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Fraud Food and Food Spoilage Detection by Non-Destructive Technologies

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ABSTRACT
The rising global population has led to increased food demand. Quality food and food products are important for healthy living. Fraud food is one of the most urgent and activetopics offoods industries. More food fraud opportunities have been created by the increasing concerns of the food supply chain and reducing customer trust. Care to instrumental finding systems such as Raman spectroscopy, Hyperspectral imaging technique, NMR, NIRS, EM, E-nose, E-eye, and Electronic tongue coupled with chemometric approaches has greatly increased because they have been demonstrated as a promising alternative for the purpose of detection and monitoring food fraud and food spoilage. Fraud food and food spoilage are closely related to foodborne diseases. Food-borne diseases affect one out of every ten people (600 million a year), and about 420, 000 people die per year. The aim of this review was to discuss the detection and controlling of fraudulent food and food spoilage by non-destructive technology. Similarly, food verification is important because food fraud sometimes has unfortunate consequences, for instance, the spoilage of milk powder reported in China in 2008, which caused the death of six children and the hospitalization of thousands of others.
Keywords: Fraud Food, Food Spoilage, Nondestructive Techniques

Introduction

Food spoilage is a biochemical reaction due to cause of different microorganisms such as bacteria, and fungus that can change the food color, texture, taste and odor. The increasing global population has resulted in increased demand for food. For healthy living needed good quality of food. Changing the original organoleptic properties of food during food processing will lead to an increase in the amount of food spoilage. Food spoilage are main cause's economy losses for both consumer and manufacturer(Odeyemi, Alegbeleye, Strateva, Stratev, & safety, 2020). Food manufacture is feasible to increase 70% to realize the global food stock demands by 2050. However, at that point, 33%, generally 1.3 billion tones, of the entire made food to be exhausted is as yet lost every year, so wasting the 0.9 million hectares of land and 306 cubic kilometers of water needed for its creation.

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Food loss and waste (FLW) seems to show not only a misuse of natural resources, but also a missed opportunity to feed the global growing population(Magalhães, Ferreira, & Silva, 2021). Food fraud is the financial advantage caused food contamination, modification, reduction, mislabeling, and replacement with low-cost or unapproved material in food purposely. It is the deception that can happen in all foods, even the raw material, ingredient, the final product, or in the food's packing(Ting, Pui, & Solihin, 2020). Commonly organic food Premium food such as Meat, spice, herbs, honey, milk, olive, and wine, and coffee have mostly susceptible to fraud when they are provided through complex supply chain(Valand, Tanna, Lawson, & Bengtström, 2020). The raw milk is mostly using for different purposes the contamination chances is very high fingerprint identity is a known tool used for the authentication of raw milk. Desi ghee made from cow and buffalo milk can be distinguished, while butter comprising lard and cream and yogurt can be illustrious with chemo metrics. Fraud in fish and other seafood is a prevalent issue, and seafood products are often graded among the top food product categories. Substitution of a high-value fish species with a cheaper alternate and mislabeling of the geographical origin are between the maximum common fraudulent activities experienced in the fish and seafood sector. Identifying whether fish is wild or farmed, tracing farming systems, and distinguishing between fresh and frozen–thawed sea foods are among the seafood authenticity topics that have been broadly studied(Hassoun et al., 2020).However, there is no comprehensive review article that has summarized commonly used different seven nondestructive techniques for fraud food and food spoilage detection together. This review also summarized nondestructive technique working, principle and application for fraud food, food spoilage detection and addressing these problems.

Classification of detected Techniques

Raman Spectroscopy

Raman spectroscopy is a nondestructive, arising laser-put together logical procedure based with respect to Raman dissipating that has been demonstrated to be a valuable instrument for the fast identification and evaluation of biotic and abiotic samples, for example, foodborne pathogens, malignant growths and harmful chemical residues(Pang, Yang, & He, 2016). Vibrational Raman spectroscopy have been used for species identification through the utilization of their sample such as lipid, proteins, nucleic acids and carbohydrates(Craig, Franca, & Irudayaraj, 2013). Raman spectroscopy was mostly used in food safety research, such as identifying pesticide residues and adulteration detection(Wang, Sun, Pu, & Cheng, 2017),(X. Chen et al., 2020). The development of spectroscopy provides a potentially new method for the finding of meat spoilage and determine the content of horse meat in its mixture with beef and to distinguish between species and fresh and frozen/ thawed fish(Hameed, Xie, & Ying, 2018). Currently fake eggs have the most common fraud food which was prepared from dangerous additives chemicals. Fake or phony eggs have no nutritious worth and adversely impact on human wellbeing. The hurtful impacts of the synthetic substances used to make counterfeit eggs (Joshi et al., 2020). The last gathering incorporates counterfeit eggs which are frequently hard to identify by eye. Such fakes have been found in various area of Asia, produced using dangerous ingredients, for example, sodium alginate, tartrazine color, gypsum powder, and paraffin wax(Joshi et al., 2020).

Hyper spectral Imaging Technique

Hyper spectral imaging tools has been created as fast, nondestructive, smart and promising insightful apparatus to produce spatial and spectral data of the tested sample concurrently(Gharib-Bibalan,

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2018). Both dry and more humid condition results affecting the wetness content of the product which may cause primary spoilage(Gutierrez, Meleddu, & Piga, 2017). Some food and foods products spoiled before expiry and utilized by people then results in dangerous effects on human healthiness. Roughly 1 out of 10 (600 million every year) people endure and around 420, 000 passed by food-borne infection (Who Estimates of the Global).Numerous new reports have been reported the capability of this technique to distinguish a few quality and validness issues of fish and meat items, like microbial spoilage texture and colour features, flavor between new and freezing thawed products, etc. The detection of spoilage and pathogenic (main discussion) microorganisms has been performed using HIS with various chemo metric tools. HSI has been applied in the recognition of spoilage microorganisms by measuring total viable counts(Khoshnoudi-Nia, Moosavi-Nasab, Nassiri, & Azimifar, 2018), and in the detection of foodborne parasites, and fungal infections(Karuppiah, Senthilkumar, Jayas, & White, 2016). Food fraud and security are carefully related to human existence and assume a huge part in human survival and improvement. Food fraud and security are strictly related human existence and play an important part in human survival and improvement(de Lima et al., 2020). The issues cause significant monetary losses for the business and produce doubt from the buyers and merchants(Orrillo et al., 2019). Commonly teas more susceptible to fraudulent compare to other foods and become a serious problem for tea traders. Conventionally, the quality evaluation of tea is marked by means of very much prepared tea specialists(Ning, Hou, Sun, Zhang, & Wan, 2019). Detection of fraud food by nondestructive technique was described in Table 1. These requirements can be accomplished by molecular spectra and hyperspectral imaging examination strategy, which through non-destructive estimation and recognition that get high exactness of dark tea quality classification. Today, HSI procedure has been effectively utilizing for observing and arranging of tea quality. Food authentication is also necessary because food fraud may have unfavorable effects, such as the adulteration of milk powder in China in 2008 six children died as a result and thousands more were hospitalized(Esteki, Shahsavari, & Simal-Gandara, 2018). Different strategies have been created utilizing developed and powerful instruments to differentiate food fraud including chromatographic methodologies, Proteomics, metabolomics and genomics-based strategies(Böhme, Calo-Mata, Barros-Velázquez, & Ortea, 2019).

Table 1. Fraud food detection by non-destructive technology

Food Sample	Techniques	Detected Compound	References
Milk	Raman	Detection of urea adulteration	(Cozzolino, 2015)
Minced beef	NIRS	meat of Lidia breed and cattle	(López-Maestresalas et al., 2019)
cocoa powders	NIR technology	carob flour	(Quelal-Vásconez, Pérez-, Barat, &Talens, 2018)
Quinoa flour	FT-MIR	Soybean maize wheat flours	(Rodríguez, Rolandelli, &Buera, 2019)
Bovine meat	FTIR	NaCl, phosphates carrageenan	(Nunes, Andrade, Santos Filho, Lasmar, &Sena, 2016)
Ninced beef	NIR	pork and duck meat	(Leng et al., 2020)
Honey	Vis-NIRS	HFCS	(Ferreiro-González et al., 2018
Milk	NIRs	milk powder	(Cattaneo& Holroyd, 2013)
palm oil	NIRs	Sudan dyes	(Teye, Elliott, , & Mingle, 2019)
pomegranate molasses	HPLC	date molasses	(El Darra et al., 2017
South African honey	NIR	glucose and fructose	(Guelpa, Marini, du Plessis, Slabbert, & Manley, 2017)
Chinese Camellia oil	NIR	cheap vegetable oils	(Hu et al., 2019)

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Egg)	UV-VIS-NIRs	lipid extract	(Puertas&Vázquez, 2019
kudzu starch	NIR	sweet potato, potato, maize starches	(Xu, Shi, Cai, Zhong, &Tu, 2015
tapioca starch	NIR-HSI	Limestone	(Song, Wang, Maguire, &Nibouche, 2016)
Organic apples)	NIRS	non-organic apples	(Song et al., 2016)
Argan oil Vis	NIRS	cheap vegetable oils	(Farres, Srata, Fethi, &Kadaoui, 2019
camel milk	FT-IR	cow milk,	(Souhassou, Bassbasi, Hirri, Kzaiber&Oussama, 2018
Orange juice	HPLC-MS	Apple or grapefruit juice	(Hong et al., 2017)
Basmati rice	NMR	Non-Basmati long-grain rice	(Cassoli, Sartori, Zampar, & Machado, 2011)
Milk	FT-IR	synthetic milk	(Zhao, Feng, Chen, &Jia, 2019)

Near infrared spectroscopy

Spectroscopy (NIRS) has been in operation for more than four decades as a food analysis instrument and is the most commonly used spectroscopic tool for food research, in particular because of its high accuracy, performance, portability, robustness and instrumentation simplicity(Porep, Kammerer, & Carle, 2015). In the food engineering industry, NIRS systems have been committed to on-line quality administration and inner process tracking for times.NIRS could be an appropriate method for quick assessment and quality control of food and other food sources(Weeranantanaphan, Downey, Allen, & Sun, 2011). Specifically, efforts have been made to create versatile and quick meat security the board conventions and information evaluation measures dependent on NIR technology to evade or minimize harmful fraud contaminating in the meat factory(Schmutzler & Huck, 2016). Gray mold rot, is one the most serious disease of strawberry caused by Botrytis cinerea in which the fast entrance of gray masses of conidia on fruitlets occur also symptoms water soaking and collapse of parenchyma tissue develop which decomposed the sugar provide a suitable condition for the development of yeasts(Williams, 2014). Report has shown that using NIR-HIS for fungal infection in strawberry shows an effective result also this techniques show the possibility of NIR-HIS method in the estimation of the fruitlet quality and characteristics but data generated from studies takes time to calculate and process, limiting the speed and feasibility for online applications. Lettuce is the best functional fresh agricultural crops in Iran(Esteghamati et al., 2012). Lettuces is like fresh and green vegetables which are slightly treated frequently only washed and usually consumed raw(Van Haute, Sampers, Holvoet, & Uyttendaele, 2013). There has been an increasing number of outbreaks reported due associated with bacteria adulteration in leafy green vegetables. Vis/NIR spectroscopy is development optical based tools that can shorten identify outside and interior limitations of food product. Now, this technique is also considered for microorganism assessment(Rahi, Mobli, & Jamshidi, 2018). Spectroscopy also used for assessing the microorganism properties for food and their products like chicken, fish, milk, cheese, apple juice and vegetables. As of not long ago, NIRS has been broadly utilized in the field of food quality assessment due to its attributes of quick investigation, great reproducibility, cheap, no sample utilization, online analysis recognitionetc(Wang et al., 2017).

On the base of quality rice is categorized, and some merchants mix low quality of rice with good quality for profit. In 2015 Wuchang rice annual output was 1.5 million tons the report published by China Industry Information Network', the industry that at least 10 million tons of "Wuchang rice" were on sale in the Chinese market, which means that a large amount of Wuchang rice was bogus.

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Moreover, some dealers polished old rice and mixed it with new rice(Lai, Hsieh, & Ko, 2014). Fake Rice in the market was, mainly detected by Near-infrared spectroscopy(Liu, Li, Peng, Yang, & Wang, 2020). The possibility of using NMR to checked the validity of food was confirmed in the case of Honey(Ribeiro, Salva, & FERREIRA, 2010) vegetable oil, and fraud milk or milk contamination ,Tomatoes, Wine Vinegar, Olive Oils that is now called the near NIR spectroscopy have been reported for different food and foods products quality analysis and authenticity determination such as oils and cow milk(Downey, McIntyre, & Davies, 2002).

Terahertz Spectroscopic Imaging Technique

The electromagnetic (EM) radiation has unique properties and range of 0.3 THz to 3 THz which make it useful and attractive for various applications including packed food and packed water contamination detention and used for different biomedical application. In the 1980s, Auston at Bell Labs and Grischkowsky at IBM developed the first demonstration of THz wave time-domain spectroscopy using femtosecond laser sources to generate and classify freely transmitting THz(Ren et al., 2019).The main idea of this application is food and liquid have unique physical features and present a unique spectral imprint when exposed in the THz frequency domain(Heyden et al., 2010). The food quality and safety monitoring comprising microbiological contamination detection including toxic metals, pesticides veterinary drug residues, organic pollutants, radionuclides and mycotoxins(Suzuki, Ogawa, & Kondo, 2011).In the chocolate manufactory industry, chocolates are more susceptible to be contaminated. Therefore, a noninvasive and rapid prediction approach for monitoring chocolate to ensure good quality is highly demanded to meet today's fiercely competitive market. Detecting contamination like metallic or nonmetallic such as stone or glass particle attracts great attention during chocolate production(Redo-Sanchez et al., 2011). The stones may origin from ingredients like nuts whilst glass may come from light. Owing to the high fat with low moisture content, the THz imaging has been intensively employed to detect foreign body in chocolate(Guillet et al., 2014). Mixture food matrices like milk powder, cereal powder, hamburgers, meatballs, patties are attractive targets for adulteration due to monetary profits. For instance, one of the largest food safety events – adulteration of milk powder with melamine–shocked everyone in China. A lot of innocent infants consumed this ‒poison milk power‖ and consequently suffered from kidney stones and other Complications. The different concentrations (0–10 wt %) of melamine mixed in flour, milk, chocolate powder, and high-density polyethylene (HDPE) were detected by using THz-TDS(Baek, Lim, & Chun, 2014).

Electronic nose

The electronic nose (e-nose), a gas sensor array technology, has recently emerged as an important technique for detecting food spoilage(Gobbi et al., 2015)،(Fujioka et al., 2013). The design of an e-nose system can be fluctuated relying upon the purpose behind the application. A commercial e-nose is ordinarily helpful and conservative. Nonetheless, there is no commercial e-nose that can test all food volatiles. Therefore, a few experts altered their e-nose to get extraordinary capacities for various samples. It copies the human olfactory framework to research and perceive complex volatiles by a cross-delicate synthetic sensor cluster(Concina et al., 2009). The benefits such as sample non-destruction, portability, cheap, and good reliability make e-nose be capable for odor valuation of food properties like process monitoring, traceability of products(Cynkar, Dambergs, Smith, & Cozzolino, 2010; Huang, Zhao, Chen, & Zhang, 2014) and detection of authenticity, shelf-life and

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microbial contamination (Gobbi et al., 2015). E-nose is a computer skilled of detecting basic smells by connection a partially unique chemical sensor array method through adequate pattern recognition. E-nose have been used for different purposes such as microorganisms like bacteria, fungus classification, identification and analyses different bacterial volatile compound compounds (VOCs). E-nose broadly uses for detection of food spoilage which causes by bacteria in food industries(Pattarapon, Zhang, Bhandari, & Gao, 2018). Detection of food spoilage by nondestructive techniques was shown in Table 2. E-nose best fast non-invasive online technique widely applied or used in food industries for food quality detection, food monitoring and food safety as more reliable compare to other nondestructive techniques(S. Chen, Wang, & Choi, 2013). Microbial metabolism cause undesirable smells in food products(Sanaeifar, ZakiDizaji, Jafari, & de la Guardia, 2017) can be identify by E nose. By E- nose technology fruit ripening, sugar content and pH value determination and Further studies E- nose used for detection primary contamination caused by microorganism in strawberry, orange, blueberry(Pallottino et al., 2012), and fruit juice contamination detection have been reported. E-nose has been utilized for observing the variations in different food products during storage time and assessment of shelf life and spoilage(Sanaeifar, Mohtasebi, Ghasemi-Varnamkhasti, & Siadat, 2014). E –nose additionally have been utilized for different foods for example, bamboo shoots, lager, saffron rice, cherry, squid, harsh chocolates, stewed chicken, pork necks, cocoa, peaches and for diagnoses different fugal disease in fruit and vegetable(Ying et al., 2019).

Table 2. Spoiled foods detection by non-destructive technology

Sample	Techniques	Detected Microbes	References
Chicken	FT-IR, NIR	Free amino acids and Peptides	(Alexandrakis,Downey,& techology, 2012)
chilled pork	NIR, Himaging	total viable count	(Barbin, ElMasry, Sun, Allen, & Morsy, 2013)
pork meat	NIRS and E-nose	TVB-N	(Huang et al., 2014)
Beef	FTIR	total viable count	(Kodogiannis & Alshejari, 2014)
Brown rice	HSI, NIR	viable colony counts	(Siripatrawan & Harte, 2015)
Beef	Vis-NIR, LS -SVM	Evaluating,colour variations	(Zhao et al., 2019)
Paneer	Radio Frequency sensor	Frequency	(Varshney, Pathak,&Sircar, 2020)
Coconut	RF technology	Measures,content water	(Varshney et al., 2020)
Meat spoilage	NFC	TVBN, BAs, NH3	(Ma et al., 2018)
cereal grains	NIR	Fungal infection	(Orina, Manley, & Williams, 2017)
Spinach	HIS	Escherichia,coli detection	(El-Mesery, Mao, & Abomohra, 2019)
Chicken	SW-NIR diffuse reflectance spectroscopy	microbial loads	(Lin et al., 2004)
Chicken	HIS	*Pseudomonas counts*	(Feng & Sun, 2013)
Chicken	HIS	TVB-N	(Khulal, Zhao, & Chen, 2016)
Grass carp	HIS	TVB-N	(Cheng, Sun, Zeng, & Pu, 2014)
Farmed salmon	HIS	*Lactic acid bacteria*	(He, Sun, & Wu, 2014)

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Pork	Hyperspectral scattering technique	*Escherichia coli*	(Tao, Peng, Li, Chao, & Dhakal, 2012)
salmon flesh	TS-HIS	TVC	(Wu & Sun, 2013)
Poultry	E-nose	*KlebsiellaEnterobacter cloaca‡*	(Arnold & Senter, 1998)
Milk and dairy products	E-nose	*Cereusluorescens§ Staphylococcus*	(Casalinuovo, Di Pierro, Coletta, & Di Francesco, 2006)
Water	E-nose	*Enterobacteraerogenes§*	(Canhoto & Magan, 2003)
Grains	E-nose	*Fusariummoniliforme‡ ‡*	(Olsson, Börjesson, Lundstedt, & Schnürer, 2002)
Bakery products	E-nose	*Eurotiumamstelodami‡*	(Keshri & Magan, 2000)
Beef	E-nose	*E. coli O57:H7, Staphylococcus*	(Abdallah, Al-Shatti, Alhajraf, Al-Hammad, & Al-Awadi, 2013)
Fresh alfalfa sprouts	E-nose	*Salmonelatyphimurium*	(Siripatrawan & Harte, 2015)
Processed tomatoes	E-nose	*Escherichia coli*	(Concina et al., 2009)
Goat meat	E-nose	*Escherichia coli*	(DING, LAN, & ZHENG, 2010)

Electronic Tongue

E-tongue has been used to assess qualitative and quantitative spoilage in a number of foods. E-Tongue has been reported for spoilage determination in different foods. E-tongue is bio inspired device developed in 1980,s as an effective experience of hardware and electrochemistry with chemo measurements. Food spoilage is complex biochemical reaction occur due to the activity of some microorganism and enzyme which involves atmospheric oxygen(Woertz, Tissen, Kleinebudde, & Breitkreutz, 2011). They try to replicate the capacity of human noses and tongues to detect particular odors and tastes, as their names indicate. Electronic noses are used in a number of research areas, including environmental monitoring(Krantz-Rülcker, Stenberg, Winquist, & Lundström, 2001), pharmacy, biotechnology (Rudnitskaya & Legin, 2008) and has been mostly used in food analysis(Deisingh, Stone, & Thompson, 2004). This isn't unexpected, considering that they try to mimic human noses and tongues, which are often used to smell and taste food (Woertz et al., 2011). Hence, for the quantitative case, various poisonous mixtures produced during the food spoilage have been resolved, particularly biogenic amines, which result from amino acids decarboxylation. The amino acids associated with these processes are free amino acids present in food sources, but also the ones which originate in proteins hydrolysis(Naila, Flint, Fletcher, Bremer, & Meerdink, 2010). Due to Microbial contamination in dry-cured ham can occur at several phases of the maturation process, and the development of a huge amount of microorganisms involved in decomposition may lead to the change of the end product(Devine & Dikeman, 2014). Initial research electronic tongue with sensor arranged was used for qualitative and quantities study for different sample taste solution such as umami, salty, sour and bitter(Khan, Rahaman, Khalilian, & Kang, 2016).Procedures and technique for the comprehensive analysis of different criteria are required for food quality control, as well as the identification of food spoilage processes. Studying food protection substances and contaminants,

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compounds that are inadvertently found in food and that may not exist under normal conditions, are the key study directions(T. McGrath, Elliott, & Fodey, 2012).

Nuclear Magnetic Resonance Spectroscopy

Nuclear magnetic resonance (NMR) is fast, precise and non-invasive equipment that is usually used to identify food quality, mainly for fruits, vegetables, meat and aquatic products. Nuclear magnetic resonance (NMR) is an alternating magnetic field energy exchange mechanism by nuclei with set magnetic enhancement of NMR technology in food manufacturing Conformational review(Youssouf et al., 2017) technical or dietary elements, identification of consistency and regulation of procedures. The benefits of NMR are that various food materials, a limited volume of sample pretreatment and preparation, as well as repeatability, non-destructive and quantitative, do not need to be isolated(E. Kirtil, S. Cikrikci, M. J. McCarthy, & M. H. Oztop, 2017). In the 1950s, NMR was first used in food science to determine the moisture content of food. They either searched for fungal disease on the inside of fruit, mostly thick-skinned fruits, or on the outside of the samples, or they neglected the sample preparation period(E. Kirtil, S. Cikrikci, M. J. McCarthy, & M. H. J. C. O. i. F. S. Oztop, 2017).

Conclusion

In this study, we described the use of non-destructive techniques such as raman spectroscopy, hyperspectral imaging technique, NMR, NIRS, EM, e-nose, electronic eye and electronic tongue to determine fraud food, food spoilage, and properties related to food quality. In our view, there are two difficulties associated with food and food engineering. First problems are food fraudulent and other is food spoilage by microorganisms like fungus and bacteria. Food fraud and security are closely linked to human life and play a major role in human survival and development. The problems cause the industry major economic losses and create mistrust among customers and traders. The key causes of foodborne disease are food spoilage and food fraud, such as the adulteration of milk powder recorded in China in 2008 that caused the death of six children and the hospitalization of thousands of others. Non-destructive technology was developed as a successful technology during the 19th century. In other conventional approaches, food spoilage and food fraud identification is possible, but time consuming and involves sample preparation.

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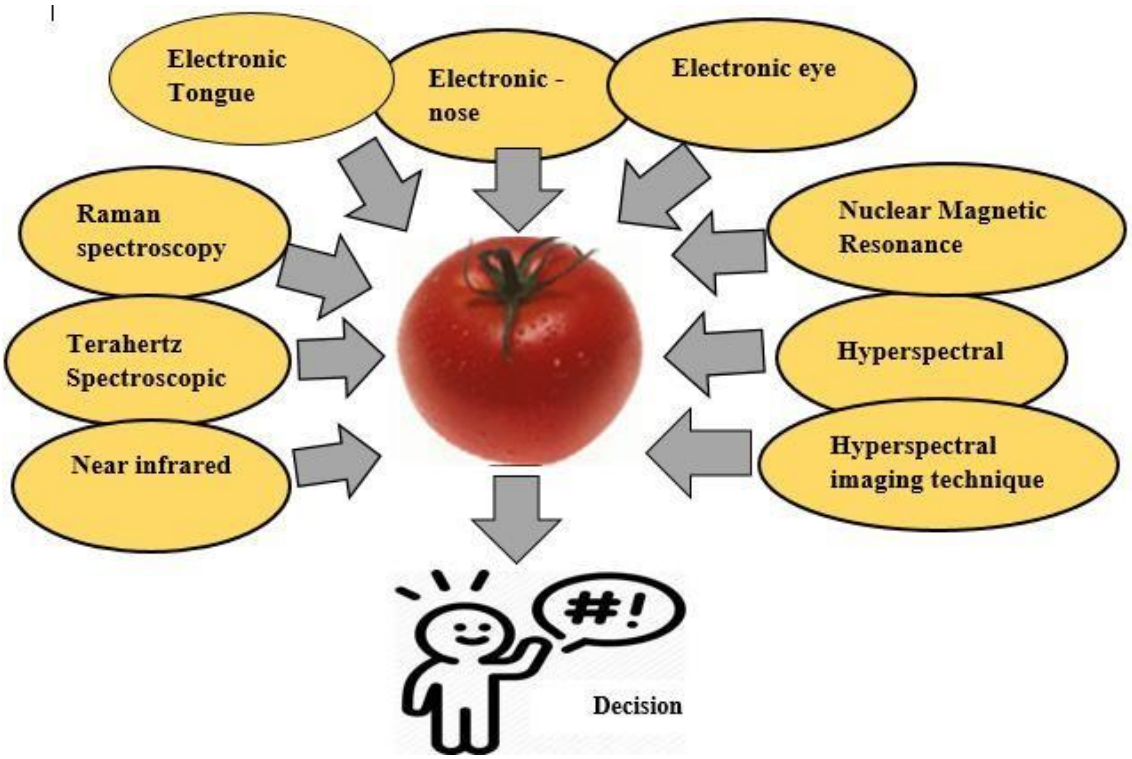

Figure show different non-destructive techniques for quick detection food fraud and food spoilage.

Significance Statement

Fraud food and food spoilage is a common problem which can causes food born disease. For addressing this problem different methods have been developed. Nondestructive technologies are the most effective, fast, cheaper, high accuracy performance and instrumentation, simplicity methods to detect qualitative and quantitative spoilage in a number of foods. They either searched fraud food and fungal, bacterial disease on the inside and outside of food without the need to cut samples or they neglected the sample preparation period.

Contribution of Author

Conceptualization and Writing of the original draft S.K, revision and editing of the final version , K.U.R, H.A, R.A.B, M.I, M.I, M.J, R.D.K and Z.L, supervision, Z.X. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare that they have no conflicts of interest.

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