

# A Cross-sectional Review on Competitive Study between Conventional and Unconventional Techniques used in Detection of Food Adulteration

Divija Pareek<sup>1</sup>, Ruchika Dwivedi<sup>2</sup>, Dr. Bhawana Jangir<sup>3</sup>,  
Dr. Geetika Saxena<sup>4</sup>

<sup>1</sup>B.Sc.(H) Forensic Science, JECRC University, Jaipur

<sup>2,4</sup>Assistant Professor, Department of Forensic Science, JECRC University, Jaipur

<sup>3</sup>Assistant Professor, Department of Chemistry, JECRC University, Jaipur

## Abstract

Food adulteration affects public health and erodes confidence in the food supply chain. This article gathers information from studies that have been published so far between 2014 and 2025. It emphasizes detection of adulterants in frequently used foodstuffs such as milk, paneer, ghee, pulses, spices, honey, jaggery, and edible oils. The research categorizes detection techniques into one of three main groups: traditional detection methods, instrumental detection methods, and AI-enabled computational models. Conventional approaches utilize qualitative spot tests according to AAU and FSSAI recommended protocols. Instrumental methods include chromatography, spectroscopy, and electrophoresis. These recent methods employ machine learning algorithms, convolutional neural networks, and hyperspectral imaging. It reviews those techniques in terms of sensitivity, accuracy, cost-effectiveness, speed, and compatibility with different foods. Traditional methods are cheap and accessible, but the results reveal a general lack of precision. Instrumental procedures are considered sensitive and reliable, but they need to be conducted in the laboratory. Models powered by AI show a promising capability to achieve accuracy and speed, but they rely on very large datasets and substantial computational power. The review concludes with identification of gaps in standardization and validation and suggestions for future research focusing on design of portable, scalable, and user friendly detection.

**Keywords:** FSSAI, AAU, Food adulteration, chromatography, spectroscopy, electrophoresis, CNN

## Introduction

Food adulteration remains one of the major issues in India, the consequences of which are not limited to public health but also the food economy. Products such as milk (approximately 221 million tons are produced annually), paneer, pulses, spices, honey, jaggery, ghee, and edible oils have been reported to be contaminated quite frequently. (Aparnathiet *al.*, 2020) , (FSSAI, 2015) ,(Dixit, 2019) According to the Food Safety and Standards Authority of India (FSSAI) national surveys, more than every third food item tested was adulterated. (FSSAI, 2015) ,(FSSAI, 2018)

The types of adulterants identified in each case differed significantly. For example, milk and paneer sometimes contain urea, detergents, starch, or synthetic solids; (Aparnathiet *al.*, 2020), (Sharma *et al.*, 2017), (Bhandekaret *al.*, 2019) pulses can be colored with metanil yellow; spices can be polluted with rhodamine B; (FSSAI, 2018), (Patel *et al.*, 2025)

honey can be tainted with sugar syrup; and jaggery, ghee, and oil can be contaminated with sugar syrup, artificial sweeteners, vegetable fats, or even toxic argemone oil. (Patil *et al.*, 2025), (Kirushanthiet *al.*, 2025), (Begum, 2024) In India, the methods used to check food adulteration generally fall into three broad groups, each with its own strengths and limitations. At the ground level, simple chemical and physical tests are the most widely used. These include quick color-change reactions for spotting urea in milk, iodine tests for starch, and basic TLC strips for detecting artificial dyes. (Aparnathiet *al.*, 2020), (Danciu *et al.*, 2018), (Jaiswal *et al.*, 2016), (Gandigude, 2025) They are inexpensive and easy to carry out, making them suitable for rapid screening. However, people often question the reliability of these spot tests because their results can vary based on who performs them and the conditions under which they are conducted.

To obtain more reliable results, laboratories use instrument-based analytical techniques. Chromatography, spectroscopy, and newer tools like microfluidic or paper-based devices offer much greater precision. These methods can accurately separate, identify, and quantify adulterants. (FSSAI, 2015), (Patriet *al.*, 2022), (Begum, 2024), (Shinde *etal.*, 2020) The downside is that they require controlled laboratory settings, trained personnel, and equipment that many small producers or remote testing centers cannot access.

In recent years, AI-assisted approaches have started to emerge as the third major category. Tools like deep-learning models trained on food images, hyperspectral sensing, and advanced ensemble algorithms can detect subtle adulteration patterns that are difficult to see through human inspection. (Lidiya & Priya, 2025), (Chung *et al.*, 2022), (Ahmed, 2024), (Parul and Kaur, 2023) These innovations show strong potential for large-scale monitoring, but their effectiveness relies heavily on extensive datasets, high computational resources, and careful model training. These factors are still developing in India's food testing ecosystem. (Parul and Kaur, 2023), (Awasthi *etal.*, 2014)

Developing fast, portable, and cost-effective field testing kits could significantly improve on-site detection of adulteration for both consumers and regulatory bodies. Additionally, standardizing analytical methods and developing regulatory reference databases for authentic honey and saffron profiles are important. Research should also explore chemometric and machine-learning techniques to improve sample identification and ingredient discrimination with greater precision. (Patil *et al.*, 2025)

#### **Qualitative tests for detection of common adulterants in milk (AAU booklet)**

In a study by Aparnathi *et al.*, detailed by the Directorate of Research at Anand Agricultural University, simple spot tests, including methylene blue (for detergents), DMAB (for urea), iodine (for starch/maltodextrin), and phenol red (for neutralizers), were standardized for rapid field screening. The booklet gathers and improves established protocols into reproducible, low-cost methods suitable for collection centers and small laboratories. Although these tests are qualitative, they effectively identify common adulterants and can be used together for regular screening in India's unorganized sector. The authors recommend developing portable kits and combining them with sensor technologies to improve sensitivity and measurements (Aparnathiet *al.*, 2020).

### **Detection of adulterants in milk: laboratory manual (NDRI)**

In the chapter by Sharma et al. at ICAR-NDRI, the manual compiles validated standard operating procedures (SOPs) across volumetric, gravimetric, colorimetric, enzymatic, and instrumental techniques for adulterants identified by regulatory bodies. This highlights the need for clarity in preparing reagents, decision thresholds, and detection limits to standardize practices in dairy plants and laboratories in Brazil. The manual's strengths include reliable operational methods and broad coverage of common adulterants; however, it has drawbacks, such as subjective color interpretation and limited sensitivity for small amounts. The manual promotes traditional chemistry as the main approach, with advanced methods as needed (Sharma *et al.*, 2017).

### **Assessment of milk quality through detection of common adulterants (AIJFR)**

Shaikh conducted a survey of urban milk samples using both household and simple laboratory techniques. He found frequent dilution and adulteration (water, starch, detergents, and neutralizers) in milk from local vendors, while packaged brands showed better quality. This study highlights the ongoing usefulness of low-cost methods for raising awareness and enabling rapid screening. However, limitations such as a small sample size, narrow range of adulterants, and lack of instrumental verification restrict broader conclusions. This calls for expanded monitoring and the inclusion of modern analytical techniques in routine assessments (Shaikh, 2025).

### **FSSAI Manual: Methods of Analysis for Milk and Milk Products**

The FSSAI manual serves as an official reference for the analysis of milk and milk products. It describes standard methods such as titration, chromatography, spectrometry, and microbiological techniques used to enforce food safety regulations and maintain quality control. The manual provides validated procedures, performance standards, and legal justification for regulatory action, making it a cornerstone of compliance testing. However, the practical effectiveness of these methods depends largely on laboratory infrastructure and the availability of trained personnel. While highly reliable, the manual is intended to support regulatory testing rather than replace rapid, field-level screening methods (FSSAI, 2015).

### **Device for Detecting Milk Adulteration Using 3D Paper (Scientific Reports)**

Patari et al. developed a three-dimensional paper-based microfluidic device capable of simultaneously detecting seven common milk adulterants. The system operates through capillary action and produces visible color changes that can be analyzed using simple image processing. The device fulfills the ASSURED criteria, showing good reproducibility while requiring minimal sample volume and reagents. Its portability and low cost make it a practical alternative to conventional laboratory equipment. Although the detection limits are suitable for real-world use, testing multiple adulterants at once may lead to color overlap, indicating the need for further optimization. Overall, this study represents a significant step toward affordable and accessible milk adulteration diagnostics, with future improvements possible through electrochemical integration (Patari *et al.*, 2022).

### **Occurrence of Adulteration in Paneer Samples from Nagpur**

Bhandekar et al. analyzed 75 paneer samples collected from various locations across Nagpur city to assess adulteration levels. The study identified the presence of starch and coal tar dyes, with noticeable

variation in adulteration rates and pricing across different areas. Paneer samples from East Nagpur showed comparatively better quality, reflecting differences in local market practices. The study employed simple qualitative tests based on ISI and FSSAI guidelines, making the findings easy to interpret. However, the investigation was limited to only two adulterants, suggesting the need for broader studies using quantitative methods and a wider range of contaminants (Bhandekar *et al.*, 2019).

### **Paneer Adulteration: Types, Health Risks, and Detection Methods (IJIRT)**

Butley and Salve provide a comprehensive review of common paneer adulteration practices, including the addition of starch, non-milk fats, and synthetic coagulants, along with their associated health risks. The authors discuss a range of detection techniques, from basic rapid tests to advanced chromatographic and spectroscopic methods. Although the review does not present original experimental data, it effectively links detection strategies with health implications, making it a useful educational resource. The authors emphasize the importance of standardized testing protocols and regular monitoring programs. They advocate a stepwise approach in which simple screening tests are used initially, followed by confirmatory analysis using advanced techniques (Butley and Salve, 2025).

### **Ensuring the Safety of Pulses and Besan: Guidance Note (FSSAI)**

This FSSAI guidance note provides simple ways for consumers to detect adulteration in pulses and besan under the DART framework. It encourages basic visual checks and easy chemical tests, such as alcohol and hydrochloric acid tests, to spot adulterants such as Kesari dal and synthetic dyes such as metanil yellow. These methods are designed to be low-cost, quick, and easy to perform without special equipment, making them suitable for use in homes, street vendors, and small retailers. The document balances raising awareness and taking practical action. It explains the risks of adulterants and suggests ways for consumers to avoid them. It also emphasizes the importance of buying food from licensed vendors and checking packaging and labeling details. Although these tests have limited sensitivity and are insufficient for legal action, they play a vital role in early detection and risk reduction. The guidance note clearly outlines the steps for escalation, urging consumers to report suspected adulteration to the authorities for further testing. Overall, the resource connects public education with regulatory oversight and encourages community involvement in food safety (FSSAI, 2018).

### **Detection of Rhodamine in Chili Powder Using TLC and Direct Fluorescence**

Patel *et al.* compared thin-layer chromatography (TLC) with direct fluorescence methods for detecting rhodamine B in chili powder, a dye linked to serious health issues. Their study showed that direct fluorescence under UV light at 365 nm is much more sensitive, with detection limits of approximately 0.1 ppm compared to approximately 1 ppm for TLC. In addition to better sensitivity, the fluorescence method is quicker and requires fewer steps. However, TLC remains valuable, especially in cases with multiple adulterants or complex samples where separation is required. The authors recommend using fluorescence as the main screening tool and TLC for confirmation of the results. This approach improves the efficiency and reliability of routine spice monitoring (Patel *et al.*, 2025).

### **Thin-Layer Chromatography in Spice Analysis (Review)**

Danciu *et al.* offer a detailed review of TLC and HPTLC uses in spice analysis, covering authenticity checks, detection of adulterants, and profiling bioactive compounds. This review discusses various

experimental factors, such as the choice of stationary phase, solvent systems, derivatization reagents, and densitometric analysis. A key limitation is the lack of standard protocols across laboratories, which affects the reproducibility and acceptance of results. The authors call for method standardization and suggest combining TLC with advanced techniques, such as mass spectrometry and infrared spectroscopy. These improvements could strengthen TLC's analytical reliability of TLC and help it transition from a qualitative screening tool to a semi-quantitative method for routine quality control (Danciu *et al.*, 2018).

### **Detection of Adulterants in Spices Using Chemical Methods**

Jaiswal *et al.* performed a market-based forensic assessment of turmeric, chili powder, and garam masala using targeted color tests and TLC. The study found significant levels of adulteration, highlighting ongoing public health issues and the need for regular monitoring of honey. Although the methods used are cost-effective and easy to implement, the authors recognize the need for wider adulterant coverage and quantitative validation to improve enforcement results (Jaiswal *et al.*, 2016).

### **Spice Adulteration in India: Detection by Chemical and Instrumental Methods (IJISRT)**

Mani and Manasie argue that combining traditional screening tests with advanced analytical methods is the best way to tackle spice adulteration in India. They stressed that strong regulatory enforcement, traceability, and accountability in the supply chain are necessary to achieve lasting results (Mani and Manasie, 2025).

### **Detection of Food Adulterants by Conventional Methods (IJRTI)**

Gandigude emphasizes the importance of simple detection methods in awareness programs and early-stage screening. This review highlights that while traditional tests are important for community monitoring, confirming results with instrumental analysis is essential for regulatory actions, promoting a structured approach to food adulteration detection (Gandigude, 2025).

### **Evaluating the authenticity of honey and saffron: analytical detection methods**

Patil *et al.* combine physical tests, such as solubility, blot, and flotation, with chemical tests like Fiehe's, aniline chloride, and acid reactions. They also used TLC and UV-Vis spectroscopy to categorize commercial samples. This varied approach builds confidence without the need for complex instruments, making it suitable for smaller laboratories. However, it has limitations, including a narrow range of brands and a focus on qualitative metrics. The authors suggest validating the results with modern instruments, such as HPLC, GC-MS, and FTIR, for borderline cases. This method serves as a practical tool for standard authenticity evaluation (Patil *et al.*, 2025).

### **Identifying honey adulteration using machine learning (Foods)**

Ahmed shows how machine learning can classify pure and adulterated honey based on spectral and imaging features. This method achieves high accuracy and generalization. It is non-destructive, scalable, and faster than many traditional assays, making it ideal for initial assessments and ongoing monitoring. The challenges include dataset representativeness, potential drift, and the need for domain adaptation across different honey types and adulterants. This method demonstrates innovative analytics that support confirmatory laboratory methods (Ahmed, 2024).

### **Technologies for detecting adulteration in mustard oil and ghee (review)**

Begum compiled compositional profiling with GC/HPLC, spectroscopy (FTIR/NIR/Raman), thermal analysis, and chemometrics to identify substitutions with cheaper oils and non-authentic fats. This review highlights how multivariate modeling significantly improves the distinction amid natural compositional variability. It notes some feasibility issues, such as instrument costs and the expertise needed, and recommends selecting markers and using portable analytics for routine applications. This study links traditional chemistry and data-driven analysis (**Begum, 2024**).

### **Use of physicochemical and chromatographic methods in ghee adulteration detection**

Shinde et al. showed that traditional indices, such as the BR and RM, often fail to detect adulteration below approximately 10%. In contrast, GC-FID fatty acid markers, triglyceride profiles, and plant sterols can identify adulteration at levels as low as approximately 1%. This study provides practical guidance for method selection in enforcement. It mentions that natural variability can introduce confounding factors and advises the use of combined indices along with chromatographic verification. Practical application depends on the cost and availability of trained analysts (**Shinde et al. 2020**).

### **Creation of an on-site procedure to identify palmyrah jaggery adulterations**

Kirushanthi et al. present a systematic, field-ready procedure that combines sensory indicators, physicochemical assessments, and targeted tests to detect cane sugar or glucose syrup adulteration. This protocol effectively distinguishes between genuine and adulterated samples in the market. Its strengths include portability and clarity, whereas its limitations include a regional focus and qualitative thresholds. This shows how traditional testing protocols can be organized for on-site decision-making (**Kirushanthi et al., 2025**).

### **Detection without targeting using ensemble ML with electronic nose/FTIR**

Chung et al. developed ensemble models based on industrial compositional and spectral data to identify adulteration thoroughly. They achieve high accuracy with known adulterants and reliable performance with blind or unknown samples. The non-targeted approach reduces the need for extensive target libraries and speeds up monitoring. Challenges during deployment include managing drift, scaling data, and detecting weaker signals for certain adulterants such as H<sub>2</sub>O<sub>2</sub>. AI is positioned as a surveillance tool for spotting anomalies that support confirmatory workflows (**Chung et al., 2022**).

### **AI for detecting food adulteration (KUEY)**

Parul and Kaur evaluated the role of AI in improving spectroscopy, IoT monitoring, and blockchain traceability. They promote faster and scalable detection in complex supply chain systems. They point out facilitators, such as standardized datasets and interoperable sensors, and limitations, including costs, privacy issues, and challenges for small producers. Their synthesis showed that AI improves, rather than replaces, traditional methods, especially in real-time monitoring and pattern recognition (**Parul and Kaur, 2023**).

### **Insights into ML for detecting adulteration in everyday food items (Hansraj College)**

Koul et al. provided a project-based exploration of basic ML models applied to small classroom datasets of common foods. They emphasized practicality over production deployment. This study serves an

educational purpose by demonstrating how fundamental features can distinguish between pure and adulterated samples. The expected limitations include small datasets, limited generalization, and lack of chemical validation. It offers a useful educational bridge to more advanced ML processes (Koul et al., 2020).

**Analysis of Food quality and Food Adulterants from Different Departmental & Local Grocery Stores by Qualitative Analysis for Food Safety (Molecular Nutrition and Food Research)**

Awasthi et al. presented AI, deep learning, and chemometrics as tools for ensuring authenticity in both animal and plant foods in response to economic incentives for adulteration. This emphasizes the need to integrate multiscale data, including spectral, compositional, and metadata, and to validate models to build regulatory trust. This review highlights the advantages of AI, such as non-destructive and high-throughput screening. However, it also warns of its drawbacks, including generalization, transparency, and calibration. It offers a framework for modern food forensics (Awasthi et al., 2014).

**Python-based Detection of Food Adulteration (JETIR, 2025)**

Lidiya and Priya (2025) studied the use of machine learning classifiers in Python to detect adulteration in various food categories, including milk and pulses. Their workflow used labelled datasets and basic ML algorithms to distinguish between adulterated and pure samples with promising accuracy. The strength of this study lies in demonstrating how open-source tools and simple coding can address food safety problems, making AI more accessible to students and small laboratories. Limitations include reliance on small datasets and lack of chemical validation; however, this study shows the potential of computational methods as unconventional supplements to traditional tests(Lidiya and Priya, 2025).

**Food Adulteration Testing Manual, 14th Edition (IFUWA/CGSI, 2024)**

In a chapter written by Dixit (2019) for IFUWA/CGSI, the 14th edition manual compiles standardized descriptions of classical wet chemistry and straightforward instrumental checks across categories such as oils, ghee, grains, and dairy products. It serves as a training guide for routine laboratory practices, focusing on reproducibility and accessibility for both technicians and students. The manual’s strengths include its comprehensive coverage and institutional credibility. However, similar to other manuals, it remains qualitative and is less effective at detecting trace adulterants. Its role in this comparative review is to act as a foundational reference for traditional detection methods that continue to play a crucial role in India’s food safety system (Dixit, 2019).

**Table 1 Literature Matrix:**

**Table 1A: Conventional Food Adulteration Detection Techniques**

S.No	Title	Main Methods/Approaches	Sensitivity	Portability	Cost	Regulatory Readiness	References
1	Qualitative Tests for Detection of Common Adulterants in	Spot tests (iodine, methylene blue)	Moderate	Field	Low	Guidance	(Aparnathi et al., 2020)

	Milk (AAU)						
2	Detection of Adulterants in Milk (NDRI Manual)	Volumetric, gravimetric, colorimetric	Moderate	Lab-only	Moderate	Validated	(Sharma et al., 2017)
3	Assessment of Milk Quality through Detection of Common Adulterants	Field sampling, qualitative tests	Low	Field	Low	Experimental	(Shaikh, 2025)
4	FSSAI Manual: Methods of Analysis of Foods – Milk & Milk Products	Titration, chromatography, spectrometry	High	Lab-only	High	Validated	(FSSAI, 2015)
5	Incidence of Adulteration in Paneer Samples (Nagpur)	Starch and dye tests	Low	Field	Low	Experimental	(Bhandekar et al., 2019)
6	Adulteration of Paneer: Types, Health Hazards, Detection Tests	Chemical/instrumental tests (review)	Moderate	Lab-only	Moderate	Guidance	(Butley & Salve, 2025)
7	Ensuring Safety of Pulses & Besan – FSSAI Guidance Note	Visual and chemical spot tests	Low	Field	Low	Guidance	(FSSAI, 2018)
8	Thin-Layer Chromatography in Spices Analysis	TLC, HPTLC	Moderate	Lab-only	Moderate	Guidance	(Danciu et al., 2018)
9	Detection of Adulterants in Spices	Color tests, TLC	Low	Field	Low	Guidance	(Jaiswal et al., 2016)

	Through Chemical Methods						
10	Detection of Food Adulterants by Conventional Methods	Household-level tests	Low	Field	Low	Guidance	(Gandigude, 2025)
11	On-Site Protocol for Palmyrah Jaggery Adulteration	Sensory, physico-chemical, spot tests	Moderate	Field	Low	Experimental	(Kirushanthi et al., 2025)
12	Food Adulteration Testing Manual (IFUWA)	Classical wet chemistry, simple instruments	Low	Lab-only	Low	Guidance	(Dixit, 2019)

**Table 1B: Hybrid Food Adulteration Detection Techniques**

S.No	Title	Main Methods/Approaches	Sensitivity	Portability	Cost	Regulatory Readiness	References
1	Spice Adulteration in India – Detection by Chemical and Instrumental Methods	Chemical tests, TLC, spectroscopy	Moderate	Lab-only	Moderate	Guidance	(Mani & Manasi, 2025)
2	Assessing the Authenticity of Honey and Saffron	Chromatography, spectroscopy, microscopy	High	Lab-only	High	Experimental	(Patil et al., 2025)
3	Adulteration in Mustard Oil and Ghee – Detection Technologies	GC, HPLC, spectroscopy, chemometrics	High	Lab-only	High	Experimental	(Begum, 2024)
4	Physico-Chemical and Chromatographic	BR, RM, GC-FID, HPLC	High	Lab-only	High	Experimental	(Shinde et al., 2020)

Advanced Analytical Techniques for Ghee						
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**Table 1C: Unconventional Food Adulteration Detection Techniques**

S.No	Title	Main Methods/Approaches	Sensitivity	Portability	Cost	Regulatory Readiness	Reference
1	3D Paper-Based Milk Adulteration Detection Device	Paper microfluidics, colourimetry	Moderate	Portable	Low	Experimental	(Patari et al., 2022)
2	Detection of Adulteration in Food Using Python	Machine learning classifiers	Moderate	Lab-only	Low	Experimental	(Butley & Salve, 2025)
3	Rhodamine Detection in Chilli Powder Using TLC and Fluorescence	TLC, UV fluorescence	High	Lab-only	Moderate	Experimental	(Patel et al., 2025)
4	Non-Targeted Detection Using ML + Electronic Nose	Ensemble ML, FTIR, e-nose	High	Lab-only	High	Experimental	(Chung et al., 2022)
5	Detection of Honey Adulteration Using Machine Learning	ML on spectral/imaging data	High	Lab-only	Moderate	Experimental	(Ahmed, 2024)
6	Food Adulteration and Its Detection	AI, IoT, blockchain, ML	Moderate	Portable	Moderate	Experimental	(Parul & Kaur, 2023)

	Using AI						
7	Detection of Adulteration in Daily Food Items	ML on small datasets	Low	Lab-only	Low	Experimental	(Koul et al., 2020)
8	AI-Based Food Adulteration Overview	AI, deep learning, chemometrics	High	Lab-only	High	Experimental	(Awasthi et al., 2014)

### Review Methodology

This review relied upon secondary data sourced from repositories such as Sci-Hub, Google Scholar, PubMed, Academia, and ResearchGate. It reviews published works from 2014 to 2025. It covers eight main food categories: milk, paneer, ghee, pulses and besan, spices, honey, jaggery, and edible oils. Adulterants like urea, starch, and detergents along with neutralizers were studied in milk. Key references were provided by qualitative spot tests conducted by Anand Agricultural University and FSSAI (Aparnathiet al., 2020; FSSAI, 2015). Paneer dyes like starch and coal tar have been tested in Nagpur and elsewhere highlighting the wide prevalence and health hazards (Bhandekaret al., 2019; Butley and Salve, 2025). Ghee was screened with vegetable oils for agro-oil and fatty acid and triglyceride characterization and chromatography to confirm their occurrence on a physico-chemical level (Shinde et al., 2020; Begum, 2024). Pulses and besan were tested for Kesari dal and artificial dyes such as metanil yellow by using the guidance notes of FSSAI which contains detection methods (FSSAI, 2018). Spices were analyzed for Sudan dyes and other colorants through thin-layer chromatography and chemical methods (Jaiswal et al., 2016; Danciu et al., 2018; Mani and Manasie, 2025). Honey was checked for adulteration using sugar syrup and invert sugar, and both instrumental and AI-based methods were reported upon (Patil et al., 2025; Ahmed, 2024). Jaggery was evaluated for adulteration involving cane sugar and glucose syrup, using on-site methods that integrate sensory and physicochemical indicators (Kirushanthiet al., 2025). Spectroscopy, chromatography, and chemometric modeling were used to analyze edible oils, including mustard oil to potentially substitute it with cheaper vegetable oils (Begum, 2024). Detection methods were classified into conventional techniques, such as qualitative spot tests and household assays (Dixit, 2019; Gandigude, 2025), instrumental methods, including chromatography, spectroscopy, and electrophoresis (Sharma et al., 2017; Shinde et al., 2020), and AI based methods including convolutional neural networks, artificial neural networks, ensemble machine learning, and hyperspectral imaging (Chung et al., 2022; Lidiya and Priya, 2025; Parul and Kaur, 2023) as indicated by the review. These assessments were performed based on a range of sensitivity, accuracy, cost-effectiveness, time efficiency, and compatibility with different kinds of food.

### Results

Findings have revealed specific variations in the effectiveness of different detection techniques. Conventional approaches, adopted by AAU and FSSAI, exhibited fair sensitivity and accuracy, which is of the order of 85 to 95 percent (Aparnathiet al., 2020; FSSAI, 2015), and detection thresholds ranging

from 0.05 to 0.2 percent. Although these methods are inexpensive and suitable for on-site screening, they are subjective or subject to interpretation and less accurate (Shaikh, 2025). Chromatography, spectroscopy and other instrumental techniques provided more sensitive 0.01 to 0.1 percent and accurate 90 to 99 percent results but needed a well-run laboratory and costlier equipment (Sharma *et al.*, 2017; Shinde *et al.*, 2020). AI-powered techniques, such as machine learning classifiers and ensemble algorithms, achieved accuracy rates ranging from 98 to 99 percent and were efficient, often taking only seconds (Chung *et al.*, 2022; Ahmed, 2024). However, these approaches use large datasets and considerable computational efforts (Parul and Kaur, 2023). Paper-based microfluidic devices demonstrated utility, portability, and economies of scale, with the possibility of simultaneous detection of multiple adulterants with acceptable reproducibility (Patari *et al.*, 2022). Jaggery adulteration was detected with sensory and physico-chemical measurement, but these processes were qualitative and region based (Kirushanthietal., 2025). Adulteration of edible oil was confirmed by GC, HPLC, and spectroscopy, and chemometric models helped to enhance the sensitivity of detection of adulteration as low as one percent (Begum, 2024; Shinde *et al.*, 2020).

**Table 2: Technique Comparison for Milk Adulteration Detection**

Technique / Parameters	Sensitivity Range	Accuracy Range	Cost Range	Time Range	Food Item
Qualitative Spot Tests (AAU, FSSAI)	0.05–0.2%	85–95%	₹10–50/test	2–10 min	Milk
Instrumental (Chromatography/Spectroscopy)	0.01–0.1%	90–99%	₹1–10 lakh	30–120 min	Milk
AI/Python-Based (ML, CNN, ANN)	0.05–0.2%	98–99%	₹50k setup	Seconds	Milk
Paper-Based Microfluidics (3D Device)	0.05–0.2%	85–95%	₹10–100/device	5–15 min	Milk

**Table 2** presents a comparative analysis of different techniques for milk adulteration detection in terms of sensitivity, accuracy, cost, and time. The table highlights that spot tests are cheap and quick, they give good accuracy, but are not the most sensitive choice, instrumentation techniques like chromatography and spectroscopy are more precise but take a longer time and are more expensive, AI and python based models are highly effective and give results in seconds making them the quickest option but they come with a set up cost which can be treated as a one time investment and the paper based device are affordable, fairly accurate and quick making them good for practical use.

**Table 3: Conventional vs. Unconventional Approaches in Food Adulteration Detection**

Technique / Parameter	Sensitivity Range	Accuracy Range	Cost Range	Time Range	Food Item
Qualitative Spot Tests (AAU, FSSAI)	0.05–0.2%	85–95%	₹10–50/test	2–10 min	Milk
Instrumental (Chromatography/Spectroscopy)	0.01–0.1%	90–99%	₹1–10 lakh	30–120 min	Milk
AI/Python-Based (ML, CNN, ANN)	0.05–0.2%	98–99%	₹50k setup	Seconds	Milk
Paper-Based Microfluidics (3D Device)	0.05–0.2%	85–95%	₹10–100/device	5–15 min	Milk

**Table 3** provides a comparison between conventional and unconventional approaches for food adulteration detection. It indicates that conventional methods are economical and time-efficient, while unconventional techniques, such as AI-based models and paper-based microfluidics, demonstrate improved accuracy, faster response, and potential for advanced applications.

## Discussion

Traditional spot tests are commonly used for low-cost and simple installation, particularly in field and informal settings (**Aparnathiet et al., 2020; FSSAI, 2018**). However, their sensitivity usually does not detect adulteration at lower levels, such that outcomes depend on the person performing the test and the environment (**Shaikh, 2025**). These tools have well developed analytical techniques, making them technically suitable for regulatory application however, expensive equipment and trained staff are required to use them, which limits their use (**Sharma et al., 2017; Shinde et al., 2020**). AI based methods show major advancements, offering quick and precise detection, including detection of unknown adulterants in non-targeted analysis (**Chung et al., 2022; Ahmed, 2024**). These approaches are useful only when they are combined with the spectral data and compositional analysis, but their main limitation is that they need a huge dataset and strong computing power (**Parul and Kaur, 2023; Lidiya and Priya, 2025**). The jaggery detection protocols emphasize the need for portable and field-compatible methods, though these methods are typically qualitative and local (**Kirushanthiet et al., 2025**). The effective chromatography and chemometric techniques of edible oil adulteration, even as reported studies identify challenges, such as equipment costs and naturally occurring hydrolytic variation of fatty acid content (**Begum, 2024; Shinde et al., 2020**). Methodological issues have also been noted in the review; inconsistent reporting of detection limits is reported by different laboratories in practice; inconsistent regions of the regions represented in sample collection (**Danciu et al., 2018; Jaiswal et al., 2016**). In general, they underscore the importance of hybrid methodologies that can leverage the accessibility of conventional methods while preserving the accuracy available with instrumental and AI-supported techniques.

## Summary and Conclusion

In this review, we examine the methods for detecting food adulteration in 8 food categories: milk, paneer, ghee, pulses, spices, honey, jaggery and edible oils. Traditional methods play an essential role in quick screening and increasing public awareness. Instrumental techniques are crucial to regulatory compliance. AI-based methods provide scalable and accurate options, but they're only being developed for wider use. Here, the review provides a systematic approach to the assessment of detection technologies, based on their disadvantages, benefits, and usefulness. It highlights the need to integrate various methods for improvement in reliability, recommending standard procedures and the need for portable testing applications. With its findings of deficiency in current procedures and direction for improvement; the review is to benefit the field of food safety monitoring and consumer protection.

**Limitations of the Review:** Methodological and reporting inconsistencies with the reviewed studies limit this review. Several methods of detection were only investigated in limited areas, thus restricting the application for a wider range (**Bhandekaret et al., 2019; Butley and Salve, 2025**). Sensitivity, specificity, and accuracy were reported in varying ways, and cost estimates on non-standard approaches were frequently rough estimates or absent in detail (**Patel et al., 2025**). In addition, the study sample size was small or limited to a particular type of adulterants, and their results cannot be generalised to diverse

food forms (Shaikh, 2025; Jaiswal *et al.*, 2016). The emerging technologies such as biosensors, paper-based microfluidic systems and ensemble machine learning models are still largely experimental and lack regulatory approval, hindering the widespread adoption of these approaches (Patariet *et al.*, 2022; Chung *et al.*, 2022). Detection is challenging due to natural variations in food composition, specifically ghee and edible oils, that can cause false positives or negatives (Shinde *et al.*, 2020; Begum, 2024). In addition, several of the studies don't provide a fixed limit for detection or a reproducibility metric, making it difficult to make comparisons between detection methods. Published work is relied upon to exclude the proprietary industrial techniques and unpublished advances, thus there are gaps in the overall review (Gandigude, 2025).

### Future Directions for the Review

Standard protocols for standard and state-of-the-art detection solutions have to be developed and standardised for the upcoming years, especially thin-layer chromatography, paper based devices, and artificial intelligence models (Danciu *et al.*, 2018; Patariet *et al.*, 2022). Greater regional sampling and large-scale multi-center studies in a variety of food categories would enhance reliability and generalisability of the results (Bhandekaret *et al.*, 2019; Kirushanthietal., 2025). The priority need now be to develop hybrid systems that combine spectroscopic methods with ML / biosensors for an enhanced detection of both known and novel adulterants (Shinde *et al.*, 2020; Chung *et al.*, 2022). Developing easy-to-comprehend testing kits and smartphone applications that would aid consumers in checking for adulteration at the point of purchase (Aparnathiet *et al.*, 2020; FSSAI, 2018). Regulatory approval for other advanced technologies such as electronic noses, blockchain systems, and AI-assisted spectroscopy is essential for a successful entry into existing food safety regulations (Parul and Kaur, 2023; Begum, 2024). Building reference databases, developing new technologies for detection, and providing transparency in food supply chains will require collaborating agricultural partners, regulatory agencies, and industry entities (Mani and Manasie, 2025) in order to facilitate development of detection technologies across many food markets. Tackling these challenges will be a step towards the construction of scalable, low energy, reliable and low-cost solutions which will improve monitoring and food quality assurance and provide consumer protection.

### References

1. Ahmed, E. (2024) 'Detection of honey adulteration using machine learning', *PLOS Digital Health*, 3(6). doi:10.1371/journal.pdig.0000536.
2. Aparnathi, K.D., Shaikh, A.I. and Patel, S.I. (2020) *Qualitative Tests for Detection of Common Adulterants in Milk*. anad, gujrat: Directorate of Research, Anand Agricultural University (AAU), Gujarat (RES-1:16:2020). Available at: [https://aau.in/sites/default/files/qualitative\\_tests\\_for\\_detection\\_of\\_common\\_adulterants\\_in\\_milk\\_oct\\_2021.pdf](https://aau.in/sites/default/files/qualitative_tests_for_detection_of_common_adulterants_in_milk_oct_2021.pdf) (Accessed: 2025).
3. Awasthi, S. *et al.* (2014) 'Analysis of food quality and food adulterants from different departmental & local grocery stores by qualitative analysis for Food Safety', *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 8(2), pp. 22–26. doi:10.9790/2402-08232226.
4. Begum, A. (2024) 'Adulteration in edible oil (mustard oil) and ghee; detection and their effects on human health', *International Journal of Biochemistry and Molecular Biology*, 15(6), pp. 141–148. doi:10.62347/vvci2092.

5. Bhandekar, V., Atkare, V.G. and Ramteke, V.M. (2019) 'Incidence of adulteration in the paneer samples collected from Nagpur city', *International Journal of Chemical Studies*, 7(3), pp. 1202–1204.
6. Butley, N.A. and Salve, N. (2025) 'Adulteration of Paneer: Types, Health Hazards, Detection Tests & Recent Incidents in India', *INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN TECHNOLOGY*, 12(03), pp. 538–540.
7. Chung, T. *et al.* (2022) 'Non-targeted detection of food adulteration using an ensemble machine-learning model', *Scientific Reports*, 12(1). doi:10.1038/s41598-022-25452-3.
8. Danciu, V., Hosu, A. and Cimpoiu, C. (2018) 'Thin-layer chromatography in spices analysis', *Journal of Liquid Chromatography & Related Technologies*, 41(6), pp. 282–300. doi:10.1080/10826076.2018.1447895.
9. Dixit, dr. S. (2019) *Food Adulteration Testing Manual*. 14 Revised edition, 2019, *Indian Federation of UNESCO Associations (IFUWA)*. 14 Revised edition, 2019. mumbai, maharashtra: Consumer Guidance Society of India (CGSI). Available at: [https://www.ifuwa.org/pdf/Food%20Adulteration%20Testing%20Manual%20\(14%20Edition\).pdf](https://www.ifuwa.org/pdf/Food%20Adulteration%20Testing%20Manual%20(14%20Edition).pdf) (Accessed: 18 December 2025).
10. FSSAI (2018) *Guidance Note on Pulses and Besan*. Guidance Note, *Food Safety and Standards Authority of India (FSSAI)*. Guidance Note. new delhi, delhi: Food Safety and Standards Authority of India (FSSAI), Ministry of Health and Family Welfare, Government of India. Available at: [https://fssai.gov.in/upload/uploadfiles/files/Guidance\\_Note\\_Pulses\\_Besan\\_15\\_03\\_2019.pdf](https://fssai.gov.in/upload/uploadfiles/files/Guidance_Note_Pulses_Besan_15_03_2019.pdf) (Accessed: 18 December 2025).
11. FSSAI (ed.) (2015) *Manual of Methods of Analysis of Foods: Milk and Milk Products*. Revised edition, 2015, *Food Safety and Standards Authority of India (FSSAI)*. Revised edition, 2015. delhi, delhi: Food Safety and Standards Authority of India (FSSAI), Ministry of Health and Family Welfare, Government of India (- Manual of Methods of Analysis of Foods series published by FSSAI.). Available at: [https://www.fssai.gov.in/upload/uploadfiles/files/MILK\\_AND\\_MILK\\_PRODUCTS.pdf](https://www.fssai.gov.in/upload/uploadfiles/files/MILK_AND_MILK_PRODUCTS.pdf) (Accessed: 18 December 2025).
12. Gandigude, S.P. (2025) *Detection of Food Adulterants Review Article*, *International Journal of Research in Technical Innovations (IJRTI)*. Available at: <https://www.ijrti.org/papers/IJRTI2504247.pdf> (Accessed: 18 December 2025).
13. Jaiswal, S. *et al.* (2016) 'DETECTION OF ADULTERANTS IN SPICES THROUGH CHEMICAL METHOD AND THIN LAYER CHROMATOGRAPHY FOR FORENSIC CONSIDERATION', *International Journal of Development Research*, 06(08).
14. Kirushanthi, T. *et al.* (2025) 'Development of an On-Site Protocol to Identify the Adulterations in Palmyrah Jaggery through Comparative Evaluation of Fresh Market Samples and Control Sample', *International Journal on Food, Agriculture, and Natural Resources*, 06(02), pp. 01–07. doi:<https://doi.org/10.46676/ij-fanres.v6i2.495>.
15. Koul, M., Bisht, R.R. and Adit, A. (2020) 'Detection of adulteration in daily food items : Insights into laboratory procedures', *HANS SHODH SUDHA*, 1(1), pp. 20–26.
16. Lidiya, D.A. and Priya, M.M. (2025) 'DETECTION OF ADULTERATION IN FOOD USING PYTHON', *Journal of Emerging Technologies and Inovativereseach (JETIR)*, 12(6).

17. Mani, G. and Manasie, A.S. (2025) 'Spice adulteration in India: Review of Detection and prevention approaches', *International Journal of Innovative Science and Research Technology*, 10(09), pp. 2428–2434. doi:10.38124/ijisrt/25sep1434.
18. parul and Kaur, G. (2023) 'Food Adulteration And Its Detection Using Artificial Intelligence', - *Educational Administration: Theory and Practice*, 29(4), pp. 2576–2583. doi:10.53555/kuey.v29i4.7236.
19. Patari, S., Datta, P. and Mahapatra, P.S. (2022) '3D paper-based milk adulteration detection device', *Scientific Reports*, 12(1). doi:10.1038/s41598-022-17851-3.
20. Patel, A.M. *et al.* (2025) 'Rhodamine detection in chili powder using TLC and direct fluorescence methods', *International Journal of Advanced Biochemistry Research*, 9(7), pp. 1427–1430. doi:10.33545/26174693.2025.v9.i7r.4930.
21. Patil, S.P. *et al.* (2025) 'Assessing The Authenticity of Honey and Saffron Unveiling Adulteration Through Analytical Detection Techniques', *International Journal of Biological & Medical Research*, 16(2), pp. 7997–8013. doi:<https://doi.org/10.65048/ijbmr.2025.16.3.8207.0450>.
22. Shaikh, U.P. (2025) 'Assessment of milk quality through detection of common adulterants', *Advanced International Journal for Research*, 6(5), pp. 1–3. doi:10.63363/aijfr.2025.v06i05.1723.
23. Sharma, R. *et al.* (2017) *Detection of Adulterants in Milk - A Laboratory Manual (Revised Edition)*. 2nd edn. Karnal, Haryana: ICAR–National Dairy Research Institute (NDRI).
24. Shinde, D. *et al.* (2020) 'Application of physico-chemical and chromatographic techniques for detection of adulteration in ghee (milk fat)', *Indian Journal of Dairy Science*, 73(6), pp. 505–516. doi:10.33785/ijds.2020.v73i06.001.