mastitis is one of the most common and costly diseases in dairy cattle. The term derives from the Greek words mastos (udder) and itis (inflammation). It refers to inflammation of the udder triggered by infectious, traumatic, or toxic agents (Bradley et al., 2007). The inflammatory reaction causes physical and chemical changes in milk and pathological alterations in udder tissue, reducing milk quality (Rainard et al., 2018).

Most mastitis cases are caused by microorganisms. These pathogens colonize milk-producing tissues and release toxins that damage the gland (Ruegg, 2017; Rainard et al., 2022). Mastitis due to trauma or chemical irritation is uncommon and usually resolves quickly without persistent inflammation (Bradley and Green, 2005). Beyond its effect on animal health, mastitis also threatens public health by lowering milk quality and leaving antibiotic residues in milk (Philpot and Nickerson, 2000).

2.1. Classification of Mastitis

Understanding mastitis requires proper classification. The most common approach is based on clinical signs (Ruegg, 2017).

2.1.1. Clinical Mastitis

Clinical mastitis is characterized by swelling, pain, heat, and redness in the udder, together with abnormal milk such as clots, flakes, or discoloration. In severe cases, the cow may also develop fever, appetite loss, or depression (Bradley and Green, 2005; Ruegg, 2017). Clinical mastitis can be peracute, acute, subacute, or chronic.

Peracute mastitis: Onset is sudden and progression rapid. Clinical signs are severe, and systemic illness may occur. In extreme cases, gangrenous mastitis develops, with necrosis, ischemia, and blue-black discoloration of the udder (Åvall-Jääskeläinen et al., 2021; Kour et al., 2023; see Figure 1).

Figure 1. Udder of a dairy cow with peracute gangrenous *Staphylococcus aureus mastitis*, showing ischemia and blue discoloration of the right hind quarter (Åvall-Jääskeläinen et al., 2021).

Acute mastitis: Udder swelling, redness, and abnormal milk are prominent. Cyanosis may occur in advanced cases. The course is severe but usually slower than peracute forms.

Subacute mastitis: Signs are mild, and obvious udder or milk changes are often absent.

Chronic mastitis: Infections persist or recur. Fibrosis and atrophy of the udder may develop, leading to reduced milk yield (see Figure 2).

Figure 2. Chronic mastitis leads to fibrosis and firm consistency of the affected quarter

2.1.2. Subclinical Mastitis

Subclinical mastitis is inflammation without visible changes in the udder or milk. It is diagnosed by increased somatic cell count and pathogen isolation from culture. This form is the most common in herds, accounting for up to 70% of cases (Halasa et al., 2007; Ruegg, 2017). Because it lacks symptoms, it spreads silently and reduces milk yield (Hogeveen et al., 2011).

2.1.3. Nonspecific (Aseptic) Mastitis

Nonspecific mastitis is inflammation without a detectable microorganism. It may result from trauma caused by milking machines, chemical irritation, or injury to the teat canal (Harmon, 1994; Philpot and Nickerson, 2000; Bradley, 2002).

2.1.4. Latent Mastitis

Latent mastitis involves bacterial colonization in the teat canal or mammary tissue without clinical or subclinical signs. Somatic cell counts may remain within normal limits (Philpot and Nickerson, 2000; Bradley and Green, 2005).

2.2. Causes of Mastitis

Mastitis is mainly bacterial in origin, though fungi, yeasts, algae, mycoplasmas, and occasionally viruses can also cause disease (Viguier et al., 2009; Morales-Ubaldo et al., 2023). Based on transmission, causes (see Table 1) are grouped as:

***Contagious agents**:* Spread from infected quarters to healthy animals during milking, via equipment or hands. Examples include *Staphylococcus aureus*, *Streptococcus agalactiae*, *Corynebacterium bovis*, and *Mycoplasma bovis* (Bruno et al., 2025).

Environmental agents: Originating from bedding, manure, soil, or water, and usually entering via the teat canal. Examples include *Escherichia coli*, *Klebsiella spp.*, *Enterobacter spp.*, *Streptococcus uberis*, and *Streptococcus dysgalactiae* (Ruegg, 2017; Cobirka et al., 2020).

***Opportunistic agents**:* Organisms such as *Candida* spp. and algae may cause mastitis when immune resistance is weakened (Viguier et al., 2009; Morales-Ubaldo et al., 2023).

Table 1. Major mastitis pathogens classified by type, species affected, and typical transmission routes (Smith and Hogan, 1993; Ruegg, 2017; Philpot and Nickerson, 2000; Cobirka et al., 2020; Morales-Ubaldo et al., 2023; Bruno et al., 2025).

Pathogen	Type	Species Affected	Transmission Route
Staphylococcus aureus	Contagious	Cattle, sheep	Milking equipment, hands
Streptococcus agalactiae	Contagious	Cattle	Milking equipment, hands
E. coli	Environmental	All ruminants	Bedding, soil, fecal contamination
Mycoplasma spp.	Contagious	Cattle, goats	Aerosol, contact, milk
Prototheca spp.	Environmental	Cattle	Water, environment

2.3. Role of Udder Microbiota in Mastitis Susceptibility

For decades, the bovine udder was considered a sterile site and mastitis was attributed solely to the invasion of pathogens such as *Staphylococcus aureus*, *Streptococcus agalactiae*, and *Escherichia coli* (Falentin et al., 2018). Advances in high-throughput sequencing and metagenomic techniques have revealed that the healthy udder harbors a complex and dynamic microbial community known as the udder microbiota (Derakhshani et al., 2018; Duarte et al., 2025).

This resident microbiota contributes to udder health by competing with pathogens for nutrients and attachment sites. It also supports epithelial barrier integrity and modulates local immune responses (Guo et al., 2022; Wang et al., 2024). Disturbance of this microbial balance, caused by prolonged antibiotic therapy, poor hygiene, environmental stress or dietary changes, can lead to dysbiosis and increase the susceptibility of the udder to infection (Luo et al., 2023; Burakova et al., 2023).

Several studies show that cows prone to mastitis often exhibit a less diverse udder microbiota, with a shift toward opportunistic or pathogenic bacteria such as *Staphylococcus*, *Streptococcus* and *Corynebacterium* (Duarte et al., 2025; Salman et al., 2023). In contrast, beneficial commensal bacteria including *Lactobacillus* and certain *Bifidobacterium* species appear to provide protection by producing antimicrobial metabolites and by limiting pathogen colonization (Reuben et al., 2025; Khan et al., 2021).

Emerging evidence also suggests a link between the gut and the mammary gland in determining mastitis risk. Alterations in intestinal microbiota can influence udder immune responses and shape the composition of the udder microbiota (Hu et al., 2019; Wang et al., 2024). This perspective broadens the understanding of mastitis pathogenesis beyond individual pathogens and underscores the significance of host–microbiota interactions.

Recognizing the contribution of the udder microbiota to udder health opens new opportunities for mastitis prevention. Future strategies may include promoting beneficial microbial communities through optimized management practices, careful use of antimicrobials, dietary modulation and the application of targeted probiotics or bioactive compounds (Khan et al., 2021; Cheng and Han, 2020; Reuben et al., 2025). Such approaches complement conventional hygiene and therapeutic programs and are consistent with the global effort to reduce antimicrobial resistance.

2.4. Mechanism of Spread

Pathogens usually enter through the teat canal and colonize alveolar tissue. They produce toxins, trigger inflammation, and increase leukocyte migration (Rainard et al., 2018; Cobirka et al., 2020). If anatomical defenses such as the keratin barrier and Fürstenberg rosette are damaged, infection risk rises (Nickerson, 1994; Ruegg, 2017). Milking errors, teat injuries, excessive vacuum pressure, and poor bedding further increase susceptibility (Blowey and Edmondson, 1995; Bradley and Green, 2021; Schukken et al., 2011).

Once pathogens gain access to the teat canal, they attach to the epithelial surface and multiply in the teat cistern. As bacterial load increases, virulence factors damage the epithelial lining. This injury stimulates the release of inflammatory mediators, which in turn attract polymorphonuclear leukocytes to the udder tissue. The influx of these cells is an essential defense mechanism, but it also causes tissue damage that predisposes the gland to further infection (Genini et al., 2011; Petzl et al., 2016).

The integrity of the keratin barrier and the Fürstenberg rosette is crucial for preventing infection. Keratin has antibacterial properties and provides a physical seal against bacterial invasion. As illustrated in Figure 3, the multilayered folds of the Fürstenberg rosette act as both a physical gate and an immunologically active zone at the junction of the teat canal and gland cistern. This visual reference helps demonstrate how trauma, chronic teat-end hyperkeratosis, or incomplete closure of the rosette compromises the barrier and facilitates the entry of mastitis-causing pathogens. When these structures are weakened, pathogens such as *Staphylococcus aureus* or *Streptococcus uberis* penetrate more easily and establish persistent intramammary infections (Ruegg, 2017; Hisaeda et al., 2025).

Milking management practices strongly influence the spread of mastitis pathogens. Over-milking prolongs teat-end exposure to mechanical stress, while inadequate pre- and post-milking teat disinfection facilitates bacterial transfer among cows. Irregular vacuum pressure in milking machines can cause microlesions in the teat canal and force contaminated milk droplets back into the udder. These conditions create opportunities for both contagious and environmental pathogens to colonize the mammary gland (Bradley et al., 2007; Heikkilä et al., 2012).

Environmental hygiene further determines the risk of new infections. Cows kept on wet or contaminated bedding encounter high bacterial exposure, particularly from environmental species such as *Escherichia coli* and *Klebsiella pneumoniae*. Poor barn sanitation, overcrowding, and inadequate ventilation increase bacterial load in the environment. When combined with teat-end damage or poor milking hygiene, these factors markedly elevate infection risk (Smith and Hogan, 1993; Oliver et al., 2011; Gomes et al., 2016; Algharib et al., 2024).

In summary, the spread of mastitis pathogens results from complex interactions between microbial virulence, teat-end integrity, milking machine function, and environmental hygiene. Preventive strategies should therefore include maintaining teat health, applying correct milking procedures, and ensuring clean housing conditions. By targeting each of these risk factors, the incidence of new intramammary infections can be minimized, and udder health can be better preserved.

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Chapter 3.
THE IMMUNOLOGY OF MASTITIS

The mammary gland has a complex defense system that protects against mastitis-causing agents. This system consists of anatomical barriers, chemical defenses, and immune responses at both the cellular and humoral levels (Nickerson, 1994; Sordillo et al., 1997; Bannerman, 2009). The efficiency of these defenses strongly influences the risk of mastitis in dairy herds.

Mammary defense is generally classified into three groups: nonspecific defenses, cellular immunity, and humoral immunity.

3.1. Nonspecific Defense Mechanisms

Non-specific defense is a general defense mechanism that protects the mammary gland during the initial stage, independent of specific antigen-antibody interactions. Its main components are as follows:

3.1.1. Anatomical Barriers

The papillary duct is lined with multilayered epithelium and a keratin layer. This barrier limits bacterial entry and the lipids in keratin provide bacteriostatic activity (Nickerson, 1994; Ruegg, 2017; see Figure 3). The Fürstenberg rosette, located at the junction of the teat canal and teat cistern, adds both a physical seal and local immune surveillance through its lymphoid tissue (Bannerman, 2009).

Recent findings emphasize that epithelial cells in this region also express pattern-recognition receptors that cooperate with the keratin barrier for early detection of invading pathogens (Rainard et al., 2022; Hisaeda et al., 2025).

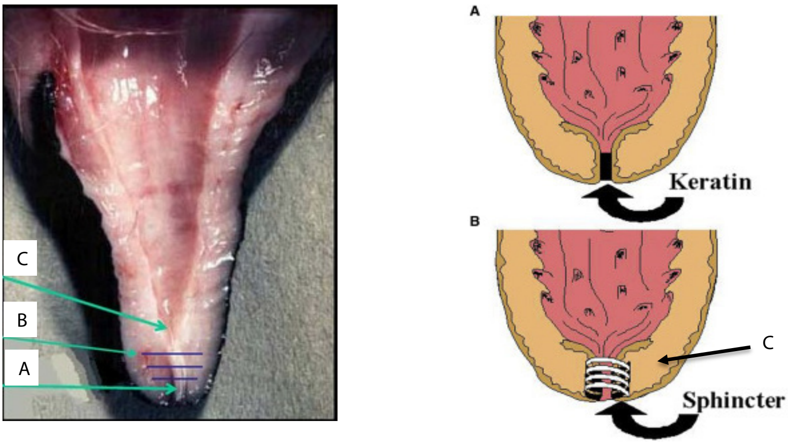

Figure 3. Longitudinal section of teat. Keratin (A), Sphincter muscle (B), Furstenberg's rosette-keratin (C). (Nickerson and Akers, 2011; Taylor, 2020).

3.1.2. Chemical Defense

Lactoferrin is an iron-binding glycoprotein secreted by mammary epithelial cells. By capturing iron, it deprives microorganisms of an essential nutrient and thereby restricts their growth. Its concentration rises markedly during the dry period, when it exerts a strong bacteriostatic effect. This activity is particularly effective against Gram-negative bacteria, making lactoferrin an important element of natural udder defense (Sordillo et al., 1997; Sordillo and Streicher, 2002; González-Chávez et al., 2009).

Lysozyme is an enzyme that cleaves the bonds in bacterial cell walls, leading to cell lysis. During infection, the amount of lysozyme in milk increases, and this rise enhances the overall antimicrobial activity of the secretion (Persson et al., 1992; Benkerroum, 2008).

The lactoperoxidase system is another innate antimicrobial mechanism of the mammary gland. When combined with thiocyanate and hydrogen peroxide, it shows strong bactericidal effects against Gram-negative bacteria and bacteriostatic effects against Gram-positive species. Since this system is naturally present in mammary secretions, it provides continuous protection against invading pathogens (Ozhan et al., 2025).

3.1.3. Physiological Defense

During milking, the teat canal is flushed with residual milk and bacteria. After milking, the sphincter muscle closes tightly, creating a mechanical barrier that prevents microorganisms from entering the gland (Bradley and Green, 2001). These mechanisms are effective in limiting the penetration of mastitis-causing pathogens at the initial stage (Neijenhuis et al., 2001). When the keratin layer is damaged by trauma or repeated milking, however, this natural protection is weakened and the risk of infection rises significantly (Hamann et al., 1993; Sandholm, 1995; Mein et al., 2001).

3.2. Cellular and Humoral Immunity

The acquired defense system of udder tissue involves the joint activity of immunoglobulins with specific antigen recognition capabilities and immune cells.

3.2.1. Cellular Immunity

Macrophages represent most of the phagocytic cells in milk and also act as antigen-presenting cells (Paape et al., 2003; Bannerman et al., 2005). Polymorphonuclear neutrophils (PMNs) rapidly migrate to infected quarters and account for the high somatic cell counts during mastitis (Paape et al., 2003; Schukken et al., 2011).

Lymphocytes, particularly T cells, orchestrate cellular and humoral responses and stimulate B cells to produce antibodies (Park et al., 1992; Sordillo, 2018).

Evidence from recent immunogenomic studies supports the view that the efficiency of early leukocyte recruitment and epithelial signaling strongly influences the outcome of infection (Genini et al., 2011; Trevisi and Minuti, 2018).

3.2.2. Humoral Immunity

Humoral immunity in the mammary gland is mediated by antibodies produced by plasma cells derived from B lymphocytes. These immunoglobulins defend the udder in several ways. They neutralize mastitis pathogens directly, enhance the efficiency of phagocytes through opsonization, and initiate the complement cascade, which amplifies immune activity (Rainard et al., 2001; Burvenich et al., 2003; Sordillo, 2018).

The main immunoglobulins secreted into milk are IgG1, IgG2, and IgA. IgG1 is the predominant form and has strong opsonizing ability, making it the most effective in supporting bacterial clearance. IgG2 contributes primarily by activating complement, which promotes bacterial destruction. IgA protects mucosal surfaces by blocking bacterial adhesion to the epithelial lining of the teat canal and alveoli (Rainard et al., 2001; Sordillo, 2018; Hurley and Theil, 2011). The complement system itself also provides an additional mechanism of protection, as it can lyse bacteria independently of antibodies (Rainard, 2003).

Overall, mammary defense relies on the integrated activity of anatomical, chemical, cellular, and humoral components. When this protective network is weakened by stress, poor hygiene, milking trauma, or nutritional deficiencies, cows become markedly more susceptible to mastitis.

3.3. Contribution of Udder Microbiota to Innate Immune Defense

The udder microbiota is now recognized as an integral component of the mammary gland's innate defense system (Derakhshani et al., 2018). This complex community interacts with epithelial cells and immune mediators to help maintain udder health.

Certain commensal bacteria, such as *Lactobacillus*, *Corynebacterium*, and *Bifidobacterium*, compete with pathogens for adhesion sites and nutrients, limiting their colonization (Guo et al., 2024; Reuben and Torres, 2025). They also secrete antimicrobial metabolites and influence the activation of neutrophils and macrophages, thereby enhancing early immune responses (Hu et al., 2019; Wang et al., 2025).

Dysbiosis, marked by the reduction of beneficial commensals and the overgrowth of opportunistic bacteria, disrupts these protective mechanisms and increases mastitis susceptibility (Burakova et al., 2023; Salman et al., 2023). A balanced microbial ecosystem therefore complements the anatomical, cellular, and humoral defenses of the mammary gland and strengthens resistance against mastitis-causing pathogens.

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Chapter 4.

SOMATIC CELL COUNT AND MILK QUALITY

Somatic cell count (SCC) is one of the most important indicators used to evaluate udder health in dairy cows. It reflects the presence of immune defense cells such as polymorphonuclear neutrophils (PMNs), macrophages, lymphocytes, and mammary epithelial cells (Harmon, 1994; Kehrli and Shuster, 1994; Paape et al., 2001; Ruegg, 2017; see Table 2).

Table 2. Summarizes the SCC thresholds commonly used to classify udder health status at different sample levels in dairy cows (Harmon, 1994; Bradley and Green, 2001; Hogeveen et al., 2011; Sharma et al., 2011; Fonseca et al., 2025)

Sample Level	SCC Threshold (cells/mL)	Interpretation	Typical Test Method*
Quarter milk	<100,000	Healthy quarter	CMT / Lab-based SCC
	100,000 – 200,000	Possible subclinical mastitis	CMT / Electronic SCC
	> 200,000	Likely intramammary infection	Electronic SCC
Cow composite milk	<200,000	Acceptable udder health	Lab-based SCC
	200,000 – 400,000	Increased risk of production loss	Lab-based SCC
	> 400,000	High risk of subclinical/ clinical mastitis	Lab-based SCC
Bulk-tank milk	<250,000	Premium-quality milk	Routine lab SCC
	250,000 – 400,000	Requires improved hygiene and milking	Routine lab SCC
	> 400,000	Regulatory penalty / reduced market value	Routine lab SCC

* Test methods include laboratory electronic counters, on-farm California Mastitis Test (CMT), and automated in-line SCC sensors

Practical Note: *SCC and Cheese Yield,*
Sustained bulk-tank SCC above 250,000 cells/mL is associated with reduced casein concentration and lower cheese yield. For every increase of 100,000 cells/mL above this threshold, cheese yield typically decreases by 3–5 %, and milk often falls into a lower payment class.
These quality losses translate into measurable economic penalties, which are explored in detail in Chapter9 (Economic Burden of Mastitis).
Maintaining quarter-level SCC below 100,000 cells/mL and bulk-tank SCC below 200,000 cells/mL maximizes both udder health and product value.

In healthy cows, SCC usually remains below 100,000 cells per milliliter of milk. When mastitis develops, however, the number rises sharply and may exceed one million cells per milliliter (Philpot and Nickerson, 2000; Paape et al., 2003; Schukken et al., 2011; Ruegg and Pantoja, 2013; Timonen et al., 2017).

In subclinical mastitis, elevated SCC is often the only detectable change. For this reason, SCC is considered an indispensable parameter in the diagnosis and monitoring of subclinical infections (Paape et al., 2003; Halasa et al., 2007; Ruegg, 2017).

4.1. Source of Somatic Cell Count

Approximately 75–90% of somatic cells in milk are polymorphonuclear neutrophils (PMNs). During infection, these cells are the first to leave the bloodstream and migrate into the mammary gland. Once there, they participate actively in the elimination of microorganisms. The remaining somatic cell population includes macrophages, lymphocytes, and mammary epithelial cells (Sordillo et al., 1997; Paape et al., 2003; Rainard and Riollet, 2006; Daley et al., 2018; Rainard et al., 2022).

An elevation in the somatic cell score (SCS) reflects inflammation within the mammary gland. While bacterial infection is the most common cause, other non-infectious factors may also contribute. Mechanical trauma, errors in milking procedures, chemical irritation, or environmental stressors can all increase SCS and compromise milk quality (Schukken et al., 2011; Halasa et al., 2007).

4.2. The Relationship Between Somatic Cell Count and Milk Quality

An increase in somatic cell count (SCC) exerts a broad impact on milk quality. As SCC rises, the concentration of lactose decreases and milk fat levels are also reduced (Harmon, 1994; Seegers et al., 2003). Changes occur in the total protein content, while the amounts of sodium and chloride increase, leading to an altered mineral balance (Lee, 2008). These biochemical alterations also affect the pH, which in turn shortens the shelf life of milk products and diminishes their overall quality (Safak and Risvanlı, 2022).

The technological properties of milk are likewise compromised. The casein ratio, which is fundamental in cheese making, deteriorates when SCC is elevated, resulting in a measurable decline in cheese yield (Blowey and Edmondson, 1995; Silva et al., 2018). At the same time, higher SCC is associated with greater activity of proteolytic and lipolytic enzymes, which can accelerate spoilage. The action of these enzymes may lead to souring and undesirable flavor defects in dairy products, further reducing their market value (Ogala et al., 2007).

4.3. Economic Importance

An increase in somatic cell count (SCC), most often linked to subclinical mastitis, exerts notable negative effects on the dairy economy. Elevated SCC reflects the presence of intramammary infections, which are frequently asymptomatic but still compromise milk quality. These changes include a reduction in lactose and casein concentrations together with an increase in sodium and chloride levels, all of which negatively affect the technological properties of milk used in processing (Philpot and Nickerson, 2000; Le Maréchal et al., 2011).

Subclinical mastitis also reduces milk yield and shortens the shelf life of dairy products. The economic burden arises from several factors, such as discarded milk, higher treatment expenses, reduced cheese yield, and penalties imposed by milk processors (Halasa et al., 2007; Ruegg and Pantoja, 2013). Effective control of SCC and subclinical mastitis is therefore essential not only for animal health and food safety but also for the long-term sustainability of dairy production systems.

4.4. Somatic Cell Count Monitoring and Management

Regular monitoring of somatic cell count (SCC) is fundamental for mastitis control and for maintaining herd health. The California Mastitis Test (CMT) continues to be one of the most practical on-farm screening tools, as it reveals increases in SCC associated with mammary gland inflammation (Viguier et al., 2009).

For accurate quantification, electronic cell counters are widely used in research as well as in routine herd health programs. These devices provide rapid and reliable measurements of somatic cell concentrations in milk samples (Bhutto et al., 2012; Hisira et al., 2023). Staining techniques have also been developed to visualize and classify different somatic cells, offering valuable information about udder health and the dynamics of infection (Kim et al., 2008; Peterson et al., 2011; Zajac et al., 2016).

SCC diagnostics therefore play a central role in mastitis management. Their use allows early detection, guides timely interventions, and helps preserve the quality of milk destined for processing.

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Chapter 5.
MILKING SYSTEMS

Milking is a central process in dairy farming and has direct consequences for udder health as well as milk quality. In recent years, significant progress has been made in milking technology. Automatic milking systems, improved liner designs, and precision-controlled vacuum levels have been developed to improve efficiency while protecting teat integrity and reducing the risk of pathogen transfer (Hovinen and Pyörälä, 2011; Tremblay et al., 2016; Fan et al., 2023; Pedrosa et al., 2024).

Despite these advances, improper machine settings, excessive vacuum levels, or inadequate cleaning of teats before milking can weaken the natural barrier of the teat canal. This condition predisposes cows to intramammary infections and increases the incidence of mastitis (Hovinen and Pyörälä, 2011; Milanesi et al., 2024). Research has also shown that poor hygiene management contributes to the persistence of contagious mastitis. Failures in post-milking teat disinfection or lapses in cleaning-in-place procedures allow pathogens such as Staphylococcus aureus and Streptococcus agalactiae to survive and spread within the herd (Hovinen and Pyörälä, 2011; Ruegg, 2017).

Maintaining udder health requires a combination of regular machine maintenance, structured milking routines, and scientifically based mastitis control protocols. These measures are essential for sustaining milk quality in both conventional and automated systems (Halasa et al., 2007; Fan et al., 2023; Pedrosa et al., 2024). Choosing the appropriate milking system, applying it under hygienic conditions, and monitoring its performance are therefore key elements of mastitis prevention.

Currently, milking systems are generally grouped into three categories: traditional hand milking, machine-based milking, and robotic milking (Figure 4).

5.1. Traditional Milking Systems

Milking by hand is commonly referred to as traditional milking (Wethal et al., 2020). In this practice, udder hygiene and careful hand washing before milking are essential. The removal of the first drops of milk is also important because it allows early detection of clinical mastitis and helps reduce the pathogen load in the udder (Philpot and Nickerson, 2000).

Manual milking offers several advantages. It is simple, requires minimal equipment, and involves low investment costs. On the other hand, it has notable disadvantages. The method is labor-intensive, prolongs milking time, and increases the risk of udder infections when hygiene measures are not carefully followed (Kashongwe et al., 2017; Siddaraju et al., 2024; Mengesha et al., 2025).

5.2. Machine Milking Systems

The rapid increase in herd size has made the transition to machine milking a necessity. These machines use an intermittent vacuum on each teat to remove milk from the udder and imitate the natural suckling reflex of the calf (Reinemann and Mein, 2018).

Modern milking systems combine several technological features. Vacuum pressure is applied to stimulate milk flow, while a pulsation phase provides massage to protect the teat from excessive pressure. At the same time, the equipment ensures that milk is collected and stored without contamination (Derea et al., 2003).

When properly calibrated, milking machines can shorten milking time, reduce labor requirements, improve animal welfare, and preserve milk quality (Reinemann and Mein, 2018; Kaskous and Pfaffl, 2023). If calibration is inadequate, however, serious problems may arise. Malfunctioning pulsators, incorrect vacuum settings, or poor hygiene of the milking units increase the risk of intramammary infections and facilitate the spread of mastitis (Mein, 2012; Kaskous and Pfaffl, 2023).

Figure 4. Hand milking and milking machine systems (Pereira, 2025a-b)

5.3. Robotic Milking Systems

Robotic milking systems provide important advantages in modern dairy farming, with positive effects on both milk yield and animal welfare. Their ability to automate the milking process reduces labor demands and eases the workload of farm personnel. Another key benefit is the flexibility of milking times, which can be adjusted to cows' natural physiological rhythms. This adaptation lowers stress and supports animal welfare (Bach and Cabrera, 2017; see Figure 5).

These systems also influence mastitis control. Research has shown that management practices on farms using robotic milking play a decisive role in mastitis incidence and related production losses (D'Anvers et al., 2023). When combined with appropriate protocols, robotic systems can decrease mastitis cases and limit economic damage. In addition, sensors and digital monitoring tools continuously track milk yield, milking frequency, and udder health. This technology enables the early detection of mastitis and other health problems (Kuczaj et al., 2020).

Milking systems and pre-milking routines also shape the microbial community in bulk tank milk. Hygiene practices in robotic systems directly affect the microbial composition of milk, which has consequences for both mastitis development and product quality (Sun et al., 2022). Therefore, automation alone is not sufficient. Effective mastitis prevention also requires rigorous hygiene and consistent equipment maintenance.

Feeding strategies are another factor that influences mastitis management under robotic milking conditions. Well-planned feeding programs can strengthen immune function, reduce mastitis risk, and improve the efficiency of robotic operations (Bach and Cabrera, 2017). Studies further emphasize the link between physiological parameters, milking performance, and health indicators. Measurements taken during robotic milking can serve as early warning signs for mastitis and other disorders (Kuczaj et al., 2020).

Robotic milking systems thus represent a promising technology for mastitis prevention and control. Their success depends on an integrated management approach that combines hygiene, maintenance, and proper feeding strategies. Each milking method has specific advantages and limitations, but the core principle for mastitis prevention is strict adherence to hygiene and regular equipment care.

Figure 5. Robotic milking machine (DeLaval, 2025).

5.3.1. Maintenance Intervals and Checklist

The efficiency of robotic milking systems depends not only on software and programming but also on regular maintenance and strict hygiene protocols. The following maintenance intervals and checkpoints help reduce mastitis risk and maintain milking performance (Hovinen and Pyörälä, 2011; Pedrosa et al., 2024; see Table 3-4).

Table 3. Routine Inspection Schedule for Robotic Milking Systems

Inspection Frequency	Key Points to Check
Daily Checks	• Condition and cleanliness of teat-cleaning brushes • Stability of vacuum and pulsation pressure • Cleanliness of milk flow sensors and milk lines • Proper timing and completion of automated cleaning cycles (CIP)
Weekly Checks	• Wear and deformation of teat cup liners • Calibration of vacuum regulators and pulsation ratios • Additional visual inspection of milk lines and robotic arms for hygiene
Monthly Checks	• Capacity and oil level of vacuum pumps • Pulsation frequency and symmetry tested with electronic devices • Hygiene and sealing of milk cooling lines • Review of software updates and error logs
Seasonal or Annual Checks	• Replacement of liners and hoses following manufacturer's guidance (typically every 2,500–3,000 milkings or every 6 months) • Comprehensive maintenance of vacuum pumps and replacement of worn parts if needed • Calibration of robotic arm sensors and mechanical connections • Hygiene verification of milk cooling tanks and pipelines using biofilm tests

Table 4. Maintenance and monitoring checklist with critical limits

Step	Action / Description	Frequency	Critical Limit / Target
Teat-cleaning brush condition	Inspect for wear, cleanliness	Daily	Replace if bristle loss >10%
Vacuum regulator	Verify stability and calibration	Weekly	42 ± 2 kPa
Liner wear	Inspect for cracks or deformation	Monthly	Replace every 2,500–3,000 milkings
Pulsation ratio and frequency	Measure with electronic device	Monthly	60:40 ± 2; 60 ± 5 cycles/min
Cooling line hygiene	Check for biofilm or residue	Monthly	No visible deposits
Robotic arm sensor calibration	Verify alignment and sensitivity	Seasonal / Annual	±2 mm tolerance from reference line

Consistent maintenance reduces teat-end trauma and mastitis risk. Stable vacuum and pulsation optimize milk flow and support both udder health and milk quality. Implementing this protocol helps lower antimicrobial usage and long-term economic losses at the farm level.

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Chapter 6.
MASTITIS PREVENTION STRATEGIES

Mastitis is one of the most common diseases in dairy cattle and is defined as inflammation of the mammary gland. This condition has major economic implications for dairy production. It reduces both the quantity and quality of milk, increases treatment costs, and raises concerns for animal welfare and public health (Ruegg, 2017).

The disease occurs in clinical and subclinical forms. Subclinical mastitis is marked by inflammation of mammary tissue and an elevation in somatic cell count (SCC) without visible clinical signs. Although less apparent, it reduces milk yield and compromises product quality. Heifers, particularly those in their first lactation, represent a special risk group. Mastitis that develops before or during the onset of milking can cause lasting reductions in production, and rapid prevention or treatment is therefore essential (Compton and McDougall, 2008; Nickerson, 2009).

Preventive strategies play a central role in mastitis management. Their effective application reduces the need for treatment, lowers costs, and minimizes the use of antibiotics. This also decreases the risk of antimicrobial resistance, which is a growing concern for both veterinary and human medicine. For this reason, understanding current preventive approaches for protecting both heifers and lactating cows is a key element of mastitis control programs.

6.1. Characteristics of Mastitis in Heifers and Lactating Cows

6.1.1. Characteristics of Mastitis in Heifers

Heifers are at risk primarily during late gestation and early lactation due to immature teat-end keratin and higher susceptibility to environmental pathogens, while lactating cows are affected by both environmental exposure and milking-related factors (Ruegg, 2017; Pedrosa et al., 2024).

Heifers are an important part of dairy herds because they preserve genetic progress and secure future milk production. For many years, however, they did not receive specific protection programs, based on the mistaken belief that mastitis would not occur before their first lactation (Compton and McDougall, 2008; Nickerson, 2009). Research has shown that the prevalence of mastitis in heifers ranges between 35% and 100%, and these infections can cause significant economic losses (Trinidad et al., 1990; Oliver et al., 2000; Jordan et al., 2002).

In the last third of pregnancy, the development of alveolar tissue and the beginning of milk secretion make the teat duct more susceptible to microbial invasion. This period is further complicated by a weakened immune system, reflected in decreased immunoglobulin levels and reduced neutrophil activity, which increases the risk of intramammary infection (Vural et al., 1999; Malinowski et al., 2003).

Mastitis in heifers usually begins as subclinical infections that are not detected during the prepartum stage. These infections often become apparent in the first lactation. The most common pathogens are Staphylococcus aureus, Streptococcus uberis, and Staphylococcus chromogenes (Trinidad et al., 1990; Nickerson et al., 1999; Fox, 2009). Additional risk factors include skin damage from fly bites, which provides a route for pathogens to enter. Heifers that experience mastitis before calving produce on average 10–15% less milk in their first lactation, highlighting the long-term impact of the disease (Shearer and Harmon, 1993; Oliver et al., 2004).

Mastitis in dairy cows can lead to several significant consequences, including permanent damage to mammary tissue, reduced milk production during the first lactation, and deterioration of milk quality due to elevated somatic cell counts. Moreover, affected herds often experience a higher incidence of mastitis cases, which further compromises overall udder health and productivity (Kirk, 2004; Nickerson, 2009). Therefore, strategies to prevent mastitis in heifers should be addressed at both the individual and herd levels.

Teat-End Hyperkeratosis Scoring in Heifers

Teat-end hyperkeratosis is a significant risk factor for early-lactation mastitis in heifers. The thickened or roughened teat-end surface compromises the natural barrier of the teat canal, facilitating bacterial entry and increasing SCC during the first weeks of lactation (Sordillo, 2018; Hisaeda et al., 2025). To address this risk, a practical checklist can be integrated into routine herd health programs. It guides field assessments, helps identify vulnerable heifers, and supports timely preventive action (Mein et al., 2001).

Regular scoring should be carried out during the last two to three months before calving and repeated within the first month after calving. The examination should be performed in a clean, well-lit area, and animals must be safely restrained to allow accurate observation of all teat ends. Scoring relies on a standardized system ranging from score 0, indicating a smooth teat end with an intact sphincter, to score 3, representing severe hyperkeratosis with rough and cracked tissue. Heifers with scores of 2 or higher are considered at increased risk for early-lactation mastitis, and they require closer monitoring and targeted management (Hisaeda et al., 2025; see Table 5).

Table 5. Teat-end hyperkeratosis scoring system in heifers

Score	Description of Teat End
0	Smooth teat end with intact sphincter
1	Slight roughness or early thickening
2	Moderate roughness with a raised ring around the sphincter
3	Severe hyperkeratosis with rough, cracked sphincter area

For these higher-risk animals, specific action steps are recommended. Pre- and post-milking teat hygiene should be improved, milking unit vacuum and pulsation settings must be optimized, and over-milking should be avoided while regularly inspecting and maintaining liners (Neijenhuis et al., 2001). Providing clean and dry bedding further reduces environmental contamination and lowers the risk of intramammary infection.

Alongside these measures, monitoring SCC in early lactation is essential. Collecting milk samples from scored heifers allows detection of subclinical infections and assessment of intervention effectiveness. Equally important is maintaining proper records. Individual logs of teat-end scores, SCC levels, and mastitis history provide valuable data to evaluate preventive programs over time and guide future management decisions.

Integrating these steps into daily herd management makes teat-end scoring a practical and efficient tool. It supports early detection of anatomical changes that compromise teat defenses, enables timely interventions, and contributes to healthier udders and better milk quality in the first lactation.

6.1.2. Characteristics of Mastitis in Dairy Cows

Mastitis is one of the most common and costly infectious diseases in dairy cows. It occurs throughout lactation and significantly reduces milk yield, animal welfare, and farm profitability. High somatic cell count (SCC) reflects intramammary infection and is closely associated with reduced milk quality and farm losses (Halasa et al., 2009; Ruegg, 2017). The risk of mastitis is highest within the first 30–60 days after calving, when immune suppression and tissue vulnerability make cows more susceptible to infection.

The early lactation period is critical because negative energy balance after calving contributes to immunosuppression and increases disease risk (LeBlanc et al., 2002). Mammary edema, increased capillary permeability, and epithelial damage further facilitate bacterial invasion (Zhao and Lacasse, 2008). Subclinical mastitis during this stage often goes unnoticed. It is characterized by elevated SCC, altered milk composition, and reduced milk yield. In clinical cases, mastitis presents with visible signs such as swelling, redness, pain, and abnormal milk containing clots or discoloration (Schukken et al., 2003; Seegers et al., 2003; Bradley and Green, 2005).

Clinical mastitis is readily identifiable because it typically develops as an acute response to bacterial infection. Subclinical mastitis, on the other hand, progresses without obvious external symptoms and is far more prevalent in dairy herds (Seegers et al., 2003). Epidemiological studies indicate that 25–40% of lactating cows are affected by subclinical mastitis at any given time (Olde Riekerink et al., 2008; Ruegg, 2017). The impact on milk quality is significant, as high SCC alters protein content, pH balance, and enzyme activity. When SCC exceeds 200,000 cells/mL, cheese yield and processability decline (Le Maréchal et al., 2011).

The causes of mastitis are broadly grouped into contagious and environmental pathogens. Contagious organisms such as Staphylococcus aureus, Streptococcus agalactiae, Mycoplasma spp., and Corynebacterium bovis are transmitted during milking through contaminated equipment, milkers' hands, or milking cups. Environmental pathogens, including Escherichia coli, Streptococcus uberis, and Klebsiella pneumoniae, originate from bedding, manure, urine, and unhygienic housing conditions. Effective mastitis prevention requires strict milking hygiene and careful environmental management to reduce pathogen exposure (Bradley and Green, 2009). Environmental mastitis often causes short but severe clinical episodes, while contagious pathogens tend to persist in subclinical or chronic forms (Schukken et al., 2011).

The level of hygiene during milking has a direct effect on mastitis development. Inadequate teat preparation, failure to apply disinfectant before milking, or improper vacuum pressure settings allow microorganisms to penetrate the teat canal (Vermaak et al., 2022). The transfer of infectious pathogens between milking clusters is particularly important in contagious mastitis.

Robotic milking systems have been associated with a reduction in mastitis compared with conventional methods. This improvement is largely due to automated cleaning systems and advanced software that monitor milking routines. Even so, consistent maintenance of teat cleaning mechanisms is essential to achieve sustainable protection (Edmondson, 2012; D'Anvers et al., 2023; Ozella et al., 2023; Zagidullin et al., 2023; Nogara et al., 2025).

Mastitis incidence also increases with parity. In first-lactation cows, the teat canal is still immature and more vulnerable to environmental pathogens. In second and third lactations, trauma from repeated milking and a higher risk of chronic infections are observed. In cows beyond the fourth lactation, epithelial thickening, loss of elasticity, and delayed closure of the teat canal further increase susceptibility to bacterial invasion (Sordillo and Streicher, 2002; Bannerman et al., 2005; Nickerson, 2009).

Mastitis prevention strategies must therefore be tailored to age and lactation stage. In older cows with recurrent or chronic mastitis, culling is often a more rational approach for both herd health and economic efficiency.

6.2. Risk Factors

These risk factors can generally be categorized under headings such as housing conditions, milking hygiene, age and lactation number of cows, udder structure, herd management, feeding practices, and climatic stress (Ruegg, 2017; Bradley and Green, 2005).

6.2.1. Animal-Related Risk Factors

I. Number of Lactations and Age

This disease remains a major health problem in dairy herds, and its incidence rises with the number of lactations. Studies report that mastitis is more common in the third and later lactations (Penev et al., 2014). The higher frequency is linked to progressive structural and functional changes in mammary tissue together with a decline in immune competence as cows grow older.

The stage of lactation also plays an important role in immune capacity. Immune suppression is most evident in early lactation, a period when mammary tissue becomes especially vulnerable to environmental pathogens (Sordillo and Streicher, 2002). For this reason, the sensitivity of the udder differs according to lactation stage. In advanced lactations, morphological alterations such as reduced tissue elasticity and delayed teat canal closure have been observed. These changes indicate increased infection risk, although further physiological and histological studies are needed for confirmation.

II. Mammary Gland Structure and Teat Characteristics

Structural features of the udder can increase the risk of infection. Asymmetry of mammary lobes, sagging udders, or teats located close to the ground make environmental contamination more likely and facilitate bacterial entry into the teat canal. Short or wide teats may also interfere with proper canal closure after milking, which prolongs the time during which pathogens can enter.

Teat-end conformation is another important factor. Flat, cracked, or inverted teat ends weaken the protective role of the epidermis and the Fürstenberg rosette, thereby increasing the likelihood of intramammary infection. Epidemiological evidence supports this link. Cows with flat or triangular teats had a 1.6-fold greater risk of clinical mastitis compared with cows that had round or pointed teats (Spellman et al., 2025).

Field investigations across different herds have reached similar conclusions. Cows with pendulous udders or damaged teat-end morphology show a higher prevalence of mastitis, and somatic cell counts are also consistently elevated in these animals (Miles et al., 2019; Kashoma, 2023).

III. The state of the Immune System

The immune system of dairy cows is weakened by several factors during the transition period. Negative energy balance, metabolic disorders such as ketosis and hypocalcemia, oxidative stress, and deficiencies in vitamins and minerals, particularly selenium, vitamin E, and folic acid, are important contributors. Postpartum stress further aggravates this condition. These factors impair leukocyte activity, reduce phagocytic capacity, and promote the release of proinflammatory cytokines, thereby increasing susceptibility to infections including mastitis (Sordillo, 2016; Bruinjé and LeBlanc, 2025).

Elevated concentrations of non-esterified fatty acids (NEFA) and beta-hydroxybutyrate (BHB) have adverse effects on the metabolic function of immune cells. During the postpartum period, these metabolites suppress neutrophil and macrophage activity, limiting their ability to eliminate pathogens (Trevisi and Minuti, 2018). Hypocalcemia also directly inhibits leukocyte function, weakening the natural defense system of the udder (Martinez et al., 2014).

Oxidative stress intensifies during the peripartum period and causes cellular injury within the immune system. Deficiencies in antioxidant compounds such as selenium and vitamin E markedly impair neutrophil migration and pathogen clearance (Xiao et al., 2021). In addition, folic acid, which is essential for DNA synthesis and immune cell proliferation, becomes critical during this time. A deficiency in this vitamin reduces the effectiveness of the immune response (Khan et al., 2020).

Energy imbalance, mineral deficiencies, and postpartum stress ultimately create a physiological environment that favors mastitis development. Low blood glucose, ketosis, and hypocalcemia further compromise immunity by suppressing essential defense mechanisms in cows.

6.2.2. Environmental Risk Factors

I. Bedding and Floor Hygiene

The environmental form of mastitis is strongly associated with bedding hygiene and the bacterial load present in bedding materials. Poorly managed bedding creates conditions favorable for pathogen growth and increases the likelihood of teat-end contamination. This problem is particularly relevant for organic bedding materials such as straw and sawdust, which carry a higher bacterial burden compared with inorganic materials like sand. Shifts in the epidemiology of mastitis, with a decline in cases caused by Streptococcus agalactiae and Staphylococcus aureus and a rise in those caused by Streptococcus uberis and Escherichia coli, have been partly linked to the use of organic bedding with higher bacterial counts (Zadoks and Fitzpatrick, 2009).

Comparative studies show that straw and sawdust provide a more suitable environment for bacterial multiplication, leading to higher infection rates. In contrast, sand bedding harbors fewer microorganisms and is associated with lower mastitis prevalence. These findings highlight that both bedding type and bacterial load are decisive factors in determining mastitis risk. Proper bedding management is therefore an essential part of mastitis prevention strategies. Daily cleaning and regular replacement of bedding are crucial to minimize bacterial contamination and reduce the incidence of environmental mastitis (Smith and Hogan, 1993; Seegers et al., 2003; Rowbotham and Ruegg, 2016; see Table 6).

Table 6. Environmental risk by bedding type

Bedding Type	Relative Risk of Environmental Mastitis	Main Pathogens of Concern	Management Recommendations
Sand bedding	Lowest risk for coliform mastitis	Mainly *Escherichia coli*	Maintain dryness and frequent replacement; monitor moisture.
Organic bedding (straw, sawdust)	Higher risk, especially under humid or wet conditions	*Streptococcus uberis*, coliforms	Keep bedding dry, replace frequently, improve ventilation.
Recycled manure solids	Highest risk without strict drying and hygiene	*Klebsiella pneumoniae*, coliforms	Ensure rapid drying, proper composting, and routine hygiene testing.

II. Housing Type and Ventilation

Environmental conditions and housing practices have a direct influence on mastitis occurrence. The incidence of clinical cases differs according to housing design, hygiene standards, and herd management practices. Poor ventilation, excessive humidity, and sudden changes in temperature weaken the immune system of cows and create a more favorable environment for infection. Stress factors linked to housing further reduce the ability of animals to resist pathogens.

During the summer months, heat stress becomes particularly important. Elevated temperatures suppress immune function and make cows more vulnerable to mastitis-causing agents. Under these conditions, contamination of teat surfaces has been reported at higher levels, further increasing the risk of intramammary infection (Olde Riekerink et al., 2008).

6.2.3. Management and Milking Hygiene-Related Risk Factors

I. Pre- and Post-Milking Practices

Effective mastitis prevention begins in the milking parlor, where hygiene practices directly determine udder health. Proper procedures carried out before and after milking are essential to reduce bacterial contamination and to limit the risk of new intramammary infections. Consistent application of these practices protects the teat canal from harmful microorganisms and significantly lowers infection rates.

Before attaching the milking unit, teats must be cleaned and disinfected through a process known as pre-dipping. The purpose of this step is to eliminate environmental bacteria such as Escherichia coli and Streptococcus uberis, which are frequently present on the skin due to contact with bedding or manure. Pre-dipping typically involves the application of a disinfectant solution such as iodine, chlorhexidine, or lactic acid, which should remain on the teat surface for approximately 30 seconds. After this period, each teat should be dried with a clean individual towel. Using the same towel for more than one cow facilitates bacterial transmission, whereas single-use paper towels or washable cloth towels that are disinfected after every milking provide a safe alternative (Kumar and Grover, 2017). Foaming pre-dip products are often preferred because they enhance coverage and reduce bacterial load more effectively. This procedure does more than clean the teat surface; it establishes the first protective barrier in a comprehensive mastitis control program (Dego, 2020).

Post-dipping is equally important because the teat canal remains open for up to 30 minutes after milking, creating an opportunity for bacteria to penetrate. Immediate application of a disinfectant within 30 seconds after cluster removal forms a barrier at the teat end and protects against pathogens such as Staphylococcus aureus, Corynebacterium bovis, and Mycoplasma species (Ruegg, 2017). Many post-dip products also contain moisturizers such as glycerin or lanolin, which maintain skin integrity and prevent teat-end cracking. Regular use of post-dip solutions is considered a cornerstone of mastitis prevention, and neglecting this step significantly increases the risk of new infections both within and between cows (Dego, 2020).

In addition to dipping procedures, proper drying techniques and equipment sanitation are vital. Each cow must be dried with a separate towel, since shared towels are a common route of bacterial spread. Milking equipment, including teat cup liners, hoses, and clusters, should be cleaned and sanitized routinely to prevent biofilm formation. Biofilms provide a habitat for pathogens and contribute to persistent infections. Over time, worn liners can harbor microorganisms and damage teat ends, further elevating mastitis risk (Ruegg, 2017). Poorly maintained equipment remains one of the most underestimated sources of mastitis outbreaks. Regular inspections and strict cleaning protocols significantly improve udder health and contribute to sustainable mastitis control (Dego, 2020).

II. Milking Machine Settings and Teat Health

Hygiene during milking is critical, but the mechanical performance and calibration of the milking machine are equally decisive in preventing mastitis.

Incorrect machine settings, particularly those related to vacuum pressure, pulsation, or liner fit, can cause injury to teat tissue and create opportunities for bacterial penetration, even when hygiene protocols are followed (Besier et al., 2015).

Vacuum pressure must be adjusted with precision. Excessive levels damage the keratin layer of the teat canal and restrict blood circulation, which promotes swelling, inflammation, and reduced resistance to infection. To prevent such outcomes, teat-end vacuum levels during peak milk flow should be maintained between 32 and 42 kPa, as this range prevents tissue trauma while supporting efficient milking (Besier et al., 2015).

The pulsation system also has a fundamental role. By alternating vacuum and rest phases, it replicates natural suckling and protects teat tissue. If pulsation ratio or frequency is incorrectly set, teats may not receive adequate rest, which can cause congestion and tissue injury. Research has demonstrated that poorly adjusted vacuum and pulsation parameters lead to thickened teat walls, slower recovery after milking, and greater susceptibility to intramammary infection (Kaskous and Pfaffl, 2023).

Teat liners must also be compatible with teat size and shape. Ill-fitting or worn liners reduce vacuum stability, cause liner slip, and increase the risk of mechanical trauma. Defective liners, such as those that are bent or cracked, further compromise teat health by providing surfaces where bacteria can persist. Regular inspection, thorough cleaning, and timely replacement after approximately 2,500 milkings are therefore required to maintain optimal function (Mein, 2012; Besier et al., 2015; Vermaak et al., 2022).

System malfunctions that lead to air leakage or liner slippage can destabilize vacuum conditions. Sudden liner slips may cause milk to spray back toward the teat end, directly introducing pathogens into the canal. Such incidents are closely associated with elevated mastitis risk and are considered warning signs of inadequate machine performance (Vermaak et al., 2022).

III. Milking Order and Infected Animals

Milking order is a frequently underestimated yet essential element of mastitis control in dairy herds. The sequence in which animals are milked directly influences the risk of transmitting contagious pathogens such as Staphylococcus aureus, Streptococcus agalactiae, and Mycoplasma bovis, all of which are commonly spread during the milking routine. To minimize cross-infection, cows showing clinical mastitis should be milked last. This practice helps prevent pathogens from being transferred through contaminated clusters, gloves, or hands of the milking staff (Schukken et al., 2011).

In practical herd management, milking often begins with first-lactation heifers and healthy cows with low somatic cell counts. These are followed by older cows or those with higher cell counts but without clinical signs. Animals with subclinical or clinical mastitis are milked at the end of the process, frequently using a separate cluster or even a dedicated group, to reduce the risk of contamination. Larger farms may also adopt separate milking units or time slots for infected animals to further limit transmission (Schukken et al., 2011; Ruegg, 2017).

Hygiene of equipment and personnel is equally important. Milking clusters used on infected cows should be disinfected before being applied to healthy animals, and this can be achieved through dipping or back-flushing systems that rinse the liners with disinfectant. Milkers are advised to wear gloves and sanitize them frequently, especially after contact with cows carrying infections. Studies have shown that adherence to these practices reduces the incidence of new intramammary infections and contributes to long-term improvements in udder health and milk quality (Ruegg, 2017).

Overall, milking order is not a matter of convenience but a strategic component of mastitis prevention. A structured and consistent routine, combined with effective cluster hygiene and the separation of infected cows, functions as a practical safeguard against the spread of mastitis-causing bacteria within the herd.

6.2.4. Nutrition and Mineral Support

Adequate energy and protein intake is fundamental for maintaining udder health, particularly during late lactation and the transition period. When cows receive insufficient nutrients in this stage, their immune systems are weakened and postpartum recovery is delayed, which increases susceptibility to mastitis (Yang and Li, 2015).

Nutritional imbalance at the cellular level impairs immune competence. Underfeeding energy or protein reduces neutrophil activity and slows the resolution of inflammatory responses. Several herd-based studies have demonstrated that subclinical negative energy balance after calving is closely associated with a higher incidence of mastitis (Yang and Li, 2015; Khan et al., 2024).

Oxidative stress is another critical factor in udder health, characterized by elevated reactive oxygen species (ROS) and reduced antioxidant activity in mammary tissue (Yang and Li, 2015). Vitamin E and selenium function synergistically to counteract oxidative stress. Vitamin E neutralizes lipid peroxides in mammary epithelial membranes and protects cell integrity, while selenium, through its role in glutathione peroxidase, detoxifies ROS (Smith et al., 1997; Yang and Li, 2015; Libera et al., 2021; Mir, 2025). Clinical studies have shown that cows with sufficient plasma vitamin E before calving experience a markedly reduced risk of clinical mastitis in early lactation, in some cases up to nine times lower than deficient cows (Xiao et al., 2021; Mir, 2025).

Vitamin A also contributes significantly by maintaining epithelial structure. Its deficiency causes hyperkeratinization, which weakens the natural barrier against bacterial penetration (Dey et al., 2019). Fragile epithelial cells allow pathogens to invade more easily, thereby increasing the likelihood of both clinical and subclinical mastitis. Blood levels of vitamin A and beta-carotene, the precursor of vitamin A, drop markedly two to three weeks before calving, which further compromises udder defense (Dey et al., 2019; Khan et al., 2024).

Evidence strongly supports the supplementation of essential micronutrients during the transition period. Vitamin E and selenium supplementation improves immune function, lowers somatic cell counts, and reduces the duration and severity of mastitis episodes (Smith et al., 1997; Mir, 2025). Other trace minerals, such as zinc, copper, and manganese, also contribute to epithelial repair and antioxidant capacity, although vitamin E and selenium remain the most important elements for sustaining udder health (Yang and Li, 2015; Dey et al., 2019).

6.2.5. Herd Management and Biosecurity

Herd management plays a decisive role in the development and control of mastitis. The introduction of new animals into the herd always carries the risk of bringing in contagious pathogens. For this reason, newly purchased or transferred animals should be kept in isolation and subjected to diagnostic testing before integration. Quarantine practices are not only effective for mastitis control but also for reducing the risk of other infectious diseases that may compromise the productivity of the entire herd (Halasa et al., 2007).

Another major concern is the presence of animals suffering from chronic mastitis. These animals act as persistent reservoirs of infection and continuously expose healthy herd members to pathogens. Research indicates that eliminating chronically infected cows from the herd can significantly reduce the incidence of new intramammary infections, particularly those caused by Staphylococcus aureus and other contagious bacteria (Rodrigues et al., 2005). Although culling decisions can create economic concerns in the short term, the long-term benefits of healthier herds, improved milk quality, and reduced treatment costs outweigh the losses.

Milking practices also constitute a critical risk factor. The order in which cows are milked directly influences the spread of pathogens. Animals with mastitis should always be milked at the end of the milking routine. This simple adjustment in management minimizes the possibility of contaminating equipment and transferring pathogens to healthy cows (Bradley and Green, 2001). In addition, regular monitoring of teat condition, proper maintenance of milking machines, and strict hygiene in the parlor contribute to the reduction of both contagious and environmental mastitis (Ruegg, 2017).

Biosecurity extends beyond animal management and includes environmental and personnel-related practices. Housing conditions such as bedding quality, ventilation, and stocking density affect the exposure of udders to pathogens. Inadequate hygiene in housing areas can increase the prevalence of environmental pathogens like Escherichia coli and Streptococcus uberis. Proper training of farm workers in udder preparation, teat disinfection, and hygiene protocols is equally essential. Even small lapses in milking hygiene can compromise biosecurity and undermine the efficacy of other preventive strategies (Ramirez et al., 2014; Tomazi et al., 2018).

6.2.6. Vaccination and Alternative Approaches

Traditional mastitis control programs have primarily focused on hygiene and antimicrobial therapy. However, the emergence of antimicrobial resistance has intensified the search for alternative approaches. Among these, vaccination has received considerable attention. Vaccines developed against Staphylococcus aureus and Escherichia coli aim to reduce the severity of infections and improve the resilience of the mammary gland. Although the protective efficacy of vaccines can vary among studies, evidence suggests that they contribute to lowering both the incidence of clinical cases and the economic impact of mastitis in herds (Schukken et al., 2011).

Probiotics and phytotherapeutic agents represent another promising group of alternative strategies for mastitis prevention. Probiotics derived from lactic acid bacteria have shown potential to modulate the mammary microbiota and enhance the local immune response, which may help reduce the incidence of new intramammary infections (Urakawa et al., 2022). Their beneficial effects are particularly relevant for cows with a history of mastitis, where supplementation can strengthen host defenses and support udder health.

In addition to probiotics, phytochemicals such as essential oils and plant extracts have demonstrated both antibacterial and anti-inflammatory properties. Lemon balm and peppermint essential oils, for example, inhibited common mastitis pathogens including Escherichia coli and Staphylococcus aureus under experimental conditions (Arbab et al., 2022). Formulations such as Phyto-Bomat, based on essential oils, have been tested in clinical cases and were shown to decrease pathogen load while maintaining milk quality and ensuring acceptable withdrawal periods, highlighting their potential for safe therapeutic application (Kovačević et al., 2022).

The antioxidant and immunomodulatory effects of plant-derived compounds, including phenolics and flavonoids, also contribute to improving resistance of the mammary gland against infection (Sharma and Sharma, 2022). Systematic reviews further confirm that medicinal plants can provide significant antibacterial activity against major mastitis pathogens, although the variability of efficacy and the need for standardized formulations remain important challenges for field application (Kaseke et al., 2023).

The role of probiotics and phytotherapeutic agents is therefore particularly important in reducing reliance on antibiotics and promoting sustainable dairy farming practices. Their integration into herd health programs can help address antimicrobial resistance while supporting animal welfare and milk quality, provided that further clinical trials and safety evaluations are carried out to optimize their use (Pathak et al., 2024).

Recent advances in nanotechnology have opened new horizons in mastitis therapy. Nanocarriers, such as liposomes, polymeric nanoparticles, and lipid-based systems, can deliver antimicrobial agents directly to the infected mammary tissue with higher efficiency and lower systemic exposure. This approach not only increases therapeutic success but also decreases the risk of antimicrobial residues in milk. Experimental studies indicate that nanotechnology-based drug delivery may soon become an integral part of mastitis control programs, particularly in cases where conventional therapies fail (Kaskous and Pfaffl, 2023).

The combination of conventional and alternative methods offers the most effective strategy. While herd management and biosecurity provide the foundation of mastitis prevention, vaccination, probiotics, phytotherapy, and nanotechnology represent valuable complementary tools. Integrating these approaches creates a multifaceted defense against both contagious and environmental pathogens. Sustainable mastitis control depends on adopting such holistic strategies, tailored to the specific conditions of each herd.

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Chapter 7.
DIAGNOSTIC METODS FOR MASTITIS

Early, precise, and cost-effective diagnosis of mastitis is essential for protecting udder health, reducing antimicrobial use, and maintaining milk quality. Despite the introduction of advanced technologies, traditional tools such as the California Mastitis Test (CMT) and somatic cell count (SCC) remain widely applied as rapid screening methods to identify subclinical infections at the cow or quarter level (Schukken et al., 2003; Bhutto et al., 2012; Ruegg, 2017). These established methods continue to provide frontline surveillance, especially in routine herd management programs.

In recent years, major progress has been achieved in diagnostic science, allowing more accurate and earlier detection of mastitis. Technologies such as MALDI-TOF mass spectrometry, real-time PCR, and next-generation molecular assays have shortened the time to diagnosis and improved pathogen identification, even for slow-growing organisms like *Mycoplasma* spp. and *Corynebacterium bovis* (El-Sayed et al., 2017; Braga et al., 2018; Cuccato et al., 2022). Complementing these approaches, metabolomic profiling has revealed specific biomarkers in milk and urine that can predict disease risk before clinical signs appear, while artificial-intelligence–based models now integrate milking data and sensor records to forecast disease onset at both cow and herd levels (Ryan et al., 2020; Du et al., 2024; Zwierzchowski et al., 2024).

The integration of traditional, molecular, metabolomic, and AI-driven systems reflects a shift from reactive to predictive mastitis management. By combining routine screening tools with rapid laboratory diagnostics and real-time digital surveillance, veterinarians and producers can make more targeted treatment decisions, limit unnecessary antimicrobial use, and ultimately enhance udder health and milk production sustainability (Viguier et al., 2009; Haxhiaj et al., 2022; Rowe et al., 2023).

Accurate diagnosis of mastitis is essential for timely treatment and targeted control strategies. Conventional methods remain useful for routine field application, whereas modern laboratory-based techniques provide higher sensitivity and specificity, supporting precision management of mastitis. The diagnostic performance and sample requirements of these methods are summarized in Table 7.

7.1. Conventional Diagnostic Methods

Although modern technologies have advanced considerably, traditional diagnostic tools remain essential for detecting mastitis in dairy herds. The California Mastitis Test (CMT) is still a widely used on-farm screening method because it is rapid, inexpensive, and provides immediate visual information about somatic cell levels in milk (see Figure 7). A positive CMT reaction is usually followed by somatic cell count (SCC) analysis using electronic cell counters. An SCC above 200,000 cells/mL is generally accepted as a marker of subclinical mastitis and indicates the need for closer monitoring or intervention (Schukken et al., 2003; Bhutto et al., 2012; Ruegg, 2017).

For definitive diagnosis, bacteriological culture combined with antimicrobial susceptibility testing remains the reference standard. These methods confirm the identity of the causative pathogen and guide the selection of effective antimicrobial therapy (Braga et al., 2018; Cuccato et al., 2022; Haxhiaj et al., 2022; Thompson et al., 2023). Accurate pathogen identification improves treatment outcomes and helps protect both animal health and the quality of milk produced.

7.2. Modern Diagnostic Techniques

Recent advances have revolutionized mastitis diagnosis by delivering rapid, precise, and predictive testing capabilities:

Rapid Pathogen Identification via MALDI TOF MS:

Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) has become an important tool for the rapid and precise identification of pathogens responsible for mastitis. Recent developments have made it possible to achieve species-level identification directly from milk samples without relying on lengthy culture procedures (Lopes et al., 2023; Thompson et al., 2023).

The integration of MALDI-TOF MS with machine learning techniques has further improved its diagnostic utility. In one study, this combined approach demonstrated a sensitivity of about 0.89 and a specificity above 0.81 in detecting subclinical mastitis (Thompson et al., 2023). Such results indicate that MALDI-TOF MS, when paired with computational analysis, provides a rapid and reliable method for identifying infections.

This diagnostic strategy offers considerable value for early detection and timely intervention in dairy herd health management. By enabling faster identification of causative pathogens, it supports more targeted treatment decisions and contributes to improved udder health and milk quality.

Real-Time PCR and Molecular Tests:

Real-time PCR and other molecular diagnostic methods have significantly advanced the detection of mastitis pathogens. These techniques identify pathogen-specific DNA sequences directly from milk samples with high sensitivity and specificity. Compared with conventional culture, they markedly reduce the time required for diagnosis and provide faster results for clinical decision-making (El-Sayed et al., 2017; Kaskous and Pfaffl, 2023).

Molecular diagnostics are particularly valuable in detecting organisms that are slow-growing or difficult to culture, such as Mycoplasma species and Corynebacterium bovis. Their application also extends to herd-level monitoring, where they support early detection of infections and allow timely interventions to limit pathogen spread (El-Sayed et al., 2017; Kajdanek et al., 2024).

Metabolomics and Biomarker-Based Approaches:

Metabolomics provides a valuable framework for the early detection of mastitis by revealing subtle metabolic alterations in biological fluids such as milk, urine, and serum. Studies have shown that mastitis changes the metabolite composition of milk, producing distinct metabolic patterns that differentiate healthy from infected cows (Du et al., 2024). These findings point to several promising biomarkers that may support earlier and more precise diagnosis.

Urinary metabolomic profiling during the prepartum period has also demonstrated predictive value. Specific metabolite panels have achieved an area under the curve (AUC) of about 0.88, reflecting high diagnostic accuracy several weeks before clinical symptoms become evident (Zwierzchowski et al., 2024). Such results suggest that metabolomic approaches may play a key role in future mastitis monitoring programs.

AI-Powered Early Warning Systems:

Artificial intelligence–based early warning systems are increasingly being implemented in dairy herd health management to support the proactive detection of mastitis. These systems employ machine learning models trained on longitudinal datasets that include somatic cell counts, milk yield, milking duration, and individual cow performance records. By analyzing these variables together, algorithms are able to recognize cases of subclinical infection or the early stages of clinical disease before visible symptoms become evident (Ryan et al., 2020).

Sensor data obtained from automatic milking systems has also been shown to enhance diagnostic performance when combined with decision-tree algorithms. This approach improves the detection of clinical mastitis by identifying changes in milk flow, conductivity, and other milking parameters, thereby complementing traditional monitoring methods (Kamphuis et al., 2008). The integration of artificial intelligence with sensor-based technologies offers a robust framework for real-time surveillance, enabling early intervention and supporting long-term improvements in udder health and milk quality.

Table 7. The diagnostic performance and sample requirements of conventional and modern tests (Ruegg, 2017; Cuccato et al., 2022; Haxhiaj et al., 2022; Du et al., 2024)

Test / Method	Type	Sensitivity (%)	Specificity (%)	Optimal Sampling Time
California Mastitis Test (CMT)	Conventional	70–80	60–75	During routine milking
Somatic Cell Count (SCC)	Conventional	75–85	65–80	Bulk tank or quarter milk
Bacteriological Culture	Conventional	75–90	85–95	Acute or chronic cases
PCR / qPCR	Modern	90–98	90–97	Acute phase or subclinical
ELISA (pathogen-specific)	Modern	85–95	88–95	Early or latent infection
MALDI-TOF MS	Modern	88–96	92–97	Subclinical and culture-positive milk
Metabolomics	Modern	85–93	85–90	Research or early subclinical stage

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Chapter 8.
TREATMENT STRATEGIES FOR MASTITIS IN DAIRY ANIMALS

Effective mastitis control requires careful consideration of the form of the disease, the causative pathogen, and the stage of lactation. Treatment should aim to restore udder health while supporting antimicrobial stewardship, an increasingly important goal given global concerns about antibiotic resistance (Ruegg, 2017). Clinical cases demand rapid and targeted therapy to minimize production losses and prevent infection spread. Subclinical mastitis, although not accompanied by visible signs, reduces milk yield and quality and therefore requires accurate detection and strategic management. Chronic infections are more challenging to resolve and may necessitate long-term approaches, including culling of persistently affected animals (Halasa et al., 2009a).

The dry period is a critical phase in mastitis prevention. Therapeutic measures applied at this stage can eliminate existing intramammary infections and protect the udder against new ones in the subsequent lactation. An integrated approach that adapts therapeutic choices to disease type and lactation stage is essential for optimizing animal health, safeguarding milk quality, and reducing economic losses (Ruegg, 2017; Halasa et al., 2009a).

8.1. Acute Clinical Cases

The clinical signs of mastitis range from mild local inflammation to systemic illness. Therapeutic decisions must therefore be adapted to the severity of the disease. In mild and moderate cases, intramammary antibiotics such as cloxacillin or cefapirin are commonly used, and systemic therapy is usually not required (Ruegg, 2017).

Severe infections, particularly those caused by environmental coliforms and accompanied by systemic signs such as fever or toxemia, often require a combination of intramammary and systemic antimicrobial treatment. This dual approach has become standard in many herds, and studies confirm the efficacy of intramammary antibiotic therapy in clinical cases caused by environmental patojense (Guterbock et al., 1993; Ruegg, 2017). The frequent use of combined protocols reflects the practical adjustment of therapy to the clinical severity of mastitis.

Nonsteroidal anti-inflammatory drugs, including meloxicam and flunixin, provide important supportive benefits. They reduce inflammation, help maintain mammary function, and improve animal comfort. When administered alongside antimicrobial therapy, they contribute to faster clinical recovery, enhanced welfare, and improved treatment efficacy (McDougall et al., 2009; Wilm et al., 2024; Muloi et al., 2025; Tomazi and Santos, 2025).

8.2. Subclinical and Chronic Cases

Subclinical mastitis is generally identified by an elevated somatic cell count, typically above 200,000 cells per milliliter, in the absence of visible abnormalities in the udder or milk. The therapeutic success of treatment in such cases is often limited, particularly when infections progress to a chronic state. Pathogens such as *Staphylococcus aureus* and *Mycoplasma bovis* are well known for their persistence and resistance to antimicrobial therapy, which makes eradication difficult. In herds facing these challenges, culling is frequently regarded as a more cost-effective and epidemiologically rational option compared with repeated or prolonged antimicrobial courses (Stanek et al., 2024; Sophorn et al., 2025).

Some farms attempt targeted dry period therapy in cows with subclinical infections. The outcome of this approach depends on accurate pathogen identification and appropriate animal selection, as indiscriminate treatment rarely provides lasting benefits. The use of antimicrobials in chronic subclinical cases should therefore be approached cautiously. Excessive or inappropriate administration increases the likelihood of antimicrobial resistance, adding further risks for both herd health and public health (White et al., 2006; Gonçalves et al., 2023; Stanek et al., 2024; Sophorn et al., 2025).

Subclinical mastitis is typically identified by an increase in somatic cell count above 200,000 cells per milliliter, in the absence of visible changes in milk or udder appearance. The success of treatment in these cases is often limited, especially when the infection becomes chronic. Pathogens such as *Staphylococcus aureus* and *Mycoplasma bovis* frequently persist due to their ability to form biofilms and to develop resistance to commonly used antimicrobials, which complicate eradication (Alfonseca-Silva et al., 2021; Vishovan et al., 2021). In herds where chronic infections remain widespread, culling is often regarded as a more cost-effective and epidemiologically sound solution compared with prolonged or repeated antimicrobial therapy (Okello et al., 2023).

On some farms, selective dry cow therapy is implemented in cows with subclinical infections to eliminate existing pathogens and to protect against new intramammary infections in the subsequent lactation. The effectiveness of this approach depends on accurate pathogen identification and proper animal selection. Evidence indicates that indiscriminate or inappropriate use of antimicrobials in such cases may contribute to antimicrobial resistance among mastitis pathogens, thereby limiting long-term success (Ruiz-Romero and Vargas-Bello-Pérez, 2023; Navaei et al., 2025). For these reasons, antimicrobial use in chronic subclinical mastitis should be carefully evaluated, and culling or alternative management strategies should be considered when therapeutic response is poor.

8.3. Dry Period Therapy

The dry period is a critical phase in dairy herd management. It provides an opportunity to eliminate existing intramammary infections (IMIs) and to prevent the development of new ones. Traditionally, Blanket Dry Cow Therapy (BDCT) has been the most common approach. In this method, all cows are treated with long-acting intramammary antibiotics at drying-off regardless of their infection status (Winder et al., 2019; Kabera et al., 2021). BDCT has historically been successful in reducing IMIs, but the continuous use of antibiotics has raised concerns about antimicrobial resistance and consumer demand for residue-free milk (Oliver and Murinda, 2012; Morales-Ubaldo et al., 2023).

In recent years, Selective Dry Cow Therapy (SDCT) has been recommended as a more sustainable alternative. In this approach, only cows that are considered high risk are treated with antibiotics. High risk cows are usually identified by elevated somatic cell counts or a history of mastitis. Cows with low infection risk receive only an internal teat sealant (Halasa et al., 2009b; Winder et al., 2019; Paiva et al., 2024). This strategy represents an important step toward protecting udder health while reducing the unnecessary use of antimicrobials (Ruegg, 2017; Navaei et al., 2025). Recent studies in different countries confirm that SDCT can be successfully implemented in both small and large dairy herds (Rowe et al., 2023; Contiero et al., 2025).

Systematic reviews and meta-analyses show that SDCT combined with internal teat sealants achieves cure rates and preventive outcomes comparable to BDCT (Halasa et al., 2009a; Winder et al., 2019; Kabera et al., 2021). Importantly, this approach reduces antibiotic use by 60–70% without increasing the incidence of clinical mastitis (Winder et al., 2019; Kabera et al., 2021). Additional evidence demonstrates that SDCT is applicable across herds with different milk production levels, reinforcing its practicality under diverse management conditions (Rowe et al., 2023).

Economic analyses also highlight the benefits of SDCT. Large-scale herd studies from North America have shown that SDCT is cost-effective and feasible, especially when combined with diagnostic testing and decision-support algorithms (Hommels et al., 2021; McCubbin et al., 2022). These findings align with European experiences, where the transition to SDCT was linked to reduced antimicrobial use and improved compliance with regulatory standards (Contiero et al., 2025).

Another essential element in SDCT is diagnostic precision. Reliable cow-level diagnostics such as somatic cell counts, bacteriological culture, and molecular tools including PCR and MALDI-TOF are increasingly used to guide treatment decisions (Lopes et al., 2023; Thompson et al., 2023; Kajdanek et al., 2024). By integrating these methods, veterinarians and producers can apply SDCT protocols more confidently and reduce the risk of overlooking subclinical infections. At the same time, research indicates that SDCT does not compromise udder health or milk yield, and culling rates remain similar to those seen with BDCT (Okello et al., 2023; Paiva et al., 2024).

Overall, SDCT has emerged as a sustainable and evidence-based alternative to BDCT. It contributes to udder health, supports milk quality, and responds to the global need for responsible antimicrobial stewardship. The integration of economic analyses, diagnostic innovations, and welfare considerations makes SDCT a cornerstone of modern dry cow management. The principles and implementation steps of SDCT are illustrated in Figure 6, while the practical treatment decision algorithm is summarized in Table 10.

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Chapter 9.
ECONOMIC BURDEN OF MASTITIS IN DAIRY CATTLE

Mastitis remains one of the most costly diseases in the dairy sector. The economic loss arises from direct factors such as reduced milk yield, discarded milk, veterinary care, and premature culling, as well as indirect costs like increased labor and reduced reproductive performance. Early studies emphasized that production losses represent the largest share of the total economic burden (Seegers et al., 2003). Subsequent analyses confirmed that both clinical and subclinical mastitis decrease milk yield, alter its composition, and reduce its processing quality, thereby affecting both farm income and the dairy industry as a whole (Hogeveen et al., 2011; Gonçalves et al., 2023).

Subclinical mastitis is particularly insidious because it often remains undetected for long periods while steadily reducing milk output and quality. In Dutch herds, new subclinical cases were estimated to reduce milk yield by several kilograms per cow per day during the affected lactation (Halasa et al., 2009). Similar observations were reported in Brazilian farms, where subclinical infections caused significant financial losses through both lower milk production and penalties associated with increased somatic cell counts (Gonçalves et al., 2023).

9.1. Costs associated with Clinical Mastitis

Clinical mastitis episodes incur additional costs beyond milk yield reduction. They lead to veterinary expenses, discarded milk during treatment and withdrawal periods, increased risk of cow removal, and elevated labor requirements. In Canadian and European herds, each clinical case has been estimated to cost between 200 and 400 USD, depending on severity and management practices (Seegers et al., 2003; Halasa et al., 2007). More recent work in Latin America and Asia has highlighted that the cost per case can be even higher in systems with limited access to prompt veterinary care and where milk prices are rising (Gonçalves et al., 2023; Morales-Ubaldo et al., 2023).

Robotic and automated milking systems have added new dimensions to the economics of mastitis. Studies show that herds with higher mastitis incidence in such systems face greater production losses because disease episodes disrupt cow traffic, reduce milking frequency, and limit the efficiency of automated equipment (D’Anvers et al., 2023; Milanesi et al., 2024). This underscores the importance of integrating udder health monitoring with precision technologies to mitigate financial losses.

9.2. Economic Burden of Mastitis Through Milk Quality Deterioration

Milk from cows with mastitis frequently has increased somatic cell counts, altered protein and fat composition, and higher levels of proteolytic enzymes, which compromise cheese yield and other processing properties (Ogola et al., 2007; Le Maréchal et al., 2011). Many dairy processors penalize farmers financially when bulk tank somatic cell counts exceed threshold levels. Consequently, persistent subclinical mastitis can affect the entire milk payment structure of a farm. Losses also occur at the processor level due to reduced shelf life and technological defects in dairy products.

To better illustrate the impact of this effect on farm profitability, a simple scenario is presented below, showing how SCC influences cheese yield, milk rejection, and labor costs (Hogeveen et al., 2011; Le Maréchal et al., 2011; see Table 8).

Table 8. Impact of SCC on cheese yield, milk rejection, and labor costs

Parameter	*Baseline (SCC <200,000 cells/mL)*	*High SCC Scenario (>400,000 cells/mL)*	*Estimated Loss*
Milk yield (L/cow/year)	*8,000 L*	*7,600 L*	*–400 L/cow*
Cheese yield (kg/1,000 L milk)	*110 kg*	*105 kg*	*–5 kg/1,000 L*
Milk rejection / discarded milk	*0%*	*2%*	*Equivalent to 1,600 L/year*
Additional labor for mastitis cases	–	*+150 labor hours/year*	*≈ €2,000 extra*
Total economic loss (milk + cheese + labor)	–	–	*≈ €12,000/year for the herd*

9.3. Role of Control Programs and Prevention

Economic modeling consistently demonstrates that well-implemented mastitis control programs are cost-effective. The classic five-point plan emphasizes post-milking teat disinfection, dry cow therapy, culling of chronically infected cows, proper milking machine maintenance, and improved hygiene. This integrated approach remains a cornerstone of prevention (Ruegg, 2017).

More recent interventions such as selective dry-cow therapy guided by culture and antimicrobial-resistance data have been shown to reduce antimicrobial usage without compromising udder health or profitability (Rowe et al., 2023; Contiero et al., 2025). Preventive nutritional strategies, including vitamin E and selenium supplementation, also improve udder immunity and can reduce both the incidence of mastitis and the associated economic losses (Smith et al., 1997; Mir, 2025).

9.4. Long-Term Herd Productivity and Sustainability

Persistent mastitis problems decrease the longevity and lifetime productivity of affected cows, often leading to premature culling. This loss of genetic potential, combined with the costs of replacing culled animals, further increases the financial burden on farms (Barkema et al., 2015). In regions aiming for sustainable milk production with lower antimicrobial use, the economics of mastitis control are particularly relevant. Adoption of evidence-based prevention, routine monitoring using precision tools such as milk metabolomics and sensor-based systems, and optimized milking protocols can substantially improve the cost–benefit ratio of mastitis management (Fan et al., 2023; Zwierzchowski et al., 2024).

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Chapter 10.
CURRENT RESEARCH ON MASTITIS DIAGNOSIS AND THERAPY

Mastitis research has advanced rapidly over the past decade, moving beyond conventional culture-based diagnosis and broad antimicrobial use. New approaches now emphasize precision, sustainability, and early intervention to protect udder health and milk quality (Ruegg, 2017; Haxhiaj et al., 2022).

Recent work highlights metabolomic profiling and artificial-intelligence–driven risk prediction as powerful tools for earlier and more accurate detection of mastitis, allowing timely and targeted interventions (Ryan et al., 2020; Cuccato et al., 2022; Du et al., 2024). In parallel, global concerns over antimicrobial resistance have accelerated the adoption of selective dry-cow therapy and the exploration of alternative treatments such as nanobiotechnology, antimicrobial peptides, and plant-derived compounds (Arbab et al., 2022; McCubbin et al., 2022; Kaskous and Pfaffl, 2023;).

These advances also align mastitis control with broader sustainability goals by reducing routine antibiotic use, supporting eco-friendly practices, and improving the economic viability of dairy farming (Gonçalves et al., 2023; Pathak et al., 2024). Together, they illustrate a transition from reactive to precision-based and prevention-focused mastitis management, shaping the future of udder health research and practice.

10.1. Diagnosis Through Metabolomic Analysis of Milk

Over the past decade, metabolomic approaches have emerged as powerful tools for early and precise detection of mastitis in dairy cows. These methods identify unique metabolite signatures associated with intramammary infections, enabling both pathogen recognition and insights into host metabolic responses. Compared to traditional culture or PCR-based assays, metabolomics can generate faster and more comprehensive diagnostic profiles (Haham et al., 2022).

Advanced technologies such as MALDI-TOF mass spectrometry (MS) and nuclear magnetic resonance (NMR) spectroscopy have enhanced the accuracy of subclinical mastitis detection. Cuccato et al. (2022) demonstrated that MALDI-TOF MS profiles of skim milk could distinguish healthy cows from those with subclinical infections. Du et al. (2024) reported marked shifts in metabolites related to energy metabolism and oxidative stress in mastitic cows, underscoring the prognostic potential of metabolic profiling.

A critical advantage of metabolomics is its dual capacity to characterize both pathogen-specific metabolites and the cow's systemic response. Zwierzchowski et al. (2024) identified urinary metabotypes as reliable biomarkers for subclinical mastitis, reflecting systemic alterations linked to udder inflammation. Looking ahead, the development of portable metabolomic devices for on-farm screening may revolutionize mastitis control programs by enabling real-time decision-making.

10.2. Artificial Intelligence-Based Risk Prediction Systems

Artificial intelligence (AI) and machine learning (ML) have transformed mastitis management by leveraging large datasets generated by automated milking systems (AMS). Algorithms can process real-time data (such as somatic cell counts, milk conductivity, yield, and milking frequency) to predict mastitis onset with high accuracy (Kamphuis et al., 2010; Fan et al., 2023).

Time-series models and decision-tree-based classifiers have been shown to outperform conventional farmer-based detection. Ryan et al. (2020) demonstrated that ML models could identify early changes in udder health prior to clinical manifestation. Furthermore, Pedrosa et al. (2024) combined genomic information with behavioral traits to build predictive models for mastitis susceptibility, paving the way for individualized herd management strategies.

Modern AI tools extend beyond diagnosis by generating herd-level risk maps. These tools allow veterinarians and farmers to implement targeted preventive measures, optimize antimicrobial use, and reduce economic losses.

10.3. Antimicrobial Resistance and Targeted Dry-Cow Therapy

The growing prevalence of antimicrobial resistance (AMR) among mastitis pathogens remains a global challenge. Surveillance studies have documented increased resistance to beta-lactams and fluoroquinolones in major mastitis-causing bacteria (Morales-Ubaldo et al., 2023). Earlier evidence from European herds highlighted the presence of multidrug-resistant isolates in dairy cows (Idriss et al., 2014), reinforcing the urgency of prudent antimicrobial use.

Transitioning from blanket dry-cow therapy to selective dry-cow therapy (SDCT) has proven effective in reducing antimicrobial consumption while maintaining udder health. McCubbin et al. (2022) reported that SDCT significantly reduced antibiotic exposure at drying-off without compromising cure rates. Similarly, Rowe et al. (2023) demonstrated that SDCT could be successfully implemented across herds with varying milk production levels, confirming its broad applicability in modern mastitis control.

10.4. Alternative Therapeutic Modalities

Nanobiotechnology and Peptide-Based Interventions

Emerging non-antibiotic therapies aim to mitigate AMR risks and enhance sustainability. Nanoparticle-based drug delivery systems improve therapeutic efficacy by enabling targeted release at the site of infection while minimizing systemic exposure (Kaskous and Pfaffl, 2023).

Antimicrobial peptides (AMPs), including bacteriocins and plant-derived compounds, offer promising alternatives. Kour et al. (2023) highlighted the potent activity of AMPs against common mastitis pathogens. Arbab et al. (2022) provided evidence that selected essential oils and herbal extracts possess strong in vitro antibacterial effects against *Staphylococcus aureus* and *Escherichia coli*, both key mastitis agents. Sharma and Sharma (2022) emphasized that plant-based therapeutics may also bolster local immune defenses, particularly valuable for subclinical mastitis control. These strategies align with the global demand for reduced antibiotic dependence in food-producing animals.

10.5. Sustainability-Driven Mastitis Control Programs

Mastitis control strategies increasingly incorporate sustainability objectives, recognizing the need to protect both economic viability and environmental health. Reducing routine antimicrobial usage, promoting eco-friendly hygiene products, and lowering the carbon footprint of dairy production are now key targets (Pathak et al., 2024).

Gonçalves et al. (2023) demonstrated the substantial economic burden imposed by subclinical mastitis on milk yield and farm profitability, reinforcing the cost-effectiveness of prevention-oriented strategies. Ethnoveterinary practices, when scientifically validated and integrated with modern programs, can play an important role in resource-limited regions, supporting both animal welfare and environmental stewardship.

10.6. Integration and Future Perspectives

Between 2015 and 2025, mastitis research has shifted from conventional diagnostic and therapeutic frameworks toward precision-based, sustainable solutions. Metabolomics and AI technologies now facilitate earlier detection and targeted interventions, while SDCT and alternative therapies address AMR concerns. Sustainability-focused programs link mastitis control to global goals for environmental responsibility and reduced antimicrobial use.

This multidisciplinary evolution reflects the future direction of udder health management, where rapid diagnostics, data-driven risk prediction, and eco-conscious therapeutic choices converge to ensure both herd health and the long-term resilience of dairy production systems.

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Chapter 11.

MODEL HERD MASTITIS CONTROL PROGRAM

A structured mastitis control program is crucial for maintaining udder health, reducing antimicrobial use, and sustaining milk quality. Implementing these coordinated measures improves udder health, reduces clinical and subclinical mastitis incidence, and lowers antimicrobial usage. In addition, it enhances milk yield and quality, with subsequent positive effects on farm profitability and animal welfare (Seegers et al., 2003; Rowe et al., 2023; Contiero et al., 2025).The following section highlights a Model Herd Protection Program that integrates regular monitoring, biosecurity, and hygiene practices (see Table 9).

Table 9 Recommended interventions for a typical well-managed dairy herd

Intervention Step	Application Frequency	Measurable Target (KPI)*
Somatic cell count (SCC) monitoring	Monthly	BTM SCC < 200,000 cells/mL
California mastitis test (CMT)	Weekly	≥ 90% of positive quarters sampled and treated
Pre- and post-milking teat dipping	Continuous at every milking	Compliance > 95%
Bedding management	Twice daily	Bedding dryness score ≥ 4/5
Quarantine of new animals	14 days for each incoming animal	Zero new infections introduced from purchases
Machine maintenance (liner replacement, etc.)	Per manufacturer guidelines (e.g., every 2,500–3,000 milkings)	Zero failures detected in routine checks
Program evaluation and feedback	Annually	New infection rate < 2% per month; Clinical mastitis incidence < 20 cases/100 cows/year

***KPI** Key Performance Indicator

11.1. SCC Monitoring

Routine SCC measurement is a cornerstone of mastitis surveillance. Monthly testing allows the early detection of subclinical infections and provides data for herd-level decision-making (Ruegg, 2017; Hisira et al., 2023). Keeping bulk tank SCC below 200,000 cells/mL reduces the risk of production losses and milk quality penalties (Hogeveen et al., 2011).

Responsible Role: Monitoring should be coordinated by the herd veterinarian and implemented by the herd manager or designated milking staff who collect and submit milk samples.

11.2. Weekly CMT Screening

On-farm CMT is an inexpensive and rapid tool for identifying quarters with elevated SCC. Weekly testing of suspicious animals improves the timeliness of intervention and prevents progression to clinical disease (Bhutto et al., 2012).

Responsible Role: The farm technician or trained milking staff should perform CMT tests and record results for veterinary follow-up.

11.3. Pre- and Post-Milking Teat Dipping

Consistent use of disinfectants during both pre- and post-milking is one of the most effective strategies to prevent the transmission of contagious pathogens such as *Staphylococcus aureus* and *Streptococcus agalactiae* (Philpot and Nickerson, 2000; Zigo et al., 2021). Post-milking dipping in particular helps close the teat canal to bacterial entry during the period of sphincter relaxation.

Responsible Role: This routine is primarily the responsibility of the milking staff, under the supervision of the herd manager, to ensure compliance and correct technique.

11.4. Bedding Management

Maintaining clean and dry bedding is essential for minimizing exposure to environmental mastitis pathogens such as *Escherichia coli* and *Streptococcus uberis*. Cleaning and renewing bedding at least twice daily has been shown to significantly reduce new infections (Rowbotham and Ruegg, 2016; Tomazi et al., 2018).

Responsible Role: Daily bedding maintenance is typically assigned to barn staff, with oversight from the herd manager to ensure that cleanliness and dryness targets are met.

11.5. Quarantine and Testing of New Animals

Introducing cows from outside herds carries the risk of importing contagious pathogens. A minimum 14-day quarantine period combined with SCC monitoring and bacteriological screening helps prevent disease introduction (Rodrigues et al., 2005; Ramírez et al., 2014).

Responsible Role: The herd veterinarian is responsible for testing and interpreting results, while the herd manager ensures isolation procedures are followed.

11.6. Machine Maintenance

Proper functioning of the milking equipment is vital for maintaining teat health and reducing infection risk. Routine checks of vacuum levels, pulsation ratio, and liner condition should be carried out according to manufacturer recommendations, typically every 2,500–3,000 milkings. Regular replacement of worn parts prevents teat-end damage and improves milking efficiency (Zecconi et al., 2024).

Responsible Role: The milking technician or service provider carries out the technical maintenance, while the herd manager oversees compliance with the maintenance schedule.

11.7. Program Evaluation and Feedback

A structured review of mastitis control performance is essential for continuous improvement. Annual assessments of key performance indicators (KPIs), such as bulk tank SCC, new infection rate, and clinical mastitis incidence, allow timely adjustments to protocols (Contiero et al., 2025). Integrating feedback from veterinarians, farm managers, and milking staff supports a collaborative approach and promotes long-term udder health.

Responsible Role: The veterinarian and herd manager jointly lead the evaluation process, supported by farm staff who collect routine data.

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Chapter 12.
FUTURE CHALLENGES AND OPPORTUNITIES

Mastitis remains one of the most persistent health and economic challenges in modern dairy production. Although advances in hygiene, antimicrobial therapy, and genetic selection have reduced the overall burden of the disease, new global priorities such as antimicrobial stewardship, sustainable milk production, and animal welfare demand a shift in control strategies. The future of mastitis prevention will depend on integrating technological innovation with sound farm management and policy guidance.

This chapter highlights the interconnected domains of AMR, technological innovation, farmer education, and alternative therapies, emphasizing that progress in mastitis control depends on harmonized efforts across science, policy, and farm practice. The following sections examine each domain in detail, outlining both the opportunities and the challenges for sustainable udder-health management in the decade ahead.

12.1. Antimicrobial Resistance as a Public Health Concern

Antimicrobial resistance (AMR) in bovine mastitis pathogens has become a critical challenge for both animal and human health. Intensive and prolonged use of intramammary antibiotics during lactation and the dry period has selected for resistant strains such as *Staphylococcus aureus* and *Escherichia coli* (Oliver and Murinda, 2012; Morales-Ubaldo et al., 2023). Recent studies highlight that resistance genes are often linked to mobile genetic elements, facilitating their horizontal transfer within the farm environment (Vishovan et al., 2021).

The One Health perspective stresses that AMR originating in dairy herds can compromise treatment efficacy in both veterinary and human medicine (Rowe et al., 2023). Selective dry-cow therapy guided by culture and antimicrobial-susceptibility testing has proved effective in reducing antimicrobial use without increasing new intramammary infections (Contiero et al., 2025; Navaei et al., 2025). However, implementing such strategies on a large scale still faces economic and logistical barriers. The challenge for the coming decade is to balance effective mastitis control with prudent antibiotic stewardship while minimizing resistance dissemination (Okello et al., 2023; Wilm et al., 2024).

12.2. Agriculture 4.0 applications:

Sensor Technologies and Robotic Milking

The integration of Agriculture 4.0 technologies is reshaping udder-health management. Automated milking systems equipped with real-time sensors record milk yield, electrical conductivity, temperature, somatic cell count, and even metabolomic or proteomic profiles, enabling early detection of mastitis (Ryan et al., 2020; Fan et al., 2023). Machine-learning approaches applied to these data streams have improved predictive accuracy for clinical mastitis by identifying subtle changes preceding visible signs (Pedrosa et al., 2024).

Robotic milking platforms also modify milking routines in ways that influence mastitis dynamics. Appropriate adjustment of vacuum level, liner design, and pre- and post-milking hygiene remains essential to prevent teat-end trauma and bacterial colonization (Vermaak et al., 2022; Kaskous and Pfaffl, 2023). Recent reports suggest that integrating smart milking robots with cloud-based decision-support systems may further enhance disease surveillance and guide selective treatments (DeLaval, 2025; Pereira, 2025). While these technologies offer opportunities for more sustainable production, their high initial cost and the need for specialized technical support limit adoption in smallholder systems.

12.3. Expanding Farmer Education and Capacity-Building Programs

The successful adoption of precision technologies and prudent antimicrobial-use policies depends largely on farmer knowledge and compliance. Studies show that farms with structured training programs on hygiene, milking procedures, and early detection of subclinical infections achieve significantly lower mastitis incidence and reduced treatment costs (Mengesha et al., 2025; Rodrigues et al., 2005).

Farmer-to-farmer extension models, participatory workshops, and digital learning platforms have recently been evaluated as efficient tools to disseminate evidence-based practices, especially in low- and middle-income dairy systems (Muloi et al., 2025). Future programs should integrate continuous training on sensor data interpretation, biosecurity, and alternative treatment strategies. Such efforts can empower producers to make informed decisions, increasing the likelihood of sustained mastitis control while reducing unnecessary antibiotic use.

12.4. Turning Toward Alternative Therapies:
Phytotherapy and Immunotherapy

The search for complementary or replacement therapies is intensifying due to AMR and consumer demand for residue-free milk. Phytotherapeutic agents such as essential oils from *Melissa officinalis*, *Mentha piperita*, and formulations containing thymol or eugenol have shown in-vitro and field-level antibacterial and anti-inflammatory effects against major mastitis pathogens (Arbab et al., 2022; Kovačević et al., 2022; Sharma and Sharma, 2022). Nevertheless, variability in composition and insufficient validation under controlled field conditions still limit their routine application.

Immunomodulatory strategies are another promising frontier. Research into vaccines targeting *Staph. aureus*, *E. coli*, and non-aureus staphylococci has advanced, yet their field efficacy remains inconsistent due to strain diversity and antigenic variability (Rainard et al., 2021; Ruiz-Romero and Vargas-Bello-Pérez, 2023). Probiotic supplementation with *Bacillus subtilis* has been reported to lower recurrence in cows with a previous history of mastitis by enhancing local immune defenses (Urakawa et al., 2022). Combining immunotherapy with precision-guided antimicrobial use may offer a more integrated approach to mastitis control in the near future.

Concluding Remarks

Addressing the dual challenge of sustaining milk production and preserving public health will require harmonized efforts in policy, technology, and field management. Innovations in Agriculture 4.0 and alternative therapies offer considerable opportunities but demand targeted farmer education and continuous surveillance to be successful. Future research must focus on long-term field trials that integrate these novel approaches while monitoring their economic feasibility and impact on antimicrobial resistance.

12.5. Microbiota-Based Interventions for Sustainable Mastitis Control

Advances in research have highlighted that maintaining or restoring a healthy udder microbiota can enhance immune resilience and reduce dependence on antimicrobials (Derakhshani et al., 2018). This understanding has shifted attention toward microbiota-based strategies as part of sustainable mastitis control.

Probiotic formulations containing selected strains of *Lactobacillus* and *Bifidobacterium* have shown promise in improving microbial balance and lowering mastitis incidence in both experimental and field studies (Khan et al., 2021; Wang et al., 2025). Such approaches complement conventional measures rather than replacing them.

Omics technologies, including metagenomics and metabolomics, now allow precise profiling of udder microbial communities and their functional roles (Reuben and Torres, 2025; Guo et al., 2024). These tools enable the development of targeted diagnostics, dietary modulation, and the combined use of probiotics with bioactive compounds.

Integrating microbiota-guided strategies with hygiene, vaccination, and prudent antimicrobial use represents a modern, sustainable approach to mastitis control. This integration aligns with global goals to combat antimicrobial resistance while preserving animal welfare and milk production efficiency.

12.6. Practical implementation guide

Culture-based selective dry-cow therapy (SDCT) algorithm

Culture-based SDCT aims to reduce unnecessary antimicrobial use, limit the emergence of antimicrobial resistance, and maintain udder health (Rowe et al., 2023; Contiero et al., 2025). The following guide integrates each step into a cohesive narrative suitable for routine application in dairy herds.

The traditional blanket dry-cow therapy approach has been increasingly replaced by SDCT to optimize antibiotic stewardship. By using milk culture results and recent SCC records, veterinarians and farm managers can target treatment only to infected or high-risk cows, avoiding unnecessary exposure in healthy animals. A systematic application of SDCT requires early assessment, careful milk sampling, accurate culture interpretation, and continuous monitoring (see Table 10).

I. Pre-Dry-Off Assessment

The process begins 6–8 weeks before the expected calving date. The primary goal is to review each cow's health record, including the last three months of SCC data, clinical mastitis episodes, and available milk culture results.

Cows with SCC below 200,000 cells/mL and no history of recent clinical mastitis are categorized as low-risk. Animals with SCC at or above 200,000 cells/mL or with mastitis in the preceding three months are considered high-risk. This early stratification allows targeted planning for the dry-off period.

II. Milk Sampling And Culture

Milk samples should be collected aseptically from each quarter 1–7 days before drying-off. A rapid 24-hour aerobic culture at 37 °C is recommended to provide timely results.

Cows with negative cultures show no pathogen growth and can often be managed without antimicrobials. Positive cultures indicate the presence of major pathogens such as *Staphylococcus aureus* or *Streptococcus agalactiae*, or minor pathogens such as coagulase-negative staphylococci, requiring targeted dry-cow therapy.

III. SDCT Decision Tree

This decision tree is a practical guide designed to limit antibiotic use during the dry period to only infected or high-risk cows. The aim is to prevent unnecessary antibiotic use, reduce the risk of antimicrobial resistance, and protect udder health in the herd. Based on milk culture results and SCC levels, cows are classified as either low-risk or high-risk, and the treatment plan is determined accordingly. The decision process is illustrated schematically in the Figure 6.

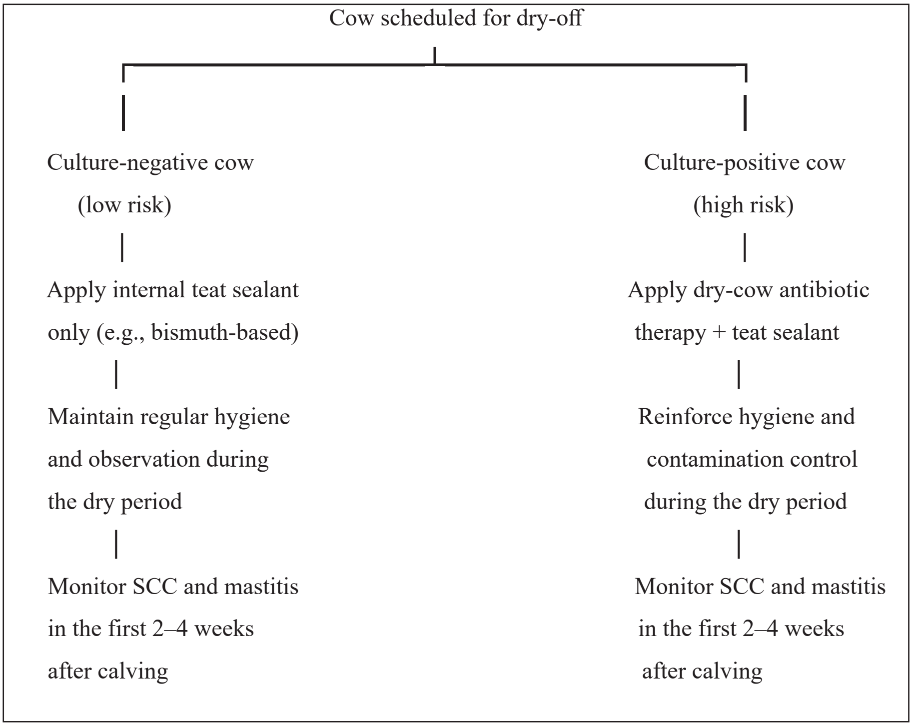

Figure 6. Decision Tree

Table 10. Tabular Summary of Key Steps

Step	Timing / Action	Key Points
1. Pre-Dry-Off Assessment	6–8 weeks before calving	Review SCC and mastitis history; classify cows as low- or high-risk.
2. Milk Sampling	Collect samples 1–7 days before drying-off	Use aseptic technique for each quarter.
3. Culture and Interpretation	Rapid 24-h aerobic culture at 37 °C	Negative = no growth; Positive = major or minor pathogens detected.
4. SDCT Decision Process	Apply decision tree based on SCC and culture results	Low-risk = teat sealant only; High-risk = antimicrobial + sealant.
5. Monitoring and Record-Keeping	2–4 weeks post-calving and annual program review	Track SCC, mastitis incidence, antimicrobial usage, and milk yield to refine the algorithm.

IV. Monitoring and Record-Keeping

During the first 2–4 weeks after calving, SCC levels and the incidence of clinical mastitis must be closely tracked. Detailed records of antimicrobial usage, mastitis cases, and milk yield allow annual evaluation of the SDCT program's impact. These data support continuous refinement of the algorithm, helping adapt it to the evolving herd health profile and farm management practices.

Overview

Sustainable mastitis control requires a multifaceted approach that balances animal health, milk production efficiency, and public health priorities. The combined use of culture-based selective dry-cow therapy, microbiota-guided interventions, and precision Agriculture 4.0 tools has the potential to reduce unnecessary antimicrobial use while maintaining udder health.

Probiotic supplementation with beneficial strains such as *Lactobacillus* and *Bifidobacterium* can help stabilize the udder microbiome and improve natural immune resilience (Derakhshani et al., 2018; Khan et al., 2021; Wang et al., 2025). When integrated with advanced sensor-based monitoring of somatic cell counts and early infection indicators, these strategies support timely and selective treatments.

By limiting antimicrobial use to truly infected or high-risk cows, these measures help slow the spread of antimicrobial resistance and safeguard treatment efficacy. They also reduce drug residues in milk and lower costs for producers.

The integration of hygiene protocols, microbiota-targeted interventions, precision diagnostics, and responsible antimicrobial stewardship provides a modern and evidence-based framework for sustainable udder-health management. This framework can be further strengthened through continuous farmer education and long-term field trials that evaluate both economic and health outcomes.

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CONCLUSION

Mastitis remains one of the most persistent challenges for dairy herds and continues to affect milk quality and profitability. Effective control relies on the integration of the cow's natural defenses, strict milking hygiene, routine surveillance, and evidence-based therapy. During the transition period, oxidative stress and weakened immunity increase the risk of infection. Balanced nutrition that supports antioxidant status with adequate vitamin E and selenium helps protect udder health (Smith et al., 1997; Sordillo, 2016).

Somatic cell count is still the most practical and reliable indicator at both herd and cow levels. Rising counts often signal hidden production losses before clinical signs appear (Paape et al., 2003; Ruegg and Pantoja, 2013). Bacteriological culture remains the reference for etiology and treatment choice, while MALDI-TOF, PCR, and metabolomic tools accelerate diagnosis and guide targeted prevention (El-Sayed et al., 2017; Du et al., 2024).

Milking hygiene and regular equipment maintenance reduce new intramammary infections in both conventional and robotic systems. Selective dry-cow therapy, supported by culture results and individual cow records, decreases unnecessary antimicrobial use without compromising udder health (Winder et al., 2019; McCubbin et al., 2022). Alternative approaches such as probiotics and phytotherapeutic agents are promising but still require consistent field evidence to confirm their effectiveness (Urakawa et al., 2022; Kaseke et al., 2023).

Economic analyses highlight that the major losses stem not only from clinical cases but also from subclinical infections that lower yield and milk quality. Well-planned control programs improve both animal health and farm profitability (Halasa et al., 2007; Ruegg, 2017).

Mastitis control is not defined by a single product or test. It is a coordinated system that combines cow biology, hygienic milking routines, clean housing, rapid and accurate diagnostics, and prudent therapy. Sustainable progress depends on consistent on-farm practices and a culture of continuous learning. When scientific knowledge aligns with daily work, udder health improves, antimicrobial use declines, and milk quality rises for the benefit of both producers and consumers.

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