RESEARCH ARTICLE

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An overview on the Impact of Food Fraud Incidences in Various Countries and its Detection Methods, Assessment Techniques and Preventive Measures

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Abstract: Food fraud is not just a local issue but perhaps a global phenomenon. If the food available in the market are undetected or poorly controlled, this can harm consumer health. Food fraud causes a lack of traceability of supply chains and may eventually be a risk to food safety. The purpose of this paper is to acquaint the various types of food fraud and to evaluate the detection methods in identifying the adulterants. It also addresses the importance of vulnerability assessment of food fraud and key actions required for its prevention. Fighting food fraud will remain a race between the fraudsters and scientists developing new methods to prevent them. The review is unique that it summarized food fraud types, basic and instrument-based detection techniques for adulterants identification and it also focuses on the international governing bodies concerned with food laws and regulations. This study also provides perceptions of the interplay between vulnerability assessment and food fraud prevention.

Keywords: Food adulteration, Food fraud, Health threat, Prevention strategy, Vulnerability assessment

1. Introduction

Food Fraud is also named as Economically Motivated Adulteration (EMA), an emerging global concern with socio-economic, physical, and environmental impacts. Food fraud is ubiquitous and has a substantial effect on a wide range of food items. It is defined as the act of defrauding the buyers of food or food ingredients for economic benefit and it can be committed by any individual person or in a group involved in the whole food supply chain including suppliers, food manufacturers, retailers, and importers [1]. It is a hazard that is growing in less awareness, concern, and danger is driven by different factors like increase in the complexity of supply chain networks, technology development, from within and outside the food supply chain.

The Grocery Manufacturers Association (GMA) in April 2018, estimates that the food fraud costs the world economy $49 billion per year. This food fraud has been a major government focus across the country. "Food Fraud is a collective term that includes the adulteration (deliberate substitution, dilution and concealment or impurities), tampering (date code tampering and refilling containers), theft or misrepresentation of food and food ingredients, food packaging or misleading statements made about a product for economic profit," as defined by the United States Pharmacopeia Convention (USP) [1]. It is the subcategory of Economically Motivated Adulteration (EMA) [2]. The key factors are non-compliance with food laws or misleading the consumer, intentional fraud, and the purpose of economic gain. Therefore, it is important to address the effect of food fraud as it leads to public health risk and create catastrophic economic impacts on countries.

There are different types of food fraud in and around the world. Food fraud generates the various level of monetary gain according to the type of fraud involved in food [3]. It influences food composition like substitution, dilution, flavor and color enhancement and concealment. Changing the composition of food fraud can be either done by the addition of poor-quality material, foreign material, or adulteration with some other constituents. The common characteristics among these types (Figure 1) and detailed review on food fraud types with recent incidents are summarised in Table I. In general, 65% of the incidents are caused by substitution or dilution, 13% due to the presence of an unapproved additive. The remaining other incidents are attributed to counterfeiting products (9%), mislabelling (7%), transshipment (5%) and unknown types of adulteration (less than 1%) [4].

2. Different types of food fraud

Replacement: Complete or partial, intentional substitution of an authentic ingredient with a cheaper product.

Addition: Inclusion of small amount of non-authentic substances to enhance the quality of the inferior product.

Removal: Dismissal or intentional ejection of an authentic or valuable ingredient from the product without consumer's knowledge.

Mislabelling: Deliberate mislabelling of food products with the intent of deceiving the consumer regarding what is actually present in the package.

Theft: Legitimate food product gets stolen from warehouses, distribution centers, parking lots, truck stops and passed off as a legitimately procured.

Diversion or Gray Market: The sales or distribution of legitimate (legal, non-counterfeit) product outside the predetermined market and it causes a decline in the sales of the legitimate product.

Counterfeiting: Intellectual Property Rights (IPR) infringement, include all aspects of fraudulent product and packaging is fully replicated. Counterfeit foods are made with no regard for safety standards, quality or efficiency and may contain the ingredients of unknown origin.

Transhipment: It includes the shipment of goods from one carrier or vessel to another destination, in order to hide the identity of the product, port or country of origin.

Tampering: Deliberate contamination of legitimate product, to cause harm to the consumer. It affects any part of the food product, packaging, and label.

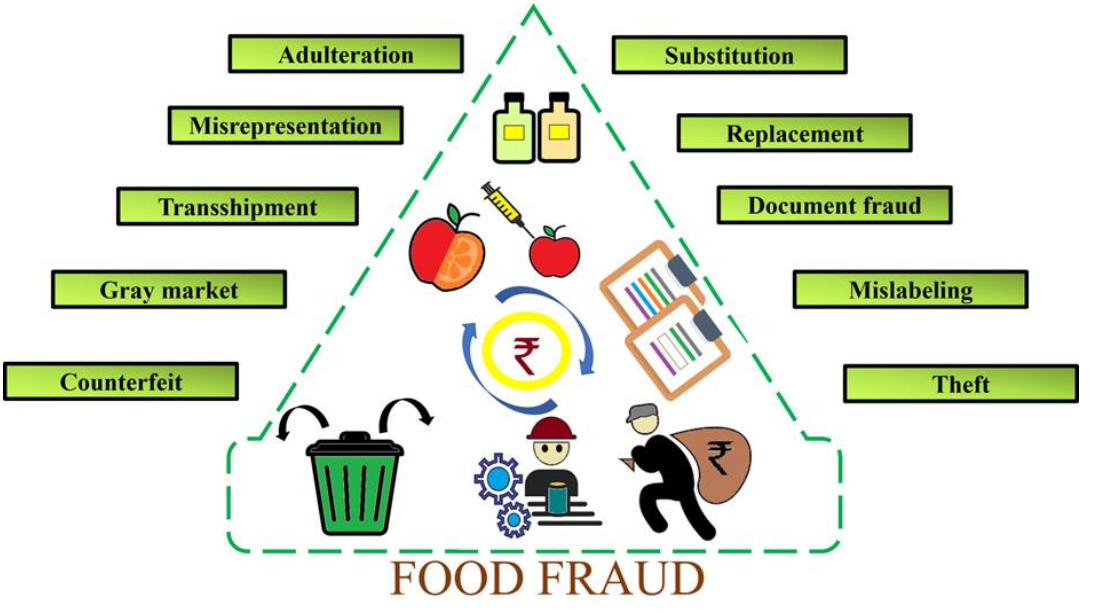

Figure 1. Types of food fraud

2.1. Global status on the different types of food fraud

Counterfeiting includes goods manufactured/packaged in illegal premises or without sufficient inspection or documentation and released with fake health certificates. Counterfeiting is the most common form of fraudulent activity. [5] Reported in the 20-year analysis (1997-2017) of beef manufacturing industry, 42.9% cases were on counterfeiting. The reports were further classified based upon supply chain in which 36.4% cases were documented on the primary manufacturing. In that almost 95.5% cases were listed on forgery cases.

Jia & Jukes (2013) [6] documented the China's biggest scandal of 2008, nearly 40 000 children were hospitalized after milk powder was intentionally poisoned by melamine (almost 300,000 ill and 6 deaths). In addition to this event, pesticides in "Jinhua" ham were confirmed in 2003, non-approved colour (Sudan) on food items in 2005 and Staphylococcus aureus in boiled dumplings in 2007.

Table 1. Major breakthroughs reported due to incidence of food fraud in various countries

Recent cases of incidence	Country	Reference
Lampante oil and soya oil is substituted with olive oil	Ministry of Agriculture, Brazil	(Moore, Spink, & Lipp, 2012) (Johnson, 2014) [1, 4]
Raided two spice producing units and notably seized yellow pigment and sawdust is mixed with turmeric to enhance the color.	Local officials from Ghaziabad, New Delhi. India	(Moore, Spink, & Lipp, 2012) (Caballero, Finglas, & Toldra, 2015) (Moyer, DeVries, & Spink, 2017) (Abress & Nateghi, 2015) [4, 7,8, 9]
Pollen is removed from 75% of honey which is sold commercially	USA	(Moore, Spink, & Lipp, 2012) (nature world news, 2014) [4, 10]
Fish and cheese have been mislabelled and seized	Sicily, Italy	(Johnson, 2014) (Spink & Moyer, 2011) (Huck, Pezzei, & 2016) [1,11,12]
Meat products and beverages are stolen	USA	(Spink & Moyer, 2011) (Burges, 2012) (food logistics, 2017)[11, 13, 14]
Legitimate Alcohol, wine, and spirits have been seized in shop	Birmingham and West Midlands, England	(Spink & Moyer, 2011) (Goel & Gupta, 2014) (Birmingham news, 2017)[11, 15,16]
Buffalo mozzarella cheese is counterfeited with cow milk in a factory	Italy	(Spink & Moyer, 2011) (Caballero, Finglas, & Toldra, 2015)[11, 7]

Imported Albanian Tomatoes are mixed with locally procured tomatoes	Bari, Italy	(Moore, Spink, & Lipp, 2012) (Johnson, 2014) [4,1]
Insecticide is added to the sweet has led to the death of 33 people.	Punjab, India	(Spink & Moyer, 2011) (Chan, Griffiths, & Chan, 2008)[11,17]
Police raided counterfeiting of branded whiskey with local brand at unhygienic condition	China	(Fullerton 2015) [18]
In the market, 20% of Australian and European honey were adulterated with sugar and sugar syrups	Australia and Europe	(Zhou et al. 2018) [19]
About 5%, chicken and turkey sausage are substituted with beef which is a carrier of *E.Coli* resulting in the risk of supply chain	Canada	(Naaum et al. 2018) [20]
In the 190 tested samples of Milk and milk product, bacteria, lead, mold, aflatoxin and other adulterants were detected by Bangladesh Food Safety Authority tested.	Bangladesh	(Neo 2019) [21]
"The Largest recall of an allergen" by FDA in the spices in which 700 products - cumin and cumin containing foods contaminated with almonds and peanuts	USA/EU/ Canada	(Agres 2015) and [22]
In the Canadian stores and restaurants, 44% of sea foods were found to be tested mislabelled by Oceana	Canada	(Levin 2018) [23]
76 Oregano samples were tested and found adulterated with higher concentration insecticide residues	Across Europe	(Drabova et al. 2019) [24]
Counterfeited Arabica coffee with Robusta or other ingredients like wheat, maize, coffee husks, stems, soybeans, brownsugar, rye, barley, seeds	-	(Sezer et al. 2018) (Toci et al. 2016) [25, 26]

Rising global concern about the number of problems encountered has impaired the China's reputation towards export and led to various safety warnings and prohibition of some imported items. In 2002, due to traces of veterinary drugs in the imports, the European Union excluded all the imports of animal produce from China. High levels of pesticide residues in frozen spinach, Japan banned the import in 2003. During 2007, live hood of the dog and cats got collapsed due to the consumption of adulterated ingredients imported from China in the US (Thompson & Ying, 2007).

Bogdan (2016) reported that based on the statistics from Russian State Statistical Service (Rosstat), the import of palm oil was shoot up to 37% than in 2014, in contradiction to the milk production was dropped down by 2% [27]. Cheese production increased by 33 per cent. It is obvious that Russia does not produce enough raw material for cheese production. At the end of 2015, market analysis of Federal Service for Veterinary and Phytosanitary Surveillance, Russia (Rosselkhoznadzor) revealed that 78% of all cheeses in the country were counterfeited. In these products, all of them has been substituted with palm oil instead of milk fat. In the same report, the share of fake goods in dairy industry ranged up to 40%. Andrei Danilenko, Head of the Russian Union of Milk Producers claims that the massive use of palm oil and related ingredients is linked to a decrease in profitability and an increase in the cost of production of the milk processing industry in the country over the last 2 years. As a result, manufacturers have resorted to such steps to remain profitable. In contradiction there is a huge impact on the overall market situation, as producers who are not using palm oil simply lose the fight and suffer huge losses [28]. stated that Food industrial fraudulent/counterfeiting was found to be the most profitable sector which accounts for 15.7% of the total counterfeiting activities in Italy.

Fox et al., (2018) [29] recognized that in Seafood Industries, fraudulent activities are done on the intention of profit which confuses the consumers. The report denotes that the supply chain of seafood is susceptible to nine types of fraud. This includes species substitution, fisheries substitution, illicit, non-reported and unauthorised adulteration, custody chain, theft by capture methods, and expansion of unreported goods, modern-day slavery and animal protection.

Walker et al., (2013) [30] summarized the press release on the investigation of horse and pig DNA in beef burger products by the Food Safety Authority of Ireland (FSAI) on 15 January 2013 about the meat substitution scandal which impacted most Europe and keyed high and long media and political visibility. They suggested that meat substitution will reoccur but not especially in the similar fashion. Continual regular vigilance can eventually defend against these fraudulent events.

The federal court of Australia penalized a sum of $750,000 for Snow dale's labelling of its eggs as misleading 'free range' in May 2016. The Snow dale producer marketed the products with a misleading or deceptive representation from April 2011 to December 2013. The Court examined that most of the hens are from Snow dale's sheds. The Court has also made an order

preventing Snow dale from using the words 'free range' in connection with its eggs unless it is grazed outside.

Farshidi et al., (2018) [31] surveyed the mislabelled meat products available in Iran market using polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP). They examined a total of 31 samples from market out of which 100% of salami (total 6 sample), 60% of hamburger (total 15 sample) and 80% of minced meat (total 10 sample) were made of chicken meat. But it is not listed in ingredient labels. The aim of the intentional betray addition of meat is mainly for financial gain.

One of the most common adulterations in meat products is nondeclared animal protein addition. Meat replacement with an unidentified animal, typically of less quality, is an agricultural scam and may have financial and health consequences. In this survey, used an agar base gel immuno-diffusion assay to distinguish species of bovine, porcine, horses and aircraft in two leaked meat products, uncooked commercial hamburger and sausage (chorizo) [32]. A total of 40 samples have been analysed at local food stores in that 9 of 23 hamburger meat samples contains non-declared equine species and 5 of 17 unreported horses and porcines in Mexican sausages. These studies have indicated the violation of regional meat industry standards. To ensure that meat products are appropriately labelled to protect consumers, regulatory authorities should be proposing initiatives.

A study was conducted on the Australian honey brands apart from imported honey [33]. found 24 of 38 samples including premium brand Manuka honey were adulterated with cheaper alternatives. There is no harm in humans due to adulteration, but it is purely meant for financial gain. A more stringent testing regime need to be followed to figure out these criminals. Oregano fraud has been found especially in Australia. A test detected only 5 out of 12 sample were 100% oregano using Fourier Transform Infrared (FT-IR) spectroscopy and chemometric modelling in Australia [33].

3. Detection of food fraud

Detection of food fraud in any food product is the most technically challenging aspect of prevention. If the fraud occurred hasverified, detection and quantification of food constituents is the logical progression. Analytical techniques that provide physical, chemical, or biochemical information for foods are the front line to detect fraudulent practices and ultimately prevent their incidence [7]. The techniques whichhave been used to detect food fraud and adulteration in food are summarized below.

3.1 Chromatographic techniques

Chromatographic techniques provide specification and sensitivity owing to the resolution of the complex mixture into their constituents. Data acquired with a detector (UV, Mass

spectroscopy) is used for targeted or non-targeted analysis. Later, the chromatogram obtained as a continuous signal can be examined with chemometrics to find the concentration of various components and thereby detecting adulteration [7].

High-Performance Liquid Chromatography (HPLC) procedures for individual components or many classes of compounds are used to check food adulteration. Some of the food fraud incidents detected by HPLC are: oligosaccharide determination is used to find addition of soy milk to cow's milk and industrial syrups to honey [7] determination of melamine in 300 samples of pasteurized and ultra-high temperature processed milk and dairy products [34] and triacylglycerol analysis may serve the detection of olive oil with canola oil [35].

Gas Chromatography (GC) is used to check the use of cheaper food ingredient substitute and used in the determination of geographical, botanical or species origin.It is used as a significant degree for spices, oils and organic foods [34]. The food fraud incidents detected by GC are:detection of extra virgin oil in sunflower, corn, peanut and coconut oil [7], through the characterization of fatty acids, butter adulteration can be detected and is also used for the study of volatile profiles like pyrazines, pyrroles and phenols of defective coffee seeds [36, 37].

3.2 Spectroscopic techniques

Spectroscopic techniques that employ electromagnetic radiation are taking a bite out of food fraud. Using spectroscopic techniques, authenticators can find the flow of deficient, mislabelled, and contaminated food and beverages.

Candoğan et al.,(2020) conducted research on detection of Beef adulteration using FTIR spectroscopy [38]. It seems to be the significant technique in the detection of beef mixtures mixed with pork, horse or donkey meat and deserves further study. The characteristic signals obtained in the study from FTIR spectral data could be effective in creating a biomarker for detection of suspicious meat mixtures.

Infra-Red Spectroscopy (IR) is popular, and the Fourier Transform (FT-IR) helps to measure various constituents in liquid and solid samples simultaneously. Penetration of Near – IR (NIR) in the sample is more and can be used to examine the samples in transparent packaging and also used in detecting adulteration like virgin olive oil with linoleic sunflower oil and canola [39], discriminate the geographical origin of green tea, detection of honey adulteration with beet invert sugar, high fructose corn syrup, detection of milk adulteration with urea, starch, dextrin and melamine and evaluating the difference between fresh and frozen-thawed shrimp [7, 40, 41].

Raman spectroscopy is another vibration technique, which authenticates the origin, identity, and purity of food. It is portable and doesn't require any sample preparation and analyse the sample packed in plastic or glass packaging. Itis capable of identifying the presence of Sudan I dye in chilli powder, detecting the addition of soybean, rapeseed, sunflower and corn oils in

olive oil detecting the adulteration of high fructose corn syrup and maltose syrup in honey and margarine in butter, and detecting the toxin paraffin addition in rice, melamine in milk and banned horse meat in beef with the aid of chemometrics [42-44, 7].

Nuclear Magnetic Resonance (NMR) Spectroscopy is a method that allows quick determination of molecular fingerprints of food and simultaneously provides a quantitative determination of compounds without prior separation. It is used in characterizing product such as beer, juice and infant formulas. Its uses are: detection of synthetic triacylglycerol in butter, Detection of refined olive oil adulteration with refined hazelnut oil and this technique is used for Sudan III and IV detection in culinary spices [7,47, 46].

3.3 Chromatography

McGrath et al., (2020) addressed the food fraud issue in rice supplies of China, India, Vietnam and Ghana [47]. They studied the effect of two-tiered testing regime of rapid screening using portable Near Infrared technology followed by second tier testing using mass spectrometry-based analysis for suspicious samples using combinations of LC-MS, GC-MS, and ICP-MS. Two-tiered approach: using orthogonal detection modalities yields significant information than any single method called as "fingerprinting" techniques which employ models and authenticating it with adequate number reference samples for detecting the diversity of the food product.

Santanu Patra et al., (2017) reported Sudan I dye is classified as a carcinogenic and mutagenic compound by the International Agency for Research on Cancer which is added to foodstuffs and cosmetics for the color enrichment for Marketability [48]. This kind of adulteration led to the panic in the international market and need for the development of a rapid Sudan I sensing system. HPLC–mass spectrometry (HPLC–MS) has been widely used for direct determination of Sudan dyes. But it is a time-consuming and expensive technique.

3.4 Differential scanning calorimetry

Differential scanning calorimetry, a thermo analytical technique used to detect fats/oils and honey adulteration. It is fast and doesn't require sample preparation and solvent. The adulteration of hazelnut oil in olive oil and high oleic sunflower, refined olive, refined olive pomace, sunflower and corn oils in extra virgin olive oil has been detected [49]. It is used in the detection of the adulterated animal fat in butter and determination of honey admixtures with industrial syrup [50, 51].

3.5 Immunochemical methods

Enzyme Linked Immuno Sorbent Assay (ELISA) is an assay technique used for detecting substances such as proteins and antibodies. It uses antibodies to detect the specific proteins of meat. It is used in the determination of melamine in milk and milk powder,

identification of meat of different animal species by using antibodies against animal protein [] and also in detecting the adulteration of sheep and goat milk with cow milk [7, 52, 53].

3.6 DNA technology

DNA analysis has been emphasized in recent years for determining the authenticity of the food. It can discriminate cooked or highly processed foods and distinguish the closely related food at the chemical level. DNA analysis makes use of Polymerase chain reaction (PCR) to detect the food by two methods. One is the detection of single nucleotide polymorphism (restricted fragment length) and the other is small sequence length polymorphism. DNA analysis used in the detection of pork in cooked meat products, determining the identity of fresh fish and fish species in processed products, distinguish between different varieties of basmati rice and long grain rice and determining the source of olive oil [54, 55].

3.7 FastFish-ID

Sanchez et al., (2019) reported that FASTFISH- IDTM's (Sample -in and response- out) a portable and cloud-based software analysis software helps in promoting, speeding up and cost-efficient authentication method of all types of fish species. Rapid and easy validation of species FASTFISH-IDTM can protect the fish sector from species substitution and mislabelling vulnerabilities. The same technology has been utilized in terms of creation of suitable PCR primers and probes comprising several genera and organisms to study virtually any category of animals, plants, or microbes on Earth [56]. FASTFISH-ID - a novel DNA-based authentication method, using qPCR and closed-tube barcoding technology will be the most promising, quick and reliable and first-screening step, in fish authentication.

3.8 Fingerprinting

Fingerprinting is a sensitive and accurate detection method to prevent the food fraud. It refers to the spectrum or image produced by certain instrumental tools. Examples are determining the traceability of food products and distinguishing cow's ear and meat to find whether the samples originate from the same animal [57].

Existing common analytical techniques are not always convenient and accessible, making it difficult to address the diverse ways of fraudulent practices in food. The simple methods can be easily employed to detect the food fraud and adulterants are summarized in Table 2.

The emerging food fraud warns about food safety and resulted in improvement in detection methods to analyse contaminants and adulterants [58]. A consumer can perform these simple detection methods at the household level, so as to have a broad picture of the status of adulteration in food and also bring this problem to an end for the victims, including millions of children in the developing countries.

Table 2. Modest techniques for detection ofseveral food adulteration and their distinguished changes

S.no	Food category	Types of food source	Adulterant	Method of detection	Distinguished observation
1.	Milk & Milk Products	Milk	Water	A drop of milk is dropped on a smoothened slanting surface.	If the milk is pure, it either stays or slowly flows leaving a white trail behind and if not, it doesn't leave any traces.
		Milk	Detergent	A sample about 5 to 10 ml is taken with equal amount of water and it is shaken thoroughly	If the milk is pure, due to agitation, it forms a thin foam layer and if not, it forms a dense lather.
		Milk and Milk Products (Khoya, chenna, paneer)	Starch	A sample of 2 to 3 ml with 5 ml of water is boiled and then 2 to 3 drops of tincture iodine is added and then cooled.	If the color is blue, it indicates presence of starch and if milk, addition and boiling is not required.
		Ghee/ Butter	Mashed potatoes, sweet potatoes and other starches	A half teaspoon of ghee/butter is taken in a glass bowl and the tincture iodine is added up to 2 to 3 drops	If the color is blue, it indicates the presence of mashed potatoes, sweet potatoes, and other starches.
2.	Oils and Fats	Coconut oil	Other oils	A glass with coconut oil is taken in a glass and placed in refrigerator for thirty minutes.	Coconut solidifies after refrigeration and if mixed, the other oils remain a layer.

		Tri-Ortho-Crestyl - Phospate (TOCP)	Oils and Fats	A sample of 2ml oil is taken and a little amount of solid yellow butter is added.	If immediate red color appears, it indicates presence of TOCP.
		Winterized Salad oils	Winterization	A sample of 100ml oil is taken in bottle and placed in a bucket filled with cracked ice and water is filled till it reaches top, and it is kept solidified by ice and excess water is removed.	After five and half hours, the bottle is removed and examined oil. If it is properly winterized, the sample is brilliant, clear and limpid and if not when the sample is not properly winterized.
3.	Sugar & Confectionery	Honey	Sugar Solution	**Method 1:** A glass of water is taken, and a drop of honey is added.	If the honey is pure, it will not disperse in water and if it disperses, it indicates presence of added sugars.
				Method 2: A cotton wick is dipped in honey and ignited with matchstick.	If honey is pure, it burns and if it is not pure, it doesn't burn, it produces a cracking sound.
		Sugar, Pithi sugar, Jaggery	Chalk powder	A water is taken in a glass and a sample of 10g is dissolved in it.	If it mixed with Chalk, the adulterant mixture would settle down at bottom.
		Silver leaves	Aluminium Leaves	1. Some part of leaf is taken and crushed between two fingers 2. The suspended silver leaves is taken and made into a ball and burned with flame.	1. Silver leaves when pure gets crushed easily and collapse to powder form but aluminium leaves break to smaller pieces. 2. Silver leaves when pure burns away with shiny balls but aluminium leaves are lessened to grey dust.

4.	Food Grains & Its Products	Food Grains	Extraneous matter (Dust, Pebble, Stone, Straw, Weed Seeds, Damaged Grain, Weevilled Grain, Insects, rodent hairs and excreta)	A small amount of sample is taken in a glass plate and impurities are examined visually.	Food grains when pure do not have any impurities and if impurities are seen when the food grains are tinted
		Food Grains	Dhatura	A small amount of food sample is taken in a glass plate and impurities are examined.	Dhatura seeds are flat edged and blackish brown in color and can be separated out by keen examination and impurities are seen in tainted food grains.
		Wheat flour	Bran	A glass of water is taken, and a spoon of wheat flour is sprinkled on the water surface.	Wheat flour when pure doesn't show excess bran on the water surface and impurities are seen in tainted food grains
		Dal (whole and Split)	Khesari Dal	A small amount of dal (whole or split) is taken, and impurities are examined visually.	Khesari dal has edged type appearance with a slant on a side and square one are separated by keen examination, also pure dal do not have any impurities.
		Food Grains	Added Colors	A glass of water is taken, and 2 teaspoons of food grains is added and mixed	Pure Food grains will not leave any color and if any color appears, then it is tainted
		Sella Rice	Turmeric	A teaspoon full of rice is taken in a glass plate and a	Pure grains don't form red color, if red color appears then it is tainted.

				small amount of soaked lime is sprinkled on the rice	
		Ragi	Rhodamine B	A cotton ball soaked in water or Vegetable oil is taken and the outer surface of ragi is rubbed with it.	If the color is absorbed, then it shows the dilution of rhodamine B by the color absorption of Ragi
		Pulses	Chakunda Beans	A small number of pulses is taken in a glass plate and impurities is examined.	Chakunda beans can be separated out by keen examination
		Atta, Maida, Suji (Rawa)	Sand Soil, insects, webs, lumps, rodent hairs and excreta	-	By visual examination, these are found out.
5.	Salt, Spices & Condiments	Asafoetida (hing)	Foreign Resin	**Method 1:** A small amount of asafoetida is ignited in a stainless-steel spoon	Asafoetida when pure burns like Camphor and if tainted, it doesn't produce flame like camphor.
			Foreign Resin	**Method 2:** A gram of asafoetida is powdered and taken in a glass container and a teaspoon of water is added and mixed by shaking	Pure asafoetida forms a Milky white solution with no bottom products.
		Black pepper	Papaya Seeds	**Method 1:** A small amount of black pepper is added to a glass of water	Black pepper when pure, settles down and if impure, papaya seeds floats.
			Papaya Seeds	**Method 2:** Spice is spreaded on a white paper and the	Black pepper is brown, has wrinkled Surface, characteristic smell with pungent

				sample is observed with a magnifying glass	taste and as for papaya seeds, it has shrunken smooth surface, oval shaped, greenish brown or blackish brown with a repulsive flavor.
		Black berries	Black pepper	Berries are pushed with fingers	Light berries breaks easily whereas black berries of pepper don't break
		Asafoetida (hing)	Soap stone or other earthly matter	A small amount of sample is shaken with water, and it is made settled.	Asafoetida when pure don't leave any soap stone or other matter at bottom and if tainted, the soap stone and other matter settles down
		Chilli Powder	Artificial/ water soluble synthetic colors	Chilli powder is sprinkled on the surface of water in a glass	The artificial color immediately settles down in color stains
		Black pepper	Light black berries	The sample black pepper is made float in alcohol (rectified spirit)	The matured ones will sink whereas light one's floats
		Chilli powder	Saw dust	Sample is added to water	Saw dust floats in water and chilli powder sinks
		Asafoetida	starch	Sample is added to water	Artificial colors settled down immediately in color stains
		Common salt	chalk	A spoonful of salt is stirred in a glass of water	The chalk makes solution white and other impurities settles down
		Clove	Exhausted Clove	Cloves are added on some water	Pure cloves settle down whereas exhausted cloves float in surface
		Cinnamon	Cassia bark	A small amount of cinnamon is taken in a glass plate	Cinnamon barks are very thin which is rolled around pencil or pen and also has distinct smell and if tainted, on close

					examination, cassia bark has several layers between rough outer and inner smooth layers
		Cumin seeds	Grass seeds	A small amount of Cumin seeds is rubbed in palms	If palm is black, then it is tainted.
		Mustard seeds	Argemone seeds	A small number of mustard seeds is taken in a glass plate and examined for argemone seeds	Seeds which have smooth surface and when pressed has yellow color inside is Mustard seeds also, seeds which are grainy, rough surface and black color are argemone seeds and inside is white color.
		Turmeric (whole)	Lead chromate	A small amount of turmeric is added in a glass of water	Turmeric when pure, doesn't leave any color whereas tainted ones leave bright color immediately.
		Turmeric powder	Artificial color	A teaspoon full of turmeric powder is added in a glass of water	Turmeric powder when pure leaves yellow color when settling down and if tainted, it leaves a strong yellow color in water when setting
		Powdered spices	Sawdust and powdered bran	Powdered spices are sprinkled in the surface of water	Pure spices don't leave sawdust on the water surface whereas in the tainted ones, the sawdust /powdered bran floats on surface
		Iodized salt	Common salt	A piece of potato is cut, and salt is added and kept for a minute and two drops of lemon juice is added	If the salt is iodized, it changes to blue color and if no blur color appears, then it is common salt
		Saffron	Maize cob	A small amount of saffron is added in a glass of water	Pure Saffron don't break easily like artificial, and the artificial ones are

					prepared by soaking in sugar and colored with coal tar, also if tainted, artificial colors dissolve quickly and pure saffron stays saffron color long.
6.	Fruits & Vegetables	Bitter gourd, Green Chilli, and others	Malachite green in green vegetables	**Method 1**: A cotton piece is soaked in water or vegetable oil and the outer part of green vegetable is rubbed with it	The malachite green color is found to be tainted ones when cotton turns green
		Bitter gourd, Green Chilli, and others	Malachite green in green vegetables	**Method 2:** A small part of sample is taken and placed on a piece of soaked white blotting paper	The color impression indicated the malachite green or any other artificial color if tainted
		Green peas	Artificial colors	A small amount of green is taken in a glass plate and water is added and mixed and made stand still for half an hour	Separation of color indicates dilution
		Sweet potatoes	Rhodamine B	A cotton ball is soaked in water or vegetable oil is taken and it is rubbed on the outer surface of sweet potatoes	The color absorption in cotton indicated the use of rhodamine B for coloring the outer surface of sweet potatoes
7.	Beverages	Coffee powder	Clay	A half teaspoon coffee powder is added in a glass of water and stirred for a minute and kept aside for	Coffee powder when pure doesn't leave any clay at bottom and if tainted, it leaves clay particles at bottom

				five minutes and it is observed	
		Coffee powder	Chicory powder	A glass of water is taken, and a teaspoon of coffee powder is added	Coffee powder floats over water whereas chicory powder sinks
		Tea leaves	Exhausted leaves	**Method 1:** A filter paper is taken, and tea leaves are spreaded and water is sprinkled to wet the paper, then it is washed in tap water and observed for stains	Tea leaves when pure don't stain the filter paper whereas if stains appears then coal tar is present in it
			Exhausted leaves	**Method 2:** A Small amount of tea leaves/dust is taken and placed in center of filter paper and water is added drop by drop at the heap of tea leaves/dust	If the tea leaves is tainted, water will dissolve the added color and leaves stains of color in the filter paper
			Exhausted leaves	**Method 3:** A little slaked lime is spreaded on white porcelain tile or glass and little tea dust is sprinkled over lime	Pure tea dust shows slight greenish yellow color because of chlorophyll and if red, orange or other color spreads over lime, then there is presence of chlorophyll
			Iron filings	A small amount of tea leaves is taken in a glass plate and a magnet is moved around tea leaves	Tea leaves when pure don't show iron filings on magnet and if tainted, iron filings are seen on magnet.

8.	Sensory evaluation quick tests	Milk	Synthetic Milk	It gives bitter after taste	If tainted, it shows soapy feel on rubbing between fingers
		Black pepper/Cloves	Coated with mineral oil	Black pepper when coated with mineral oil smells like kerosene	-
		Chilli powder	Brick powder, salt powder or talc powder	A teaspoon of chilli powder is taken in a glass of water and examined for wastes	When rubbed, if shows any rawness, then it is brick powder or sand and if shows a soapy and smoothness, then it is soap stone
		Cloves	Volatile oil extracted cloves (extracted cloves)	Exhausted cloves can be found out by its size and shrunk appearance	Its pungency characteristic is pure cloves is less in exhausted cloves
		Sugar	Urea	A little sugar is rubbed on palm and smelled and it is dissolved with small amount of sugar in water	If tainted, urea in sugar smells like ammonia
		Wheat, rice, maize, jowar, bajra, channa, barley, etc.	Kernel Bunt	The non-Characteristic grains are separated out and examined	Kernel bunt shows dull appearance and black in color and smells like rotten fish
		Atta	Resultant atta/ Maida	For resultant atta, dough requires less water	The taste of chapati is little sweet as normal and the tainted ones are tasteless (insipid)
		Sago	Sand/ Talcum	A small quantity of sago is put in mouth	If tainted, it has a raw feel

		Powdered Spices	Common salt	Taste for addition of common salt	It tastes salty when present
		Sweet meats	Artificial Sweetener	A small amount of sample is tasted	Artificial sweetener leaves a persisting sweetness on the tongue for a long time and leaves a bitter aftertaste.

*Source: www.fssai.gov.in

4. Food fraud vulnerability assessment

According to Global Food Safety Initiative (GFSI), "Food fraud vulnerability is the susceptibility to a food fraud risk, which could cause consumer health threat if not properly addressed [11]." Food fraud vulnerability can be explained by opportunity related fraud risk factors, Motivation related fraud risk factors and absence of fraud control measures [59]. The analysis of these three aspects helps to estimate food fraud vulnerability for any food product or ingredient.

Opportunities and Motivations, the potential risk factors are determined by internal and external environment. Opportunities are created by poor management, oversight and through the abuse of one's authority. For any product, the food fraud opportunity can be determined by the composition, qualities, production process, supply chain, and its geographic origin. Factors include physical characteristics and composition, the presence of adulteration and transparency of the supply chain [60].

Motivation is a need of a person who commits food fraud for economic profit [61]. It can take two forms: revenue or cost minimization and its factors are level of competition, financial strains, and economic health and condition. It is also affected by factors like blackmail, corruption level, ethical business culture, and personal gain. It is increased by commercial or personal desperation. The potential risk resulting from these two factors can be mitigated by fraud control measures, which is implemented for detecting and preventing food fraud.

Specific controls include fraud monitoring and verification system, legal framework, enforcement and traceability [60]. The vulnerability to food fraud will continue as long as the potential for profit exceeds the chance of getting caught and the potential consequences do not act as an obstacle [2].

5. Food fraud prevention

When the vulnerability is assessed, it is necessary to find the issue which includes the intervention, detection, and monitoring and to take immediate action and prosecute the fraudsters. Whenever the public health is threatened, Prevention is the next step after intervention and response [11]. Food fraud prevention is a challenging aspect since fraudsters are opportunistic and actively keen on avoiding the detection. It is necessary to understand the food fraud opportunity before put forwarding the efficient and effective control systems or countermeasures [62].

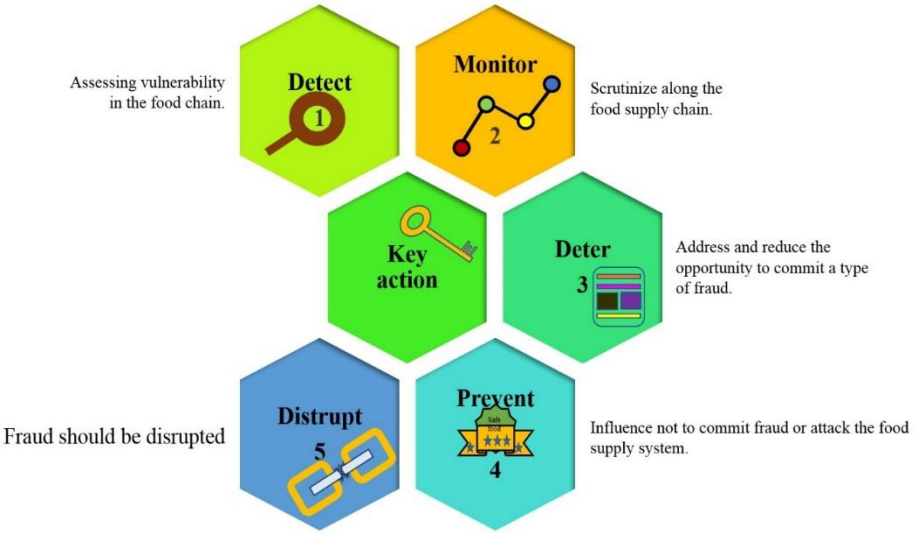

Figure 2. Key actions for food prevention

For perceiving the fraud opportunity, each incident should be analyzed for a specific or group of products, market channel, and type of consumer, company, industry, and country. Those incidents will give insights on who is perpetrating the fraud, with what technologies, on what scale, to which consumer and with what economic, public risk and subsequently the specific countermeasures can be assessed for the detection and deterrence of the specific incident.

Countermeasures or control systems which are intended to reduce fraud opportunity and degree of mitigation depend on the food fraud type and by the involvement of management to decrease the vulnerability to fraud. The key actions to reduce or counteract the fraud opportunity fall into five distinct (Figure 2) categories [63].

Table 3. International Food laws and regulatory bodies

S.no	International regulatory bodies	Roles & responsibilities	Sites
1.	WHO • Food Safety • Food Born Diseases • Genetically Modified Food • Food Additives	Access to sufficient amounts of safe and nutritious food for promoting sustained good health.	https://www.who.int/health-topics/food-safety/
2.	FAO • Food and Agricultural Organization • Food Safety and Quality Emergency Prevention	To achieve food security for all, eradicate hunger and malnutrition	http://www.fao.org/home/en/
3.	Codex Alimentarius commission	Developed by FAO and WHO to develop food standards, guidelines, codes of practice, etc.	http://www.fao.org/fao-who-codexalimentarius/committees/cac/about/en/
4.	Sanitary and Phytosanitary Measures (SPS)	Agreement on how governments can apply food safety and animal and plant health measures based on World Trade Organization (WTO)	https://www.wto.org/english/tratop_e/sps_e/sps_e.htm

5.	FAOLEX	Comprehensive and up-to-date largest electronic collection legislative database. of national laws and regulations on food, agriculture and renewable natural resources.	http://www.fao.org/faolex/en/
6.	International Plant Protection Convention	To protect cultivated and wild plants by preventing the introduction and spread of pests	https://www.ippc.int/en/
7.	World Organization for Animal Health (OIE)	Aids in improving animal health worldwide.	https://www.oie.int/
8.	International Trade Centre's Standards Map	To strengthen the capacity of producers, exporters, policymakers, and buyers, to participate in more sustainable production and trade.	https://www.intracen.org/standardsMap/
9.	OECD Agriculture and Fisheries – Organization of Economic Co-operation and Development	To improve the economic and social well-being of people around the world.	https://www.oecd.org/agriculture/

Table 4. Governing Authority, Food laws and reporting sites in various countries

Country	Governing food authority	Food law	Incident of adulteration/ complaint registration
Africa	National Agency for Food and drug administration and control National Food Safety Situations in Africa	Sections 5 and 30 of NAFDAC and Control Act Cap NI Laws of the Federation of Nigeria (LFN) 2004	-
Australia and New Zealand	Food Standards Australia New Zealand	Food Standards Australia New Zealand Act 1991 Food Standards Australia New Zealand Regulations 1994 Imported Food Control Act 1992 New Zealand legislation - Food Act 2014	https://www.foodstandards.gov.au/publications/Pages/Report-on-Emerging-and-Ongoing-Issues-Annual-Report-2019.aspx
Bangladesh	Bangladesh Food Safety Authority (BFSA)	Food Safety (Contaminants, Toxins and Harmful Residues) Regulations, 2017 Food Safety Act 2013	https://www.consumerbd.org/complaints/ To be launched hotline '333' for complain against adulteration
Burma	Food and Drug Administration (Burma)	National food law	-
Canada	Canadian Food Inspection Agency Agriculture and Agri-Food Canada	Canadian Food Inspection Agency Acts & Regulations Canada Agricultural Products Act Canada Food Inspection Agency Act	https://www.inspection.gc.ca/food-recall-warnings-and-allergy-alerts/eng/1351519587174/1351519588221?ay=0&fr=0&fc=0&fd=0&ft=2

		Consumer Packaging and Labelling Act Food and Drugs Act Safe Food for Canadians Act	
China	Ministry of Agriculture of the People's Republic of China: • Agri-Product Quality and Safety • Animal Health • Biotechnology • Laws and Regulations General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China	Food Safety Law of the People's Republic of China HFG Law & Intellectual Property People's Republic of China Food Safety Law	http://www.cca.cn/en/process.html
Japan	Food Safety Commission of Japan Food and Agricultural Materials Inspection Center	Food Safety Basic Law Law on Special Measures Against Bovine Spongiform Encephalopathy Poultry Slaughtering Business Control and Poultry Inspection Law Food Sanitation Act	https://www.caa.go.jp/en/
Hongkong	Centre for Food Safety	Part V of the Public Health and Municipal Services Ordinance (Cap. 132) Food Safety Ordinance (Cap. 612)	https://www.cfs.gov.hk/english/rc/subject/fi_list.html

India	Food Safety and Standards Authority of India	Food Safety and Standards Act, 2006 Food Safety and Standards Regulations	https://foodregulatory.fssai.gov.in/grievance-redressal https://www.onlinelegalindia.com/services/consumer-complaint/ https://consumerhelpline.gov.in/faqdetails.php?fid=Food%20and%20Food%20Safety
Nepal	Department of Food Technology and Quality Control	Food Regulation, 2027 (1970). Food Act, 2023	-
Philippines	Food and Drug Administration	Food safety act 2013	-
South Korea	Ministry of Food and Drug Safety Food Safety Bureau	Food Sanitation Act Food Code	https://www.kca.go.kr/eng/main.do
European Union	Rapid Alert System for Food and Feed (RASFF) European Food Safety Authority (EFSA).	General Food Law - Regulation (EC) No. 178/2002 Treaty Functioning of the EU - Art. 168 - Public Health Protection Functioning of the EU - Art. 169- Consumer Protection	https://webgate.ec.europa.eu/rasff-window/portal/?event=notificationsList&StartRow=1
Belgium	Federal Agency for the Safety of the Food Chain	-	-
Greece	Hellenic Food Authority	Food and Beverage code	https://www.efet.gr/index.php/el/consumers/kataggelies
Germany	Federal Ministry of Food, Agriculture and Consumer Protection	German Food Law of Article 61 of Lebensmittel und	-

		Bedarfsgegenstaendegesetze (LMBG)	
Netherland	Food and Consumer Product Safety Authority (NVWA) under Ministry of Economic Affairs, Agriculture and Innovation	Food safety regulations in commodity act	-
Spain	Ministry of Agriculture, Food and Environment	-	-
UK	Food standard Agency, Department for Environment, Food and Rural Affairs	Food and feed law The Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) Committee on Mutagenicity of Chemicals in Food, Consumer Products and the Environment	https://www.food.gov.uk/contact/consumers/report-problem
USA	Food and Drug Administration (FDA) Center for Food Safety and Applied Nutrition (CFSAN) International Food Protection Training Institute (IFPTI) Joint Expert Committee on Food Additives (JECFA) United States Department of Agriculture (USDA) Under Secretary for Food Safety Food Safety and Inspection Service (FSIS)	FDA Food Safety Modernization Act (FSMA) Retail Food Protection *Federal/state food programs*	https://www.foodsafety.gov/recalls-and-outbreaks -

The control systems developed for this problem are the usage of unique serial numbers, traceability of the product and special inks, the hologram on the packaging of individual items. Also, Food fraud prevention relies on the presence of the well-resourced and capable guardian. The government can reduce the food fraud opportunity through a public-private partnership by bringing all the relevant enforcement agencies to work together with food industry resources [64]. Various regulatory and governing bodies are involved in framing the rules, preventative methods and mitigations, to reduce food fraud risk have been established. Some of the international regulatory bodies and their food law are summarized in the Table3 and 4.

6. Conclusion

Fighting fraud and adulteration will remain a race between the fraudsters and the scientists developing new methods to prevent them. Food fraud occurs from antiquity and is a concern for all food business. It can be an eminently commercial crime and contribute economic vulnerability for food manufacturers and food brand owners. Forecasting the food fraud incidents is difficult for consumers, as producers don't provide information about fraud practices. The countermeasure for this issue is to centralize on creating an innovative method for prevention and mitigation. To prevent the food fraud, issue each factor should be considered. Additionally, advanced systems of fraud deterrence that are cost-effectiveare being applied to address the emerging food quality issues and to create trust in food manufacturers, retailers, importers and consumers and thereby ensuring the protection of public health.

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