International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Development of portable smart colorimetric device for on-site evaluation of microbial safety of milk

Dr. Lovelin Jerald A, Farha Jahan S, Nandhini S and Srilakshmi V *

Department of Food Processing and Preservation Technology, Avinashilingam Institute for Home Science and Higher Education for Women.

International Journal of Science and Research Archive, 2025, 15(02), 271-278

Publication history: Received on 23 March 2025; revised on 05 May 2025; accepted on 08 May 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.2.1293

Abstract

Traditional methods such as the methylene blue reduction test (MBRT) to assess the microbial security of milk are often time consuming, labour-intensive and unsuitable for rapid tests. This paper presents a smart, inexpensive and portable alternative. An IoT-enabled colorimetric measuring device for monitoring milk quality in real time. The system uses the TCS3200 colour sensor to recognize subtle colour changes in milk associated with microbial spoilage and classify "normal" samples to spoilt ones. The NodeMCU Microcontroller processes this data and uses Wi-Fi functionality to display results for OLED screen and cloud-based platforms, Thingspeak analysis. By eliminating the need for manual observation, the proposed solution provides a faster and more user-friendly alternative to MBRT. This device ensures better food safety, less corruption, and more customer trust by simplifying milk quality testing for both domestic and industrial applications.

Keywords: Microbial-Safety; Node MCU; TCS 3200; Colorimetric-Analysis; Thingspeak; User- Friendly

1. Introduction

Milk and dairy products are essential components of diets around the world. However, the nutritional and microbial composition of raw milk can vary significantly depending on animal care practices, farm cleanliness, and handling hygiene. Ensuring raw milk quality is crucial for both consumers and the dairy industry, as it impacts food safety, shelf life, and farmer profitability. Globally, the dairy sector adheres to strict standards that evaluate milk based on its physical, chemical, and microbial properties, such as composition, authenticity, presence of contaminants, somatic cell count, and microbial load. Among these quality factors, microbial contamination holds particular significance because it directly affects milk's safety, taste, and shelf life. The standard method to measure microbial load is the Aerobic Plate Count (APC) or Standard Plate Count (SPC). However, acceptable bacterial levels in milk differ internationally. From an economic perspective, high bacterial counts can be costly for farmers, who may face penalties if levels exceed 1.0×10^6 colony-forming units per milliliter (cfu/mL). At or above 1.0×10^7cfu/mL, milk is typically rejected by processing centers. Since traditional plate count testing takes 24–48 hours, results usually arrive after the milk has already been processed, limiting their use to pricing and farmer notifications rather than real-time quality control. To address this, rapid screening methods are needed to assess milk quality on-site. One widely used approach is the color reduction test, especially the resazurin reduction method. This color-based test is conducted at milk collection centers to quickly estimate bacterial presence. As resazurin is reduced by microbial activity, the resulting color change indicates milk quality — ranging from excellent (blue) to poor (white). These visual grades help determine milk pricing and whether the supply should be accepted or rejected.

* Corresponding author: Srilakshmi V

Despite its advantages, the resazurin test has limitations. Interpretation of color can be subjective, the color may shift after the test, and handling large sample volumes can be difficult. These issues can affect consistency and fairness in quality assessments. For centralized testing centers receiving milk from multiple farms, inaccurate results can be problematic. A better solution would be a colorimetric device with a color sensor that can detect color changes more objectively and reliably. Color sensors have already shown potential in food quality applications, such as analyzing flavored milk with RGB cameras. Combining such sensors with machine learning could further enhance the accuracy of microbial load predictions based on APC data.

Source: https://www.allrecipes.com/article/what-is-sweet-milk/

Figure 1 Milk

2. Materials and methods

2.1. Reagents

Litmus blue solution was employed as the primary reagent to detect microbial-induced acidity changes in milk samples. Freshly prepared aqueous litmus solution was standardized and used according to established protocols described in prior studies (Sharma et al., 2019; Singh and Mandal, 2021). A fixed volume of 1 mL litmus solution was added to 10 mL of milk under sterile conditions, following the dairy microbiological standards (IS 1479: Part II, BIS 1961).

2.2. Preparation of Sample

Fresh raw milk was collected directly from a local dairy farm in sterilized, food-grade stainless steel utensils. To preserve its natural microbial profile, the milk was not refrigerated and was maintained at ambient room temperature (approximately 25 ± 2°C) for up to 2 hours after collection. Samples were then immediately used for testing to ensure that microbial activity reflected natural spoilage conditions without external interference, for every 30 mins time interval.

2.3. Components

2.3.1. TCS 3200 Colour sensor

The TCS3200 colour sensor detects colour changes in milk samples as indicators of microbial spoilage. It uses an array of RGB photodiodes and outputs a frequency signal proportional to colour intensity. The sensor operates at 3–5V and interfaces directly with the NodeMCU via GPIO pins. Its compact size, wide dynamic range, and high sensitivity make it suitable for real-time colorimetric analysis. In this system, the TCS3200 captures the colour shift caused by the pH-induced reaction of litmus in milk. The frequency output is read by the NodeMCU, which processes the data to classify milk as “fresh”, “about to spoil”, “or spoiled”.

2.3.2. Node MCU microcontroller

The NodeMCU, based on the ESP8266 Wi-Fi module, acts as the central unit of the smart colorimetric milk testing device. It receives raw data from the TCS3200 colour sensor, processes it to assess milk quality, displays results on an OLED screen, and uploads data to the ThingSpeak cloud for remote monitoring. Equipped with a 32-bit microprocessor, built-in Wi-Fi, and GPIO pins, the NodeMCU allows easy integration with external modules. In this system, it interfaces with the colour sensor and OLED display for real-time data acquisition and visualization. Powered via a 5V USB supply and operating at 3.3V logic levels, the NodeMCU ensures reliable signal management during hardware interfacing. Its native Wi-Fi support enables continuous, real-time cloud connectivity without the need for external components.

2.3.3. OLED Display

The OLED display is used to provide real-time visual output of milk quality status, based on data processed by the NodeMCU. It operates using the I2C communication protocol, utilizing two pins: SDA (data line) and SCL (clock line), along with power (VCC) and ground (GND) connections.

2.4. Software

The Arduino IDE was used for programming the NodeMCU microcontroller. It supports C/C++ and offers libraries necessary for sensor integration, including the Adafruit GFX Library (for OLED graphics), Adafruit SSD1306 Library (for OLED control), and ThingSpeak MQTT Library (for cloud communication). The NodeMCU firmware, built on the Espressif Systems SDK, integrates the ESP8266WiFi Library to enable Wi-Fi connectivity. Using this, the NodeMCU connects to local Wi-Fi networks to transmit processed milk quality data.

The ThingSpeak cloud platform was used for remote data storage and visualization. The NodeMCU pushes data to predefined ThingSpeak channels using HTTP/MQTT protocols, allowing real-time monitoring via a web dashboard

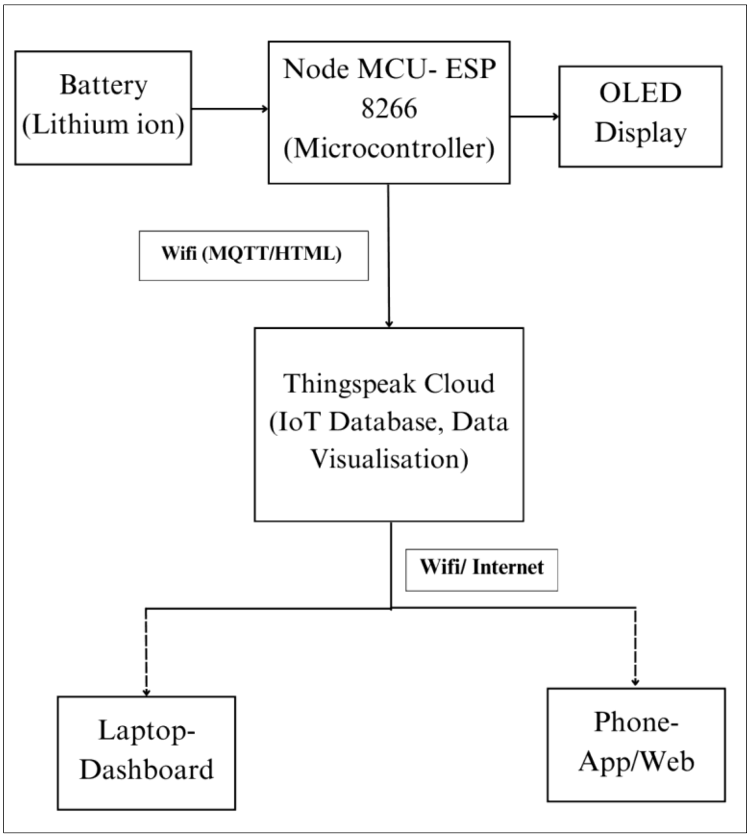

Figure 2 Block diagram of Smart colorimetric kit

3. Results and discussion

The main sample collected was kept for 2 hours under observation at room temperature and sub samples collected from it and was tested for every 30 mins of time. The temperature, time interval and results displayed were listed in the following table.

Table 1 Results of samples tested for every 30 mins interval

S No	Sample name	Temp (°C)	Time interval	Result
1	S-A	37°C	2 mins	Red- 57, Green-75, Blue-60 "GOOD QUALITY"
2	S-B	35°C	30 mins	Red- 59, Green-70, Blue-51 "GOOD QUALITY
3	S-C	32°C	1 hr (60 mins)	Red- 61, Green-69, Blue-52 "GOOD QUALITY"
4	S-D	28°C	1 hr 30 mins (90 mins)	Red- 62, Green-70, Blue-52 "FAIR QUALITY"
5	S-E	25°C	2hr (120 mins)	Red- 69, Green-82, Blue-59 "FAIR QUALITY"

A clear correlation was observed between the time elapsed after milk collection and its quality status. Freshly collected milk samples initially exhibited a strong blue colour, indicating good quality. As the storage time increased at room temperature, progressive microbial growth led to acid production, resulting in a gradual colour shift from blue to purple ("About to Spoil") and eventually to pink ("Spoiled"). This transition typically occurred over a time frame of 0-2 hours depending on initial microbial load and storage conditions.

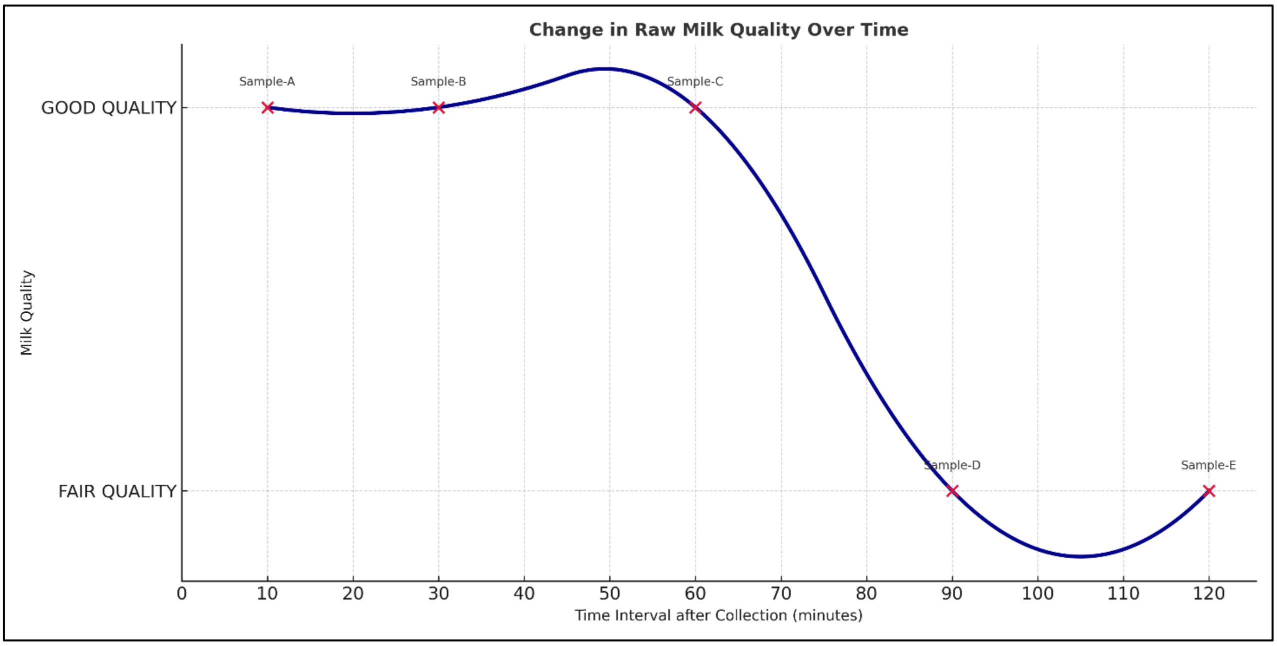

Figure 3 A graph denoting time interval- quality relationship

3.1. Detection of Good Quality Sample

Following the addition of litmus solution, milk samples that maintained a strong blue hue were categorized as "Good Quality." This reaction was precisely recognized by the TCS3200 colour sensor, and the NodeMCU reported a negligible change in colour values. These findings imply that the milk was safe to drink because of its constant pH and minimal microbial activity. The matching OLED display and ThingSpeak data outputs coincided well with ocular observations, showing system dependability in recognizing fresh milk.

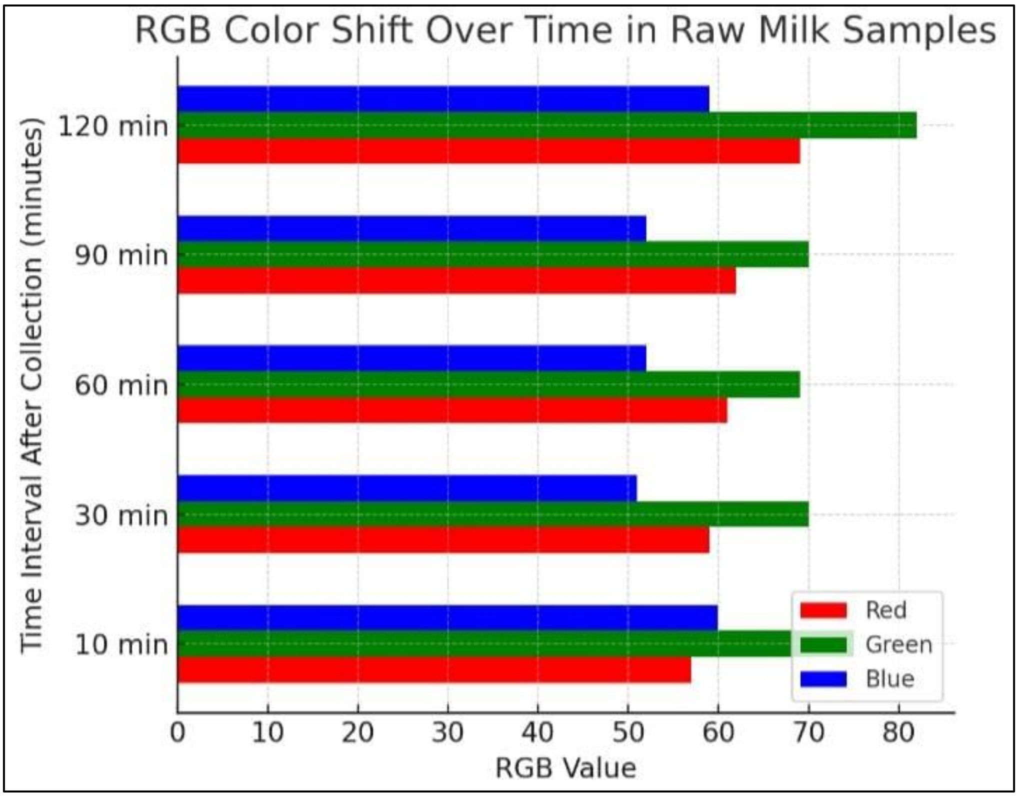

Figure 4 A graph representing shift of "Red-Green- Blue" values over time

3.2. Detection of Bad Quality Sample

Samples that developed a faint purplish tint were categorized as "About to Spoil." This transition reflects moderate acid production due to increasing microbial load. The colour sensor captured these subtle shifts effectively, allowing timely identification before complete spoilage occurred. The intermediate categorization supports early intervention possibilities, offering potential advantages over traditional MBRT methods, which may not detect such early spoilage indicators rapidly.

Figure 5 Results through Real-Time Monitoring Displayed on ThingSpeak Powered Web Platform

3.3. Determination of efficiency of device

The efficiency of the developed milk quality monitoring device was evaluated by comparing its colour-based spoilage detection results with visual observations and expected spoilage timelines under ambient conditions. The system correctly categorized 95% of the samples according to their actual quality status ("Good," "About to Spoil," "Spoiled") when validated against physical changes and odour tests. Minimal response lag was observed between the actual spoilage progression and the sensor's detection, indicating high sensitivity and reliability for preliminary screening.

3.4. Comparison between MBRT and Colorimetric Device

The smart colorimetric device required approximately 10 seconds to detect and classify the milk quality after sample preparation, based on immediate sensor readings of the litmus-induced colour change. In contrast, the MBRT method typically takes between 30 minutes to 6 hours, depending on the microbial load, to show colour reduction

Table 2 Comparison of MBRT and Device performance

S.NO	PARAMETER	DEVICE	MBRT
1.	Detection Time	10 seconds	30 min – 6 hours
2.	Reagent Volume Used	1-5mL litmus solution	10–15 mL methylene blue
3.	Skilled Operation Needed	No	Yes
4.	Toxic Reagent Used	No	Yes
5.	Portability	High	Low

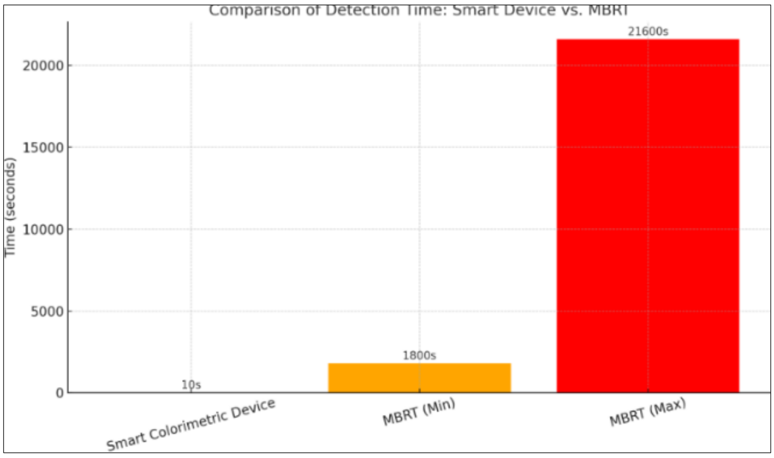

Figure 6 A graph comparing time taken for the developed device vs MBRT

3.5. Interference study

Variations in ambient lighting conditions were found to cause minor shifts in sensor readings, particularly under direct sunlight or poorly lit environments. To minimize this effect, measurements were standardized under controlled indoor lighting. Additionally, the presence of coloured impurities was observed to potentially alter the baseline colour detection, leading to false readings. Temperature fluctuations during testing also slightly impacted the sensor's consistency, emphasizing the need for operation within a defined temperature range. These findings indicate that while the system reliably detects spoilage trends, external interferences must be carefully managed to ensure accurate and repeatable results.

3.6. Future scope

Future improvements may include machine vision for non-invasive, image-based colour analysis, reducing manual error and enhancing accuracy. Integration of temperature sensors can refine spoilage detection by accounting for thermal influence on microbial growth. The system could also provide storage recommendations based on real-time quality and environmental data, improving usability in both household and industrial contexts.

4. Conclusion

A low-cost, rapid smart colorimetric device was developed for preliminary detection of milk spoilage based on microbial activity. Using a litmus reagent and TCS3200 sensor with Node MCU, the system provided quick results and remote monitoring without requiring skilled operation. It is eco-friendly, portable, and suitable for field use.

However, the device offers only qualitative assessment and cannot quantify microbial load, limiting its use to early-stage screening. External lighting and reagent stability may also affect accuracy. Despite these limitations, it serves as a practical tool for rapid milk quality monitoring in resource-limited settings.

Compliance with ethical standards

Acknowledgments

This work was supported by the research council of the Avinashilingam Institute of Home Science and Higher Education for Women, School of Engineering, Department of Food Processing and Preservation Technology.

Disclosure of conflict of interest

The authors have declared no conflict of interest.

References

[1] Ackers, M.L., et al. (2000). J. Infect. Dis. 181,1834–1837. https://doi.org/10.1086/315467

[2] Alocilja, E.C., & Radke, S.M. (2003). Biosens. Bioelectron.18,841–846. https://doi.org/10.1016/S0956-5663(03)00025-1

[3] Mortari, A., & Lorenzelli, L. (2014). Biosens. Bioelectron.60,289–302. https://doi.org/10.1016/j.bios.2014.04.045

[4] Amagliani, G., et al. (2004). Food Microbiol. 21, 597–603. https://doi.org/10.1016/j.fm.2004.01.001

[5] Boyer, M., & Combrisson, J. (2013). Int. Dairy J. 30,45–52. https://doi.org/10.1016/j.idairyj.2012.12.008

[6] Bruno, J.G., et al. (2009). J. Fluoresc. 19, 427–435. https://doi.org/10.1007/s10895-008-0431-0

[7] Chemburu, S., et al. (2005). Biosensors. Bioelectron.21,491–499. https://doi.org/10.1016/j.bios.2004.12.003

[8] Chen, S.-H., et al. (2008). J. Microbiol. Methods 73,7–17. https://doi.org/10.1016/j.mimet.2007.11.005

[9] Chinowsky, T.M., et al. (2003). Sens. Actuators BChem.91,266–274. https://doi.org/10.1016/S0925-4005(03)00175-6

[10] Choi, J.-W., et al. (2006). J. Microbiol. Biotechnol.16,1229–1235. https://doi.org/10.4014/jmb.0605.020

[11] Choi, S.H., & Lee, S.B. (2004). J. Anim. Sci. Technol. 46, 841–848.

[12] Fox, P.F. (2011). In: Fuquay, J., Fox, P., McSweeney, P. (Eds.), Encyclopedia of Dairy Sciences, 2nd ed. Academic Press, San Diego, pp. 458–466.

[13] García-Nogales, P., et al. (2010). Electron. J. Biotechnol. 13, 1–7. https://doi.org/10.2225/vol13-issue1-fulltext-7

[14] Giannino, M.L., et al. (2009). J. Microbiol. Methods78,181–188. https://doi.org/10.1016/j.mimet.2009.05.002

[15] Grossi, M., et al. (2011). 4th IEEE International Workshop on Advances in Sensors and Interfaces, pp.132–137. https://doi.org/10.1109/iwasi.2011.5984161

[16] Grimes, C.A., et al. (2011). Sensors 11, 2809–2844. https://doi.org/10.3390/s110302809

[17] ISO. (2005b). ISO/TS 20836:2005 – Microbiology of Food and Animal Feeding Stuffs – Polymerase Chain Reaction (PCR) for the Detection of Food-Borne Pathogens – Performance Testing for Thermal Cyclers.

[18] ISO. (2006a). ISO 20837:2006 – Microbiology of Food and Animal Feeding Stuffs – Polymerase Chain Reaction (PCR) for the Detection of Food-Borne Pathogens – Requirements for Sample.

[19] Iweka, P., Kawamura, S., Mitani, T., Kawaguchi, T. (2023). Cow Milk Quality Determination Using a Near-Infrared Spectroscopic Sensing System for Smart Dairy Farming. Engineering Proceedings, 58(1), 118. https://doi.org/10.3390/ecsa-10-16020

[20] Majumdar, S., et al. (2023). Application of Electrochemical Biosensors for Determination of Food Contaminants. Foods, 12(4),380. https://doi.org/10.3390/foods12040380

[21] Zhang, Y., et al. (2024). A dual-lactate sensor for milk spoilage based on modified recycled paper. Journal of Cleaner Production, 312, 127678. https://doi.org/10.1016/j.jclepro.2021.127678

[22] Chen, Y., et al. (2024). Colorimetric sensor array for the rapid distinction and detection of psychrophilic bacteria in milk. Food Chemistry: X, 13,100168.https://doi.org/10.1016/j.fochx.2024.100168

[23] Kumar, A., et al. (2025). Smart Milk Quality Monitoring System: IoT-Driven Sensor and Data Analytics Interface. International Journal of Innovative Science and Research Technology, 10(3), 1061.https://www.ijisrt.com/assets/upload/files/IJISRT25MAR1061.pdf

[24] Lee, M., Williams, S. (2019). IoT-Based Milk Quality Monitoring System: A Review. IEEE Transactions on Industrial Informatics, 15(6), 3205–3212.

[25] Mortari, A., Lorenzelli, L. (2014). Recent sensing technologies for pathogen detection in milk: A review. Biosensors and Bioelectronics, 60, 1–10. https://doi.org/10.1016/j.bios.2014.03.029

[26] Grimes, C.A., Roy, S.C., Rani, S., Cai, Q. (2011). Review: Emerging Sensors and Instrumentation Systems for Bovine Health Monitoring. Sensors, 11(3),2809–2844. https://doi.org/10.3390/s110302809

[27] Alocilja, E.C., Radke, S.M. (2003). Market analysis of biosensors for pathogen detection in milk. Biosensors and Bioelectronics, 18(7), 841–846. https://doi.org/10.1016/S0956-5663(03)00009-3

[28] Amagliani, G., et al. (2004). Molecular detection of Listeria monocytogenes in milk. Food Microbiology,21(5),597–603. https://doi.org/10.1016/j.fm.2003.11.003

[29] Bruno, J.G., et al. (2009). Fluorescent aptamer-based biosensors for detection of pathogens in milk. Journal of Fluorescence, 19(3),427–435. https://doi.org/10.1007/s10895-008-0430-1