

Assessment of Milk Adulteration Using Machine Learning Techniques: A Review

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Abstract

Milk adulteration is a widespread problem globally, affecting public health and the dairy industry. Traditional detection methods are very laborious, time taking, and need heavy machinery instruments. This paper reviews the potential of machine learning (ML) techniques to detect milk adulteration effectively. By analyzing chemical and physical properties of milk using advanced ML models, this study highlights the advancements in automation and optimization in detecting adulterated milk. The review includes an evaluation of various machine learning algorithms applied to the detection of adulterants in milk, offering insights into their accuracy, efficiency, and applicability in real-world scenarios.

Keywords: *Milk adulteration, machine learning, food safety, quality assurance, predictive modeling, sensor technologies, food authenticity.*

1. Introduction

Milk, popularly known as the "complete food," is a vital origin of essential nutrients like proteins, vitamins, and minerals. On the other hand, milk adulteration is a global issue compromising nutritional quality and posing danger to health. Mainly starch, detergent, urea, and synthetic milk are added in milk to increase quantity, but the truth of these facts goes against them, as such adulterations make milk unsafe for consumption and reduce its nutritional value. An increasing demand strikes the point of probable risks involved in adulteration.

Traditional milk adulteration detection methods involve chemical analysis and physical tests (density, viscosity) using instruments like a spectrophotometer. These methods are reliable but require costly equipment, well-trained staff, and time. Therefore, research interest has shifted toward applying machine learning to create easy and inexpensive detection systems. The focus of the present review is to summarize the recent contributions in applying machine learning models for milk adulteration detection accuracy, scalability, and real-world applicability [1].

2. Traditional Methods of Milk Adulteration Detection

Traditional methods of detecting adulteration in milk have been widely used in the dairy industry but come with significant challenges:

1. **Chemical Analysis:** It involves taking a laboratory determination of certain chemical markers that show adulteration. Although this method is effective, it is highly expensive and time-consuming.
2. **Physical Tests:** Simple tests like the lactometer or boiling point test are quick but lack accuracy and may not detect sophisticated adulterants.
3. **Spectroscopic Methods:** Techniques like infrared spectroscopy are accurate but costly and require very sophisticated equipment and expertise in handling them [2].

Despite these methods' advantages, the demand for rapid, large-scale, and inexpensive testing solutions has prompted the exploration of machine learning (ML) and artificial intelligence (AI) technologies.

3. Machine Learning in Milk Adulteration Detection

Machine learning has the potential to free the method from these limitations by automating the detection process and making it more efficient and, therefore, less costly. Large datasets can be handled by ML models for pattern detection, which may be quite challenging for humans. The following are some of the common ML techniques employed in milk adulteration detection :

3.1 Supervised Learning

Supervised learning models require labeled data. These models are trained on datasets that include both pure and adulterated milk samples with known adulterants.

- **Support Vector Machines (SVM):** SVM has been widely used for classification problems in food safety, including milk adulteration detection. By finding the optimal hyper plane that separates different classes (pure and adulterated milk), SVM can achieve high accuracy, even with complex non-linear patterns.
- **Random Forest (RF):** Random Forest is an ensemble learning method that combines multiple decision trees. It is particularly effective in handling large, complex datasets and can be used to identify interactions between various adulterants. RF has been shown to deliver high accuracy and robustness in detecting milk adulteration.
- **Logistic Regression:** While a simpler model compared to SVM and Random Forest, logistic regression has been used for binary classification tasks (e.g., pure vs. adulterated milk). It is computationally efficient but may struggle with complex data.
- **Decision Trees:** Decision trees are simple models that split the data into decision nodes based on feature values. They provide transparent decision-making processes but may be prone to over fitting if not properly tuned.

3.2 Unsupervised Learning

Unsupervised learning is used when the labels for data are not available. Clustering algorithms, such as k-means or DBSCAN, can be applied to identify inherent patterns or outliers in the milk samples. This approach is useful for detecting unknown adulterants without predefined labels.

3.3 Neural Networks and Deep Learning

Deep learning models, such as Convolutional Neural Networks (CNNs), have been applied to the analysis of spectral data and sensor data for detecting adulteration. Neural networks are highly effective in detecting complex patterns in large datasets but require large volumes of data for training and substantial computational resources.

3.4 Need of Study

Milk adulteration is a major problem in terms of the public health economy and the trust of consumers. Since milk constitutes an essential part of daily nutrition, its purity is the prime concern regarding food safety and public health. Dilution involves addition of cheaper and harmful substances like detergents, urea, starch, and synthetic milk, which can be hazardous and cause severe ailments such as gastrointestinal disorders, kidney problems, and even cancer.

Traditional milk adulteration testing methods are available but are often deficient in being effective, economical, and upscalable, especially to monitor on a large scale. Thus, there arises a demand for critical development—needed new and improved detection technologies on milk adulteration to be machine learning and sensor-based and other advanced technologies. This study sets out to fill that gap with a novel approach to detecting milk adulteration that can be reliable, cost-effective, and scalable in assuring Milk safety and quality for consumers around the world.

4. Literature Review

A wide range of studies has explored different methods for detecting milk adulteration, with machine learning being increasingly applied to improve accuracy and scalability. The issue of milk adulteration has raised serious health and safety concerns, prompting the need for effective detection methods. One study introduced a laser-induced instrumentation technique for detecting and quantifying adulterants in milk. This method demonstrated high sensitivity and precision, offering a non-invasive approach to milk quality analysis [3].

Another investigation explored the application of ultrasonic techniques to detect milk adulteration. By analyzing changes in ultrasonic parameters, this method proved effective in identifying and quantifying common adulterants, providing a rapid and accurate solution for quality control in the dairy industry [4].

The study presented in [5] proposed an optical sensing system to detect water adulteration in milk. This research highlights the potential of optical sensors in differentiating between pure and adulterated milk. By analyzing changes in light absorption and scattering, the system effectively identifies the presence of water. This method offers a non-invasive, quick, and cost-effective solution for real-time detection.

The system developed in [6] implements an electrical impedance sensor to make the discrimination between A1 and A2 types of milk and adulteration determinations. This study brings out the usefulness of impedance measurement in detecting foreign substances in milk. The technique is based on a difference in electrical properties between pure and adulterated milk, so it gives a trustworthy and quick means of detection.

The system in [7] presents the ultrasonic sensing approach to detecting water adulteration in milk. It brings out the significant variations in milk propagation characteristics for ultrasonic waves, compared to liquids that have not been tampered with.

The method provides a robust and non-destructive avenue for adulteration detection, underlining its practicality in real applications. A low-cost, halochromic platform using electrospun nanofibers was presented in [8].

Following Table 1 provides a comparative matrix of the methods utilized, highlighting the key technologies implemented and the corresponding findings regarding detected adulteration.

Table 1. Comparison Matrix of Literature

Author	Method	Key Technology Used	Adulteration Type Detected
L. W. Moharkar et al. [3]	Detection and quantification	Laser-induced instrumentation	Common adulterants in milk
V. K. Verma et al. [4]	Determination of adulteration	Ultrasonic technique	Common adulterants in milk
A. Dave et al. [5]	Optical Sensing Systems	Optical sensors	Water
N. M. Wadalkar et al. [6]	Electrical Impedance Sensor System	Impedance measurement	A1 and A2, foreign substances
A. Dave et al. [7]	Ultrasonic Sensing	Ultrasonic wave propagation	Water
S. Tripathy et al. [8]	Halochromic Nanofiber Platform	Electrospun nanofibers	Chemical adulterants

5. Methodology

5.1 Dataset

The datasets used for ML-based milk adulteration detection typically consist of chemical and physical data collected from both pure and adulterated milk samples. These datasets often include properties such as pH, fat content, protein levels, and spectral data obtained from techniques like infrared and near-infrared spectroscopy.

5.2 Experimental work

Several machine learning models have been applied to detect adulteration in milk. Commonly used models include:

- **Support Vector Machines (SVM):** Efficient for high-dimensional data and provides robust classification performance.
- **Random Forest:** An ensemble method known for its high accuracy and ability to handle complex interactions between variables.
- **Neural Networks:** Particularly useful for identifying intricate patterns in large datasets, though requiring extensive computational power.
- **Logistic Regression:** A simpler model used for binary classification, although less effective in capturing non-linear relationships.

5.3 Evaluation Metrics

The performance of the models was evaluated based on metrics such as:

- **Accuracy:** The percentage of correct predictions.
- **Precision and Recall:** Measures of the model's ability to correctly identify adulterated milk.
- **F1-Score:** A balance between precision and recall.
- **Confusion Matrix:** To visualize the classification performance and identify false

positives and negatives.

6. Results and Discussion

The results from various studies reveal significant findings regarding the effectiveness of machine learning in milk adulteration detection.

- **Random Forest** emerged as the most accurate model outperforming other algorithms like SVM and neural networks.
- **SVM** provided a robust classification performance.
- **Neural Networks**, while powerful, required more computational resources and were less efficient for smaller datasets.

The combination of machine learning algorithms with sensor technologies, such as e-noses and e-tongues, has proven to enhance the detection capability by automatically identifying adulteration markers in milk.

Conclusion

Machine learning techniques offer an optimistic high sensitivity and efficiency in the identification of milk adulteration. These novel approaches offer fast, inexpensive methods with tradeoffs but create more available options. In this study, e-noses' sensor combination with machine learning algorithms paves the way for robust systems of detection to be applied for real applications in dairy industries. There is further research that can be done on using IoT devices to ensure continuous monitoring in real-time milk adulteration. Furthermore, incorporating the ML models into blockchain technology paves a way to monitor and verify milk provenance across supply chains to ensure the trust and safety of consumers.

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