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Artificial Intelligence Based Techniques for Authenticity of Food Products in Food Fraud

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ABSTRACT

Food fraud is a widespread issue affecting almost all food commodities, leading to significant economic losses, public health risks, and violations of quality and consumer rights. Traditional detection methods are time-consuming, labor-intensive, and require costly equipment. With increasing competition in the food industry, there is a growing demand for faster, more efficient detection methods. Artificial intelligence (AI) and machine learning (ML) have emerged as powerful tools for predictive analysis in food fraud detection. These technologies allow for rapid analysis, aiding legal investigations ensuring food safety, authenticity, and traceability. Electronic nose (E-nose) systems, which identify organic compounds based on their unique aromas, are evaluated with chemometric methods to verify authenticity and help prevent fraudulent practices.

Keywords: Artificial intelligence; machine learning; food integrity; food safety; food quality.

1. INTRODUCTION

Food quality, food safety and food defense are part of the range within it falls "food fraud". The classification includes both intended and unintended events true, whether the described result is actual harm to public health. The inspection and tracking of foodstuffs through forensic techniques is categorized under the heading Food Forensics. While the global food supply chain is becoming increasingly complex and scalable, major changes in environmental as well population-related aspects seem to have an influence on how our systems produce edible substances. But these changes could lead to more food fraud and safety issues, threatening public health. This is why we are beginning to see widespread use of artificial intelligence (AI) in the food supply chain as a serious method of mitigating these risks [1].

Other types of supply chain and traceability systems are also being considered for development to meet additional requirements surrounding food fraud. This surge of recent attention has food fraud now being pitched by commercial organizations as well as by governments in many countries. In the possibility of using forensic methods to authenticate and trace food products is included under an umbrella referred to as food forensics. From farm to fork, significant shifts in the environment, population and economy have an impact on how food producing systems will operate. These changes could result into higher risks related to food fraud which would also compromise safety and ultimately affect the health of people. One way to reduce these risks would be through applying artificial intelligence (AI) technologies within food supply chains. Artificial Intelligence is the ability of a machine to learn from big datasets statistically and then apply the results of this analysis to subsequent learning. The output produced as a result of this learning is algorithms, which are then used to meet specific needs. These needs are further improved because of autonomous learning, which is learning without human intervention. Machine Learning, as seen in the above definition related to Artificial Intelligence, involves giving structured massive data plus continuous inputs on algorithms (way of improving them) and eventually train robots on how best they can respond. It’s quite uncommon for a day to pass without hearing some headlines about how AI is going to revolutionize our lives. The potential uses are many because it can range from self-driving cars to sophisticated healthcare systems where machine learning algorithms help pathologists analyze tissue samples to generative AI that can produce text, images and audio. And it’s all customized to what individual clients want. While the jury is still out on the benefits versus drawbacks of this technology, one area where AI/ML will greatly help humanity is in detecting food fraud and ensuring better food safety [2].

Food fraud is one of the major global challenges of our time, with AI/ML topping the list of technologies most applied in this sphere. Food fraud is an intentional act by food suppliers where products are misrepresented to the customer regarding composition, origin or quality. According to U.S. Food and Drug Administration stolen foodstuffs costs businesses between $10 and $15 billion annually. The cost to industry from yearly food fraud has been estimated at anywhere from $10 billion to as high as $40 billion with some figures going even higher than this range. Besides its financial implications, trust and safety in food because of fraud harmed customers. Fraud can take place in almost every field related with food sector and diverse varieties of foods including meat, fish & vegetable oils apart from beverages get impacted because of it [1].

Hardly does a day pass without some news feature reminding you about how AI will change the way we live our lives. Hardly a day passes without one of these news stories about the way AI is set to change our lives. The extent to which artificial intelligence (AI) and machine learning (ML) affect humanity are constantly evolving. Generative AI: Text can be made germane to customer requirements when they need text, images when customers have image demands as well sound; infact the generative field seems limitless that could range from self-driving automobiles or taking machine learning on healthcare management perspectives like pathologists inputting tissue samples. One way AI and ML will help humanity is to improve food security by detecting food fraud. My sites that offer algorithms, convert large over time data sets to do statistical analysis learn through Artificial Intelligence [2].

AI (Artificial Intelligence) is the ability of a computer to analyze and learn through statistical analysis with large data. These things that these entities learn from is used other purposes, in the form of algorithms. An automated process, this continues unabated for as long as the algorithm is running and they get better with time. Structured big data sets and continuous algorithmic (product supervision) & human feedback with machine learning combines, AI systems can learn more precise. Food theft is the biggest global issue today and AI/ML is harshly being implemented on it. Simply put, food fraud is when a supplier gives inaccurate information to the consumer about what they are actually eating, an intentional act by any person or business for economic gain that misleads consumers as to what with product sold (composition, provenance and/or quality).

Aside from the financial implications, there is also a safety and consumer experience risk. Food fraud is a multibillion dollar industry, and food fraud incidents are rampant in nearly all common household staples like beverages, vegetable oils, fish, meat and poultry. A multiple consortium has always opposed food fraud in the food business. This includes assessments for raw material risk to identify high-risk supply chains/materials. Analytical testing is conducted in response to these assessments to confirm non-negligible levels of adulterants that may be present in given foods [3].

These remain fruitful when the focus is on identifying adulterants, and fraud strategies have changed. However, the world of food fraud is a highly fluid one. Analytical chemists are always being fooled by criminals who add new adulterants, scam the tests and take advantage of this! This underscores the need for the non-aimed approach and establishes a sort of ongoing war between the scientists and scammers [4].

1.1. Leveraging AI

The ability of Artificial Intelligence (AI) to detect fraud cases which would have gone unnoticed with traditional approaches, is its capability of recognizing patterns in massive datasets. There are many online research articles and programs that work on chemistry and AI. One notable program is the United States National Institute of Standards and Technology's (NIST) "Machine Learning to Predict Food Provenance". The quality and the way consumers perceive food is heavily influenced by its origin in detecting food fraud. This is known as food provenance. Therefore, this is important to the economy as spoiled goods can be confused with much better commodities. At the 2019 NIST Food Safety Workshop, NIST identified one of the four main pillars of food safety as establishing computational tools and databases for determining food authenticity. They highlighted flaws in mathematical approaches to take on vast databases of biological and chemical information that would be necessary to define the fingerprint of food. The current focus of the NIST project to secure the American food supply is the generation of chemometric fingerprints [2].

Food adulteration affects various types of goods e.g., Dairy, grains, and shellfish, oils and alcoholic drinks, honey. Even our fruits and vegetables are sometimes contaminated with toxic chemicals and pesticides. Adulteration almost always involves living essential things like food and water but can be made by removing key elements of a product, covering up lesser goods or substituting the real stuff with lesser products. Adulterants (Abuse) of food, food kept in harmful containers, and perverted pesticides or chemicals added to edibles, further damaging the quality. There are several factors in food potentially making it adulterated other than intentional adulteration, spoilage can also occur to fruits and vegetables or perishable goods such as dairy and drinks from microbial decay. The adulteration and contamination of food are serious health hazards that can cause inferior quality [5].

Initially such worries were trivial but with the social and economic upliftment of society there is a growing concern over safety and standardization of food. As more and more people are becoming aware of the benefits of living healthy a good food pollution detection serves the primary objective for which it is needed. Currently, the rapid increase in the international turnover of food has been accompanied by a rising demand for high-quality food. Nonetheless, traditional food analysis methods are often limited as they rely heavily on subjective quality assessment [3, 4, 5].

In this context, biosensors and artificial intelligence (AI) bring new approaches for food quality evaluation. Thus, this study puts forward a detailed work on designing evaluation models suitable for any level of aggregation for data which will in turn be combined with food quality indices. This is to demonstrate the precision and effectiveness of AI and bio-sensors for food quality testing. The use of AI and ML for food fraud detection has been well researched. When the rice's origin was asked about or premium-quality rice had been mixed with low-quality rice, there were some cases in which fake rice samples were distinguished using E-nose sensors and near-infrared spectroscopy. In another study, a machine-learning model was developed and applied to Fourier-transform infrared spectroscopy data from milk adulterated with eighteen different substances (from melamine to water) [6].

Another study conducted hyperspectral sensing and RGB imaging data with AI/ML to detect artificial ripening of bananas using expression of calcium carbide, which is carcinogenic in ethylene based ripening. All these as well as many other examples show how AI and ML are being used to perform an untargeted manner of this approach may surprise older generation of analytical chemists. Traditionally, identifying an adulterant meant first figuring out what the adulterant was and then devising an analytical technique to screen for it. For years, this targeted approach was the main strategy. Computer evolution allows the effective analysis of vast data collections employing data never done before. The data scientist of today reviews the data available and tells if a sample is skewed, hence tampered with or not. It is now good enough to determine whether the material is identical or not; it no longer has to be this same Molecule you wanted. AI and ML shines in this type of non-targeted approach. It can be from any of the data sets to analyze [7].

Artificial intelligence used in identifying food fraud can be greatly enhanced with the establishment of new cutting-edge chemical databases and their widespread publication. To solve this problem, this enclosed world of food firms will eventually need to open up and share data with one another in order to develop important algorithms that can be used for creating a safe and reliable food chain [8].

Food adulteration is a dangerous and morally corruptive practice that contravenes the most elementary rules of food science and puts public health at risk. It is the act of surreptitiously substituting harmful elements in substandard goods with a high margin for profit. He said the unethical practice has evolved into a billion-dollar industry, with shopkeepers, vendors and others seeking to turn fast profits at the expense of health safety requirements. Dairy, grains, shellfish, oils, alcoholic beverages and honey are just a few of the many products affected by food adulteration. Pesticides and other hazardous chemicals ruin even the fruits and vegetables. Adulteration is the use of dishonest methods or impurities in food and drugs with the intent to deceive consumers; for instance, removing vital ingredients from food hiding low-quality goods or selling one thing as another. Along with the unclear components going in, food is also stored in hazardous containers, and there are dangerous chemicals or pesticides that come along. In addition, food contamination can occur spontaneously with the deterioration of perishable items such as dairy and liquids or when microorganisms spoil fruit and vegetables. Due to adulteration and contamination, it becomes an important issue that affects the health of the consumer [6].

As such, food safety and quality are increasingly of concern as society develops socioeconomically. As awareness grows about the importance of healthy eating, so does the need for a food pollution detector. Meanwhile-thanks to the incredible pace of global food trade as well the need for better quality food has become even more pressing. The vast subjective nature of traditional food analysis methods to underpin the quality assessment and, therefore, often with their limits. Therefore, the development of biosensors and artificial intelligence (AI) enable new strategies of food quality assessment. This work provides an extensive methodology, which deals with evaluation models consistent to the food quality indices and their associated information. This aims to showcase the broad scope and effectiveness of AI and biosensors in analyzing food quality. This study also addresses the difficulties and opportunities that these technologies may present [9].

1.2. Transformative potential of AI and ML in detecting Food Integrity

The integrity of food is a complex and multi-dimensional problem. Conventional ways of monitoring food quality and safety are manual inspection testing, which is time-consuming and even prone to errors made by human. A solid monitoring process is needed to address these concerns and to catch misappropriation of quality in food, before it becomes a common thread at a source. Such technologies, which is why AI and ML are blossoming as a silver lining and new conquest. Tied to the aforementioned benefits, these technologies have the capacity of resolving intricate issues and producing novel solutions with practical use cases, notably in strengthening food safety and quality monitoring systems by making them more accurate, quicker and efficient as well. But the issue of food integrity is much more complex, and traditional methods for safeguarding food safety and quality rely on time-consuming, manual testing or observation susceptible to human error. To respond to these challenges, food companies must deploy robust track-and-trace solutions capable of spotting problems with food quality as early in the production process as possible. Artificial intelligence (AI) and Machine Learning (ML) technologies are indeed a relatively newer space that is beginning to provide potential solutions to these critical issues faced by the food chain. Beyond gaming, AI and ML are proven to handle hard-to-tackle problems, as demonstrated by recent publications that have proposed innovative solutions to address practical issues related to enhancing the precision, efficacy, and efficiency of food-safety or -quality monitoring systems [10].

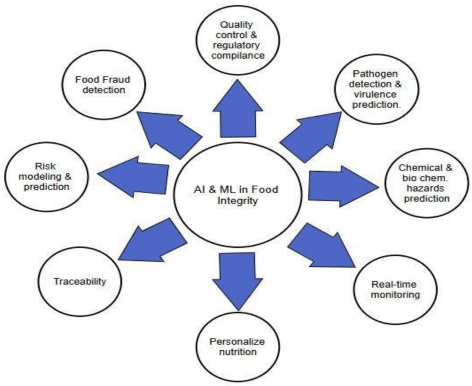


Figure 1: Applications of AI and ML in Food Integrity

By using AI and ML technologies, the automated systems can establish accurate and uniform quality parameters for different types of food products based on changes in shape, size, color, texture, and nutraceutical composition; they maintain product quality during processing. By processing large food safety datasets such as those of Food Safety Modernization Act (FSMA), the predictive AI/ML models can forecast future occurrences, identify attention deficient areas and aid in develop useful food safety management plans. The information helps food safety people make decisions ensuring a safe food supply, and to develop interventions that can be more responsive with resources [10, 11].

A study for instance that enhanced the border inspection of imported food to Taiwan developed a range of ensemble learning models anticipates food security risks. These models were used online, and it will be a long non-conformity hit rate with that, which shows how nicely ensemble learning works to give us signals of where the food safety hazards are going into. Alternatively, Support Vector Machines (SVM) were using to devise an intelligent early warning system for the detection of food safety threats and their possible outcrops [12].

The distribution of records on food, health, and agriculture across multiple domains and many not in digitalized formats raises a challenge for food safety. By merging data from numerous places and transforming those documents into a computable format, modeling can become quite effective. Combining data from different sources together can provide a more complete picture of the attributes and factors that influence food safety outcomes e.g. mycotoxins, toxic compounds produced by some fungi, depend on temperature and humidity Incorporating climatic data into modeling contexts allows for an appraisal of which environmental factors influence mycotoxin levels in food products [13].

This richer data source expands the types of inputs that can be used to build models, allowing for larger quantities of related (or even weakly related) data to be factored into model creation thereby uncovering more intricate relationships and patterns between varying prismatic product elements that might not otherwise become clear in a significantly smaller set. In this broader sense, we can learn more accurately and in a nuanced way about what affects food security, resulting in stronger, more capable models. At present, AI and ML technologies are now capable of grade quality attributes of different food staples as shape, size, color, texture etc. and help to keep them in good condition while they undergo processing under automated systems [14].

Predictive AI and ML models can accurately predict the probability of future occurrences, identify hot spot areas and can enable greater data analytics from large food safety datasets for designing effective food safety management systems. Food safety experts can leverage this information to help them design more resource-efficient treatments so as to maintain quality and integrity. The study [15] analyzed the prediction for food safety risks across many ensemble learning models but mainly prioritizing measures to enhance border inspection of imported food into Taiwan. This improved the hit rate of non-conformities drastically with the implementation of their online approach models; this is a good example of Ensemble Learning for forecasting the risks related to food safety. An intelligent early warning system for food safety issues was developed utilizing SVM for prediction of potential alerts related to food safety other than conventional QSAR processes for more secure food supply chain [14, 15, 16].

Another area of concern is the pervasive anonymity of numerous food safety records, which still exist in non-digitized format and are dispersed across various sectors (such as food, health, agriculture). These papers were then combined digitally so it would be computationally friendly, and additional information was added from numerous sources which allow for the creation of large datasets to enhance its efficiency and capability. By aggregating data from multiple sources, one is better able to capture a broader set of characteristics and covariates that contribute to the outcomes of food safety Test Category This integrated view leads to a more comprehensive understanding of the complex interconnected relationships and dynamics in food safety. Mycotoxins, here represented by toxic compounds produced by certain types of molds, are a good example which can be altered or catalyzed by environmental agents such as temperature and humidity. The climate data can then be incorporated in the form of covariates into the modeling and provide insights to know about the environmental factors that drive higher or lower mycotoxin levels in food products. The higher number of data allows revealing subtle connections and clues which become invisible if you use a small volume, moreover there is more material for modeling. This enables to more accurately (as well as more complexly) describe the multiplicity of factors that can influence food safety, leading eventually to models that generalize much better [17].

1.3. Role of AI and ML Techniques in Food Safety and Quality Control Assessment

AI and ML techniques have transformed the field of food quality management by providing innovative methods for enhancing the consistency and safety of food products [18]. A few most common methods used by the industry are:

1.3.1. Computer vision

AI and machine vision have literally been a landmark solution in food process engineering [19]. And this duo is paving the way for a transform in the industry of food, whereof allows thorough and automated visual inspections. Food testing through image and video analysis is precisely and quickly examined by AI-powered computer vision systems. Those systems are critical for things like sorting, grading and evaluating quality. By detecting deviations from quality standards in time, they ensure that only the goods complying with these stringent requirements are delivered to consumers. This has effects on numerous food processing segments. During Sorting, AI can identify very fine variation in color, size, and form during the process of sorting by using computer vision system. This ability to very finely group makes product identification straightforward and it is particularly useful where uniform good quality of fruit/vegetable grading / sorting products is needed.

In addition, computer vision gets rid of food safety concerns by quickly spotting pollutants or pathogens. It allows organizations to respond quickly, which, in turn, minimizes food safety vulnerabilities or threats and avoids recalls. They provide objective scores over the consistent aspects of qualities defining customer preferences within quality evaluation. They make product evaluation standard as far as possible by reducing human subjectivity that in turn fulfills customer satisfaction and confidence. Shorter Procedures AI and computer vision combine to improve resource use/resource planning. By detecting defects earlier thereby reducing waste, which reduces costs and increases sustainability.

1.3.2. Sensors and spectroscopy

Research stated that machine learning (ML) algorithms assess key properties moisture, pH values and chemical structure by examining data from diverse sensors as well as spectroscopic methods. Given AI's knack for gauging nutritional value, ripeness and freshness estimation, producers might be in a better position to optimize production and storage methods based on this data-driven analysis. Safety assessment and quality control the analysis of sensor data or spectroscopy that AIs can do typically far exceeds that of what a human can handle.

AI enables producers to identify patterns and thus minimise resource wastage or maximise their manufacturing efficiency. Also, Real-time sensor data streams align with contemporary paradigms such as Industry 4.0 and The Internet of Things (IoT) which allows to predict quality deviations and take appropriate actions in a timelier manner. This hybrid AI and ML in conjunction with spectroscopy and sensors is an incredibly powerful yet underused magic wand which can not only improve the efficiency of operations in food manufacturing but also protect the foundation of food safety and quality laying into ever-changing complexities of the dynamic field of food process engineering [20].

1.3.3. Predictive modeling

AI and ML interactions in the predictive modeling are of great to concern to quality assurance over precise notions of food quality. Si et al discussed this approach in detail, which derives plausible anomalies through training a ML model on historical data and also estimating the perishable shelf-life of food items as part of forecasting quality issues [21]. AI and ML enable easy monitoring of various parameters during production and storage. This allows the system to make an estimate on when contamination, spoilage or other forms of decay will happen. Producers can make faster and informed decisions with such AI-powered predictive models, as it helps to discover patterns and connections in the data. As a result, immediate response can be given to protect end product integrity, minimize waste and ensure that food producers market high quality and safe products to customers. In other words, using predictive modeling enhanced by AI could provide a big jump in the food process engineering field. This strategy improves the industry's capacity to reduce risks, maximize resources, and eventually provide goods that satisfy the highest standards of quality and safety by utilizing historical insights and real-time data.

1.3.4. IoT-enabled real-time monitoring

Another research reported AI and ML integration had led to the development of a variety of IoT devices with built-in sensors. It is also possible to monitor vital metrics in real time thanks to this collaboration which makes quality control proactive. This new breed of BI (Business Intelligence) technologies can capture the data in real time with these IoT devices, ensuring that the quality standards are always met. AI systems check data when deviations detected send out notifications quickly alerting when you need to take action fast. This entire process allows for minimal intervention, potentially preventing errors and cross-contamination, creating faster reaction times.

Quality control processes can be facilitated by means of robotics and automation propelled by AI as well. By eliminating human involvement, these technologies make the chances of errors drop to almost nil and hence offer precision. So, that Food products can easily be examined, and handled more consistently so the quality is there, with no unnecessary wastages. In short Utilizing AI, ML and IoT with Food Process Engineering make the industry even more bolstered to maintain its quality. Trust, satisfaction and general efficacy are raised by the application of real-time monitoring and automatic reactivity which ensure stakeholders that only top-notch products are delivered to the customer [21].

1.3.5. Data-driven decision making

Si et al. [22] a recent perspective and forecast paper in the area of food process engineering have brought AI and ML at a similar pace toward convergence using extensive data (big data) for high-throughput decision-making. This approach involves the aggregation of multiple datasets like manufacturing logs, customer feedback or lab results. Since the solution is capable of analyzing and processing immense datasets, it opened doors to AI-powered improved quality control systems. This combination also makes it easier to find complex patterns and issues which can be missed using traditional methods. Artificial Intelligence (AI) to improve SAS quality assessment accuracy through identifying trends and abnormalities across a number of dimensions. It also allows you to identify potential problems proactively. An applaud able step toward data-driven decision-making is the advent of AI and ML in food process engineering. This clearly not only promotes industry involvement and improvement but also enforces meaningful consumer perception of product quality.

1.3.6. Greater transparency and traceability

The fusion of AI and block chain has proven beneficial in notably improving transparency as well as traceability throughout the food value chain. Recently, in a study tracing food from where it is produced to its final consumption point using these new technologies was highlighted and found to be very beneficial. The use of AI-powered block chain data analysis allows targeted and immediate source identification in cases of contamination or recalls. This provides more leverage on corrective actions and enhances consumer safety as well as underscores the need for efficiency in traceability systems. More than extraordinary data clarity to supply chain keeping actors, this convergence of block chain and AI along with food process engineering also asserts for the moral pillar and responsibility. These solutions offer a new generation of food safety and quality assurance that innovation will propel by fostering transparency for higher industry standards to ensure customer trust [22].

1.3.7. The connection of AI and ML

Techniques are a game changer that caused important transformation in the management area, mainly food quality control as this will help us to be more customer centric and have lesser coming back with dissatisfaction giving less waste and more power in safety. Even in the developed world, there is open space for further improvement in quality of food control systems that would assure a constant supply of safe and good food products. These technologies have made the food process engineering field very different from what it was before in a sense of how much more efficient, accurate and reliable it has become. This is a very relevant key testimony for the direction of quality assurance in food, as its outcomes reveal a cooperative synergy between food science and AI and ML [20, 21, 22].

2. Enhancement of Food Safety and Quality Control by Sensor based AI and ML

AI-based sensing technologies have successfully applied to collect and analyze data by utilizing the AI algorithms built on sensor data, which enables the extraction of useful information. For various domains ranging from environmental monitoring, healthcare to agriculture and so forth we are using modern sensing technologies. Fig. [1] depicts application of AI and ML in the food business Artificial Intelligence (AI)-enabled sensing technologies have emerged as the next frontier in managing food qualities across their supply chain while maintaining safety and integrity [23, 24, 25].

2.1. Food Manufacturing, Processing, and Storage IoT-enabled smart sensors

The IoT devices and intelligent sensors are changing the way the food is produced, processed and stored. The sensors can monitor chemical compositions, pH levels temperature, and humidity, as well gas emissions. The intelligence gained from these sensors, in real time, can provide notifications on the quality and safety. By joining together, we can take the monitoring system to the next level of dynamicity that provides better possibility in food manufacturing by maintaining ideal conditions while avoiding the creation of microorganisms and other bad impacts caused by moisture. Furthermore, it ensures safety by detecting unusual gas emissions and following chemical compositions, allowing prompt involvements and preemptive actions [26].

2.1.1. Sensors for image and spectroscopy

In contrast, others studies described AI-driven images in addition to the acquired spectroscopy sensors that can transmit information on some chemical and sensorystate of food products. Computer vision algorithms driven by artificial intelligence (AI) can inspect images much more thoroughly than the human eye, for both defects and anything inside food. It then benefits the quality control process in food manufacturing. Moreover, by capturing the phenomenon of food and light interaction in detail, spectroscopic sensors have a crucial role to play in understanding what lies beneath with regard to nutrition and composition as well as freshness of food. That's where this AI enable in an advance analysis which leads to more accurate and faster to determine food quality. [23] [24] [25].

2.1.2. AI based gas and odour sensors

A study demonstrated the significance of AI-enabled gas detection for food production and safety highlighted twelve dangerous substances, spoilage and malodorous compounds that are released from food materials [25]. These sensors are able to utilize the capacities of AI and interpret sensor data quickly and accurately. So products that do not meet the standards or wear out very quickly, ensuring they will be push out of the production line before buyers purchase them. Besides this, reducing potential well-being risks, this active strategy guards the integrity of the food supply chain overall and the producers' reputation. The consequences provide a strong illustration of how merging AI and sensor technology develops food safety methods ensuing raised quality assurance and higher consumer confidence.

2.1.3. Nanosensors

A study looked at the changing game around food safety and processing in relation to nanotechnology namely nanosensors. As it allows the identification of substances and diseases on a molecular level, AI-nanosensors are indispensable for determining food safety with the newest technology. Thus, these nanosensors enable a quick and accurate detection of contaminants in essential consumables. With the help of nanosensors, which can pack the power of AI woodchip processors to secure automated food safety practices. The fusion of artificial intelligence with nanotechnology in food safety scenarios is a revolutionary breakthrough. Not only this ushers in a new era of precision and reliability in the food supply but also enhance the monitoring and controlling of contaminants. Manufacturers can, therefore, strictly follow safety regulations and consumers are more confident about the products that they use [26, 27].

2.1.4. Integration of Blockchain

In another study, integration of blockchain technology with AI sensing was referred to as potential disruptive technology and found solution to enhance food processing and safety that records immutable ledger across the entire supply chain of the food, increasing data security and track-ability, this win-win cooperation. When the data is from sensors, it is recorded with block chain technology to guarantee transparent and durable. This seamless integration of capabilities ensures compliance with stringent QA norms, facilitates a risk reduction and enhances operational efficiency. One major evolution is the integration of blockchain with artificial intelligence (AI). This fosters accountability, enables transparency in sourcing and tracking real-time information by the stakeholders as well as builds customer confidence in food items.

2.1.5. Remote sensing

Studies shows the authors consider AI-powered methods that could be employed to enhance sustainability of food safety and processing. Drone and satellite-based technologies help the quality of food stay up to par by evaluating crop vitality and environmental factors identifying abnormalities, such as pest infestations and temperature swings. Remote sensing using AI gives real time results, which helps in decision-making and quick actions to avoid some sort of disasters. Responsible for supporting all Food Safety & Quality Control systems and abiding by the requisite regulatory requirements to ensure the integrity of food production in accordance with Food Safety Guidelines. [25] [26].

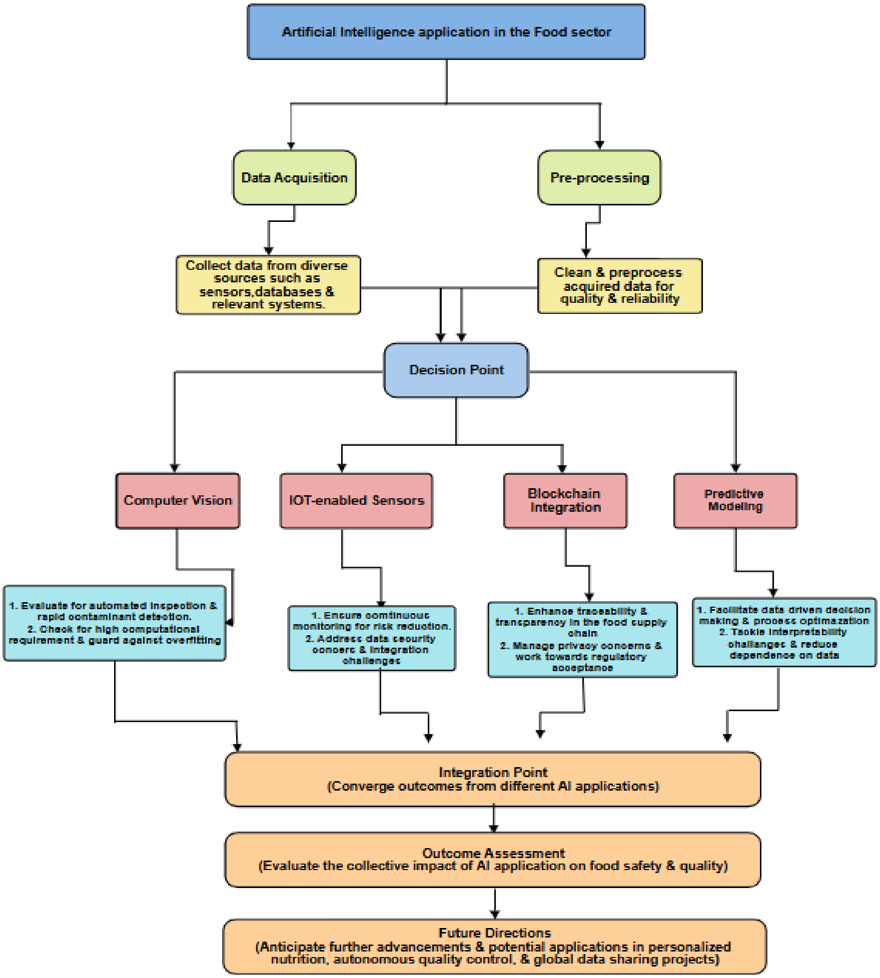


Figure. 2: Flow chart showing an important role of artificial intelligence in food sector [12]

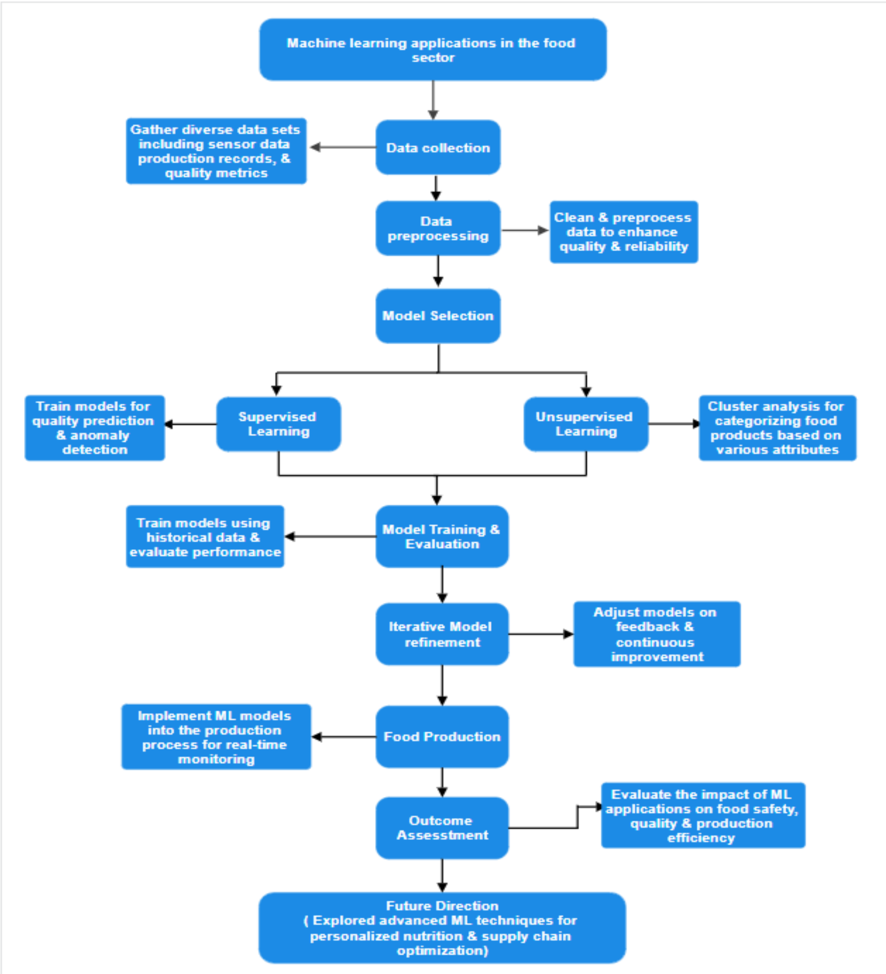
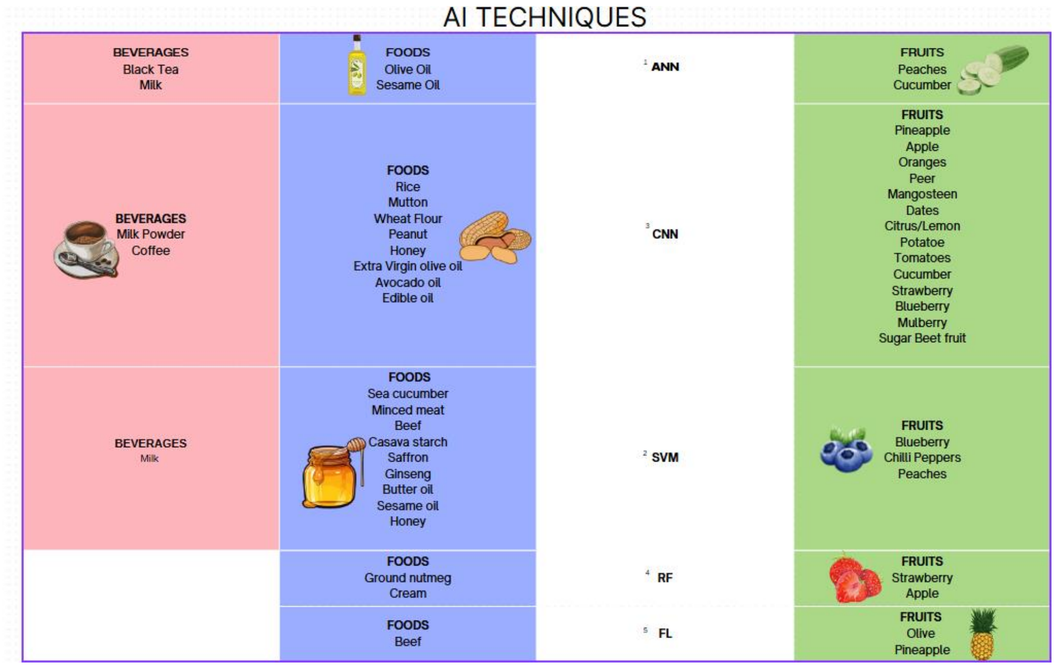


Figure 3: **Flow chart showing a crucial role of machine learning in food sector [12]**

3. Overview of AI techniques used in food quality and adulteration

Computer systems capable of doing human like tasks are generally called Artificial Intelligence (AI). Machine learning and deep learning, for instance, typically used in the intricate systems for modeling, control, optimization identification prediction estimation and more. Summary of AI techniques applied to food and beverages adulteration and defect detection in fruits illustrated in Fig 4.



[1]Artificial neural network (ANN), [2]Support vector machine (SVM), [3]R Convolutional Neural Network (CNN), [4]Ranom Forest (RF), [5]Federated learning (FL)

Figure 4. **Overview of AI techniques used in food and beverages adulteration and fruit defect detection.**

This demands a collaborative approach so that all the players of food supply chain are identified, verified and certified; bad ones get ousted; and food is traced back in real time. The review discusses numerous technologies currently found in the market to detect food adulteration and multicultural pattern recognition tools. This article provides some context about the forces behind food fraud, such as economically motivated adulteration, from both the perspectives of industry and consumers. Key points in this issue are policies for the integrity of food chains. In future, it can even be useful for academics to consider the approach these challenges more interdisciplinary and concentrate in areas such as food adulterers, food security and climate change.

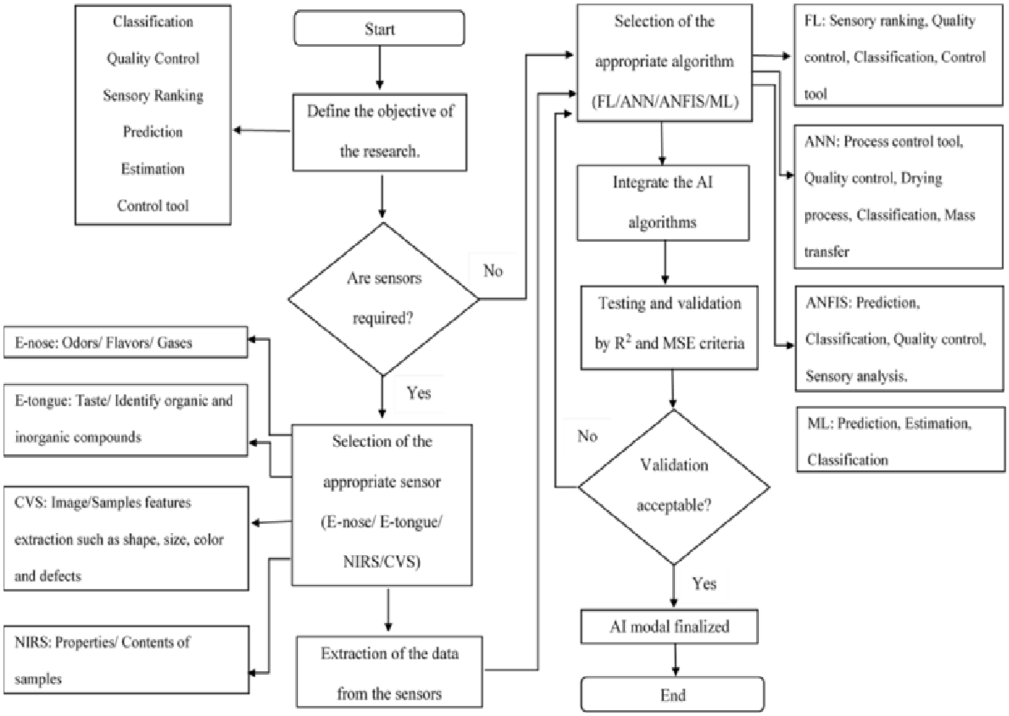


Figure 5. Flowchart for developing AI model in Food Processing

4. Use of E-Nose and E-Tongue for Food Authentications

E-nose and E-tongue, employed to mimic the capability to smell and taste perceived by human beings, provide an In-situ, rapid, reliable, and objective way of assessing food samples and mitigating increasing concerns regarding food integrity. Thus, integrating electronic sensors with chemometrics and pattern recognition methods appears to be an effective approach for food authenticity study. Introduction Analysis of food supplies is now performed with the help of powerful analytical instruments known as E-nose and E-tongue. Possible future applications of E-nose and E-tongue to food authentication are promising. Hence, advances in sensor technology combined with developments in data analytics and ML will bring new possibilities to the next level of food quality control and consumer protection. Besides representing massive real-world uses in the area of food validity, a number of policies can be used to upsurge their critical efficacy. It has been presented that food safety is ensured by integrating E-nose and E-tongue technology into altered phases of the food supply chain [23, 24, 25, 26].

5. Food Fraud Investigation with special context to Pakistan

A number of food Authorities are now working at both federal and provincial level in Pakistan. In particular, the Punjab Food Authority (PFA). Founded in 2011, it has been engaged in improving the food safety and quality of Punjab. It checks, runs the sampling and testing of the food campaigns and is responsible to set food safety and hygiene quality standards only to make aware about food safety among public and manufacturers and also guide the same for ethical safe and hygiene food process, assure compliance as per established guidelines /Standards. The first specific food safety legislation at the national level was enacted with the West Pakistan Pure Food Ordinance of 1960 and cantonment Pure Food Act of 1966. The basis of these laws ensured that foods were safe at every level from production to the consumption. There are also various regulatory bodies such as the Pakistan Standards and Quality Control Authority, which is tasked to regulate food safety in general. They offer consultancy, testing, certification services and control quality specifications and monitoring. Consumers: Consumers are critical to safe food production and accurate labeling [26].

6. Conclusion

In recent years, the global food supply has become more complex and dynamic. The functioning of the food industry from farm to fork is affected by the changes in the environment, population, and economy. These changes will increase the number of food frauds and insecurities that will harm people's health. The use of artificial intelligence (AI) in the food industry is one strategy to reduce these dangers. The use of AI has increased in many sectors such as food safety, automotive, precision agriculture, precision medicine, and food security. This study has several implications for practitioners and researchers. It is believed that research on artificial intelligence (XAI) can help bridge the gap between machine learning models and human decision-making in food safety. In addition, consumers, regulators, and other stakeholders can better understand how to predict and manage food safety with the help of educational models. For scientists, more accurate models can be created by analyzing existing models interpreting their predictions, because with the help of the XAI model, the advantages and disadvantages of the model can be seen. This article provides a practical review of food justice imaging, particularly AI and machine learning, and outlines current advances and trends in this area. Key areas of focus include the use of AI and machine learning in quality control and monitoring, food fraud detection, process control, risk monitoring, prediction and management, and chain traceability. The use of AI and machine learning in the food industry has improved health standards, thereby improving consumer health and confidence, and making food more energy efficient. While these applications hold great promise, this article also acknowledged some of the challenges in using these capabilities in certain areas of the food industry. This article highlighted the prospects and trends, and emphasized the importance of overcoming these challenges to achieve the potential of AI and machine learning. The food industry faces challenges such as changing consumer behavior, competition, food safety risks, and the responsibility of those working in the industry to adhere to strict safety standards, ensuring the integrity of food and the quality of the production process. In this review, general approaches toward research and development of AI and machine learning in food fraud detection is examined including food research, quality control, chain traceability and transparency in risk assessment and hazard prediction, health point monitoring, foodborne illness detection, and prediction. The document concludes with a call to action to continue research, innovation and collaboration, highlighting the incredible promise of combining AI and machine learning with technology to create a safe and sustainable global food supply.

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