



Forensic Detection of Ghee Adulteration: Analytical Approaches in the Dairy Industry

Mr. Karan J. Mehta (KM) (M.Sc., Ph.D Pursuing)

Assistant Professor - Department of Forensic Science, Parul University (NAAC A++),

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

Ms. Shivangi D. Parmar (SP) (M.Sc., Ph.D Pursuing)

Assistant Professor - Department of Forensic Science, Parul University (NAAC A++),

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

Dr. Debesh Nilendu (DN) (M.Sc., Ph.D Pursuing)

Assistant Professor - Department of Forensic Science, Parul University (NAAC A++),

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

Ms. Akshara Yesodharan (AY) (M.Sc.)

Assistant Professor - Department of Forensic Science, Parul University (NAAC A++),

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

Mr. Adarsh Tiwari (AT) (M.Sc.)

Assistant Professor - Department of Forensic Science, Parul University (NAAC A++),

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

Ms. Janhavi U. Gawande (JG) (M.Sc. Pursuing)

Student - Department of Forensic Science, Parul University, NAAC A++

P.O. Limda, Tal. Waghodia, Dist. Vadodara – 391760, Gujarat State, India.

(Received: 16 May 2025

Revised: 11 June 2025

Accepted: 11 July 2025)

KEYWORDS

Adulteration
, Dairy
Detection,
Food
Forensics,
Quality
Control,

ABSTRACT:

This comprehensive review synthesizes recent research on detecting food adulteration, with a particular emphasis on dairy products such as milk and ghee, which are highly susceptible to fraudulent practices. It highlights the advantages of integrating cutting edge analytical techniques with conventional physicochemical methods to enhance the identification of contaminants like vegetable oils, animal fats, and synthetic additives. Advanced tools, including gas chromatography mass spectrometry (GC-MS), Fourier transform infrared (FTIR) spectroscopy, microfluidic systems, and sensor-based technologies, enable rapid, cost-effective, and non-



Rapid Detection.

invasive detection of adulterants. These methods support routine quality assurance and real time, on-site monitoring, playing a critical role in ensuring consumer safety and maintaining trust in the food market. The review also explores the potential of emerging innovations and digital tools to address the challenges of complex modern food supply chains. It discusses limitations related to method sensitivity, standardization, and regulatory oversight, offering a balanced assessment of both traditional and modern approaches. By consolidating findings from diverse studies, this paper underscores the importance of food forensics in safeguarding public health and promoting transparency in food production.

Introduction

To supply the population's nutritional needs and sustain the agricultural economy, the dairy industry is essential. In this market, ghee a clarified butter has a prominent position, particularly in India, where its distinct flavour, aroma, and health advantages make it highly valued. However, because of its high demand and market worth, it is susceptible to being tampered with less than ideal chemicals to profit.

A subfield of forensic science called "**Food Forensics**" is crucial to guarantee the safety and authenticity of food items like ghee. To find, identify, and measure adulterants in dairy products, this field uses sophisticated procedures. To safeguard customers from health hazards, maintain quality control, and preserve the integrity of the food supply chain, it is essential to detect ghee adulteration. [1]

To replicate the texture and flavour of ghee, adulteration frequently entails the use of inexpensive oils, animal fats, or synthetic materials. These behaviours may result in long-term metabolic problems, cardiovascular problems, and gastrointestinal diseases, among other health risks. In the interest of public health, forensic specialists and food safety authorities work together to create and apply reliable detection techniques for locating adulterants and prosecuting offenders. [2]

The importance of food forensics in the identification and examination of tainted ghee is examined in this study. It emphasizes the prevalent adulterants, their effects on health, and the cutting-edge analytical methods used to look into these adulterations. The results are intended to support consumer education,

regulatory actions in the dairy sector, and the creation of more efficient food safety protocols.

By producing valuable dairy products like milk, cheese, yogurt, and ghee, the dairy industry plays a vital role in the global food economy and improves human nutrition. Ghee is unique among them, especially in South Asian nations like India, where it is prized for its cultural and medicinal significance in addition to being a staple in cooking. Ghee is highly valued in the market due to its distinct flavor, potent scent, and health advantages. However, it is a prime target for adulteration due to its high economic worth and rising demand. [3]

The Dairy Industry's Need for Food Forensics

Food forensics is a new and important branch of forensic science that focuses on food product safety, quality assurance, and authentication. It is essential for identifying dishonest business activities, examining the makeup of products, and guaranteeing adherence to food safety regulations in the dairy sector. Finding adulterants in ghee is essential for protecting consumer health and preserving the dairy industry's reputation.

Common Ways to Adulterate Ghee can be adulterated in several ways, such as by adding Refined soybean oil, palm oil, and vanaspati, which are vegetable oils that can be used to simulate the viscosity and texture of pure ghee.

- ✓ **Animal fats:** Lard or tallow are less expensive substitutes for pure milk fat.
- ✓ **Synthetic substances:** Chemical additions that mimic the look and smell of ghee, such as colorants, flavour enhancers, and starches.



Significant health hazards are associated with certain adulterants, such as:

- Digestive issues brought on by incorrect digestion of contaminated lipids.
- Heart problems brought on by excessive intake of dangerous Trans fats.
- Synthetic chemicals' possible toxicity.

Methods of Analysis for Detection In food forensic investigations, sophisticated analytical techniques are essential for identifying and measuring adulterants in ghee. Typical methods include:

- **Chromatographic techniques:** High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) for fatty acid profile analysis.
- Spectroscopic methods for determining the chemical structures of adulterants include nuclear magnetic resonance (NMR) and Fourier transform infrared (FTIR) spectroscopy.
- **Titrimetric and gravimetric methods:** Conventional chemical approaches to assess fat quality and content. Polymerase Chain Reaction (PCR) is one DNA-based technique for identifying non-dairy animal lipids.

In light of these worries, food forensics has grown in significance as a means of guaranteeing food authenticity and safety. Advanced scientific methods are used in food forensics to identify, examine, and measure adulterants in food products, particularly dairy products like ghee. Molecular, biological, and chemical techniques are all used in the study of ghee adulteration by examining the chemical makeup of ghee samples, methods including Gas Chromatography (GC), High-Performance Liquid Chromatography (HPLC), and Fourier Transform Infrared Spectroscopy (FTIR) are frequently employed to detect adulterants. While new DNA-based techniques like Polymerase Chain Reaction (PCR) are becoming more popular for identifying non-dairy animal fats in ghee products, gravimetric methods and titrimetric tests are still helpful for determining fat content.

To boost profit margins, adulteration of ghee usually entails the purposeful addition of less expensive alternatives such as animal fats, refined vegetable oils, and synthetic additives. To replicate the texture, look,

and scent of genuine ghee, dishonest manufacturers frequently mix these subpar ingredients. Even while unwary consumers might not notice the adulteration at first, consuming contaminated ghee over time can lead to serious health problems, such as metabolic disorders, cardiovascular diseases, and gastrointestinal troubles. Particularly when synthetic adulterants are used, hazardous substances that are detrimental to human health may be introduced. [4]

Identification and Evaluation of Adulterated Ghee:

1. **Typical Ghee Adulterants:** In the dairy sector, adulteration of ghee is a common problem that is mostly caused by financial incentives to boost profit margins. Vegetable oils, including refined soybean oil, palm oil, and vanaspati, are the most often used adulterants. They are combined with pure ghee to simulate its viscosity and texture. Furthermore, some manufacturers employ animal fats like tallow and lard as inexpensive alternatives to milk fat, and they add fake ingredients like starch, colorants, and taste enhancers to mimic the look and smell of real ghee. In addition to misleading customers, these techniques jeopardize the product's safety and nutritional value, increasing the risk of cardiovascular illnesses, gastrointestinal problems, and exposure to dangerous synthetic chemicals.

2. **Methods for Identifying Ghee Adulterants:** Both conventional and cutting-edge analytical methods must be used in the detection and examination of tainted ghee. Chromatographic techniques like High-Performance Liquid Chromatography (HPLC) and Gas Chromatography (GC) are frequently used to determine the presence of non-dairy fats and oils and to examine fatty acid profiles. Nuclear Magnetic Resonance (NMR) and Fourier Transform Infrared (FTIR) Spectroscopy are two spectroscopic methods that offer comprehensive details on the molecular makeup of ghee components. Chemical techniques, such as titrimetric and gravimetric studies, aid in determining the purity and amount of fat. For the detection of non-dairy animal lipids, new DNA-based techniques like Polymerase Chain Reaction (PCR) are very helpful. When combined, these methods are essential to food forensic investigations. [5]

3. **Quality Standards and the Regulatory Framework:** Strict legal frameworks and adherence to



quality standards are necessary to guarantee the safety and authenticity of ghee on the market. The Food Safety and Standards Authority of India (FSSAI) in India has strict regulations on the ingredients and labelling of ghee. Dairy products are also subject to international food safety regulations set forth by the Codex Alimentarius. Because many areas lack sophisticated testing infrastructure, implementation of these restrictions is still difficult. To reduce the threat of adulteration and safeguard consumers, regulatory mechanisms must be strengthened, inspections must be increased, and violators must be punished. [6]

4. New Developments and Trends in Adulteration Detection: The identification of adulterants in ghee is being revolutionized by technological breakthroughs. Analytical systems are incorporating machine learning and artificial intelligence (AI) to increase detection speed and accuracy. Additionally, portable on-site testing devices are being developed to enable faster identification of adulterants without requiring sophisticated laboratory equipment. To improve the sensitivity and specificity of detection procedures, molecular approaches like next-generation sequencing (NGS) are being investigated. These developments have enormous potential to improve food safety regulations and lower the incidence of adulteration. [7] Ghee's unique flavour, aroma, and health advantages make it an important component of the dairy business, especially in India. However, dishonest producers target it for adulteration due to its high market demand and economic importance. Vegetable oils like palm and vanaspati, non-dairy animal fats like tallow, and artificial substances that imitate the look and feel of genuine ghee are examples of common adulterants. In addition to misleading customers, these techniques present major health hazards, such as exposure to synthetic substances that can be poisonous, cardiovascular disorders, and digestive problems. The detection and analysis of such adulterants are greatly aided by the developing discipline of food forensics.

Literature Review

1. Researchers Kandiah Pakeerathan and Samuddrika T.D.Y. carried out a study in July 2023 called "Screening of Market Cow's Ghee Samples to Detect Adulteration." To detect adulteration, the study

compared the physicochemical characteristics of genuine cow ghee with market samples. Thirteen market samples from different provinces were examined in addition to a pure cow ghee sample generated in a lab. According to established procedures, the analyses comprised evaluations of the following parameters: moisture content, relative density, refractive index, acid value, iodine value, saponification value, and peroxide value. Furthermore, chromogenic tests were used, including the furfural and Modified Salkowski tests. According to the results of the Gas Chromatography-Mass Spectrometry (GC-MS) examination, eleven of the thirteen market samples showed indications of adulteration with edible oils. This study emphasizes how common adulteration is in commercially available cow ghee and how well physicochemical analysis and chromogenic tests work together to detect it. [8]

2. Fourier Transform Infrared (FTIR) spectroscopy was used by Astha Pandey and Krupal N. Jariwala in their 2015 work, "Detection of Adulteration in Ghee from Markets of Ahmedabad by FTIR Spectroscopy," to examine ghee samples for possible adulteration. As a contemporary analytical method that detects chemicals by identifying their functional groups, FTIR spectroscopy is useful for constituent analysis in forensic science. By analyzing the spectrograms of ghee samples, the study aimed to identify Tran's fatty acids and other adulterants. According to the researchers, FTIR spectroscopy is a straightforward, affordable, and non-destructive way to detect adulteration in ghee. It offers forensic analysts a trustworthy substitute for determining the purity of ghee and spotting dangerous materials. [9]

3. The widespread problem of food adulteration the deliberate addition, removal, or substitution of subpar ingredients for financial benefit is examined by author Misgana Banti in her June 2020 review article, "Food Adulteration and Some Methods of Detection," which was published in the International Journal of Nutrition and Food Sciences. The assessment emphasizes that in addition to misleading customers, these activities present serious health hazards, such as exposure to harmful substances. Banti highlights the difficulties in recognizing adulterants, particularly when



their physicochemical characteristics closely mimic those of the original meal. He also covers different detection approaches, classifying them into physical, chemical, and biological techniques. The report emphasizes the need for more study and urges individuals, groups, and governments to take collective responsibility in the fight against food adulteration. [10]

4. Fumin Chi and colleagues' review, "*Tibetan Butter and Indian Ghee: A Review on Their Production and Adulteration*," looks at the adulteration problems and manufacturing methods related to these two dairy products. Although both are made from cow's milk and go through processes including filtering, heating, and separating Indian ghee is heated further to become clarified butter, while Tibetan butter is made similarly to ordinary butter. The article points out that while Tibetan butter is frequently tainted with animal body fats and non-fat ingredients like mashed potatoes, Indian ghee is frequently tainted with vegetable oils, animal fats, and other non-fat ingredients. The authors point out that there is a dearth of research on Tibetan butter, whereas several studies have looked into methods for detecting adulteration in Indian ghee. They propose that techniques like electronic nose (E-nose) technology, gas chromatography (GC), and Fourier-transform infrared spectroscopy (FTIR), which are successful in detecting adulterants in Indian ghee, could be used to guarantee the safety and purity of Tibetan butter. [11]

5. Tanzina Azad and Shoeb Ahmed discuss the worldwide issue of milk adulteration in their 2016 review paper, "*Common Milk Adulteration and Their Detection Techniques*," which was published in the International Journal of Food Contamination. They focus on developing nations where policies and monitoring may be deficient. The authors point out that, in contrast to popular opinion, milk adulterants can present significant health risks and result in deadly illnesses. A thorough analysis of common milk adulterants is included in the study, along with various qualitative and quantitative detection techniques. In this 'adulterant-based' review, the qualitative detection techniques for the most prevalent adulterants are enumerated, while the quantitative detection techniques for a few important adulterants are described. The

authors also discuss recent developments in detection techniques, emphasizing the need for advanced research to address increasingly sophisticated adulteration methods. The review aims to contribute to the common knowledge base regarding possible milk adulterants and their detection techniques. [12]

6. Rita Narayanan explores the pervasive problem of adulteration in milk and its derivatives in her 2019 review article, "*Review on Adulteration of Milk and Milk Products and Detection*," which was published in the Asian Journal of Home Science. The study addresses the different adulterants that are frequently added to dairy products, including water, flour, detergents, and artificial milk, which reduce their nutritional value and present health hazards. To identify these adulterants, Narayanan highlights the significance of quick and easy detection methods. She lists methods such as iodine tests for starch, lactometer tests for diluted milk, and particular assays for synthetic components. The study emphasizes how important it is to raise public awareness and implement strict regulations to guarantee the safety and purity of milk products. [13]

7. In "*Innovation Techniques to Assess Adulterated Ghee: A Review*," published in 2022, Heena Kauser gives a thorough summary of the developing analytical techniques used to identify adulteration in ghee, a valuable dairy commodity that is susceptible to financial crime. The assessment underscores the need for more accurate, quick, and dependable methodologies while pointing out the drawbacks of conventional detection methods. Kauser talks about how sophisticated chromatographic techniques like GC-MS and HPLC, as well as spectroscopic techniques like FTIR, have greatly increased the sensitivity and specificity of detecting adulterants. The review also looks at new developments that are opening the way, such as sensor-based technology and chemometric analysis. To guarantee the safety and authenticity of ghee on the market, the study emphasizes how crucial it is to incorporate these cutting-edge methods into conventional quality control procedures.

8. In this review, Ray et al. provide a thorough examination of paper-based microfluidic devices as



novel, reasonably priced methods of identifying food contaminants. The design principles and manufacturing techniques of microfluidic paper analytical devices (PADs) are described by the authors. They highlight the devices' affordability, portability, and ease of use, which make them ideal for on-site food quality monitoring, particularly in environments with limited resources. The article discusses a variety of detection tactics, from colorimetric and electrochemical to fluorescence-based approaches, emphasizing how these technologies allow for the quick and accurate identification of adulterants in a variety of food matrices. The review proposes future research approaches to enhance device performance and integration with digital tools like smartphones for real-time analysis while also addressing contemporary obstacles, including sensitivity, reproducibility, and scalability. Overall, by offering easily accessible and effective monitoring systems for adulteration detection, the article highlights the substantial potential of paper-based microfluidic devices as useful technical instruments to improve food safety. [14]

9. The use of Fourier Transform Infrared (FT-IR) spectroscopy as a reliable analytical method for detecting adulterants in ghee is examined in the review paper "*Detection of Adulteration in Market Ghee Using FT-IR Spectroscopy*" by Priya Subramanian Kalaimani, Suman Thamburaj, Ashish Rawson, and Suresh Kumar Kalakandan. The authors describe the basic ideas of FT-IR spectroscopy, highlighting how it may identify variations brought on by the presence of adulterants such as vegetable oils and other fats and capture the distinct chemical fingerprint of pure ghee. Through a review of numerous papers and experimental techniques, the paper shows that FT-IR spectroscopy, in conjunction with chemometric analysis, provides a quick, non-destructive, and economical way to distinguish genuine ghee from tainted samples. While addressing the obstacles and constraints that must be removed for wider use, the assessment also highlights the benefits of this technique above conventional approaches, emphasizing its potential for routine quality control in the dairy business. [15]

10. Fernandes Glorita's 2018 review paper, "*Food Forensics: Detection of Hidden Toxins Present in Common Household Consumables*," offers a thorough analysis of the possible harmful pollutants present in

common food items as well as the forensic techniques employed to find them. The review describes several toxin types that can jeopardize food safety, such as pesticides, heavy metals, mycotoxins, microbial toxins, and intentional adulterants. Gloria talks about contemporary analytical techniques like chromatography, mass spectrometry, immunoassays, and DNA-based methods that allow for the quick, precise, and sensitive detection of these dangerous substances even at trace levels, highlighting the vital role that forensic science plays in protecting public health. Additionally, case studies of actual food poisoning and contamination episodes are highlighted in the study, highlighting the need for ongoing surveillance, enhanced detection techniques, and more stringent regulation. [16]

11. Shabbir Ahmed, Mohammad Abdul Hamid, and Md. Morshedur Rahman's paper "*Assessment of Ghee Adulterated with Oils and Fats in Bangladesh*" offers a thorough analysis of the degree and kind of adulteration in commercially available ghee in Bangladesh. The study uses a variety of analytical methods to find non-dairy fats and oils that are frequently added to ghee illegally to reduce expenses and boost profit margins. Through the examination of important physicochemical characteristics such as moisture content, acidity, saponification value, and refractive index, the researchers were able to distinguish genuine ghee from fakes. Serious concerns regarding consumer health and the general integrity of dairy products were raised by the findings, which showed considerable levels of adulteration in the market samples. To guarantee that ghee marketed in Bangladesh satisfies set purity criteria and protects public health, the study emphasizes the urgent need for enhanced regulatory oversight, stringent quality control procedures, and ongoing monitoring. [17]

12. B. Kamalapreetha, R. Gayathri, K. Geetika Gopi, and R. Mahendran explore the global problem of food fraud in the review article "*An Overview on the Impact of Food Fraud Incidences in Various Countries and its Detection Methods, Assessment Techniques, and Preventive Measures*," looking at how common it is and the serious risks it poses to the economy and public health. The study emphasizes the necessity for efficient detection and evaluation techniques while highlighting several food fraud cases from various nations. The



authors examine several cutting-edge methods used to detect phony food products, including spectroscopy, chromatography, and DNA profiling. To guarantee food authenticity, they also go over preventive measures, highlighting the necessity of more robust regulatory frameworks, greater public awareness, and the incorporation of contemporary technology like blockchain. The necessity of international cooperation in preventing food fraud and preserving customer confidence in the food business is emphasized in the review's conclusion. [18]

13. The methods created for the analysis of the lard and pork content in food and pharmaceutical goods are thoroughly evaluated in this review study by Prihandiwati et al., especially about halal authentication. The authors draw attention to the rising need to guarantee the legitimacy of goods with halal certification to safeguard customers' dietary requirements and preferences. To accurately identify trace amounts of pig or fat in goods deemed unfit for halal consumption, a variety of detection techniques are covered, including chromatographic methods, spectroscopic, and DNA-based approaches. To guarantee the integrity of food products in the halal market, the article also discusses the difficulties in obtaining halal certification and stresses the significance of employing accurate, sensitive, and quick analytical methods. To improve the precision and effectiveness of halal food verification procedures, the authors support ongoing developments in analytical technology. [19]

14. Akshay Ramani offers a novel and efficient method for detecting palm oil adulteration in ghee in his 2019 work "A Simple Rapid Technique for Detection of Palm Oil in Ghee," which was published in the Indian Journal of Dairy Science. The analysis highlights the urgent problem of ghee adulteration, including the financial and health consequences of mixing palm oil with real dairy fat, and criticizes traditional approaches for being labor-intensive and requiring complex equipment. By using a simple chemical assay that generates a definite visual or spectral reaction when palm oil is present, Ramani's method, in contrast, is intended to be quick, affordable, and simple to use. The study describes how this method was validated against

accepted standards, proving its sensitivity and dependability for regular quality monitoring in the dairy industry. [20]

Results

1. To identify adulteration, market cow ghee samples are screened (Pakeerathan & Samuddrika T.D.Y., July 2023). By evaluating variables such as moisture, density, refractive index, acid value, iodine value, saponification value, and peroxide value, this study compared the physicochemical characteristics of 13 market samples and laboratory-prepared pure cow ghee. The researchers discovered that 11 of the 13 samples had evidence of adulteration with edible oils using GC-MS analysis and chromogenic tests (furfural and Modified Salkowski), underscoring the frequency of fraud and the value of combining analytical methods.

2. FTIR Spectroscopy for the Identification of Adulteration in Ghee from Ahmedabad Markets (Pandey & Jariwala, 2015): This study examined ghee samples using FTIR spectroscopy to find adulterants such as Tran's fatty acids and other non-dairy fats. The procedure was straightforward, reasonably priced, and non-destructive, providing forensic scientists with a trustworthy way to evaluate the purity of ghee and spot harmful adulterants.

3. A Few Detection Techniques for Food Adulteration (Banti, June 2020): The intentional alteration of food products by adding, removing, or changing ingredients for financial benefit is covered in this review. It highlights the difficulties in identifying adulterants that closely resemble genuine items and divides detection techniques into physical, chemical, and biological categories. To combat food adulteration and safeguard public health, the study urges more research and coordinated action.

4. A Review of the Production and Adulteration of Indian Ghee and Tibetan Butter (Chi et al.): This article compares the methods used to produce Indian ghee and Tibetan butter, with an emphasis on dairy products made from cow's milk. It demonstrates that Indian ghee is usually tainted with vegetable oils and animal fats, but Tibetan butter is frequently tainted with animal fats and non-fat ingredients (such as mashed



potatoes). Since there isn't much research on Tibetan butter, the authors recommend using sophisticated detection methods like GC, FTIR, and E-nose technologies to guarantee product purity.

5. **Typical Milk Adulteration and How to Spot It (Azad & Ahmed, 2016):** This review lists prevalent adulterants and describes qualitative and quantitative detection techniques, with a focus on the worldwide problem of milk adulteration, especially in developing nations. It emphasizes the serious health hazards associated with milk adulteration and the necessity of creating more sophisticated methods to combat increasingly complex fraudulent schemes.

6. **Review of Milk and Milk Product Adulteration and Detection (Narayanan, 2019):** This review highlights common adulterants such as water, wheat, detergents, and synthetic milk to investigate the adulteration of milk and dairy products. To protect food quality and safety, Narayanan highlights the necessity of quick and easy detection techniques, such as iodine testing for starch and lactometer tests for dilution. She also advocates for increased public awareness and more stringent laws.

7. **A Review of Innovative Methods for Evaluating Adulterated Ghee (Kausar, 2022):** This paper outlines the most recent analytical methods for detecting ghee adulteration, addressing the shortcomings of traditional approaches. It highlights the necessity of incorporating these cutting-edge technologies into standard quality control procedures in the dairy industry by discussing sophisticated chromatographic (GC-MS, HPLC) and spectroscopic (FTIR) techniques, as well as new sensor-based and chemo-metric approaches.

8. **Cost-effective Technological Monitoring Systems for Paper-based Microfluidic Devices for Food Adulterants (Ray et al.):** The development of microfluidic paper analytical devices (PADs) for the on-site detection of food adulterants is examined in this article. Along with a variety of detection techniques (colorimetric, electrochemical, and fluorescence), the authors emphasize the devices' cost, mobility, and simplicity of use. To further develop this technology,

future enhancements such as increased sensitivity, repeatability, scalability, and digital integration (such as smartphone connectivity) are recommended.

9. **FT-IR Spectroscopy for the Identification of Adulteration in Market Ghee (Kalaimani et al.):** The authors of this paper concentrate on FT-IR spectroscopy in conjunction with chemometric analysis as a quick, non-destructive and cost-effective way to distinguish pure ghee from tainted samples. The method identifies adulterants such as vegetable oils and captures the distinct chemical fingerprints of authentic ghee, making it a viable tool for regular quality monitoring in the dairy industry.

10. **Food Forensics: Identification of Hidden Toxins in Typical Home Goods (Glorita, 2018):** This review offers a thorough examination of the harmful substances found in common foods, such as pesticides, heavy metals, mycotoxins, and microbial toxins. Supported by real-world case studies and a need for stronger regulatory measures, it highlights the importance of forensic science in detecting these toxins at trace levels utilizing contemporary techniques, including chromatography, mass spectrometry, immunoassays, and DNA-based technologies.

11. **Evaluation of Oil and Fat-Induced Ghee in Bangladesh (Ahmed, Hamid, & Rahman):** This study, which focuses on the Bangladeshi market, separates authentic ghee from samples tainted with non-dairy fats and oils using physicochemical parameters (moisture content, acidity, saponification value, and refractive index). Concerns about consumer health are raised by the high levels of adulteration discovered, which also emphasize the need for better regulatory supervision and quality control in the dairy sector.

12. **A Summary of the Effects of Food Fraud Incidents in Different Nations and Their Detection, Evaluation, and Prevention Strategies (Kamalapreetha et al.):** The effects of food fraud on consumer trust, economic stability, and public health are discussed in this international assessment. To guarantee food authenticity, it examines cutting-edge detection techniques like spectroscopy, chromatography, and



DNA profiling, as well as preventive strategies, including strong regulatory frameworks, public awareness campaigns, and cutting-edge technology like blockchain.

13. Prihandiwati et al. reviewed the developed techniques for analyzing pork and lard in food and pharmaceutical products for halal authentication. This review assesses analytical techniques for identifying lard and pork adulteration in food and medicinal goods with an emphasis on halal verification. It discusses chromatographic, spectroscopic, and DNA-based methods, emphasizing both their advantages and disadvantages in guaranteeing that goods fulfil halal requirements. It also recommends continued technological advancements to improve detection precision.

14. A Quick and Easy Method for Finding Palm Oil in Ghee (Ramani, 2019): This study presents a brand-new, quick, and affordable chemical test for identifying ghee that contains adulterated palm oil. Ramani's technology is suited for routine quality control in the dairy industry because it has been tested against standard protocols and, in contrast to existing, labor-intensive methods, produces a clear visual or spectral reaction upon the presence of palm oil

Discussion

These reviews highlight how the field of food adulteration detection is changing, especially in dairy products like milk and ghee. To ensure product authenticity, a variety of analytical techniques have been used, ranging from sophisticated spectroscopic tools (FTIR) and chromatographic methods (GC-MS, HPLC) to traditional physicochemical assessments and novel sensor-based approaches like microfluidic paper devices. [21] Even though individual studies show how common adulterants like animal fats, edible oils, and even non-dairy fillers are, they also point to recurring issues like the need for quick, easy, and affordable methods as well as strong validation against a variety of adulteration techniques. The use of cutting-edge technology for traceability, such as blockchain, digital connection, and chemometric analysis, suggests that on-site testing and improved regulatory control may become more dependable and accessible in the future.

[22] In general, these results support concerted efforts by researchers, industry participants, and regulatory agencies to enhance detection methods throughout time and protect public health from the complex dangers of food fraud. In conclusion, the reviewed research on food adulteration detection highlights the urgent need for creative, practical, and affordable methods to stop the pervasive adulteration of milk, ghee, and other food items. These evaluations highlight developments that improve the sensitivity, speed, and accessibility of detection, ranging from traditional techniques like GC-MS and FTIR spectroscopy to cutting-edge technologies like microfluidic paper devices and AI-driven solutions. Together, the results highlight how crucial it is to conduct more research, strengthen regulations, and raise public knowledge to guarantee the safety and integrity of food products, lower health risks, and increase customer trust in the food sector.

Conclusion

The combined knowledge from these investigations highlights the urgent need for sophisticated, quick, and trustworthy techniques to identify food adulteration, especially in dairy products like milk and ghee. Modern approaches, from chromatographic and spectroscopic methods to novel sensor-based and microfluidic technologies, have been combined with classical physicochemical investigations to greatly improve our ability to detect adulterants with high sensitivity and specificity. In the end, these advancements protect consumer health and uphold market integrity by enabling more thorough quality control and regulatory oversight, as well as opening the door for on-site, real-time monitoring. In an increasingly intricate global supply chain, ongoing research and cross-sector cooperation are still crucial to addressing new issues and guaranteeing the authenticity of food products. In summary, the thorough analysis of numerous studies shows that although there have been notable advancements in the identification of food adulteration, especially in dairy products like milk and ghee, there are still issues that call for more creativity and the fusion of different analytical methods. Together, the studies show that sophisticated chromatographic (GC-MS, HPLC) and spectroscopic (FTIR) techniques, in conjunction with conventional physicochemical methods, provide reliable, non-destructive, and quick



ways to detect adulterants, which can range from synthetic additives to edible oils and animal fats.

Furthermore, the advent of digital integration (including chemometric analysis and possible smartphone connectivity), sensor-based technologies, and microfluidic paper analytical tools has made it possible for real-time, on-site monitoring, which has increased the overall effectiveness of quality control procedures. Despite these developments, standardized procedures increased sensitivity and reproducibility of detection techniques, and more stringent regulatory monitoring are still necessary due to the complexity of contemporary food supply chains and the changing tactics of food fraudsters. The development and application of creative solutions that not only guarantee the authenticity of food items but also safeguard consumer health and uphold market integrity globally ultimately depend on ongoing research and cross-sector cooperation.

References

1. Wijayasiriwardena C. 2023. Screening of market cow's ghee samples to detect adulteration.
2. Ahmed TA, Ahmed S. 2016. Common milk adulteration and their detection techniques. *Int J Food Contamination*. 3:5.
3. Anagaw YK, Woldemichael AW, Lewi DTG, Wolelaw MC, Ayele TA, Tadele WS, Mamuye LM. 2024. Food adulteration: causes, risks, and detection techniques—review. *SAGE Open Med*. 12:1–12.
4. Agrawal U, Nasrin BN, Mohapatra SA. 2024. Design & development of adulteration detection system by fumigation method & machine learning techniques. *Sci Rep*. 14:1843.
5. Bharti A. 2024. Progressive analytical techniques utilized for the detection of contaminants attributed to food safety and security. *Talanta Open*. 10:100218.
6. Nagalla SY. 2020. Detection of adulteration in ghee - a spoonful of yellow magic. *Int J Futur Manag Res (IJFMR)*. 7(5):16–23.
7. Wijayasiriwardena C. 2023. Screening of market cow's ghee samples to detect adulteration.
8. Jariwala AP, Patel KN. 2015. Detection of adulteration in ghee from markets of Ahmedabad by FTIR spectroscopy. *J Chem Pharm Res*. 7(5):950–954.
9. Kaushal S. 2024. Overview of food adulteration: causes, impacts and detection. *J Sci Res Rep*. 30(3):72–83.
10. Chi F. 2024. Tibetan butter and Indian ghee: a review on their production and adulteration. *Agriculture*. 14(2):300.
11. Ahmed S. 2016. Common milk adulteration and their detection techniques. *Int J Food Contamination*. 3:5.
12. Narayanan R. 2019. Review on adulteration of milk and milk products and detection. *Asian J Home Sci*. 14(1):85–90.
13. Ray R. 2022. Paper-based microfluidic devices for food adulterants: cost-effective technological monitoring systems. *Food Chem*. 376:131902.
14. Kalaimani PS, Subramanian K, Stars SK. 2004. Detection of adulteration in market ghee using FT-IR spectroscopy. *Int J Res Appl Sci Eng Technol*. 2(1):18–23.
15. Glorita F. 2018. Food forensics: detection of hidden toxins present in common household consumables. *J Forensic Sci Crim Investig*. 7(1):555705.
16. Ahmed S. 2020. Assessment of ghee adulterated with oils and fats in Bangladesh. *J Adv Vet Anim Res*. 7(4):785–791.
17. KB. 2023. An overview on the impact of food fraud incidences in various countries and its



detection methods, assessment techniques and preventive measures. SIET. 6(1):45–57.

18. Prihandiwati E. 2024. A review of the developed methods for the analysis of lard and pork in food and pharmaceutical products for halal authentication. Food Res. 8(3):128–140.
19. Ramani A. 2019. A simple rapid technique for detection of palm oil in ghee. Int J Food Sci. 4(2):55–60.
20. Ramani THA. 2025. Comprehensive studies on detection of palm oil adulteration in clarified milk fat (ghee). Int J Food Sci. 5(1):15–28.
21. Gandhi K. 2022. Detection of coconut oil in ghee using ATR-FTIR and chemometrics. Appl Food Res. 2:100125.