

FOOD ADULTERATION AND ITS IMPACT ON PUBLIC HEALTH: DETECTION TECHNIQUES AND LEGAL FRAMEWORK

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Abstract

Food adulteration has become a serious public health issue with implications for food safety, consumer rights, and trust in the food supply system. Intentional or accidental alteration, substitution, addition, or removal of substances from food means that food products may no longer have the necessary quality, adequate nutritional value, or safety. Consumption of contaminated food products might result in occurrence of illnesses caused by consumption of food with pathogenic agents in it, nutritional deficiencies, chronic health problems, and negative socio-economic effects.

In India, supervision over food safety is implemented through the Food Safety and Standards Act of 2006, creating the Food Safety and Standards Authority of India (FSSAI) aimed at making safe and quality food available to consumers. Though India has been using a well-structured legal approach to food supervision, several issues call for attention, such as insufficient enforcement of the law, inadequate availability of testing facilities, lack of awareness, and changing nature of fraud. Judicial practice has also proved to be helpful in making food safety regulation more effective through appearance of courtsdecisions protecting consumers from adverse impact of food adulteration.

This paper explores the idea, types, and effects of food adulteration on consumer health. It also reviews the various detection methods, including traditional techniques, chromatography

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processes, and DNA analysis. The study shows substantial advancements in science and technology that help in developing better methods for food adulteration detection and effective enforcement mechanisms.

Keywords: *Food Adulteration, Food Safety, FSSAI, Food Safety and Standards Act, Consumer Protection, Public Health, Food Fraud, Detection Methods, Food Regulation, India.*

INTRODUCTION

Provision of safe and nutritious food is essential for both the protection of public health and the preservation of human dignity. Changes in food safety over time from being a public health concern have changed food safety into an important issue concerning law and regulation due to the increasing number of fraud cases.

To maintain a healthy population and society, it is important to have access to safe and nutritious food. Food adulteration, which refers to the intentional or unintentional addition, replacement, omission, or modification of a food ingredient in such a way that it alters its quality, safety, or nutritional value, is an obstacle to food safety in countries around the world;³ this has become even more true recently with the increasing incidence of food adulteration, especially in developing countries like India.⁴ Food adulteration is largely motivated by economic profit, where unscrupulous traders deliberately impair food quality with the aim of making money at the expense of the health of the people.

While some of the negative effects of food adulteration can occur (e.g., through consumption of contaminated food) and others can occur at a later time (e.g., through chronic diseases caused by occasional consumption of contaminated food), the effects of food adulteration are widespread and no one is exempt from food-related health problems caused by consuming adulterated food. Health risks of food adulteration depend on both the type of adulteration, as well as on exposure time.

³S. Bansal, A. Singh, M. Mangal, A. Mangal & S. Kumar, Food Adulteration: Sources, Health Risks, and Detection Methods, 57(6) Critical Reviews in Food Science and Nutrition 1174 (2017).

⁴A. Haji, K. Desalegn & H. Hassen, Selected Food Items Adulteration, Their Impacts on Public Health, and Detection Methods: A Review, 11 Food Science & Nutrition 7534 (2023).

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The prevalence of insecure goods such as milk, cooking oil, seasonings, confectionery items, fruit, and all other everyday household food items proves to us that food adulteration is more than just an issue for the consumer; it also represents a huge public health and legal issues.

A comprehensive framework of legislation exists in India designed to control the safety of foods, primarily the Food Safety and Standards Act, 2006, and the subsequent establishment of the Food Safety and Standards Authority of India (FSSAI) with oversight authority over that Act. Although this legislation was intended to regulate and control food safety and functionality of these functions the FSSAI has encountered many difficulties in carrying out those functions. Some of the reasons for this failure are limited to insufficient inspection of foods and their ingredients by the FSSAI, not having the proper equipment to test samples, being unaware of their rights, and the ever-changing techniques of unscrupulous individuals who produce and sell food products, etc. In the case of *Pyarali K. Tejani v. Mahadeo Ramchandra Dange*, the Apex Court held that offences of food adulteration are crimes related to social welfare, leads to strict punishment in order to protect public health.⁵ Advances in forensic science and food testing have added a great deal of strength to the implementation of food safety regulations and ensured accuracy in identifying cases of food adulteration.

The Supreme Court focused on the implementation of the Prevention of Food Adulteration Act in the case of *Municipal Corporation of Delhi v. Kacheroo Mal*, and stated that the purpose of the Act is to protect consumers against the negative consequences of eating adulterated food and therefore needs to be interpreted in ways that would contribute to the achievement of its protective objectives.⁶

2. FOOD ADULTERATION - THE CONCEPT AND FORMS

Food adulteration can be defined as every act that is carried out either deliberately or unknowingly so that the quality, purity, composition, or safety of food is compromised by adding something that shouldn't be there and/or removing something essential from the food, thus resulting in food that can be considered unsafe for consumers. Food adulteration is a major problem for food safety and affects consumer health (and nutrition) and consumer confidence in

⁵*Pyarali K. Tejani v. Mahadeo Ramchandra Dange*, (1974) 1 S.C.C. 167.

⁶*Municipal Corporation of Delhi v. Kacheroo Mal*, A.I.R. 1976 S.C. 394.

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the food supply chain. Food adulteration can occur at all stages of the food supply chain; from the time food ingredients are produced until they reach consumers following storage, transportation and marketing. The forms of food adulteration can vary, depending upon the type and source of contamination, as follows.

2.1 Intentional Adulteration

Deliberate tampering is among the most severe instances of food crime since it is primarily driven by profit and not by carelessness. Dishonest producers knowingly use less expensive ingredients or add dangerous substances to maximize their profits, all while deceiving consumers. For example, mixing water with milk, adding artificial colours to spices, blending edible oils with lower-cost oils, or mixing stones and sand with grains are all examples of intentional adulteration. Similarly, the High Court observed that the provisions of Food Safety law should be interpreted generously, since a narrow construction of those provisions would negate the objective of food safety law - to protect consumers from the risk of consuming food that has been adulterated.⁷ Intentional adulteration not only deceives consumers but also creates potential health risks to consumers. The Food Safety and Standards Act, 2006 places a legal responsibility on food business operators to ensure that food supplied to consumers is safe and of the required standard. A person who knowingly puts these standards in jeopardy might be punished following Food Safety and Standards Act, 2006. In the cases of food adulteration that leads to grievous hurt, death, or fraud, a liability for such actions might follow the relevant provisions of the Bharatiya Nyaya Sanhita, 2023. These laws work together to discourage fraudulent practices, protect consumers, and ensure that only safe and wholesome food reaches the public and also this could include instances of food adulteration that cause injury to individuals' health or result in threat to health and life of the individuals.⁸ Courts in accordance with their authority to interpret/establish laws will impose penalties for acts of food adulteration in accordance with the principles and procedures established by the food safety law and will hold individuals liable.

The purpose of the above-discussed laws and their interpretation is to create a framework of protection for consumers, protect food and the environment, maintain the high quality and safe

⁷ *State of Kerala v. Allassery Mohammed*, (1978) 1 S.C.C. 552.

⁸ Bharatiya Nyaya Sanhita, No. 45 of 2023.

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products produced by food operations, and prohibit unfair operating practices in the food industry.

2.2 Incidental Adulteration

Incidental adulteration is unintentional food adulteration that may occur due to poor personal hygiene of those handling food, improper food storage practices, improper transportation or processing of food, environmental contamination (pesticide residues, industrial pollutants or packaging materials), or accidental contamination with chemicals during the manufacturing process.⁹ While these substances may unintentionally circulate through the supply chain, they can have major impact the overall safety and quality of the finished product. The Food Safety and Standards Act, 2006, requires that food business owners take reasonable steps to ensure food safety at every stage of production, storage, transportation, and sale. If food business operators breach the prescribed food safety requirements, they may face serious legal consequences for selling unsafe food to consumers.¹⁰ Accidental adulteration differs from intentional adulteration and usually occurs because of negligence, lack of sanitation, poor manufacturing methods, or pollution in the environment. Therefore, regardless of their possible lack of fraudulent intention, food businesses have to comply with established regulations.

2.3 Metallic Adulteration

Heavy metal contamination also known as metallic adulteration is when food becomes contaminated with heavy toxic metals like lead, arsenic, mercury, cadmium, etc. Heavy metals can enter our food supply from numerous sources such as soil and water contamination, industrial waste, or during the processing and preparation of food. Long-term exposure to heavy metals can damage the nervous system, kidneys, liver, and many other vital organs.¹¹ In *Vellore Citizens' Welfare Forum v. Union of India*, the Supreme Court recognised the Precautionary Principle and the Polluter Pays Principle to ensure that pollution of the environment is prevented before it causes harm. These principles are equally applicable to pollution by an industrial

⁹ Srivastava, S., *Food Adulteration Affecting the Nutrition and Health of Human Beings* (2016), pp. 65–70.

¹⁰ Food Safety and Standards Act, 2006, ss. 26, 27 & 59.

¹¹ K. R. Gopalan, V. Mahin Koska, Y. Alwin Fredrick, A. N. Logu, K. Anusree & M. Sivaswamy, *Contaminated Consumption: Unveiling the Health Hazards of Food Adulteration and Its Profound Impact on Public Health in India*, 13(7) *J. Pioneer. Med. Sci.* 75 (2024).

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activity such as the contamination of agricultural land or water sources resulting in heavy metals entering the food chain.¹²

2.4 Biological (Microbial) Adulteration

Biological or microbial adulteration refers to when food is contaminated by harmful bacteria, viruses, fungi or parasites as a result of improper hygiene, inadequate sanitation, or improper food storage. Adulterated food can cause foodborne illness or serious disease and has severe effects on children, the elderly and on people with weakened immune systems. The Food Safety and Standards Authority of India (FSSAI) has the responsibility to focus on food safety through inspections, surveillance, and the enforcement of hygiene requirements. These measures support fulfilment of with food safety laws and help prevent microbial contamination¹³

2.5 Chemical Adulteration

Chemical adulteration occurs when there are harmful chemicals present in foods either caused by intent or accident. Examples include the use of artificial ripening agents, excessive pesticide residues, use of synthetic coloring agents, the use of prohibited food additives, and the addition of detergent to milk among others. Continuing to consume chemically adulterated foods can lead to poisoning, organ damage, allergic reactions and other long-term effects of health.¹⁴ Although the Legal Metrology Act of 2009 does not specifically mention chemical adulteration, it does enhance transparency in the sale of packaged foods through the requirement of accurate declarations of quantity, identity and branding. This allows customers to identify “false packaging” for chemically contaminated and/or non-compliant food goods, as well as laying the groundwork for the Legal Metrology Act (2009), which provides regulations to assist the implementation of food safety legislation.¹⁵

3. PUBLIC HEALTH IMPLICATIONS OF FOOD ADULTERATION

¹²*Vellore Citizens' Welfare Forum v. Union of India*, (1996) 5 S.C.C. 647.

¹³Food Safety and Standards Act 2006, s 16; Food Safety and Standards Authority of India, Food Safety Management System (FSMS) Guidance Documents.

¹⁴S. K. Beepala, Food Adulteration: Public Health Hazards and Socio-Economic Risks—A Critical Review, 13(10) Int'l J. for Rsch. in Applied Sci. & Eng'g Tech. 695 (2025).

¹⁵Legal Metrology Act, 2009, §§ 18–19; Legal Metrology (Packaged Commodities) Rules, 2011, rr. 6–9; Food Safety and Standards Act, 2006, §§ 23–24.

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Food adulteration endangers people's health. The use of unsafe or low-quality ingredients in food can have negative impacts on people's health and lives. Food adulteration is a global issue that concerns food safety agencies and policy makers because it has short-term and long-term negative effects on human health.¹⁶

3.1 Diseases; Physical Health

Food adulteration may result in foodborne illness (food poisoning) and allergic reactions from ingesting toxic chemicals, food coloring materials or additives, or pathogenic organisms on contaminated foods. Increased vulnerability to these types of foodborne illnesses occurs among children, pregnant women and older adults.¹⁷ Whether someone becomes ill from consuming tainted food from a restaurant or elsewhere depends on two factors: (1) what kind of contaminant was present and (2) how healthy that person was at the time they ingested that food. The World Health Organization continues to state that food borne illnesses are still a major cause of morbidity for all people. If someone eats contaminated food and develops the illness, they can develop further complications; and often they require emergency medical treatment and/or hospitalization.¹⁸

3.2 Dietary Shortcomings and Nutritional Deficiencies

When food is adulterated with lower quality products (diluted), or valuable nutrients are removed. This may result in people not receiving adequate nutrition. For example, people living in poverty and on food assistance programmes are at risk of developing a nutritional deficiency due to food adulteration. Consistent eating of nutritionally deficient or watered down food can cause abnormal growth, poor physical development, and lesser overall health. Children are at a special risk since malnutrition in early childhood can negatively impact on both cognitive development

¹⁶K. R. Gopalan, V. Mahin Koska, Y. Alwin Fredrick, Akalya Nathan Logu, K. Anusree & Muthukumaran Sivaswamy, *Contaminated Consumption: Unveiling the Health Hazards of Food Adulteration and Its Profound Impact on Public Health in India*, 13(7) J. Pioneering Med. Sci. 75 (2024).

¹⁷Yeniewa Kerie Anagaw et al., *Food Adulteration: Causes, Risks, and Detection Techniques - Review*, 12 SAGE Open Med. 20503121241250184 (2024).

¹⁸World Health Org., *Estimating the Burden of Foodborne Diseases* (2015); World Health Org., *Food Safety: Key Facts* (2022).

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and immunity in the long term. The FAO also states that safe and healthy food is part of a sustainable food supply.¹⁹

3.3 Chronic Health Problems and Diseases

People who consume adulterated foods regularly may develop chronic diseases such as liver disease, kidney disease, heart disease, neurological disease, and some forms of cancer. As people continue to consume these chemicals and metals, they become more likely to develop these diseases.²⁰

3.4 Socio-economics Impact of Food Adulteration

The health effects of food adulteration and the economic burden placed on individuals and/or the healthcare system is twofold when it comes to the implications of food fraud, which include increased medical costs associated with food, lost productivity due to food injuries/illnesses, and reduced consumer confidence in food products.²¹ Preventing food adulteration is vital in protecting public health, providing nutritional security, and supporting consumer welfare.

Food adulteration has effects on health that go beyond just illness. It has increased the burden on our healthcare system, caused people not to work properly, and caused the loss of confidence in the government, which manages the food market.

4. LEGAL AND REGULATORY FRAMEWORK:

4.1 Indian Legal Framework and The Role of FSSAI

In India, the legal framework governing food safety is, in general, the Food Safety and Standards Act, 2006 (FSSA). This Act was created to provide a unified legal framework for the regulation of food safety in India. Before the establishment of this framework under the FSSA, food safety

¹⁹Food & Agric. Org. of the U.N., *The State of Food Security and Nutrition in the World 2024* (2024).

²⁰Gopalan et al., *supra* note 1; S. K. Beepala, *Food Adulteration: Public Health Hazards and Socio-Economic Risks - A Critical Review*, 13(10) Int'l J. for Rsch. in Applied Sci. & Eng'g Tech. 695 (2025).

²¹S. K. Beepala, *Food Adulteration: Public Health Hazards and Socio-Economic Risks - A Critical Review*, 13(10) Int'l J. for Rsch. in Applied Sci. & Eng'g Tech. 695 (2025).

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regulations were governed by a multitude of different pieces of legislation. As a result, there was duplication of authority to regulate food and inconsistency in the enforcement of these food safety laws across the many different jurisdictions regulating food. The FSSA was an attempt to bring together all of the separate statutes regulating food safety in order to create one law that used a risk-based, scientific approach for regulating food safety with the health of consumers being the primary concern of the regulation of food.²²

The Food Safety and Standards Authority of India (FSSAI) is the apex statutory body created by the FSSA that is responsible for developing food safety standards and regulating the manufacturing, storage, distribution, sale and importing of food to make sure that all food available to the public for human consumption is safe.²³

The Food Safety and Standards Act, 2006 provides a complete system of governance to ensure food safety in India. The Act gives Food Safety Officers authority to inspect food businesses, collect samples and conduct investigations and initiate relevant legal actions for violation of food safety norms. The enforcement powers enable regulatory bodies to ensure the implementation of safety rules and prevent the production, distribution, and sale of unsafe food products.²⁴

In addition to setting standards, the FSSAI has various regulatory functions including licensing, inspection, surveillance, sampling food, testing food in laboratories, and forcing legal action against the offenders of the Food Safety and Standard Act, 2006.

The Act's effective implementation is achievable through a set of subordinate laws that deal with registration, packaging, labeling, food recalls, and compliance. Among them, the Food safety and Standards (Licensing and Registration of Food Businesses) Regulations, 2011 outlines the requirement of registration or license for food businesses depending on their scale of operations.

²²The Food Safety and Standards Bill, 2005, Statement of Objects and Reasons, Bill No. 98 of 2005.

²³Food Safety and Standards Act, 2006, §§ 16–18.

²⁴Food Safety and Standards Act, 2006, §§ 16, 38, 41, 42.

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Registration and licensing is not only an administrative necessity but also an important means of enforcing accountability and regulation of all activities of the licensees.²⁵

Another integral aspect of the legal framework consists of the Food safety and standards(packing)Regulation, 2018 and the Food safety and standards(Labelling and display) Regulation, 2020 These regulations obligate food operators to disclose information to the consumers with respect to the contents and nutrition information concerning the food products, and declarations about allergens, date of expiry, and origin of product as required. This provision makes the food consumer informed and adds to their rights through the disclosure of transparent information.²⁶

The Food Safety and Standards Act of 2006 divides food offences into different categories covering sub-standard food, misbranded food, food containing extraneous matter, misleading advertisements, and unsafe food. The Act provides for penalties according to the seriousness of the offence; usually, less serious offences attract only fines while in cases where violations lead to bodily injury or death, imprisonment could also be handed down besides fines.²⁷ The law on consumer protection in India also plays its role in protecting consumers because, along with the food safety law, A Consumer may seek compensation under the consumer protection Act,2019.²⁸

Judicial activism has also played a pivotal role in contributing to food safety governance in India. The courts in India have time and again accepted that food safety forms part of the right to life under Article 21 of the Indian Constitution; hence, it is the duty of the different statutory authorities to ensure the maintenance of food safety standards. It must be noted that there is also the aspect of judicial interpretation that has played an important role in guiding the authorities involved in maintaining food safety.²⁹

²⁵Food Safety and Standards (Licensing and Registration of Food Businesses) Regulations, 2011.

²⁶Food Safety and Standards (Packaging) Regulations, 2018; Food Safety and Standards (Labelling and Display) Regulations, 2020.

²⁷Food Safety and Standards Act, 2006, §§ 48–67.

²⁸Consumer Protection Act, 2019, §§ 2(10), 2(34), 2(47), 35.

²⁹*Centre for Public Interest Litigation v. Union of India*, (2012) 3 S.C.C. 1.

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The highest level of courts has directed the different statutory authorities to put in place Sufficient enforcement measures, failings in which entails violations of their statutory duties. There is also the complicity of the factors which are contributing to the challenges being faced in the implementation and enforcement of the food safety laws, such as lack of proper laboratory facilities, unavailability of trained manpower, delay in prosecution of offenders, and inconsistency in enforcement across the regions as result of different levels of economic development, among others.

4.2 International Framework

Food fraud has turned into a global regulatory issue because a lot of contaminated and deceptively represented food products travel internationally. To respond to this emerging trend, countries are adopting harmonized legal principles or internationally accepted norms, among other things, for efficient monitoring food integrity and guaranteeing consumer protection.³⁰

The Codex Alimentarius Commission, set up by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), represents the main institution of international food regulation. Codex standards are not mandatory, but they act as worldwide standards for food safety, food hygiene, additives, contaminants, pesticide residue levels, food labeling, and methods of testing and analysis. Such principles are being incorporated into national laws, such as in India.³¹

Trade in food products is also regulated on the international level through the World Trade Organization (WTO) with the help of the Agreement on the Application of Sanitary and Phytosanitary Measures. The SPS Agreement allows Members to implement any necessary

³⁰M. Esteki, J. Regueiro& J. Simal-Gándara, *Tackling Fraudsters with Global Strategies to Expose Fraud in the Food Chain*, 18(2) Comprehensive Revs. Food Sci. & Food Safety 425 (2019).

³¹Codex Alimentarius Commission, *General Principles of Food Hygiene (latest edition).

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measures for protecting human beings and animals or plants, but such a measure should be scientifically based and not an unreasonable barrier to trade.³²

The TBT Agreement complements the provisions of the SPS Agreement by removing unnecessary barriers posed by technical regulations, such as technical standards, packaging, and labeling regulations. In general, the agreement covers such aspects as transparency, standardization, and mutual recognition of the agreements and enables the states to retain the right to pursue their legitimate public interests, which include food safety and consumer protection.³³

Some countries have already introduced the concept of traceability as a tool of combatting food-related crimes. For example, the General Food Law (EC) No. 178/2002 implies that the concept of traceability mandates the identification of the food product suppliers and consumers for the purpose of fast recalls of foods, accountability of the products, and determining the source of tainted foods. International regulatory bodies are starting to lend increased attention to information-sharing and cooperation mechanisms among authorities.³⁴

The International Food Safety Authorities Network (INFOSAN) is one such initiative that was set up with the objective of facilitating information exchange regarding food safety issues during crisis situations (food safety emergencies).³⁵ There has been an increasing trend in the recent international policymaking debates to use high-technology means of combating the food fraud, such as DNA analysis, isotope testing, blockchain-based traceability systems, artificial intelligence, and digital authentication devices as a means of detection of fraudulent practices and improving the transparency of the supply chains. Such advanced technologies facilitate

³²Agreement on the Application of Sanitary and Phytosanitary Measures, arts. 2, 3, 5, Apr. 15, 1994, Marrakesh Agreement Establishing the World Trade Organization, Annex 1A, 1867 U.N.T.S. 493.

³³Agreement on Technical Barriers to Trade, arts. 2, 5, Apr. 15, 1994, Marrakesh Agreement Establishing the World Trade Organization, Annex 1A, 1868 U.N.T.S. 120.

³⁴Regulation (EC) No. 178/2002 of the European Parliament and of the Council, arts. 17–19, 2002 O.J. (L 31) 1.

³⁵World Health Organization & Food and Agriculture Organization of the United Nations, *International Food Safety Authorities Network (INFOSAN): Operational Framework* (2020).

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enforcement of regulatory measures as they are used by the regulators to make their investigations more effective.³⁶

Research shows that jurisdictions that have established integrated regulatory systems, have developed inspection systems, accredited laboratories for food analysis, and maintain efficient inter-agency coordination are more effective in prevention of food fraud. This means that international experience indicates the need for reforming food safety regulations in order to include capacity building, scientific infrastructure, technological capacity, and active cooperation between regulatory authorities.

5. DETECTION TECHNIQUES FOR FOOD ADULTERATION

5.1 Conventional Techniques

Conventional techniques are some of the earliest and most common methods for detecting food adulteration. Conventional techniques rely primarily on visual observation; microscopic examination; basic chemical tests and sensory evaluation of food using attributes such as appearance, flavour, aroma and texture. These methods tend to be inexpensive, simple to utilise, and do not require specialised laboratory equipment or highly trained staff. In a majority of instances, conventional techniques can provide the initial identification of suspicious food, prior to conducting thorough testing in a laboratory setting. For example, straightforward chemical testing methods can reveal commonly used food adulterants such as starches added to milk, colourants added to spices, and/or chalk powder added to flour. Microscopic analysis is also useful in detecting foreign bodies, impurities or food ingredient substitution. While there are many practical advantages to traditional methods there are some limitations that exist with their use. Traditional techniques are generally less sensitive than modern analytical methods; therefore, there is the potential for them to not identify an adulterant that is present in very small quantities or that is chemically similar in nature to the product being tested. As such, conventional analytical methods continue to have value as initial screening tests, but they are frequently used

³⁶Anushree Bose & Sanjay Sharma, *Global Regulatory Trends and Comparative Insights: Nutraceuticals in the USA, India, and Europe*, 31 PharmaNutrition 100430 (2025).

in conjunction with more advanced analytical methods to provide reliable results in the identification of food adulteration.³⁷

5.2 Chromatographic Techniques

Chromatographic techniques are some of the most reliable and accurate methods for the detection of food adulteration, and therefore, some of the most widely used techniques in modern food analysis. Chromatography allows the separation of individual chemical components of food samples so that both genuine and adulterated components can be identified with a high level of accuracy. Some examples of chromatographic methods include gas chromatography (GC), liquid chromatography (LC), and high-performance liquid chromatography (HPLC). Each method has a different analytical capability, and the choice of which method to use depends on the type of food sample being analysed, and which specific type of adulterant is being tested for. Chromatography has been used extensively to detect adulteration of products such as edible oils, milk and dairy products, honey, spices, beverages, and herbal products. When used in combination with mass spectrometry, chromatographic techniques provide very sensitive qualitative and quantitative results, making them useful tools in the routine testing of laboratories and legal enforcement. Chromatographic techniques are trusted by many as a basis for confirming food authenticity and protecting consumers from food fraud, even though they require specialised equipment, highly trained personnel, and often result in higher overall costs for performing the analysis.^{38, 39} The scientific evidence that chromatography provides helps feel more certain with the statement regarding the presence of forbidden substances allowing both prosecution and enforcement of regulations.

³⁷Misgana Banti, *Food Adulteration and Some Methods of Detection, Review*, 9(3) International Journal of Nutrition and Food Sciences 86, 86–94 (2020), <https://doi.org/10.11648/j.ijnfs.20200903.13>.

³⁸Polu, P., Vyas, M., & Babu, M. R. (2026). State-of-the-Art Analytical Technologies for Detection of Food Adulteration: Advances, Validation, and Future Horizons. *Critical Reviews in Analytical Chemistry*, 1–27. <https://doi.org/10.1080/10408347.2026.2625392>.

³⁹Jan Hansen, Christoph Kunert, Hendrik Münstermann, Klaus-Peter Ræzke & Stefan Seifert, *Application of Untargeted Liquid Chromatography-Mass Spectrometry to Routine Analysis of Food Using Three-Dimensional Bucketing and Machine Learning*, 14 Scientific Reports art. 17123 (2024), <https://doi.org/10.1038/s41598-024-67459-y>.

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5.3 Spectroscopic Methods

To detect food adulteration, scientists use spectroscopic methods because they can provide rapid, precise, and non-destructive evaluation of food samples by measuring how food constituents react when subjected to light or radio-frequency radiation to determine if chemistries within food samples have changed through time/space. Spectroscopy is the process that can be used to evaluate the presence of additives in such products as milk, cooking oils, honey, spices, coffee and fruit juices, and has already been shown to be very effective. With an advantage of requiring little or no preparation, the overall speed and efficiency of the testing process when using spectroscopy is greater than almost any other laboratory methods. Currently, many researchers are working on combining spectrographic methods with advanced data processing and machine-deep learning techniques to improve the ability to identify food adulteration, and to enable even small differences between real and altered foods to be as accurately quantified. For this reason, modern-day spectroscopic analysis techniques have become increasingly vital in the advancement of testing food for quality and authenticity.⁴⁰

5.4 DNA-Based Detection Techniques

Techniques based on DNA analysis of the ingredients of foods are considered highly effective methods of detecting food fraud, especially in cases of species substitution, mislabelling and use of undeclared ingredients. The DNA-based methods permit analysis of the genetic content of food products and allow the identification of their biological origin, even after processing. The PCR (Polymerase Chain Reaction) method, DNA barcoding and DNA sequencing are some of the methods used to determine the authenticity of meat, fish, dairy products, herbal medicine and plant-based foods. DNA methods offer exceptional specificity and sensitivity when compared to traditional strategies since they can detect very small amounts of the adulterants in question. The methods are especially useful in discovering the use of components that cannot be detected using

⁴⁰Ritu Goyal, Priyanka Singha & S.K. Singh, *Spectroscopic Food Adulteration Detection Using Machine Learning: Current Challenges and Future Prospects*, 150 Trends in Food Science & Technology 104377 (2024), <https://doi.org/10.1016/j.tifs.2024.104377>.

physical and chemical tests.⁴¹With the help of DNA methods, case related to species substitution, fraudulent food activities, or misleading labeling can be easily won.

5.5Biosensors and Nanotechnology

The growing importance of biosensors and nanotechnology is transforming food quality control and its systems. These devices are able to provide fast, sensitive and portable analytical methods. Biosensors are devices which use biological recognition components and are fitted with a measuring device which detects suspicious substances. The introduction of nanomaterials into biosensor design helps increase detection speed, sensitivity and precision. These devices can detect food adulteration even at very low concentrations. Recently portable at paper biosensors were developed. These devices offer simple testing options. The main advantage of biosensors is time and cost-effective testing.^{42, 43}

Recommendations

The Government must regularly evaluate and modify the Food Safety and Standards Act of 2006 to keep in step with new forms of food adulteration brought about by improving technologies, It is important to include more precise provisions on traceability, mandatory product recalls, and compliance by food business operators to improve enforcement.⁴⁴

Regulatory bodies must make use of risk-based inspections, create better laboratory infrastructure, and implement new scientific techniques of detecting food adulteration. There

⁴¹P. Polu, M. Vyas& M.R. Babu,*State-of-the-Art Analytical Technologies for Detection of Food Adulteration: Advances, Validation, and Future Horizons*, Critical Reviews in Analytical Chemistry 1–27 (2026), <https://doi.org/10.1080/10408347.2026.2625392>.

⁴²Han, B., Xie, X., Zhao, Y., Zhang, J., Yang, X., Jiang, Y., Zhang, W., & Zhang, X. (2025). Recent Development and Applications of Emerging Biosensing Technologies and On-Site Analytical Devices for Food Adulteration Detection: A Critical Review. *Critical Reviews in Food Science and Nutrition*, 66, 2139–2158. <https://doi.org/10.1080/10408398.2025.2564216>.

⁴³Zahra Mohammadi& S. Jafari, *Detection of Food Spoilage and Adulteration by Novel Nanomaterial-Based Sensors*, 286 *Advances in Colloid and Interface Science* 102297 (2020), <https://doi.org/10.1016/j.cis.2020.102297>.

⁴⁴*Food Safety and Standards Act, 2006*, No. 34 of 2006, §§ 16, 18, 26, 27, 59 (India).

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needs to be more cooperation among food safety agencies, law enforcement organizations, and consumer protection bodies for effective implementation of food safety laws.

Programs aimed at creating public awareness should be expanded so that consumers become aware of food adulteration, food labeling, and possible remedies. Information channels for whistle-blowers should be improved.

India must continue to align its food safety regulations with international standards through effective enforcement and thorough inspections, as well as stricter penalties for repeated offenders and high speed of settling food safety cases.⁴⁵

CONCLUSION

Food adulteration remains a serious and pressing legal and health problem that affects the safety of consumers and destroys their trust in food industry while influencing the health of the nation in general. Even though in India the process of creating a wonderful legislative base for food safety has already been completed thanks to the Food Safety and Standards Act of 2006, the problem of food adulteration still takes place in the country. Thus, the analysis of both the nature of crimes committed in this area and the nature of methods used to execute food adulteration shows that the laws alone cannot solve the problem. The fact that the extent of food adulteration has transferred from incidental acts of food adulteration to severe and complicated fraud requires the involvement of the cooperation of several stakeholders like legislators, regulatory agencies, judiciary, food industry representatives and consumers. Using modern methods of food testing and having a well-working system of rules and regulations, it is possible to fight against food adulteration.

Laws alone will not be able to solve the problem of food adulteration effectively. In order to do so, it is necessary to have scientific innovations, good regulatory bodies, efficient judicial enforcement, ethical business practices, and knowledgeable consumers. An integrated technological and legislative framework is the only option for ensuring food integrity, protecting public health, and increasing trust of people in the food safety system of India.

⁴⁵Codex Alimentarius Comm'n, *General Principles of Food Hygiene*, CXC 1-1969 (rev. 2022).

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