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Assessment of Electrical Resistance, Dielectric Constant, Dielectric Loss Factor and SCC for Diagnosis of Clinical and Subclinical Mastitis

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ABSTRACT

This study was carried out during December, 2024–February, 2025 at the cattle farm of Lala Lajpat Rai University of Veterinary and Animal Sciences, Hissar, Haryana, India to examine the relationship between various milk quality parameters (Electrical resistance; E.R), Dielectric constant (ε′) and Somatic cell count (SCC) for mastitis detection. Total 982 milk samples were collected from the cattle farm of LUVAS, HISSAR. E.R was measured using Dramiński mastitis detector and SCC was determined using a Lactoscan SCC analyser. Based on SCC values, the samples were classified as healthy, subclinical and clinical. The dielectric constant was measured using the open-ended coaxial probe method. Pearson correlation analysis was performed using RStudio. The results showed that electrical conductivity had a weak negative relationship with both dielectric constant and SCC. In contrast, the dielectric constant at higher frequencies (500-2450 MHz) showed a moderate positive correlation with SCC. However, low-frequency values showed little association with SCC. Dielectric loss factor showed significant correlation with SCC at all six frequencies (54 MHz, 104 MHz, 254 MHz, 500 MHz, 915 MHz and 2450 MHz). Overall, dielectric properties at higher frequencies were found to be more reliable indicators of mastitis. The combined use of electrical and dielectric measurements provided a rapid and non-invasive method for early detection of mastitis in dairy cows. Therefore, the present study was undertaken to bridge this gap by investigating the correlation between electrical conductivity, dielectric constant at multiple frequencies and SCC.

KEYWORDS: Correlation analysis, dielectric constant, mastitis, somatic cell count

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1. INTRODUCTION

One of the most deadly diseases affecting dairy farming worldwide is mastitis. It results in an annual loss of $22 billion due to decreased milk production, deteriorated quality, and higher treatment expenses (Rasmussen et al., 2024). The inflammation of the mammary gland is known as mastitis. While chemical, physical, or biological factors can cause it, biological factors are primarily responsible. Although viruses or archaea can occasionally cause mastitis, bacteria are mostly responsible for these infections (Guo et al., 2024). Mastitis can be categorized as clinical or subclinical based on the intensity of the symptoms. Both forms are correlated with somatic cell count (SCC) that exceed 2,00,000 cells ml^{-1} (Liu et al., 2023). Clinical mastitis is characterized by obvious physical, chemical and microbiological alterations in milk. It is also accompanied by symptoms such as dehydration, fever and tiredness. Subclinical mastitis is a more common and often undetected type of mastitis in dairy cows. It is difficult to identify in the field because it shows no obvious clinical signs (Saidee and Tawfeeq, 2025). The milk and udder appear normal compared to clinical mastitis. However, the mammary gland undergoes major physiological and biochemical changes. Most notably, there is an increase in somatic cell count (SCC), which is a vital indicator of infection (Jung et al., 2024). As it is commonly undiagnosed for long periods, this disease is regarded as a serious concern in the dairy sector. It leads to continuous and unnoticed declines in milk supply and quality (Jin et al., 2025). Electromagnetic properties of milk consist of electrical conductivity and dielectric properties such as dielectric constant. Electrical conductivity is inversely proportional to electrical resistance. Milk's electrical conductivity (EC) reflects changes in the ionic balance during udder inflammation. Therefore, it plays an important role in monitoring mastitis in dairy cows. Increased sodium (Na^+) and chlorine (Cl^-) ions concentrations occur due to the rupture of the blood-milk barrier. This leads to an increase in electrical conductivity (E.C) (Lu et al., 2024). Electrical resistance is inversely proportional to electrical conductivity. This rise in E.C serves as a reliable early detection parameter. It can detect infection even before visible symptoms appear (Tian et al., 2024). Dielectric spectroscopy is also a useful method for identifying changes in milk caused by mastitis. Recent research supports its application. The dielectric constant increases proportionately with infection severity. This is due to increased ionic mobility and interfacial polarization (Yang et al., 2024). Moreover, dielectric analysis at various frequencies shows that the mastitic milk has higher dielectric loss and dielectric constant values. This is especially evident at lower frequencies where ionic conduction predominates (Kumari et al., 2025). When used alone, E.C may show variations due to environmental factors. These include temperature and stage of lactation (Gokce et al., 2024). Dielectric characteristics are also affected by compositional and frequency variations. This limits their independent applications. Considering these limitations, combining electrical resistance with dielectric constant provides a more reliable evaluation. It is more effective than depending on a single indicator (Kumari et al., 2025). This combined approach is particularly useful for detecting subclinical mastitis. In such cases, changes are subtle and difficult to detect using conventional methods (Yang at el., 2024). Additionally, the relationship between E.R and Dielectric constant can be quantified using correlation analysis. Statistical methods such as Pearson correlation are commonly used. This helps in developing more dependable and robust detection models. Hence, this study examined the relationship between various milk quality parameters (Electrical resistance; E.R), Dielectric constant (ε'), Dielectric loss factor ($\boldsymbol{\varepsilon''}$) and Somatic cell count (SCC) for mastitis detection.

2. MATERIALS AND METHODS

2.1. Description of samples

This study was carried out during December, 2024–February, 2025 at the cattle farm of Lala Lajpat Rai University of Veterinary and Animal Sciences, Hissar, Haryana, India. A total of 982 milk samples were collected. The electrical resistance of the samples were measured directly at the farm. After collection, the samples were stored at 4°C. They were later used for the determination of somatic cell count (SCC) using Lactoscan SCC analyser. Based on the SCC values, the samples were classified for mastitis status. Milk samples with SCC less than 2,00,000 cells ml^{-1} were considered healthy. Samples with SCC between 2,00,000 and 5,00,000 cells ml^{-1} were identified as subclinical cases. Samples with SCC greater than 5,00,000 cells ml^{-1} were categorized as clinical cases. All observations were systematically recorded. Subsequently, the remaining samples were analysed for dielectric constant using the open-ended coaxial line probe method. The corresponding readings were documented.

2.2. Measurement of electrical resistance

Electrical resistance (E.R) was measured using a Dramiński Mastitis Detector (4×4Q_Mast). This is a commercial available machine for detecting mastitis in various types of milk. A standardized procedure was followed for rapid assessment of udder health at the cow's side. The electrical resistance of milk was then evaluated (Alterisio et al., 2026; Tian et al., 2024). Fresh milk samples were collected from each udder teat using proper sampling protocols. This was done to avoid contamination. It also ensured that representative samples were obtained for analysis (Pan et al., 2025). For quarter-wise measurement, milk from each udder quarter was transferred into the respective cups of the detector (Tian et al., 2024). After switching on the device, electrical resistance or corresponding electrical conductivity readings were recorded within a few seconds. This enabled quick and real time monitoring (Pan et al., 2025). The device displayed readings for all four quarters at the same time. This allowed comparison of inter-quarter variation. Such variation was commonly used to identify affected or infected quarters (Tian et al., 2024; Lu et al., 2024). The user's manual was followed for the interpretation of results.

2.3. Measurement of milk somatic cell count

Somatic cell counts (SCC) were evaluated using a Lactoscan SCC Analyzer (Milkotronic Ltd., Stara Zagora, Bulgaria). This is a commercial available machine for detecting somatic cell count in various types of milk. The instrument used fluorescence microscopy to accurately quantify cells in milk samples (Damm et al., 2017). Fluorescence-based SCC determination was commonly used for mastitis detection. This was because fluorescent dyes bind to leukocyte nucleic acids, allowing rapid and precise cell counting (Sun et al., 2024). The milk samples were first mixed thoroughly using a small vortex mixer. This helped to obtain a uniform distribution of somatic cells. It also prevented underestimation or overestimation of SCC values (Damm et al., 2017). After mixing, 100 µl of fresh milk was carefully pipetted into a micro-centrifuge tube containing Sofia Green lyophilized dye. This dye enhanced fluorescence intensity and improved detection sensitivity under the microscope (Sun et al., 2024). The mixture was then vortexed properly to ensure complete mixing of the dye with the sample. This step was necessary for uniform staining of all nucleated cells. It also ensured reliable fluorescence imaging and reproducible results (Mondini et al., 2025). About 8 µl of the prepared sample was then placed onto a suitable Lacto-chip. The chip provides stable positioning of the sample and optimal conditions for image capture (Damm et al., 2017). The Lacto-chip was inserted into the analyzer. Automated fluorescence microscopy was performed for about two to four minutes. During this process, multiple microscopic fields were captured and analyzed. This improved repeatability and reduced operator dependency while generating SCC values (Zecconi et al., 2025). The results were recorded for further analysis.

2.4. Measurement of dielectric constant and dielectric loss factor

The dielectric constant (ε′) of biological and food samples were often measured using the open-ended coaxial probe method as shown in Figure 1. This method was considered simple, fast, and non-destructive for dielectric characterization (Meaney et al., 2014). In this technique, a coaxial probe with an open-ended tip was brought into direct contact with the sample. This allowed the electromagnetic field generated at the probe tip to penetrate into the material (Sarolic and Matkovic, 2022). The interaction between the electric field and the sample depends on its dielectric properties. It was particularly influenced by how effectively the material could store and dissipate electrical energy (La Gioia et al., 2018). A vector network analyzer (VNA) sent a signal through the probe. It then measured the portion of the signal that was reflected back from the sample surface. This reflection was interpreted as a complex reflection coefficient (Naik, 2022). The dielectric constant was calculated from this reflection coefficient. It included both the amplitude and phase information of the reflected signal (Samaddar et al., 2022).

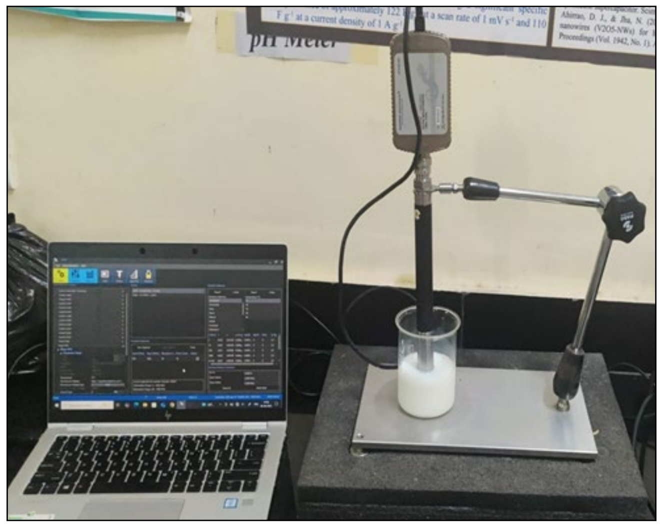

Figure 1: Open-ended coaxial probe method

2.5. Correlation coefficient

RStudio was used to calculate the Pearson correlation between Somatic cell count (SCC), Electrical resistance (E.R) and Dielectric constant (ε′) of milk. It was widely used software for statistical computing and data analysis. Once the data were properly organized and loaded into the software, initial pre-processing steps were performed. These included identifying missing values and examining the distribution of data. These steps helped to ensure accuracy and reliability of the analysis (Wickham and Grolemund, 2017). The Pearson correlation coefficient was then used to evaluate the relationships among the variables. To determine whether the observed relationships were meaningful, their statistical ($p<0.05$) significance was assessed. This was done using a p value (Schober et al., 2012).

3. RESULTS AND DISCUSSION

Significant ($p<0.05$) correlations between various milk quality parameters (i.e. Somatic cell count (SCC), Dielectric constant (ε′) and Electrical resistance (E.R.) were found via. correlation analysis as shown in Table 1.

Table 1: Relationship between SCC, E.R and dielectric constant at different frequencies

Characteristics	E.R	ε′ (54)	ε′ (104)	ε′ (254)	ε′ (500)	ε′ (915)	ε′(2450)	SCC
E.R	1	-0.010	-0.009	-0.043	-0.145*	-0.139*	-0.112*	-0.242*
ε′ (54)		1	0.986*	0.964*	0.041	-0.001	0.001	0.002
ε′ (104)			1	0.970*	0.042	-0.001	0.001	0.002
ε′ (254)				1	0.078*	0.036	0.040	0.122*
ε′ (500)					1	0.967*	0.901*	0.363*
ε′ (915)						1	0.891*	0.366*
ε′ (2450)							1	0.357*
SCC								1

Correlation coefficients marked with * were significant at p<0.05; E.R: Electrical resistance; ε′: Dielectric constant; SCC: Somatic cell count

Electrical resistance showed negative correlation with the dielectric constant at six (54 MHz, 104 MHz, 254 MHz, 500 MHz, 915 MHz and 2450 MHz) selected frequencies. This inverse relationship between electrical resistance and dielectric constant showed that milk ionic composition and polarization mechanism influence dielectric constant across frequencies (Zhu et al., 2022). At higher frequencies, this correlation became statistically (p<0.05) significant. This was observed at 500 MHz (r=-0.145*), 915 MHz (r=-0.139*) and 2450 MHz (r=-0.112*). Increased sensitivity of dielectric properties at microwave frequencies (Galindo et al., 2024). Electrical resistance and SCC also showed a significant (p<0.05) negative correlation (r=-0.242*). This indicated an inverse relationship between these two variables. Samples with higher SCC tended to have lower electrical resistance values. This relationship might be linked to changes in milk composition (Zhu et al., 2023). It might also be influenced by variations in ionic concentration. These factors affect both electrical and dielectric properties. Strong positive correlations (r=0.964-0.986*) were observed among the dielectric constant values at lower frequencies (54, 104 and 254 MHz). These results indicated a strong relationship between the variables. This suggested that the dielectric behaviour was consistent across this frequency range (Zhu et al., 2022). However, the correlation with SCC was very weak (r=0.002). This indicated that low frequency dielectric properties were not sensitive indicators of mastitis or udder health. Strong positive correlations were observed among dielectric constant values at higher frequencies, particularly at 500 MHz, 915 MHz, and 2450 MHz (r=0.891-0.967*). This indicated that the dielectric behaviour remained consistent across these frequencies. In addition, these frequencies showed moderate positive correlations with SCC (r=0.363*, 0.366* and 0.357* respectively). This suggested that the dielectric constant increases with an increase in somatic cell count. Therefore, dielectric measurements at higher frequencies might serve as a useful indicator for detecting mastitis (Yang et al., 2024). Overall, the results indicated that the dielectric constant at higher frequencies showed a stronger and more meaningful relationship with SCC. In contrast, electrical conductivity exhibited a weak negative association with both dielectric constant and SCC.

Table 2: Relationship between SCC, ER and dielectric loss factor at different frequencies

Characteristics	ER	ε″ (54)	ε″ (104)	ε″ (254)	ε″ (500)	ε″ (915)	ε″ (2450)	SCC
E.R	1	-0.248*	-0.254*	-0.247*	-0.284*	-0.280*	-0.282*	-0.242*
ε″ (54)		1	0.926*	0.995*	0.710*	0.704*	0.716*	0.707*
ε″ (104)			1	0.929*	0.710*	0.704*	0.716*	0.706*
ε″ (254)				1	0.708*	0.703*	0.714*	0.705*
ε″ (500)					1	0.994*	0.984*	0.644*
ε″ (915)						1	0.981*	0.645*
ε″ (2450)							1	0.654*
SCC								1

Correlation coefficients marked with * were significant at p<0.05; E.R- Electrical Resistance; ε″- Dielectric loss factor; SCC: Somatic cell count

Table 2 showed significant relationships among electrical resistance (E.R), dielectric loss factor (ε″) and somatic cell count (SCC). Electrical resistance showed negative correlation with the dielectric loss factor at six (54 MHz, 104 MHz, 254 MHz, 500 MHz, 915 MHz and 2450 MHz) selected frequencies (r=-0.247 to -0.284) and the difference is significant (p<0.05). While dielectric loss factor values at different frequencies were highly and positively correlated with each other. SCC also showed significant positive correlations with dielectric loss factor (r=0.644 to 0.707). This indicates that dielectric loss factor increased with increasing SCC. The higher dielectric loss factor may result from greater ionic movement and polarization effects in milk. These findings suggested that high- frequency dielectric measurements could be effectively used as a diagnostic tool for detecting both clinical and subclinical mastitis (Galindo et al., 2024).

4. CONCLUSION

Mastitis in dairy cows caused significant changes in the electrical and dielectric properties of milk. Analysis of 982 milk samples was carried out. A significant (p<0.05) negative correlation was observed between the electrical resistance and SCC. Dielectric constant and dielectric loss factor measurements values at higher frequencies (500 MHz, 915 MHz and 2450 MHz) showed significant (p<0.05) positive relationships with SCC, while lower frequency showed little association with SCC in dielectric constant.

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