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REVIEW: RECENT DEVELOPMENT IN FOOD ADULTERATION ANALYTICAL TECHNIQUES

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ABSTRACT: Food adulteration is an enduring concern to date, and its detection and food authentication are some of the major approaches which can eradicate adulteration. This article reviews modern analytical techniques which are currently used for optimization and identification of adulterants. The Analytical techniques reviewed are distributed in three sections- Computer vision, Spectral and spectral Imaging techniques, and Electrical Techniques. Computer vision is a very advanced technique, allowing the analysis of several parameters with accurate and precise results. The hazardous effect of adulteration and future challenges and impacts are briefly discussed. The Previous decade is considered to be a massive success for food adulterant detection as it involved a chemometrics study. The use of chemometrics with analytical techniques is briefly discussed. Chemometrics is the science of extracting information from the chemical system by data-driven means. The inevitability of food in perspective to the current COVID-19 pandemic is very strong and authenticated food is a prior requirement.

INTRODUCTION: This review article focuses on the current analytical techniques used worldwide for qualitative and quantitative analysis of food adulteration. Food safety as a concern was first brought up by the great German scientist "Friedrich Accum [1]. He composed a book, "A treatise on Adulteration of Food and Culinary Poisons" in 1820, stating the unscrupulous details of food processing practices in London [1]. As per FDA, CFR Title 21- "Section 501(a) (2) (B) of the Federal Food, Drug and Cosmetic Act provides that a drug (including a drug contained in a medicated feed) shall be deemed to be adulterated if the methods used in, or the facilities or controls used for, its manufacture, processing, packing, or holding do not conform to or are not operated or administered in conformity with current good manufacturing practice to assure that such drug meets the requirement of the act as to safety and has the identity and strength and meets the quality and purity characteristics, which it purports or is represented to possess [2]. Food is life's essential need and plays a crucial role in our development.

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But this food is tainted accidentally or intentionally. This is known as adulteration and is amutual problem in food, flavors and cosmetics. Adulteration is practiced globally with a large number of food products used for adulteration. Food adulteration is a process of removing vital nutrients or additional contaminants or adulterants to cause harm. Adulteration has been practiced since ancient times and is considered to be profanity for mankind. The major reason for food adulteration is the profit in food marketing. The turnover boundary in food production is much less as compared to other industrial sectors [3]. One of the recent cases of March 2020 was reported in New Delhi. The Regional Drug Testing Laboratory (RTDL) confirmed a report that syrup "Coldbest" [4] was adulterated with the chemical 'Diethylene glycol', which led to the death of nine children in Jammu. Some common examples of food adulteration like the addition of water in milk to increase the volume of milk, the use of papaya seed in mustard oil to increase the weight of oil, the addition of wheat flour in ice cream to thicken the cream [5]. There is a large number of such examples for food adulteration. According to [6] there are two types of adulteration- Intentional / deliberately / knowingly [6] adulteration and Unintentional / unknowingly / incidental adulteration [6].

Intentional adulteration [6] involves the purposeful addition of extraneous substances that have similar properties to food. A reason why detection of adulterants becomes difficult. The level of nutrients is decreased, which is compromised by the addition of similar characteristics adulterants. This increases the income margin by consumption of urea, melamine, starch, flour, barley powder, *etc*. into various food items [5]. Due to negligence, poor hygiene, manufacturing, transportation, Transport, and marketing environments, accidental adulteration occurs, for example- insecticides, residues, droppings of rodents, and food larvae. Metallic adulteration occurs due to arsenic from pesticides, lead from water, and chemical industries effluent [5]. Authentication of food is a top priority to discontinue the malpractice of food adulteration. But, there are a few questions to eradicate the food adulteration process.

- Are there any detection techniques to identify the adulterants in food?
- In case of intentional adulteration, identify and detect the adulterant having the same properties as food.
- How chemometrics can be useful for the detection of adulterants.

The number of analytical techniques used to detect adulterants involves Chromatographic and/or spectroscopic techniques coupled with chemometrics. Chemometrics is the substance discipline that applies mathematical, authentic, and various methodologies using formal reasoning to design or pick ideal assessment procedures and tests and to give most limited critical synthetic data by breaking down compound material [7]. The various techniques used for the detection of adulterants are:

- Scanning Electron Microscopy
- HPLC-MS
- GC, GC-FTIR, and GC-MS
- UV-VISIBLE SPECTROPHOTOMETRY
- AAS/AES/ICP-AES
- IRMS
- DSC
- IR and NMR

Now answer to the 2nd question is perfectly explained by [8] in the review article. He mentioned that if ratios of chemical constituents could be identified, it can be compared if adulterant is added to the food product. Adulterated food will have a different ratio and can be detected by suitable techniques, including chemometrics. He added to his work that a special commodity marker could prove the adulteration or authenticity of the product. The thermal analysis could provide a different approach as thermal behaviour deals with the change of temperature and/or time [8]. Food adulteration is the foulest practice that deals with human health and great economic loss. Food regulatory committees should certify the conservation and safety of food from start to end with a certain set of rules and standards. These regulations are meant to protect human standards across the nation [9]. Some of the common regulations are as follows:

- Codex Alimentarius
- HACCP
- ISO 22000

From this introduction, we can conclude that food adulteration is nothing but more than a criminal activity. Some people also term it as an act of selfishness or greed for money. Certain acts and regulations can improve food safety and quality along with systematic food trading. Methods are available to detect the adulterants but are sophisticated [3]. Analytical and food chemists are tested to create refined strategies to distinguish these deceitful practices and shield customers from financial misfortune and wellbeing risks.

Hazardous Effects of Food Adulteration: A study conducted by [10], stated that 54.2% of citizens in India were unaware of the fact that diarrhoea is a symptom of food-borne disease. 50-70% of citizens did not relate abdominal pain, nausea, and vomiting as a symptom of food-borne disease. 75% of people were found to store the heated food at room temperature, while 29.4% of people preferred to devour stowed food after heating. 6% of people did not care about the food adulteration as a threat to their life. 50% of people were not able to identify the spoilage of food by odour [10]. This indicates the need for awareness and knowledge pertaining to food adulteration and safety, characteristics of food spoilage and storage of food products in the surroundings.

Several surveys were conducted by scientists, committees, and organizations comparing the health effect of food adulteration in urban and rural areas. Such similar survey was conducted by [11] for Urea adulterated milk in Varanasi, India. The results of the survey indicated that children and adults are affected more in urban areas than in rural areas. About 28% of metropolitan offspring old enough gathering 6-18 have been influenced by migraine, while the same age gathering influenced just 4% of country youngsters. According to the National Institution of Nutrition, around 4 lakhs of children below five years of age die each year due to diarrhoea. The cause of many deaths is unhygienic conditions and contaminated food and water supplies [10]. Certain chronic health diseases caused by food adulteration, such as peptic ulcers, cirrhosis, Cardiac disorders, Blood disturbances, Bone marrow irregularities, and renal failure, have been seen due to adulterants such as colours, calcium carbide, urea and overabundance utilisation of preservatives [12]. The awareness of food adulteration and its associated hazards is a major concern in our society and should be motivated by food organizations and committees. Adulterated food is impure, contaminated, and causes serious life-threatening effects. Along with this, food safety, food fraud and food crime, such words should be understood by the people. Hygiene and proper sanitation play a key role in maintaining good health [13].

Food Adulteration: Challenges and Impact: Food adulteration is a major challenge in 2020, including the COVID-19 pandemic, which remains at first. Adulteration disturbs our whole routine life, directly affecting our health. The major impact of food adulteration occurs on farmers, manufacturers or enterprises, consumers, and the government [14].

Undertakings are affected by a deficiency of buyer trust in their items, reviews, and annihilation of sullied items, objection costs and increments of protection expenses and costs identified with hardware substitution or cleaning [5]. According to [15] there are three sorts of food extortion chances that represent a danger to the general population:

- Immediate risk to consumers from short-term experience leading to poisonous or toxic effects.
- Long-term exposure risk with possible lasting effects.
- Technical errors such as an error in food documentation. Example: allergic reaction caused by an unknown ingredient not included in label [15].

Like big enterprises, food fraud and adulteration have caused a massive impact on farmers. Numerous farmers endured enormous misfortunes, cost increments because of taking care of costs, and cow milk deficiency brought about by mass deals or butcher during the crisis.

Analytical Techniques used for Determination of Food Adulteration: In this 20th century, science creates a history every new day by innovations, new methods and concepts which makes human life easier and more adaptable. Similarly, today, several techniques are used to detect food adulteration. These include spectroscopic methods such as UV/Visible spectroscopy, IR spectroscopy, AAS/AES spectroscopy, and photo-luminescent spectroscopy. Chromatographic techniques such as HPLC, GC, and hyphenated techniques like GC-MS, LC-MS, and GC-MS-MS are the most recommended techniques in food adulteration detection. Another important term- is chemometrics which is defined as “Chemometrics is the chemical discipline that uses mathematical, statistical and other methods employing formal logic to design or select optimal measurement procedures and experiments and provide maximum relevant chemical information by analyzing chemical data” [16].

In a review by [17], the author tried to explain the non-destructive analytical techniques for food adulteration. These techniques do not require a large part of the sample and little or no pre-treatment sample. Conventional techniques involve the demolition of the sample in the method/process and operation process, which ultimately results in the complexity of the detection process. Non-destructive technique analysis is an alternative to conventional techniques with better and more accurate results. Sample information could be gathered quickly without damaging its veracity and great significance [17]. Non-destructive techniques include optical techniques, electrical techniques, and Nuclear magnetic techniques. These techniques are combined with chemometrics and multivariate data analysis to achieve Quantitative and Qualitative data of adulteration. We have tried to cover traditional and non-destructive analysis techniques for relevant information to teachers, students, researchers, and workers. We have reviewed recent and old articles for each following technique and briefly introduced the application and instrumentation in food adulteration. We have included different food adulteration detection by each technique for researchers and workers.

1. Computer Vision: Computer vision is a reproduction of natural vision utilizing PCs and related equipment. The most important parameter of food adulterant is the shape, size, and texture, which is easily and accurately determined by computer techniques to provide sufficient information. One of the research work by [18], beautifully implemented this technique to solve instinctive statistics analysis. The author proposed work on identifying and differentiating between bare and malting types of 22 flour variations with the help of machine learning and image features. The author combined Computer Vision System (CVS) and Spatial Pyramid Partition ensemble (SPPEs) technique. SPPE uses the investigation of examples from various spatial locales, giving more solid characterization. Support Vector Machine (SVM), k-Nearest Neighbors (k-NN), J48 decision tree, and Random Forest (RF) were used for comparison of sample classification. The result was observed with 75-100 % accuracy proving the proposed method of combining CVS with SPPEs is highly accurate and can be a budding method for instinctive flour barely classification. This technique would be best suitable in food industries with the advantage of a reduction in cost and effective automatic inspection of Quality [18].

Another remarkable work performed by [19] dealing with detection of adulteration in saffron by a combination of electric nose and computer vision system (CVS). Ten adulterated saffron samples were used for this study. The combined CVS and e-nose unit system was used for the removal of colour and aroma features of each sample. The principal component analysis (PCA), Hierarchical cluster analysis (HCA), and support vector machines (SVM) were used for the processing of extracted variables. These techniques exposed the results that adulterated saffron had a different aroma and color than authentic saffron and was easy to distinguish. Two multilayer neural networks were developed for saffron colour and aroma authentication providing high correlation coefficients. The conclusion was that aroma features are more effective than color features in detecting saffron adulteration [19].

Another work carried out by [20], classified six different varieties of rice based on morphological, colour and texture-based features. CVS was used as a tool and the results help to easily understand and identify the adulterated/fraud rice labelling. A neural network was used for the classification and for detection of fraud labels, a fuzzy classification database was employed for the correct labelling of rice. The method was cost-effective, efficient, and easy to practice in the industry, with highly accurate results [20]. There are many flowers and products which involve dying in their processing.

The quality of such products degrades because of concerns in colouring and adulteration. A similar case of safflower (*Carthamus tinctorius. L*) was solved by [21] using the application of CVS and near-Infrared.

The author combined CVS and NIR for the analysis of safflower. First, dyed safflower was identified from 150 samples by use of partial least square discrimination analysis (PLS-DA).

The PLS model quantitatively recognizes the “Hydroxy Safflower yellow pigment A (HSYA). The pigment was separated by PLS-DA method, and the Residual predictive deviation was found to be 2.5046 for HSYA. The results of this work can be used in the formulation and identification of safflower standards in the market [21].

CVS has wide applications in the detection of different food products and categories, for example:

- **In Fruits and Vegetables:** In 2010 [22] established a novel system for the detection of blemishes in potatoes using CVS as equipment. The inspection was carried based on shape, size, and colour and the results were signed up to the mark with around 90% accuracy level.
- **In Cereals [23]:** In his study, he used image processing as a utility for classifying kernels of barley with negligible error. Morphological features were used to classify kernels of five varieties of barley.

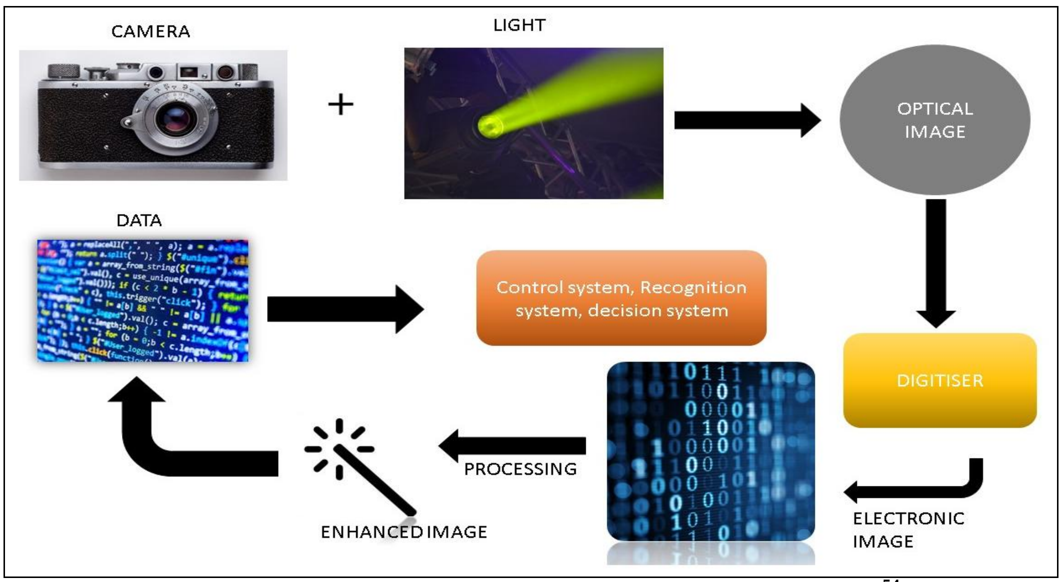

FIG. 1: PRINCIPLE OF COMPUTER VISION TECHNIQUE [54]

2. Spectral and Spectral Imaging Techniques:

A. Infrared Spectroscopy: Spectroscopy investigates the association between light and matter. Various types of spectroscopies can be utilized to assemble information about an atom's structure. In IR spectroscopy, a sample is irradiated with Infrared light, and molecules of a sample will absorb a certain frequency of IR radiation, which will cause the transition of vibrational and rotational energy levels of molecules. IR absorption spectra can be obtained by detecting the absorption of IR rays. The infra-red area (IR) measures the molecular vibration, where each functional group (or structural feature) has a single vibrational frequency to classify sample functional groups.

The product of a single molecular "fingerprint" to validate the distinctiveness of a sample if the results of all feature groups are considered together. For NIR, a nominal wavelength is between 750 and 2500 nm, and for MIR between 2500 and 25000 nm (4000 to 400 cm^{-1}).

A fingerprint or spectrum may result from solid, fluid or gaseous samples that may absorb any input IR radiation at particular wavelengths [24]. Fourier transform FT-IR has been designed to address the shortcomings of dispersive instruments. FT-IR has been developed. The scanning process was the big obstacle. A way to simultaneously and not independently quantify all infrared frequencies was required. A very simple optical instrument called an Interferometer has been developed for a solution. It creates a special signal type, which includes all the infrared frequencies. Many interferometers use a beam splitter, taking the inboard beam into two optical beams. The first beam mirror is attached to a flat mirror. The second beam represents an unbroken mirror that travels away from the beam splitter to a very short distance. The two beams are recombined as they meet at beam division and reflect the respective mirrors. The warning that the Interferometer occurs is the product of the interference of these two beams. The signal is called an interferogram of special properties where each signalling data point includes knowledge about each infrared frequency that comes from the source [255, 26]. Fourier change is performed by the PC, which gives the client the ideal ghostly data for examination.

A study conducted by [27] to recognize green pea defilement in ground pistachio nuts utilizing close and mid-infrared spectroscopy techniques shows that NIR is a more accurate and optimized technique. The author collected 63 samples of green pea, which was made adulterated in pistachio nuts. NIR and MIR-ATR (Mid-infrared attenuated total reflectance) spectra were carried out. The PLSR model (Partial least square regression) gave the estimated quantity of green pea ratio in pistachio nuts. The Standard error of prediction (SEP) for NIR was 2.55%, and MIR-ATR showed 9.14%. The prediction correlation coefficient was 0.99 and 0.80 for NIR and MIR-ATR, respectively. Residual predictive deviation values were 5.7 and 1.6, respectively. These results conclude that NIR has a wide advantage over the MIR-ATR technique for green pea detection in ground pistachio nuts [27]. In January 2020, [28] proposed using portable near-infra-red spectroscopy for fast identification of adulterated paprika powder. The potato starch, acacia, and annatto had adulterated nine paprika samples at varying concentration levels. NIR spectra were recorded for each sample and considered a forecaster to govern adulteration using partial least square-discriminant analysis (PLS-DA) and the PLSR method. The adulterated and non-adulterated samples were separated by PLS-DA, which is an efficient method by>90% specificity and <2% error rate. For an estimation of adulterant concentration in the paprika samples, the PLSR method was applied. Parameters determined were the discovery of green pea adulteration in ground pistachio nuts utilizing close and mid-infrared spectroscopy [28]. In 2004, [29] developed another methodology for order and assessment for corruption of unadulterated olive oil by near Infrared spectroscopy. The gravimetric method was employed for olive oil adulteration, and NIR spectra were carried out of these adulterated mixtures. The model involved in the study predicted the results accurately for adulterants and other oils intricated in olive oil with their respective error limits. PCA classified unknown adulterated olive oils mixtures developed models [29]. In 2002, [30] worked on detecting adulteration in cooked meat with the help of Mid-infrared spectroscopy. The pure beef and adulterated meat were separated by applying chemometrics along with the spectra.

Adulterants observed in cooking meat are the heart, tripe, kidney, and liver. The author has used raw samples and samples cooked with two different commands. Cooking takes up most of the water, showing a significant reduction in water peak in IR spectra. As the level of cooking increases, spectral data becomes fluctuating. This is because the over-drying of the product/sample makes the experimental properties difficult. The author concludes that MIR spectroscopy combined with chemometrics is a reliable and appropriate method for adulterant detection in cooked meat [30].

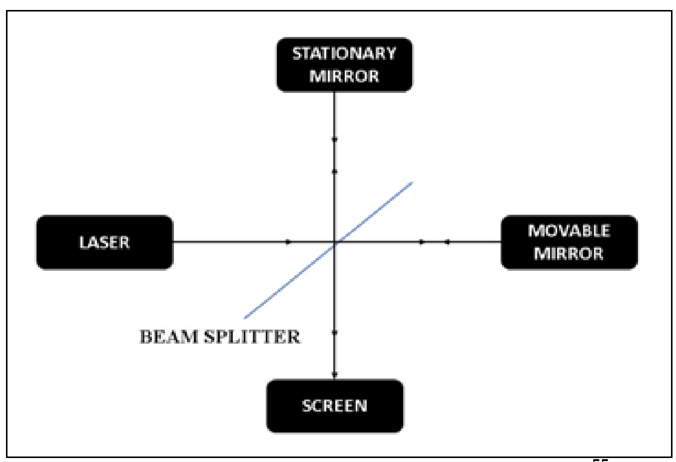

FIG. 2: MICHELSON INTERFEROMETER [55]

B. Raman Spectroscopy and Raman Imaging: In 1928, C.V. Raman discovered Raman's spectroscopy. It's a technique employed to witness vibration, rotation and other modes in a system with low frequency. Raman spectroscopy is also used in chemistry as a fingerprint to classify molecules. When the radiation travels through a transparent medium, a portion of the beam is spread in all directions. Raman dispersion is the result of vibration variations associated with the same form of IR spectrum. The wavelength difference from the event to the dispersed visible radiation corresponds to the wavelength from the center of the IR field.

If a sample is influenced by monochromatic radiation, the light interacts with the sample in some way. The radiation dispersal that occurs provides knowledge about the molecular structure can be mirrored, absorbed, or distributed. A coherent source, normally a laser, irradiates the sample.

The greater part of the radiation is flexibly dissipated. (Rayleigh scatter). A little part is in elastically dissipated (Stokes and anti-Stokes portions), the latter portion consists of desired information. The laser line is used as a reference for measuring spectrum.

The peaks are then calculated as the laser line shift. Vibrational energies characterize the peak positions identified with the bonds in the particles of which the example is made up. The groups accentuated in a Raman range are profoundly polarizable bonds, for example, π electrons.

The sources utilized in current Raman spectrometry are consistently lasers. It is important that focused energy creates Raman dispersing of adequate power to be estimated with a sensible sign to commotion proportion. The sample used could be in a solid, liquid or gas form.

Raman spectrometers are similar as UV-Visible spectrometers. Double grating systems are used widely for minimizing the forged radiation reaching the transducer.

Different types of Raman spectroscopy:

- Resonance Raman Spectroscopy (RRS).
- Surface-enhanced Raman Spectroscopy (SERS).
- Micro-Raman Spectroscopy.
- Nonlinear Raman spectroscopic technique.

In 2017, [31] used Raman Spectroscopic technique for detection of adulterants in Honey. The author analysed massive number of samples which showed fascinating results. 56 samples of original honey and 900 adulterated samples were used for this study.

With the help of PLS-LDA analysis, 96.54% and 90.00% accuracy observed in original honey and adulterated honey respectively. The method was found to be accurate, simple, and efficient with the use of chemometrics. The Raman spectroscopic technique is like IR technique and can be more advantageous if both are combined.

In 2020, [32] used FT-IR spectroscopy technique with Raman spectroscopy to authentic Turmeric powder adulterated with Sudan red and white Turmeric powder. The study shows that Sudan red peaks were identifiable in Raman spectral peaks, and white Turmeric powder peaks were easily identified in IR spectral peaks.

Using PLS model, correlation coefficient was determined and concluded to use IR imaging technique simultaneously with Raman spectroscopy for efficient results. In 2018, [33] designed a calibrated instrument known as Raman Hyperspectral Imaging Technique (RHSI) with in-built software. The instrument has a rapid line scan and is used to detect adulterants and analyze powdered food samples.

Therefore, the findings indicate that the combination of this RHSI method with data analysis descriptive and inferential statistical techniques is an easy and powerful tool for detecting chemical adulteration in food powders. With the globalization of food and its confounded systems administration framework, a wide scope of food toxins brought into the food framework coincidentally, purposefully, or normally.

Surface enhanced Raman Spectroscopy is a highly sensitive, rapid and highly interpretable technique that allows for molecule detection at its lowest level. A review by [34] sparks the importance of SERS in the study of perilous elements and microbial impurities in edible food and water.

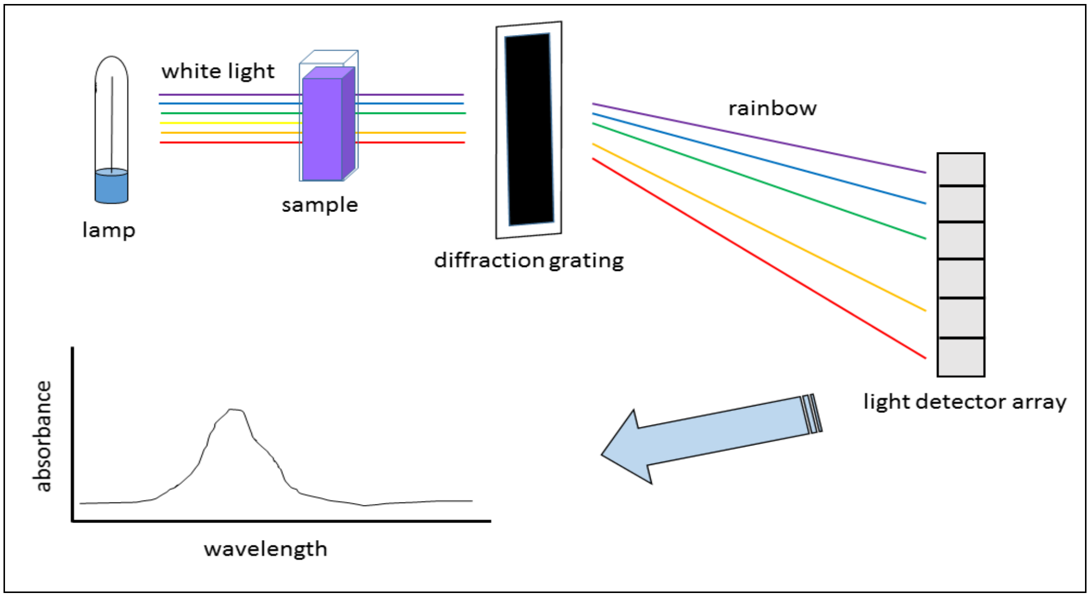

FIG. 3: RAMAN SPECTROSCOPY

C. Laser-Induced Breakdown Spectroscopy (LIBS): LIBS or Laser ablation is a spectroscopic technique that involves excluding material from a sample surface by treating it with a laser beam. LIBS detection sensitivity is in parts per million. LIBS is a type of AES which used as an adrenaline trigger, a highly intense laser pulse. A laser is concentrated to create a plasma that expands and stimulates the sample before a spectrometer ionizes and tests it. The spectrum formed consists of lines that match the elements evaporated from the surface of the sample.

The most common lasers used are Nd: YAG and eximer. PMT detector is used for Monochromator spectrometer and CCD detector for polychromator spectrometer. The detector connects to the spectrograph, which analyses collected plasma light interpreted by PC connected to the spectrograph. LIBS requires little or no sample preparation with analysis of extremely hard materials. It is a simple and time-efficient analytical technique. The limitation of this technique is the expensiveness and complexity of the system and poor precision. However, LIBS has various applications in the pharmaceutical industry and environment. The recent development of LIBS are as follows:

- Hyphenated Techniques with Raman and Fluorescence spectroscopy.
- Use of fem to the second laser for LIBS applications.
- One-shot multielement analysis using Echelle spectrograph tunable laser.

In 2018, [35] used LIBS technique for the determination of adulterants in butter. The adulterant determined was margarine, and spectra of both butter and adulterant were determined. LIBS spectra show a significant difference in bands of sodium (Na), potassium (K), and calcium (Ca) for butter and margarine. A Chemometric tool was used for analysis, which showed minor and major differences between sample and adulterant. The chemometrics data combined with the LIBS technique showed that the method is better than FAAS and ICP-MS and is eco-friendly, safe, and rapid with no pre-extraction and chemical requirements.

In 2017, [36] used the LBIS technique to detect adulteration in milk coupled with the chemometrics method. Identification of meat adulteration was carried out by [37] using LIBS technique for the identification of three meat species with the help of mass proteins and protein divisions (actin and myosin).

D. Terahertz Spectroscopy and Terahertz Imaging: Terahertz represents one thousand triples a second. Infrared subset Terahertz is typically used as radiation. Terahertz waves slip between long infra-red and short wavelengths of microwave irradiation.

The terahertz waves will enter the other parts of the EM spectrum through the opaque material. It has low photon energy (4 Mev at 1Thz, meaning that radiation cannot change organic buildings. It has a high penetration depth and a low dispersion with a 1mm resolution. Compared with X-rays or NMR images, knowledge obtained via the Terahertz spectroscopy is special. This disparity is due to the unusual translation, vibration, and rotational effect on the substance [38]. THz imaging has proved itself to be a new, non-destructive tool in food inspections. The key uses of THz in food industries include dampness identification, unfamiliar bodies, measurement and quality management. Others include antibiotics, microorganisms, carbohydrate recognition, amino acids, fatty acids and vitamins. THz is therefore a costly process and no database for foodstuffs is available until now [39]. In 2014, [40] carried out melamine detection in foods using THz imaging. Melamine is used as an adulterant in various food materials to increase the net nitrogen concentration. Melamine can cause serious effects to reproductive system or kidney and even death in some cases. Using THz spectra, images of melamine were captured in a frequency range of 0.1-3 THz. In 2020, [41] used THz spectroscopy combined with chemometrics to identify rice adulteration in five levels with different mixing proportions.

E. Fluorescence Spectroscopy: Fluorescence is indeed an emission occurrence and is determined by the observation of the emissions instead of absorption, through the energy transfer from a higher state to a lower state within the molecule concerned. A molecule absorbs wavelength light and emits it again at long wavelengths. A fluorescing atom or molecule is called a fluorophore. A range of close-spaced energy levels is found in each molecule. The absorption by a molecule of a light energy quantum allows an electron to transition from an actual ground to one of many potential vibrational stages in the first singlet. The total number of molecules in an excited state and excited with a standard 150-W light source is incredibly small, and approximately 10-13 molecules per mole of fluorophore are calculated. It is an extremely sensitive tool for calculating an examination level of 10-8 M. Factors that influence flowering calculation include concentration, solvent, sample, temperature, and background effects. The approach is sensitive, reliable, precise, and can have a wide variety of uses in Quantitative Analysis, Biochemistry, Environmental Importance, Chemistry, and, of course, Medicines. In December 2019, [42] applied fluorescence spectroscopy combined with chemometrics to detect adulteration in Desi Ghee. Adulteration of Vanaspati in mixed Ghee was successfully demonstrated, and the method was found to be efficient for adulterant detection in Desi Ghee [42]. In June 2020 [43] developed a method to detect adulterated sesame oil by 3D fluorescence spectra with wavelet moments. The qualitative wavelet moments were identified, and the model was suitable for online measurement. Recently, many papers have been published on cow and buffalo mix milk species authentication using fluorescence spectroscopy [44, 45, 46].

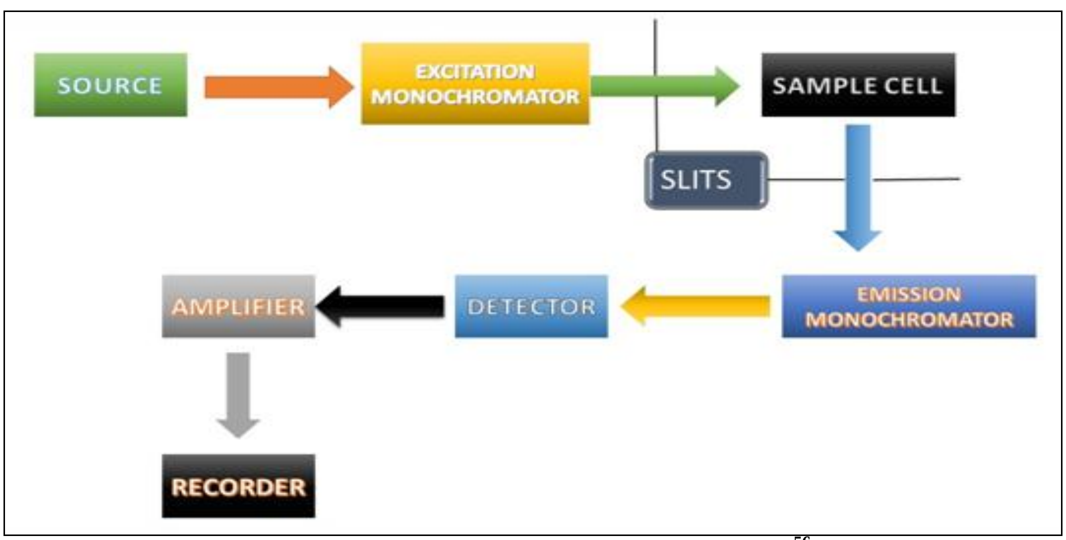

FIG. 4: FLUORESCENCE SPECTROSCOPY [56]

3. Electrical Techniques: There are many developed methods available to detect adulterants, but they are sophisticated in nature. The scientists thus took the initiative to use electrical methods, which have a major advantage of data storage, automation, and easy handling of instruments [47]. Some electrical techniques for food authentication are described below:

- Potentiometric method
- Conductance measurement
- E-nose and E-tongue
- Ultrasonic detectors
- Piezoelectric sensors

The E-nose operating theory concerns the distribution of samples, the identification mechanism, and the computer system. Polymers, metal oxides, or optical sensors that operate with the ability to variate light are mounted on sensors. In December 2020, [48] implied Optimized Electrical Nose System (OENS) for accurate detection of pork adulteration in beef. Similarly, E-tongue devices are used for adulterant detection, and this device involves a sensor array, reaction container, transducers, data collecting and processing devices. [49] In 2018 [50] reviewed all the methods till date available for detection of honey adulteration with the help of E-tongue.

4. NMR Spectroscopy: NMR spectroscopy depends on the assimilation of EMR in the radio recurrence locale 4 to 900 MHz by cores of particles. Two sorts of NMR are utilized 13C NMR and 1H NMR (Proton NMR). The theory behind NMR comes from the movement of a core and it creates an attractive field, the atomic twists are irregular in headings. Yet, when the appealing external field is accessible, the centers change themselves either with or against the field of the external magnet. If an appealing external field is applied, energy move is possible between ground state to an excited state. At the point when turn re-visitations of its ground state level, retained radiofrequency energy is produced at a similar recurrence level. The transmitted radiofrequency indication gives the NMR range of concerned qualities.

In May 2020, [51] used proton NMR for the detection of peanut adulteration in different food samples. In July 2020, [52] implemented NMR for butter authentication adulterated with margarine. In June 2020, [53] quantitated present adulterants in roasted and ground coffee samples using NMR spectroscopy and imaging combined with chemometric style. Similar works have been performed using NMR as an essential tool for qualitative and quantitative detection of adulterants in food products.

CONCLUSION: Food adulteration is understood as a major criterion in food authentication. In the above literature work, we have studied the different methods and techniques that can be used to detect adulterants. We have also reviewed the literature on recent and past years' work of adulteration in different food products like Honey, Butter, Coffee, Milk, and Oils. We have also looked at each method's instrumentation and principle, including their limitations and advantages. So, to conclude here, the paper shows the importance of the detection of adulterants and food authenticity. With new emerging electrical techniques, food adulteration can be eradicated easily, and the world can suffer a smaller number of health effects.

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