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Beyond the Surface: Infrared Thermography and Biomarker Insights in Mastitis Detection

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Abstract: Mastitis, a mammary gland inflammation, remains one of the most prevalent and economically significant diseases in the dairy industry. Traditional diagnostic methods such as somatic cell counts, microbiological cultures, and the California Mastitis Test, though widely used, often lack the sensitivity to detect subclinical forms or the capacity to localize early inflammatory changes. In recent years, advancements in non-invasive technologies have opened new frontiers in early mastitis detection, with infrared thermography (IRT) and molecular biomarkers emerging as powerful complementary tools. This review explores the potential of infrared thermography to detect mastitis-related thermal asymmetries in the udder, offering a rapid, stress-free, and animal-friendly diagnostic approach. In parallel, the review examines biomarkers in milk and blood as indicators of mammary gland inflammation and systemic stress. These biomarkers not only reflect the host immune response but also provide valuable insight into the severity and progression of infection. When combined, thermographic imaging and biomarker profiling offer a holistic, multi-dimensional approach to mastitis monitoring, particularly valuable for detecting subclinical or emerging cases. This paper highlights current findings, technological limitations, and future research directions in integrating IRT and biomarker-based diagnostics into herd health management programs.

Keywords: Dairy Cattle, Non-Invasive Diagnostics, Inflammation, Subclinical Mastitis, Heat Shock Proteins, Precision Livestock Farming

Introduction:

Traditional diagnostic approaches like the California Mastitis Test (CMT) and somatic cell count (SCC) have limitations, including subjective interpretation and external influences that cause inconsistent results. Bacterial cultures, although standard for identifying pathogens, are time-consuming and delay intervention. Thus, there's a need for non-invasive techniques to improve early detection and management practices. Innovative diagnostic methods, such as infrared thermography (IRT) and biomarker analysis, offer promising solutions for improving mastitis detection. IRT is a non-invasive technique that reveals thermal changes on the udder surface, indicating inflammation linked to mastitis. This literature review synthesizes knowledge on infrared thermography and biomarkers in mastitis detection, showing their potential to overcome conventional methods' limitations and improve dairy herd health management. Integrating these techniques may enhance early detection, benefiting animals and producers.

Figure 1. "Thermal windows" for reliable IRT measurements in livestock

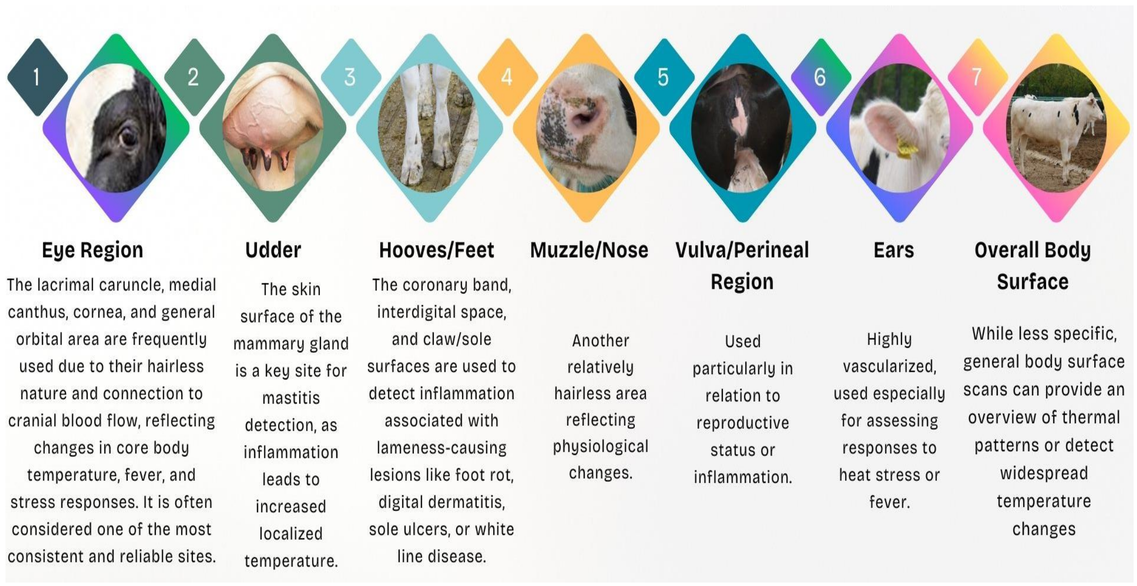

Table 1 Overview of Milk-Based Biomarkers for Mastitis

Biomarker	*Biological Role in Mammary Gland*	*Primary Indication*	*Reported Advantages*	*Reported Disadvantages/Limitations*
SCC	Indicator of immune cell influx (mainly PMNs) into the udder	Inflammation, IMI	Established global standard, correlates with inflammation severity, milk quality parameter	Lacks specificity (affected by non-infectious factors), persists after infection, requires lab analysis (usually), doesn't identify pathogen
Lactoferrin (LF)	Iron-binding glycoprotein with antimicrobial and immunomodulatory functions; secreted by MECs and released from PMNs	Inflammation, Immune Defense	Increases during inflammation, potential SCM marker, involved in local immune response	Lack of reported diagnostic performance data (sensitivity/specificity) in systematic reviews, requires further validation
Haptoglobin (Hp)	Acute phase protein, binds free hemoglobin (antioxidant); produced systemically and potentially locally in mammary tissue	Inflammation, Infection	Major APP in cattle, increases rapidly in milk post-infection (potentially before serum), promising diagnostic performance reported in some studies	Variable results across studies (esp. chronic SCM), potential confounding by parity, some studies show no significant difference/correlation with SCC/CMT, requires specific assays (ELISA)
MAA / M-SAA	Milk isoform of SAA (major APP); produced by mammary epithelial cells during inflammation	Inflammation, Infection	Potentially more sensitive than SCC for early SCM detection, low baseline in healthy milk, less affected by non-mastitis factors (vs SCC), stable sample	Variable results across studies, unsuitable in goats (lactation effect), lack of standardized assays/cut-offs, differentiation from SAA in assays can be unclear

Table 2 Overview of Blood-Based Biomarkers for Systemic Health

Biomarker Category	*Specific Examples*	*Biological Role/Systemic*	*Primary Indication*	*Reported Advantages*	*Reported Disadvantages Limitations*
Acute Phase Proteins (APPs)	SAA, Hp, CRP, AGP, Fibrinogen	Proteins synthesized mainly by liver during APR; involved in immunity, defense, repair	Systemic Inflammation, Infection, Stress, Trauma	Large concentration changes (major APPs), relatively stable, sensitive indicator of systemic disturbance, useful for monitoring/prognosis	Non-specific (indicate problem, not cause/location), levels vary by species/protein, negative APPs decrease
Interleukins (ILs) / Cytokines	IL-1β, IL-6, IL-8, IL-10, TNF-α, IFN-γ etc.	Signaling molecules regulating immune and inflammatory cell communication and function	Immune Activation, Specific Inflammatory Pathways	Can provide more specific information on immune response type, IL-6/IL-8 show diagnostic/prognostic potential for specific diseases	Short half-life, less stable than APPs, assays can be costly/complex, less routinely used in clinical practice
Cortisol	Glucocorticoid Hormone	Primary hormone of HPA axis stress response; mobilizes energy, modulates immunity	Acute & Chronic Stress (Physiological/Psychological)	Established stress marker, measurable in multiple matrices (blood, saliva, milk, hair, feces) reflecting different timeframes	Blood levels affected by handling stress & diurnal rhythm, interpretation complex (influenced by breed, BCS, etc.), requires careful sampling /contextualization

Conclusions:

Integrating non-invasive diagnostic tools like infrared thermography (IRT) and biomarker analysis from milk enhances livestock health management. IRT's non-contact method reduces animal stress, aligning with welfare-focused farming and Precision Livestock Farming (PLF) goals. This integration allows for earlier detection of health issues, especially mastitis, as IRT can quickly identify thermal anomalies indicating inflammation. Healthier animals and efficient treatment improve farm economics by lowering production losses and veterinary costs. Implementing IRT and biomarkers in PLF practices shows promise despite challenges like cost and data interpretation. A tiered approach using automated IRT for screening followed by biomarker analysis is viable. Ongoing research and collaboration are essential for maximizing the potential of integrated non-invasive diagnostics, enhancing animal health and sustainability in livestock production.