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Improving Food Safety Traceability with Artificial Intelligence

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Abstract: Artificial Intelligence (AI) has been increasingly applied in the field of food safety, offering solutions to improve food yield, quality, nutrition, safety, and traceability, while also reducing resource consumption and food waste. This review highlights the potential of AI for improving food safety across the entire food production process, from precision agriculture to precision nutrition. It also identifies research hotspots and future trends, providing valuable insights for researchers, practitioners, and policymakers in the field. In conclusion, AI technologies have shown promising potential in enhancing food safety and quality. The ongoing research and development in this field are expected to bring about significant improvements in food quality and safety management.

Keywords: Artificial Intelligence (AI), Food contaminants, Food labelling, Food safety, Nutritional health.

I. Introduction and Literature Survey

Artificial intelligence (AI) is the ability of a computer or computer-controlled robot to perform tasks that are commonly associated with the intelligent process's characteristic of humans, such as pattern recognition, prediction, classification, understanding and generating responses in natural language etc. AI models trained on large amounts of data can deliver the most complete and targeted screening of food safety data and offer key insights. These insights are then contextualized with real-time laboratory data, enabling the identification and connection of previously unseen emerging risks.

AI can play a crucial role in enhancing food safety across various stages of the food supply chain. Here are some keyways AI can be utilized in food safety:

- *Predictive Analytics for Contamination Prevention:* AI algorithms can analyse vast amounts of data from various sources (e.g., weather patterns, supply chain logistics, historical contamination events) to predict potential contamination risks. This helps in taking proactive measures to prevent foodborne illnesses.

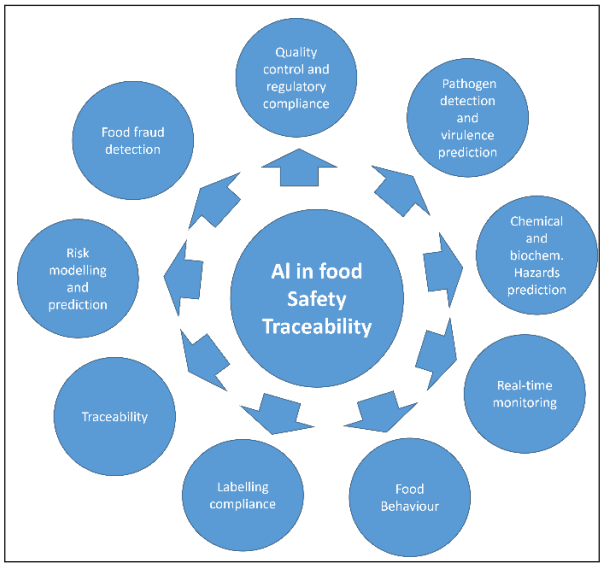

Fig. 1: Task of AI to Improve Food Safety Traceability

- *Quality Control and Inspection:* AI-powered computer vision systems can be used to inspect food products for defects, contamination, and spoilage more efficiently and accurately than manual inspection. These systems can detect issues such as discoloration, mould, or foreign objects on production lines.
- *Supply Chain Monitoring:* AI can monitor and analyse data from the entire food supply chain to ensure transparency. Blockchain technology, combined with AI, can track the journey of food products from farm to table, ensuring that any safety breaches can be quickly identified and addressed.
- *Temperature and Environmental Monitoring:* IoT devices equipped with AI can continuously monitor the temperature and environmental conditions of storage and transportation facilities. AI can predict potential failures in refrigeration units and alert relevant personnel before food safety is compromised.

- *Predicting Shelf Life:* Machine learning algorithms can predict the shelf life of perishable products more accurately by analysing factors like temperature, humidity, and packaging. This helps in reducing food waste and ensuring that consumers receive fresh products.
- *Automated Hazard Detection:* AI can automate the detection of hazardous substances and contaminants in food products. Techniques such as spectroscopy combined with machine learning can identify harmful chemicals, pathogens, and other contaminants in real-time.
- *Consumer Feedback Analysis:* AI can analyse consumer feedback from various platforms (e.g., social media, review sites) to identify emerging food safety issues. Natural language processing (NLP) can help in extracting relevant information from large volumes of unstructured data.
- *Regulatory Compliance:* AI can assist food producers and processors in ensuring compliance with food safety regulations. AI systems can monitor production processes, maintain records, and alert operators to any deviations from regulatory standards.
- *Personalized Recommendations for Allergen Management:* AI can provide personalized dietary recommendations and allergen alerts to consumers based on their health data. This is particularly useful for individuals with specific dietary restrictions or allergies.
- *Robotic Process Automation (RPA):* RPA can handle repetitive tasks related to food safety, such as data entry, report generation, and compliance monitoring, thereby reducing human error and increasing efficiency.
- *Detection of Food Fraud:* Food fraud refers to any deliberate misrepresentation in food products, which includes the substitution, adulteration, or mislabelling of ingredients to achieve economic gain. With the help of appropriate sensors and detectors, AI systems can help detect food fraud.

Several research articles have been published that showcase the case studies of artificial intelligence for the detection of pathogens, preventing contamination incidents, enhancing traceability and transparency throughout the supply chain [1] [2]. The below table summarizes the findings of some articles as:

Table I: Literature Review

Sr. No.	*Review Title*	*Method Used*	*Remarks*	*References*
1.	The Utility of Machine Learning Models for Predicting Chemical Contaminants in Drinking Water: Promise, Challenges, and Opportunities.	Machine Learning, Binary Models	The review article discussed the role of AI in the contamination detection & quality testing of drinking water. They analysed the data available in articles to predict the efficiency of big data, machine learning & AI modelling in identification & prediction of water contamination that includes regulated contaminants like As, Nitrates & even organic contaminants like PFAS & other unregulated chemicals. The article concludes with the fact that machine learning models can be utilized in water contamination prediction but there are certain gaps that should be fulfilled by adopting standardised methodologies.	[3]
2.	Food Fraud Detection Using Explainable Artificial Intelligence.	XAI tools, LIME (Local Interpretable Model-Agnostic Explanations), SHAP (Shapley Additive exPlanations), WIT, Deep Learning	The article interprets the food safety contexts using AI techniques to predict the fraud & safety hazards in food to human health. Interprets & compares the three tools on basis of their performance. The tools were evaluated on terms such as speed, style, usability, etc. It was found that the prediction of food safety is greatly affected by the source of data that is used to predict in the models. The XAI models can act as a bridge between ML & human decision making.	[4]
3.	AI-enabled Efficient and Safe Food Supply Chain.	Full Convolutional Networks, Long Short term memories, CRNN, Encoder-Decoder models, Attention Mechanism, Performance Visualization, Domain Adaptation.	This experimental study conducted revealed that the use of AI-ML techniques regularizes the food supply chain, better with safety & efficiency. This included case studies where the first study revealed that RNN techniques has multi-step prediction of harvesting processes. The second case tells about the RNN/LSTM models being utilised for managing energy efficiency in the supply chain. The third case study gives illustrations that how deep leaning methodologies has been used for expiry date identification & packaging verification processes.	[5]

Sr. No.	*Review Title*	*Method Used*	*Remarks*	*References*
4.	IoT-Blockchain Driven Traceability Techniques for Improved Safety Measures in Food Supply Chain.	Blockchain Technology, IoT (Internet of Things)	The article provides insights about the Blockchain technique & IoT mechanism of AI-ML, where they are used for solving food safety, efficiency & traceability problems. The technology allows decentralization, provide better data security & integration into the supply chain system.	[6]
5.	The Review of Food Safety Inspection System Based on Artificial Intelligence, Image Processing, and Robotic.	AI-Automated Analysis Techniques, Computer Vision, Other Sensor Systems	The article aims to reveal that how AI enabled sensor systems have facilitated food quality inspection. The system can be used for characterization, detection of contamination like pesticides or any hazardous substances. They can also be used for monitoring quality of meat products, fruits by use of thermal cameras & sensors.	[7]
6.	Designing Food with Bayesian Belief Networks.	Bayesian Belief Networks	The article uses Bayesian network models to design & develop new products using computer intelligence. It creates probabilistic models with AI to design & predict the future of a developed product in the market. It can aid modelling systems that are consumer preferred.	[8]
7.	Smart Chemical Taste Sensor for Determination and Prediction of Taste Qualities Based on a Two-Phase Optimized Radial Basis Function Network.	RBFN (Radial basis Function Network) with Chemical Sensors	The aim was to propose a sensor system that can imitate the gustatory reception of human sense. It introduces the RBFN technique which is an optimised algorithm-based function that predicts as human brain sense reception.	[9]
8.	Artificial Intelligence-Based Techniques for Adulteration and Defect Detections in Food and Agricultural Industry: A review.	ANN (Artificial Neural Network), FL (Fuzzy Logic), SVM (Support Vector Machine), RF (Random Forest)	The article focuses on the application of AI techniques for the optimization of fraud detection, contamination detection, streamlining of supply chain, etc. It concludes with the fact that the application of the AI tools emphasizes the quality, efficiency & safety of food products & smoothens the processing of products in food industry.	[10]
9.	Prediction of Food Fraud Type Using Data from Rapid Alert System for Food and Feed (RASFF) and Bayesian network modelling.	BN (Bayesian Network), RASFF (Rapid Alert System for Food & Feed)	It aims to identify the type of food fraud being prevalent in imported food using AI modelling based on Bayesian Network & RASFF, which are used in food fraud detection. The authors collect & evaluate the food fraud cases RASFF data analysis. It concluded that BNs are efficient in food fraud detection with the help of adulteration & fraud detection RASFF data & notifications.	[11]
10.	Application of Computer-aided Artificial Intelligence Techniques in Food Industry.	ML, NLP, Computer Vision, Genetic Algorithms	The article discusses the coexistent relationship between human & AI that aid the food industry boosting efficiency & providing consumer-oriented services. It refers to modernization in farming techniques, crop monitoring & disease detection. Collectively, AI acts as a beacon adding safety & efficiency to food industry.	[12]

Food Safety and Predictive Analytics

Predictive analytics plays a crucial role in preventing contamination in various domains, including food safety. Let's explore how predictive analytics can enhance contamination prevention.

The New Era of Smarter Food Safety Blueprint by the FDA emphasizes the use of predictive analytics to enhance food safety. This blueprint outlines achievable goals to improve traceability, respond more rapidly to outbreaks, and reduce contamination of food. The AI algorithms can successfully analyse the past record of consumer complaints, food borne illness, etc.

- *Tech-Enabled Traceability:* Predictive analytics can help track production and operations, improving food verification and enabling faster response to potential contamination events [13]. Consisting of transparent system of ledgers allowing a traceable system of information through blockchain system, that may be combined IoT for more enhanced management of data of food industry [1].
- *Smarter Tools for Prevention:* By analysing historical data, predictive models can identify patterns and potential risks, allowing proactive measures to prevent contamination [13]. Services like real time tracking also allows identify contamination sources. The algorithms have the ability to predict the risks if associated with particular product, process or particular region. This will allow correct utilization of resources by the industries. It can support decision making of policy makers & food regulators[1]. Random Forest algorithms, machine learning tool in AI are themed to smoothen & facilitate the process of decision-making.
- *Business Models and Retail Modernization:* Predictive analytics can inform business decisions, supply chain optimization, and risk management, contributing to safer food handling [2]. The technology helps easy data sharing with the stakeholders allowing a coordinated response between all peers involved in the system starting from the producers to the regulators. It authenticates food safety management & reduces the chances of outbreaks [1].
- *Food Safety Culture:* Cultivating a culture of food safety involves using predictive insights to drive behaviour change and adherence to best practices [13]. AI application can help retail modernization by personalised recommendation of product categories for the consumers based on their region, preferences, cooking habits, consumption, dietary habits. This type of developed models empowers the consumers & lessens the existence of food borne illness [14].
- *Fraud Risk Prevention:* With growing population there is always need for resources & for the same food industry has also not been left behind in the race. In order to meet the need & grow in terms of profit there is high chance of intentional substitution of ingredients & bulking up in order to be profitable with expensive pricing [15]. Mislabelling about the quality of product & dilution of the pure product for cutting the cost of production. All these concerns can be tackled due developed & advanced application of the AI technology that is coming up with risk intelligence techniques [16] [17].

Examples of Predictive Analytics in Food Safety

- *Smart Sensors:* These sensors collect real-time data on factors like temperature, humidity, and storage conditions. Predictive models analyse this data to identify potential risks and prevent contamination [18]. The predictive AI uses various statistical analytics, deep learning & other advanced machine learning techniques for predicting risk & outcomes. The standard of performance & their accuracy depends on the data input, its cleaning, updates & validation which will conclude its reliability. The predicted analytics works as, once the data sets are ready, it uses various algorithmic techniques such as linear regression, decision trees, k-means cluster, neural networks [19]. AI based smart farming being used including soil monitoring, robo-farming & predictive analysis of weather forecasting & crop monitoring as well [13]
- *Contamination Pathways:* The FDA has developed predictive models to understand contamination pathways in various food supply events, including restaurants, delicatessens, and production of commodities like tree nuts, cheese, and fresh-cut produce [3]. These models inform prevention strategies and policies. The food safety prediction is described as model-based approach to predict the future food hazards or related outcomes. It requires setting up of food safety plans, focussing on parts which are predicted to be having probability of possible hazards. Studies focusses on classification of bacteria & parasites classification in order to predict presence of microbial growth & insect infestation, Logitboost algorithms has been verified to predict the presence of Salmonelosis from especially meat sources. BN & NN models used for bacterial growth & their activity for food safety [13].
- *Machine Learning for Drinking Water Contamination:* Beyond food, predictive analytics also aids in predicting chemical contamination in drinking water [4]. Machine learning models analyse historical data to identify risks and improve water safety. The water being an essential resource is facing threat due growing globalization & industrialization. Contamination from heavy metals like Ar, biological contamination from microorganisms, pharmaceuticals, pesticides, micro-plastics, etc. AI techniques such as regression algorithms & artificial

neural networks (ANN) being used for determining the Water Quality Index (WQI). Deep learning network model determines the chemical components that is dissolved oxygen (DO) level & pH level [10].

There are different approaches in machine learning like KNN, XGBoost, sequential ANN that have been tested for testing of drinking water. IoT services with array of sensors also being used to examine the parameters such as turbidity, pH, temperature, dissolved oxygen, etc. Thus, the technique of ML helps in making predictions through already available data with analysis & visualization equipping to help serve better resources to consumers [6].

In summary, predictive analytics is a powerful tool for preventing contamination, enhancing food safety, and ensuring a healthier and safer environment for consumers.

II. Case Studies and Applications

a) IBM's Food Trust: IBM's blockchain-based solution uses AI to enhance traceability and transparency in the food supply chain, helping to quickly identify and address food safety issues [20].

Concept of Blockchain System

It is a ledger technology that allows the data to be traceable, available & unimpaired enabling data storage & exchange in the supply chain. It is a decentralized distributed ledger system. It operates on peer-to-peer network linking neighbouring peers with no possible access to central authority. Health & living industries are the existing markets of the blockchain technology. Stepping into the agro-food supply industry it can help preserve food value, secure information technology & strengthening traceability.

Any transaction made in the system can be traced by all the parties whereas the technique of decentralization is used as a measure for protection against intruders & cyber threats. Third party authentications not required in Blockchain, which makes the system cheaper, more reliable, simple, more stable and time efficient while removing possibility of human errors.

Popularity of the Blockchain method is due to record keeping of transactions. In a distribution system each transaction is linked to each other forming a chain. Consumers can trace specific information about the food product producer, raw materials, location and destination. Transactions and interactions can be much easier to handle when included into IoT data system. Crypt based IoT systems consisting of local IoT, blockchain network and server can be quite useful [6].

b) *Inspecto:* An Israeli start up using AI and spectroscopy to detect contaminants in food products in real-time [21].

Food Inspection System with AI, Imaging & Robotics

With increase in globalization, there is a requirement of strengthening of food safety with incorporation of modern technologies which may include AI assisted Automated Analysis Techniques (AAT) utilizing computer vision and array of sensors. Both internal and external parameters are needed to be examined in order to check food quality. External parameters may consist of opacity, color, texture, etc. whereas internal parameters include hardness, acidity, flavour, any contamination from pesticides, faecal matter, pathogenic bacteria etc. Newly developed techniques reduce cost and tedium. They can allow non-destructive rapid analysis.

Machine vision is the technique that acquires the information from samples with the help of images or video. It consists of various steps such as image acquisition, pre-processing, segmentation, recognition, etc. Computer Vision systems have the ability to detect defects and to determine food properties.

Computer vision can use visual range cameras or infrared thermal cameras or even hyperspectral imaging systems which acquire images in several wavelengths including ultraviolet. The hyperspectral imaging system can detect contamination in meat products such as faeces, toxins, etc [7].

c) *TOMRA Sorting Solutions:* Utilizes AI-driven optical sorting systems to ensure the quality and safety of food products by removing defective items from production lines [9]. AI driven sorting system gained popularity recently which were previously used in waste management in industries of metals, wood, plastics etc. They can detect defective coffee beans, rotten or unripe fruits and any other food products that do not satisfy the quality standards [22].

d) *Deep Neural Network (DNN):* XAI Technologies developed DNN model to predict food fraud categories, analyse the outcomes, and explain the forecasts generated by the AI model [23].

Deep Neural Network (DNN) – New Era of Machine Learning

DNN is an advanced AI technique based on multilayer artificial neural networks. The hardware and software improvements combined with availability of large amounts of training data has led to many remarkable successes by DNNs and its popularity is now replacing the traditional machine learning [24]. In traditional machine learning, features of the data to be used for various machine learning tasks were hand crafted by humans. DNNs have the ability to determine features from raw data, which can be utilized by final layers of the neural network for tasks such as classification and segmentation. DNNs efficiently capture the information & patterns in the given data to determine complex data relations. DNNs utilize modern hardware advancements like Graphical Processing Units

(GPUs) and Tensor Processing Units (TPUs) for massively parallelized neural network operations to give unprecedented speed and power. DNNs work with different data forms such as videos, images, speech, text etc. and perform better with larger data sets [25].

e) *Bayesian Network (BN):* Predict several types of food fraud using Rapid Alert System for Food and Feed (RASFF) [11]**.** It is a graph-based model that works on probabilistic relation between variables. It helps in optimal design predictions that can aid consumer modelling. It operates on a technique called Bayesian belief network and can be applied to a typical type of food design issue [8].

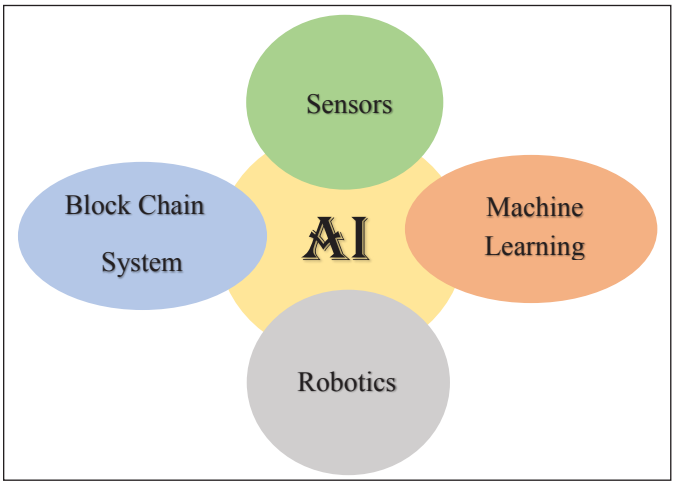

Fig. 2: Technology Associated with AI in Food Technology

III. Challenges in Implementing AI Based Quality Control and Inspection

AI-based quality control and inspection comes with several challenges. Let's explore some of these challenges:

a) *Limited Attention Span and Fatigue:* Visual inspections require sustained focus and attention to detail, which can be challenging for human inspectors over extended periods. AI systems can operate continuously without fatigue, improving consistency and accuracy [26].

b) *Inefficiency and Speed:* Manual inspections are time-consuming. AI-powered systems can process images rapidly, enabling real-time decision-making and faster inspections [13]. Automation not only saves time but also reduces the cost of labour & reduces the requirement of manual examination [27].

c) *Complexity and Multidimensional Analysis:* Inspecting complex products with multiple dimensions (such as intricate machinery or electronic components) requires analysing various features simultaneously. AI algorithms can handle multidimensional data more effectively than human inspectors [26]. Advancing technologies of the AI are being applied for precision farming to optimize the agricultural produce [28]. To ensure food safety and standard compliance, real-time quality evaluation is conducted using computer vision and machine learning technologies [29].

d) *Lack of Consistency and Replicability:* Human inspectors may interpret criteria differently, leading to inconsistent results. AI models provide consistent and replicable assessments, reducing variability [26].

e) *Cost and Scalability:* Developing and deploying AI systems involves initial costs, but they can lead to long-term savings by improving efficiency and reducing defects. Scaling AI solutions across different production lines or facilities can be challenging [26].

f) *Human Inspection Limitations:* Human inspectors may miss subtle defects or anomalies due to limitations in perception. AI algorithms can detect even minor deviations from standards [26]. AI techniques work with CNN (Convolutional Neural Network) with improved detection ability & precision [30].

g) *Documentation and Reporting:* Proper documentation of inspection results is crucial for compliance. AI systems can automatically generate detailed reports, streamlining the documentation process [26]. Automation in the data collection process becomes hassle free, quick & organised when driven by AI software & technology.

h) *Lack of Traceability and Data Analysis:* Tracking defects and analysing historical data for process improvement is essential. AI systems can maintain traceability and provide insights for continuous enhancement [6]. Bayesian network & blockchain system are widely reliable techniques being used in data analytics & promoting good produce [11].

Supply Chain Monitoring: Food supply chain is crucial for ensuring food safety, quality and efficiency. Here are some key aspects to consider:

a) *Traceability:* Implement a robust system that allows tracking food products from farm to fork. This involves recording information at each stage of the supply chain, including production, processing, transportation, and distribution. Blockchain technology can enhance traceability by providing an immutable record of transactions. The technique allows real time tracking services assuring quality, minimizes communication error, overall contributing to efficient services [31].

b) *Temperature Control:* Proper temperature control is essential to prevent spoilage and maintain food quality. Use temperature sensors during transportation and

storage to monitor conditions. If temperatures deviate from safe ranges, automated alerts can be sent to relevant parties.

Network systems called Fuzzy neural systems are being used for temperature monitoring, which is a kind of mathematical model incorporated into AI. It works on basis of approximation system in neural networks, helps in maintaining optimal temperature conditions [32].

c) *Quality Assurance:* Regular inspections and quality checks are necessary. AI can analyse data from sensors, cameras, and other sources to identify anomalies or signs of deterioration. For example, image recognition can detect bruised fruits or spoiled vegetables. Quality assurance being a broad & wide aspect, AI tech can prove to be a boon for assuring quality & efficiency [33].

d) *Predictive Analytics:* AI algorithms can predict potential supply chain disruptions. By analysing historical data, weather patterns, and other factors, you can anticipate challenges and take preventive measures. Smart sensors are bring used for detecting irregularities & high-risk areas. AI computed algorithms also predict the possible degradation pathways in association with health hazards, that has helped in developing responsible products into the market [18]. Fluorescence detectors have been used to detect adulteration in oil with hyperspectral images [10].

e) *Risk Assessment:* Assess risks related to food safety, fraud, and compliance. AI can analyse data to identify high-risk areas or suppliers. For instance, it can flag suppliers with a history of non-compliance or suspicious activities. It can be helpful in predicting food borne hazards, allergies, etc. from already available data input with food substances with risk such as mushrooms, poultry meat & others [34].

f) *Collaboration:* Foster collaboration among stakeholders. AI-powered platforms can facilitate communication between farmers, distributors, retailers, and regulatory bodies. Real-time data sharing helps address issues promptly. The AI can also help in incorporating personalisation ideas for new product ventures for specified region or ethnic groups. This enhances customer satisfaction aided by transparency in communication & trust building in the chain of production [12].

g) *Regulatory Compliance:* Stay updated with food safety regulations. AI can assist & automates in compliance monitoring by analysing documents, identifying gaps, and suggesting corrective actions. It helps in strategic drives & ease the handling of bulky data sets [35]. The method streamlines the process of implementation of regulatory policies & generates compliance. The incorporation of AI can provide scalable outputs along with simplifying tasks, easily updating to the newly developed regulations.

Remember that AI can play a significant role in enhancing food supply chain monitoring, but it should complement human expertise and decision-making.

Implementing predictive models for food safety can be challenging due to various factors. The challenge most probably arises from data variability, model selection & complexity of system. Here are some common challenges:

a) Data Availability and Accessibility

- *Obtaining Relevant Data:* Predictive models require historical data on food safety incidents, microbial growth, and other relevant factors. However, collecting accurate and comprehensive data can be difficult. Since the process is relied on data & records it becomes quite necessary to produce the accurate & right quality of the data. Precise & accurate data can only be helpful in these processes.
- *Data Accessibility:* Sometimes, valuable information from scientific literature is not widely available to industry professionals or is in a format that is not easily accessible [36]. And the knowledge of AI is highly technical & complex, thus it becomes quite difficult if significant resources & data science expertise is unavailable.

b) Model Development and Validity

- *Model Creation:* Developing accurate predictive models involves selecting appropriate algorithms, features, and parameters.
- *Expense of Creation:* Building models from scratch can be time-consuming and costly. It requires considerable investment in developing technology & expertise. Thus, financial burden may become a backlog to build such large advanced systems to get implemented.
- *Validity:* Ensuring that the model's predictions align with real-world behaviour is crucial. Validating the model against experimental data or existing knowledge is essential [36]. Standardization of the data is a task as well, because data comes from various sources & in various formats, thus organization & standardization of them plays a crucial role.

c) Software and Format Compatibility

- *Software Limitations:* Predictive models may be accessible only within specific software formats. Users might face challenges uploading data due to compatibility issues.
- *File Types:* Different software tools handle various file types. The different formats produce difficulty in organising, aligning & incorporation of data into a single

system. Ensuring seamless data exchange can be tricky sometimes [36].

d) Bias and Generalization

- *Bias:* Predictive models can inherit biases from the training data. Addressing bias is essential to ensure fair and accurate predictions.
- *Generalization:* Models trained on specific datasets may not generalize well to different scenarios or food products. Achieving robustness across diverse contexts is challenging [37].

e) Privacy and Security

- *Data Privacy:* Handling sensitive data while maintaining privacy is critical. Balancing transparency and privacy can be complex.
- *Security:* Protecting models and data from unauthorized access or malicious attacks is an ongoing challenge [38]. Data breach is a real problem with development of data science technology which can be quite difficult situation to manage.

f) Interpretability and Transparency

- *Interpretability:* Understanding how a model arrives at its predictions is crucial for user trust. Black-box models can be problematic.
- *Transparency:* Making the model's decision-making process transparent allows stakeholders to assess its reliability [39].

g) Integration with Existing Systems

- *Legacy Systems:* Integrating predictive models into existing food safety management systems can be challenging. Compatibility and seamless integration are key considerations. The food regulatory authorities have their own set of rules and regulations that are necessary to be compliant of.
- *Real-Time Monitoring System***:** For predictive models to be effective, they typically require real-time data. It can be expensive and logistically difficult to implement systems for ongoing observation and data gathering, particularly in vast supply chains [40].
- *Interpretability & Trustworthiness***:** Investors must comprehend and require faith in AI forecasts. It is crucial to create interpretable models that can give concise explanations for their predictions, particularly in situations where food safety is at risk [13]. For such challenges the user might resist the idea of using newer technology & methods, thus it becomes quite a task to build that level of trust for the method to be implemented & be successful.
- *Cultural and Behavioural Factors:* Food safety is significantly impacted by human activity. Cultural norms and behaviours around the preparation and consumption of food must be taken into account in predictive models, as these might differ greatly between locations.

Despite these challenges, predictive models offer significant benefits in improving food safety. Researchers and industry professionals continue to work on overcoming these obstacles to enhance food security and consumer well-being.

Quality control and inspection play crucial roles in maintaining food safety, consistency, and consumer satisfaction. AI has revolutionized quality control and inspection in manufacturing:

a) Visual Inspection AI by Google Cloud: Google Cloud's Visual Inspection AI solution automates visual inspection tasks using AI and computer vision technologies. It's purpose-built for the industry to address production quality challenges at scale.

Benefits:

- *Reduced Cognitive Load:* Operators experience less mental strain, leading to fewer defects slipping through.
- *No Programming Required:* The system adapts to product changes without manual programming.
- *Detects Multiple Defects:* It can analyse hundreds of areas of interest on a product within seconds [13].

b) Minimizing Human Error: Traditional manual inspections are slow and prone to errors. AI-powered systems analyse images, detect defects, and sort products in real-time. And the AI systems being already validated makes them even more reliant in their task accuracy. By automating checks, AI reduces human work and keeps quality high while significantly improving inspection accuracy [41]. The process can facilitate the process of decision making & its accuracy by identifying high-risk areas. The AI can be augment the human capabilities by assisting with real-time feedbacks & guidance. AI algorithms can analyse patterns & errors that humans can miss, that might require rectification [42].

c) Streamlining Inspections with AI Algorithms: Organizations utilize AI-powered systems for data collection and analysis. AI algorithms quickly process vast amounts of data, enabling real-time decision-making and reducing the need for manual effort during inspections and testing [43]. Enhanced compliance & efficiency with automated visual defects inspection like adulteration with foreign particles or spoilage in order to consistently evaluate the product to meet the quality standards. IoT entangled immediate alert systems for promoting high risk management into parameters such as temperature, humidity, microbial infestation & their real time monitoring. AI applications have expertise in adaptive learning thus they can read from past records & feedback to improve its efficiency [44].

d) Limited Attention Span and Fatigue: Visual inspections require sustained focus and attention to detail, which can be challenging for human inspectors over extended periods. AI systems can operate continuously without fatigue, improving consistency and accuracy [26].

e) Inefficiency and Speed: Manual inspections are time-consuming. AI-powered systems can process images rapidly, enabling real-time decision-making and faster inspections [13]. Automation not only saves time but also reduces the cost of labour & reduces the requirement of manual examination [27]

f) Complexity and Multidimensional Analysis: Inspecting complex products with multiple dimensions (such as intricate machinery or electronic components) requires analysing various features simultaneously [24]. Advancing technologies of the AI are being applied for precision farming to optimize the agricultural produce [28]. To ensure food safety and standard compliance, real-time quality evaluation is conducted using computer vision and machine learning technologies [29]

g) Lack of Consistency and Replicability: Human inspectors may interpret criteria differently, leading to inconsistent results, whereas AI has the benefit of being accurate in outcomes [26].

h) Cost and Scalability: Developing and deploying AI systems involves initial costs, but they can lead to long-term savings by improving efficiency and reducing defects. Scaling AI solutions across different production lines or facilities can be challenging [45].

i) Human Inspection Limitations: Manual inspections might not have expected precision which automation provides [45]. AI techniques work with CNN (Convolutional Neural Network) with improved detection ability & precision [41] [26].

j) Documentation and Reporting: Proper documentation is crucial for inspection. Automation in generation of detailed reports is simplified by AI tools [26]. Automation in the data collection process becomes hassle free, quick & organised when driven by AI software & technology.

k) Lack of Traceability and Data Analysis: Tracking defects and analysing historical data for process improvement is essential. AI systems can maintain traceability and provide insights for continuous enhancement [46]. Bayesian network & blockchain system are widely reliable techniques being used in data analytics & promoting produce.

In summary, AI-driven quality control enhances accuracy, reduces inspection time, and ensures consistent product quality. The food business can improve compliance, expedite inspection procedures, lower human error, and ultimately guarantee safer food products for customers by utilizing these AI-driven tactics.

IV. Conclusion and Future Scope

AI's ability to process and analyse large datasets quickly and accurately makes it a powerful tool for improving food safety. By integrating AI into various stages of the food supply chain, stakeholders can enhance predictive capabilities, improve quality control, ensure regulatory compliance, and ultimately provide safer food products to consumers.

Ultimately, the findings suggest that AI technology has been proved to be an eminent tool that can help boost up an industry with its immense benefits. Similarly, it has acted synergistically to food industry as well. The article here reveals the different techniques in AI being used in the food industry as automated analytical techniques that includes DNN (Deep Neural Network), CNN (Convolutional Neural Network), systems & other natural learning programs which have been successfully used as detection & analysing tools. Blockchain Systems & IoT (Internet of Things) are techniques that increase transparency in data storage & exchange with ease of traceability in the supply chain.

AI imaging & robotics have been applied in the analysing the external parameters of the food particles like texture, colour, opacity etc. DNN being an advanced machine learning can interpret & organize different forms of data through advanced processing units. Bayesian Network (BN) a probabilistic graphical modelling used in fraud & risk assessment. AI driven sensors used as alert systems for control & monitoring temperature, pressure, moisture etc. Thus, AI proves to be a boon by streamlining & simplifying the entire industry taking from the process of procurement to gathering consumer feedback reducing the chance of human errors.

Apart from having so many benefits the AI techniques have their challenge of implementation. Relative high cost of contrivance, mostly industry is led back by putting the technology into use. Their involvement might reduce the need of manual workforce which might lead to loss of human intellectual & critical thinking. Automation & dependence on software tech now days have a risk of data & information breach which is a greater difficulty leading to complete collapse of the system. And application of the latest technologies also requires new resources & updated levels of skills & trainings.

But on a positive note, the AI has a greater applicability with a future scope of automation, smart farming, providing better quality control, consumer insights & benefits when applied into field of food industry eliminating its challenges. Thus, the challenges can be abolished with better planning, analysis & standardised resolutions on whether, where & how to incorporate the AI to streamline the processes of food industry.

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