A COMPREHENSIVE REVIEW ON APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN FOOD TECHNOLOGY

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Abstract: *AI has emerged as a transformative tool in a variety of industries and its integration into food technology has significantly impacted all aspects of Food processing from farm to plate. This review explores AI applications across various aspects of the food industry, from crop production, food processing, quality control, and packaging. AI's role in enhancing food safety through improved detection of contaminants, adulterants, and pathogens mentioned in the literature is discussed in detail. The use of AI in food quality assessment, highlighting the advancements in machine learning and computer vision that allow for automated inspection and grading of food products is highlighted. Furthermore, the review explores how AI-driven robotics and automation are optimizing food processing and packaging processes. The paper delves into AI's contributions to sustainable food production, including precision agriculture, resource management, and waste reduction. Additionally, it investigates the role of AI in developing new food products and flavor profiles, showcasing the potential for AI-driven innovation in the culinary arts. Lastly, the review considers the ethical implications and challenges associated with AI adoption in food technology, addressing issues such as data privacy, transparency, and job displacement. By synthesizing current research and identifying trends, this paper aims to provide a comprehensive understanding of AI's impact on food technology and propose future directions for research and industry development.*

Keywords:AI, Food technology, Automation, Robotics

1. INTRODUCTION TO ARTIFICIALINTELLIGENCE

Artificial Intelligence (AI) refers to the development of computer systems capable of performing tasks that typically require human intelligence. These tasks include reasoning, learning, problem-solving, understanding natural language, recognizing patterns, perceiving the environment, and making decisions. AI has become a transformative force across various industries, with applications ranging from automation and data analysis to customer service and medical diagnostics.

1.1. Categorization in artificial intelligence

Artificial intelligence can be classified in different ways, depending on its capabilities, functionalities, learning methods, and applications. The following is categorization of AI based on applications

1.1.1. Machine Learning

It is a subset of AI focused on developing algorithms that allow computers to learn from and make predictions based on data. Machine learning is Data-driven, and improves performance over time with more data, and can be applied in various fields such as healthcare, finance, and marketing. It is further categorized into supervised learning, unsupervised learning, and reinforcement learning.

1.1.2. Deep learning

Deep learning uses neural networks with many layers to analyze various factors of data. It is having high accuracy in complex tasks, and requires large amounts of data, and computational power. It is often used in applications such as autonomous vehicles and advanced robotics, Image and Speech recognition systems.

1.1.3. Natural Language Processing

Natural Language Processing (NLP) deals with AI systems that enable computers to understand, interpret, and generate human language. It involves Text and speech understanding, interaction with humans in natural language, and applications in customer service and content analysis. The applications of NLP includes Text and speech understanding, interaction with humans in natural language, and applications in customer service and content analysis.

1.1.4. Computer Vision

It is the field of AI that enables computers to interpret and make decisions based on visual data from the world. It involves Visual data processing, pattern recognition. Applications Computer vision includes Facial recognition systems, medical image analysis, and object detection in autonomous vehicles.

1.1.5.Robotics and Automation

Robotics and Automation is the branch of AI systems that enable robots to perform tasks autonomously or with minimal human intervention. It is characterized by Physical interaction with the environment, task automation, and applications can be found in manufacturing, logistics, and home assistance.

2. APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN FOOD TECHNOLOGY

Food technology includes various aspects from farm to plate. The food industry struggles with rising demand, safety issues, and inefficiencies. AI helps by automating processes, improving quality, and managing supply chains.AI automates tasks, ensures food quality, and reduces waste. Machine learning helps predict demand and improve food safety, making the industry smarter and more efficient. Table 1, depicts the applications of various fields of AI in Food technology.

Table 1: Applications of various fields of AI in Food industry

Field in AI	Application
Expert Systems	Help machines make decisions like humans to automate food production
Neural Networks	Analyze food quality patterns.
Computer Vision	Detect defects and sort food items.
Big Data	Food Market analysis, Demand forecasting
Natural Language Processing	Automate customer interactions.
Robotics	Perform sorting, packaging, and processing.
Fuzzy Logic	Handle uncertain data for better decisions.
Machine Learning	Predict demand, track inventory, and detect fraud.

Agbai et al (2020) states that the food industry faces problems like slow and in accurate sorting, supply chain delays, food contamination, and difficulty in predicting customer needs. Earlier methods depended on manual work, which was time- consuming and had a higher chance of mistakes. AI based technologies, like machine learning, cameras, and robots, help automate these processes, making them faster and more accurate. AI can detect food defects and contamination with over 95% accuracy, ensuring better quality and less waste. It also helps manage supply chains efficiently and predicts demand to avoid shortages. Compared to older methods, AI works much faster, reduces cost, and requires less human effort. Though setting up AI systems can be expensive and overall performance in the long run.

Kumar et al (2021) highlights inefficiencies in food production, packaging, and supply chains due to human involvement, which causes issues in safety, quality, and waste management. AI and ML automate these processes, improving efficiency, accuracy, and decision-making while reducing human errors. AI plays a role in smart farming by monitoring soil, predicting yields, and using robotics. In food processing, it enhances sorting, packaging, sanitation, and demand forecasting. AI-driven safety tools like next-generation sequencing (NGS) and electric noses (ENs) detect contamination and ensure compliance. AI-powered sorting systems achieve 90% accuracy, while AI-driven supply chains reduce surplus stock and optimize inventory. The US wastes 30-40% of its food supply, worth $161 billion annually. AI improves food safety compliance by 30% and makes agriculture more efficient by reducing waste. The main goal of AI and ML in the food industry is automation, better supply chain management, and waste reduction. AI improves food safety, enhances customer experiences, and ensures regulatory compliance.AI and ML transform the food industry by increasing efficiency, reducing waste, improving safety, and optimizing supply chains. As technology advances, AI continues to revolutionize food production and distribution.

Ding et al (2023) talks about how AI and Big Data are helping in the foodindustry.The main goal is to make food production better,Faster and safer.The problem is that the old methods are slow and can't handle today's needs like food safety,customer demands and supply chain issues.So,the food industry needs smart technology to solve these problems.AI and Big Data help by making smart decisions using data.AI can check food quality,find problems early,and even guess what customers like.Big Data collects a lot of information from farms,factories,and shops to help reduce waste,improve safety and trace food from start to end.This makes the whole process better and more trusted.There are many types of projects using these tools.Some focus on food safety,some on smart farming using drones and robots, some check quality with cameras and others help companies give better offers to customers.In the end, the article says AI and Big Data are very useful, but we still need to fix issues like data safety and training people to use these tools properly.

Sharma et al (2021) Stated that agri-food sector is facing so many problems to feed the growing global population, expected to increase by 30% in the year 2050. While tackling challenges like limited resources, climate changes and supply chain inefficiencies. Artificial intelligence and big data analysis are being used to optimize processes, reduce food waste by up to 20%, and improve food production, supply chains, and quality control. Data is collected from sensors and drones, and AI tools like ML and robotics help predict demand, check food quality, and automate tasks. This makes food production faster, reduces waste, and works better.AI improves efficiency by cutting production time by 30%, while reducing food waste by 10-15% and energy use by 12%. Sensors provide real-time data to prevent spoilage and ensure better performance.

Addanki et al (2022)., forecasted that AI and ML help reduce food waste by 20% and boost supply chain efficiency by 15-20%. With 68% of the global population expected to live in cities by 2050, demand for high-quality, nutritious food is rising. Challenges like 1.3 billion tons of annual waste, nutrient loss, and contamination persist. AI offers efficient solutions to address these issues. AI, ML, robotics, and 3D printing applications in food sectors like dairy, bakery, and beverages. It focuses on their role in enhancing food quality, nutrition, and shelf life while meeting consumer needs. AI improves efficiency by 15-20% and reduces food waste by 20%, ensuring better quality and optimized food processing.AI and ML achieve high accuracy, such as 95% in shelf-life prediction and 99% in contamination detection, ensuring better food quality and consumer safety.

Zhou et al (2022), explored the applications of AI in various stages of food production.The process is divided into five stages data collection, storage and transferring, analysis, visualization, and security. Introduced databases such as SQL, NoSQL, MongoDB for data storage, and then data analysis methods such as support vector machine (SVM) and artificial neural networks (ANNs), and tools including PyTorch, Hadoop are also presented. For data visualization, programming tools HTML, R are introduced, and business tools such as IBM system are also recommended. Blockchain is used for security. Big data, AI, and blockchain technologies are used.Various types of data sources with useful information can be utilized for food safety, such as online databases, sensor data, genomics data, and social media data.SQL, NoSQL, MySQL, Oracle, PostgreSQL, MongoDB, Cassandra, Hbase are used to storage and Aspera, Talend, and Elasticsearch are used for transferring.ML algorithms such as Naive Bayes, SVM, MLP, and ANN are deployedto make decisions by learning from data for applications of food safety. Deep learning models, the deep denoising auto-encoder to find the food contamination on gastrointestinal infections and provided a valuable tool for morbidity.To detect the quality convolutional neural networks (CNNs) are used by images, Stacked Auto-Encoders(SAEs) detects spoiled or damaged, classification algorithm combining Stacked Sparse Auto-Encoders (SSAE) and CNN detecting fefeacts in pickling cucumbers using hyperspectral imaging. recognized the plum varieties by applying image analysis and deep CNNs. Computer vision and deep learning based methods were also applied in the quality assessment of meat products For data visualization R and IBM, for data security Blockchain are used.

Nunes et al (2023) reviewed the use of AI in sensory and consumer studies.AI can help sensory and consumer science by finding pattern company data from machines and humans to predict consumer preference deep learning to analyze complex data.

Sahni et al (2021) reviewed the use of AI in food security with specific focus to food accessibility, food availability, food use, and strength. It recommended the use of AI in Agriculture, and emphasized on the fact that usage of AI will enable continuous data access that reflects the information related to food products at various stages and also enables traceability of the product from farm to plate.

Ali et al (2021)., emphasized on Checking the quality of food and agricultural products better and faster using new technologies, especially Artificial Intelligence(AI). AI methods like expert systems, artificial neural networks(ANN) and fuzzy logic are used for quality checking.ANNprovides the best result for modeling, and effective in real-time monitoring techniques.

Gonzalez et al (2019), reviewed the applications of AI in beverage industry. AI play crucial role in designing low-cost, reliable, and accurate, remote or non-contact techniques for various applications within the beverage industry.

Specifically the AI in the form of robotics, computer vision, and Machine learning find wide range of applications in alcohol, non alcohol and hot beverages.

In this work, applications of AI in Agriculture, Food quality, Food processing, and Packaging that are demonstrated in literature are presented.

2.1. Application of AI in Food Production

AI and ML are transforming agriculture by enhancing sustainability, food safety, and efficiency. Artificial Intelligence (AI) is helping farmers make better decisions and improve their work. It can analyze data from the soil, weather, and crops to suggest the best time to plant, water, or harvest. AI-powered machines, like drones and robots, can help with planting, spraying, and picking crops, making farming faster and more efficient. This technology also helps reduce waste and use resources like water and fertilizer more wisely, making farming more sustainable. However, many farmers find AI expensive and difficult to use, which slows down its adoption.

To make AI more affordable, new business models allow farmers to use AI tools without buying them outright. For example, some companies offer AI-powered farming equipment on a subscription basis, where farmers pay a monthly fee instead of buying the machines. Others allow farmers to pay only for the services they use, like checking soil quality or predicting crop diseases. Some farmers even share AI-powered equipment with others to reduce costs. As AI technology becomes more available and affordable, more farms are expected to adopt it, leading to increased productivity and better food production worldwide.

Ben Ayed et al. (2021), explored how AI is revolutionizing agriculture by improving sustainability,accuracy and productivity. It provides high-accuracy solutions for crop disease detection (98%),soil health monitoring (90%), and weather forecasting, making it a crucial tool for modern farming.AI and ML optimize the agriculture supply chain across four stages: Pre-production,production,processing,and distribution.Inpre-production,ML predicts crop yield, analyzes soil properties(LSSVM),and improves irrigation using sensors.In production,AI enhances weather forecasting,detects crop diseases(VGG-16),and optimizes harvesting.In Processing,AI checks food quality and removes bad products.In distribution,ML for storage,transportation,and consumer analytics.AI technologies like agricultural drones,block-chain for food traceability, and satellite-guided smart farming further enhance efficiency and sustainability. AI and ML help farming by using smart machines,sensors, and satellite data to monitor crops and water.They also track food from farms to stores and make production more efficient.This makes farming easier, reduces waste,and helps deal with challenges like climate change.

Varriale et al (2021).,presents how combining Artificial Intelligence (AI) with emerging technologies like IoT, big data, and block chain can improves business performance, particularly in production systems. By using a "Co-Occurrence ratio," the study systematically reviews how AI interacts with these technologies to improve business operations such as inventory management, supply chain optimization, and predictive maintenance. AI helps businesses make smarter decisions, predict customer needs, and improve product quality, boosting customer satisfaction and operational efficiency. This integration innovation, reduces costs, and improves competitive advantage, transforming traditional production systems into more intelligent, automated operations.

Yu et al (2024) explored the AI-based additive manufacturing in food industry. It faces challenges in ensuring food safety, personalization, efficiency, and material selection for 3D, 4D, and 5D food printing. AI optimizes food design, material selection, print path planning, and real-time monitoring using machine learning and deep learning algorithms.AI improves food printing accuracy, enhances quality, increases production efficiency, and reduces waste while enabling personalization.AI-driven monitoring and predictive analytics enhance defect detection, ensuring safer and higher-quality food production.

Bedoya et al (2023) explored the usage of AI and 3D food printing (3D-FP) to create high-protein, personalized foods more efficiently and sustainably.AI helps choose the best ingredients,improves food texture,and customizes nutrition for different needs.It also automates the printing process and ensures food safety by detecting defects.3D-FP allows precise,layer-by-layer food production,reducing waste and supporting eco-friendly protein sources.It is useful for making special diet foods,such as meals for medical patients or athletes.Together, AI and 3D-FP make food production smarter,more personalized,and better for the environment.AI and 3D food printing (3D-FP) are emerging technologies in future food trends,enabling the development of novel protein based foods from alternative sources.This review explores their evolution,highlighting how AI enhances 3D-FP to improve food functionality and personalized nutrition.It emphasizes the need for further research to optimize their integration for efficient food production.

Magdas et al (2022)proposed a method for determination of authenticity of the fruit spirit by combining FT Raman spectroscopy with Machine learning, the proposed model including KNN, SVM, LDA and ensemble models resulted in an accuracy of 96.5%.

Kudashkina et al (2023) developed AI based leading indicators to replace the traditional lagging indicators for food safety to ensure avoiding the losses due to recall of food products from market. Food safety management systems feed the behavioral data to the AI methods for prediction of the leading indicators.

The Mexican coffee industry depends heavily on human experts for selecting processing methods. When these experts are unavailable, production halts, leading to inefficiencies and increased costs.Beatriz et al (2017), introduces an AI-based expert system utilizing fuzzy logic to automate decision-making, ensuring consistency and minimizingdelays.The system employs a Mamdani-Fuzzy Logic Model in MATLAB, analyzing inputs such as weight, defects, and green appearance to determine the optimal production process. It follows three primary steps namely, Fuzzification, Inference Engine, and Defuzzification. Fuzzificationconverts input values into categories like "low" or "high." and Inference Engine applies IF-THEN rules for decision-making. Further Defuzzification translates fuzzy outputs into final process decisions.A Discrete Event Simulation Model (Tecnomatix Plant Simulation) validates the system by comparing its results with expert decisions. Achieves 93% accuracy, aligning with expert selections.AI-based selection increases coffee output by 10% through process optimization, and prevents production delays and enhances equipment utilization.

2.2. Application of AI in Food Processing & Food industry

Chen et al (2020) works on physical fields that improve drying but have drawbacks including high power consumption uneven drying loss of nutrients and flavors.AI enables real-time monitoring,optimizes drying for better efficiency and quality without losing its water,nutrients and flavors.Noninvasive sensors and CVS monitor and control drying, improving quality.AI methods like ANN,FL,Ga and GWO optimize drying parameters and models.AI with physical field drying enhances efficiency and resulted in an improved accuracy to 95%.

Ushada et al (2017), employed AI for temperature control.The temperature control in food small and medium-sized enterprises (SMEs) is not optimized, affecting worker comfort and productivity. Data is collected from six food SMEs in Yogyakarta Special Region, Indonesia, and the data of temperature set points are verified using a simulated confined room. Further ANN model is developed to predict the temperature set points based on worker heart rate, workstation temperature, relative humidity distribution, and light intensity. The ANN model is trained and validated using 315 and 41 data sets, respectively and a sensitivity analysis is performed to determine the optimal number of hidden neurons and iterations for the ANN model.

Domínguez et al (2021)., presents a new method for classifying dried Guajillo chili peppers using artificial neural networks (ANNs) to automate and standardize the sorting process. The system analyzes 8-bit grayscale images of the peppers and classifies them into three quality levels: Extra, First Class, and Second Class, based on size, shape, color, and condition. The ANN-based system achieves an accuracy of 82.13%, improving speed, consistency, and reducing labor costs compared to manual sorting. This AI-driven approach offers a more efficient, reliable, and cost-effective solution for quality control in agriculture, particularly for the sorting and grading of dried chili peppers.

Soltani-Fesaghandiset al (2018)., focuses on helping food companies predict the success of new products before launch and identify strategies if the product fails. By using AI-based systems, specifically the Adaptive Network-based Fuzzy Inference System (ANFIS), companies can make more accurate and faster predictions about product success, traditional methods that rely on intuition or surveys. The system analyzes data from past product launches and helps choose the right strategy, such as market penetration or diversification. It helps companies optimize their product development strategies, allocate resources efficiently, and improve decision-making, with an accuracy rate of over 80%. This AI-driven approach supports better product launch decisions and market strategy optimization.

Gerschütz et al (2023)., discusses how digitalization, AI, and cloud computing are transforming product development by making physical products smarter and more connected with digital systems. Small and medium-sized companies (SMEs) often struggle to keep up due to a lack of ability in using data-driven methods like AI, Data Mining (DM), and Machine Learning (ML). To help these companies, the paper introduces AI4PD, an ontology that links product development with AI methods. AI4PD organizes knowledge into clear categories, helping SMEs easily choose the right tools and methods for product development. It simplifies the process of adopting new techniques and helps companies use their data more effectively to make better decisions, optimize processes, and stay competitive.AI helps analyze large amounts of data, enabling better decision-making, optimization of processes, and automation. Specifically, AI supports SMEs in identifying the best methods and tools for product development tasks, improving their efficiency and competitiveness. The AI4PD ontology helps companies connect AI-driven methods with their product development processes in a proper way, making it easier for them to adopt these new technologies.

Predicting food sales in marts helps optimize stock and maximize profit. Irfan et al (2021) employed the AI-based TOR method for business intelligence, and neural networks to analyze past sales data and forecast future demand.The model outperforms traditional methods, achieving better sales predictions with low mean squared error and variance.The TOR AI model achieves a mean squared error of 1032.38 and a variance of 0.184, ensuring reliable food sales forecasting

Many food tracking and recommendation apps exist, but their AI-based functionalities, quality, and evidence-based effectiveness remain unclear.Samad et al (2022) evaluate 80 apps from major app stores using a custom rating tool, assessing AI features, software quality, and user feedback.Most of the apps lack automation in food tracking and recommendation. "Foodvisor" is the only app with the capability of automatic food recognition and provide the nutrition information.

The adoption of artificial intelligence (AI) in food supply chains faces challenges due to ethical concerns, lack of a common language among stakeholders, and issues related to transparency, accountability, and responsibility.A literature review and expert workshops analyzed by *Manning et al (2022)* ethical aspects like explainability, traceability, and accessibility to develop a common language framework.The study enhances AI governance, stakeholder trust, and ethical compliance, improving decision-making and AI applicability.

Hassoun et al (2023) is focused on reviewing the adoption of Industry 4.0 tools including Smart sensors, robotics, AI, and IoT to build novel food processing technologies. Jagtap et al (2020).,stressed primarily on food logistics, including resource planning, warehouse management, transportation management, predictive maintenance, and data security.

2.3. Application of AI in Food quality

Maharajan et al (2024)., focused on problems in quality maintenance, hygiene,optimizingproduction,resource management,efficiency,labour,time,economy and environmental degradation.Human-centric approaches human-robot collaboration reduces errors,saves time and enhances efficiency.AI improves data accessibility,optimizes production supports economic growth and sustainability.Ml and DL plays a vital role in the field of food processing.Sorting food photos into multiple groups using convolution neural networks (CNNs).AI in food processing including Smart farming AI utilized in numerous ways, soil surveillance,robocropping and statistical analysis,Smart transportation,Smart processing of food and handling it assists landowners with weather estimation which save income,ML can resolve distribution route obstacles.Deep learning(DL) with CNN improved performance with the accuracy of 99.5%.

Barthwal et al(2024).,discussesed how Artificial Intelligence (AI) is transforming the food processing industry by improving efficiency, quality, and automation. AI technologies like machine learning, deep learning, and computer vision are used to optimize food production, sorting, grading, and quality control. For example, AI systems can sort fruits and vegetables with high accuracy, predict equipment maintenance needs, and ensure consistent product quality by detecting defects or contaminants. AI also helps in process optimization by analyzing production data and minimizing waste. Additionally, AI can predict future demand and provide valuable insights into consumer preferences, and food companies to develop better products and improve supply chain management.

Silver nanoparticles (AgNPs) have antimicrobial properties but are underutilized in food analysis. Integrating AgNPs with artificial intelligence (AI) can enhance food safety monitoring. The study in Moulahoumet al (2024) reviews AgNP-based biosensors for detecting contaminants like bacteria, pesticides, and heavy metals. AI and machine learning (ML) models, including neural networks and decision trees, optimize detection accuracy and interpretation.AI-integrated biosensors improve sensitivity, reduce detection time, and enhance real-time monitoring. ML models achieving up to 97.6% accuracy in food contaminant identification.

Iymen et al (2020). examined the challenges of Food adulteration, falsification, mislabeling food products by manufacturers in dairy industry. Dairy products are major adulterated products, dairy fat in butter is often adulterated with fats of plant origin such as palm oil and sesame oil. Some techniques such as chromatographic analysis, polymerase chain reaction (PCR), hyperspectral imaging, Raman spectroscopy, and nuclear magnetic resonance (NMR) are developed to detect adulterants but these methods are restricted to well-equipped laboratories, so not suitable for consumer use. In this with simple sound vobrations neural networks trained with frequency responses for identifying dairy products with or without non-dairy additives (NDA), organic and non organic components. One butter sample is selected by trusted brand and another by conformed adulteration by government. Prepare samples collected in uniform shape and thickness with plastic wrap. Sound vibrations are generated using an external speaker passing through the food sample external microphone record sound from opposite end. The samples are tested with two sound types one is constant frequency of 400Hz for 60 seconds and another is frequency sweep with 200Hz to 10 KHz for 440 seconds.Split them into chunks with 2 seconds. Total 10013 audio chunks are created for four different classes. By using FFT it takes much time to get conclusion. Artificial Intelligence can used to extract the features and compare then identifies adulterations and non organics without additives. The algorithm can integrate in smart phones. Consumers can easily accessible. The data is split into 90% for model training and 10% for model testing. Mel-Frequency Cepstral Coefficients (MFCC) are used in speech and sound recognition. By using this raw wave form is converted into coefficients. Deep learning models parallel CNN-RNN and CRNN with 5 fold validation and optimization with learning rate 0.001 and epochs are taken as 25 for parallel CNN-RNN and 50 for CRNN. Parallel CNN-RNN get accuracy of 100%, validation loss with 0.0333 and CRNN get accuracy with 100%, validation loss with 0.0089 on training data. In test set samples both models get accuracy of 100% on the test samples. On testing with smart phone CRNN model get accuracy of 82.66% and parallel CNN-RNN model get accuracy of 4.86%.

The goal of food safety is to enable all people to have safe, nutritious, and enough food. There are many cases of food-borne diseases, which cause deaths every year. The demand of food from all over the world increases the risks of food safety during the process of food production, foodprocessing, food transportation, and food retail. Food safety problems may occur in any stage. Agriculture is the main source of food production. Chemicals, pesticides, fertilizers are used to produce food. In the food processing many additives are added in the food. During the transportation of food it may deteriorates due to changes in the external environment. Food retail is mainly to prevent expired food from being sold by mistake. These four processes influencefood safety. In the past, it was difficult for people to believe where the food they bought came from. Nowadays, food traceability can easily realize information for the whole process of the food. In the food production process, sensors and other devices are used for the monitoring of food safety. Then records during the food processing, food transportation, and food retail are kept for the data processing. Large amount of data are collected during these stages, and the data is used in AI and big data to analyze.

The process is divided into five stages data collection, storage and transferring, analysis, visualization, and security. Introduced databases such as SQL, NoSQL, MongoDB for data storage, and then data analysis methods such as support vector machine (SVM) and artificial neural networks (ANNs), and tools including PyTorch, Hadoop are also presented. For data visualization, programming tools HTML, R are introduced, and business tools such as IBM system are also recommended. Blockchain is used for security. Big data, AI, and blockchain technologies are used.

Data collection: Various types of data sources with useful information can be utilized for food safety, such as online databases, sensor data, genomics data, and social media data.

Data storage and transferring: SQL, NoSQL, MySQL, Oracle, PostgreSQL, MongoDB, Cassandra, Hbase are used to storage and Aspera, Talend, and Elasticsearch are used for transfering.

Data analysis: ML algorithms such as Naive Bayes, SVM, MLP, and ANN are deployedto make decisions by learning from data for applications of food safety. Deep learning models, the deep denoising auto-encoder to find the food contamination on gastrointestinal infections and provided a valuable tool for morbidity.To detect the quality convolutional neural networks (CNNs) are used by images, Stacked Auto-Encoders(SAEs) detects spoiled or damaged, classification algorithm combining Stacked Sparse Auto-Encoders (SSAE) and CNN detecting in pickling cucumbers using hyperspectral imaging to recognize the plum varieties by applying image analysis and deep CNNs. Computer vision and deep learning based methods were also applied in the quality assessment of meat products For data visualization R and IBM, for data security Blockchain are used.

Goyache et al (2001)talks about the problem of checking food quality, which is usually done by humans and can be inconsistent. To solve this, the study suggests using artificial intelligence (AI) methods like NEURALNETWORKS and FUZZYLOGICS. These techniques help in analyzing food qualities like taste, texture, and appearance more accurately and consistently. AI improves accuracy by reducing human errors and making quality checks more reliable. This is useful for making sure, food products are the same quality every time and keeping costumers happy. Compared to old methods, AI provides a more systematic and efficient way to check food quality, making the process faster and more dependable.

Food spoilage happens due to weather, humidity, temperature and other environmental conditions. The traditional storage method does not track food well. The global amount of meal wastage is estimated as 1.3 billion tons. A smart tracking system is needed to keep food long last.Sonwani et al (2022)., used convolution neural network (CNN) to identify and classify fruits and vegetables. Sensor monitoring tracks gas levels, humidity and temperature using Gas detector, Humidity, temperature, light sensor, and camera sensor. Automated Alerts send mobile notifications on food freshers, environmental control adjusts conditions to prevent spoilage. The CNN model has an accuracy of 95% detecting food type and condition tracking of food spoilage.

Castillo et al (2024), used Fractal dimension analysis to classify micro-organism and chemicals in food samples to help in ensuring quality. The computer Automation reduces manual intermitting to eliminate a long sequence of microbiological and chemical techniques. It includes collecting food samples, processing a laser scan microscope capture image of food samples that shows bacteria and chemicals, further factor analysis for identify and classify various bacteria's and chemical's unique pattern shape. The expert system for decision making applies set of rules in PROLOG to identify harmful bacteria. The AI-fractal theory improves accuracy of detecting food quality issues compared to traditional method.

Sabanciet al (2020) studied the critical issues related to the impact of sunn pests on wheat production and how can reduce the damage using artificial intelligence.Artificial bee colony (ABC) algorithm in this study, two different AITs that determine SunnDamaged Grains (SDG) among healthy wheat grains (HWG) by using image-processing techniques (IPTs).In the experiments improve the recognition of SDG and HWG, the dimensions,texture features and Fourier property of each wheat grain are considered. Extreme learning machines (ELM) in the measurement setup, a total of 300 wheat grains,150 HWG and 150 SDG, are used. 17 features of each wheat grain are obtained using IPTs. Then 5 of the 17 features most effective on the classification are determined by means of a correlation-based feature selection (CFS) method. The error rate in the classification is reduced by 5%.

Bagnulo et al (2024) reviewed the use of AI in various stages and aspects of Tea, Coffee and Coca industry to ensure quality. Tools like SVM,ANN, KNN, and LDA are used for flavor study, further the fermentation level is predicted using PCA based methods.

2.4. Application of AI in Food Packaging

Li et al (2023) talks about the problem of keeping food freshness during storage and transport. Traditional packaging does not give real-time information about food quality, which can lead to waste and safety issues. Studies indicate that conventional packaging results in an 8% error rate, whereas AI-powered systems reduce errors to 2%. To solve this, smart packaging with artificial intelligence (AI) is used. Sensors check things like temperature, humidity, and gases, and AI analyzes this data to give real-time updates on freshness. Research shows that AI-driven freshness monitoring improves accuracy by 324% compared to traditional methods. This method is more accurate than old techniques and helps in reducing food waste, keeping food safe, and managing storage better. Unlike traditional packaging, which cannot monitor freshness in real-time, AI-powered packaging is a big improvement as it provides quick and reliable food quality checks. AI-based packaging solutions have also been shown to increase efficiency by 311% and reduce processing time by 70%.TTI used to detect temperature.

Wang et al (2022) discusses the problem of traditional food packaging not being attractive or interactive enough, especially for popular online foods. To solve this, a new method uses artificial (AI) to design an interactive packaging that engages consumers. The method combines expert opinions using a special rule to balance different ideas and create the best design. This AI-based approach improves accuracy by ensuring the packaging is both visually appealing and functional. It helps food brands attract more customers and improve the overall user experience. Compares to old packaging design, which lacked engagement, the AI-powered method creates more innovative and consumer friendly packaging, making products more marketable and appealing.

Fish processing industries generates about 70% waste. Sam et al (2018) addressed the economic loses of the fishing industry, and to reduce biological residues and to extend the shelf life of packaged products. They employed the K Nearest Neighbor(KNN) algorithm that classifies and selects biodegradable packaging made from fish gelatin with palm oil and essential oils. Films with these essential oils shoe tensile strength with clove oil 53.18MPa the packaging has antioxidant and antimicrobial properties with inhibition zones of 11.73mm. The thickness of the film was measured using digital micrometer with a resolution of 0.001mm.fish gelatin based film with vegetable oils offer a promising solution for food packaging. Environment friendly packaging with antioxidant and antimicrobial properties improve the state of the art in packaging in Fishery industry.

3. CONCLUSION

Artificial Intelligence is influencing every aspect of Food industry. This work focused on a critical review of recent literature on application of AI in Food production, Food processing and food industry, Food quality and Food Packaging. Introduction of AI based methods not only reduced the burden of labor cost, human efforts, further improves the quality of food production process, hygiene, and safety. It also reduced the risk of losses, and improved the profitability by suggesting business models and explored new dimension of the integration of AI with additive manufacturing in food production. Review of AI in Food processing and food industry presented an overall perspective of food business from processing to consumer reviews. Inclusion of AI in food quality improved the state of the art in the traditional human intervened methods for food quality to automatic process that yielded a significant improvement in accuracy of detection of contaminations, defects in food products. AI in food packaging helped in presenting the products attractively with improved shelf life.

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