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Artificial Intelligence and its Applications in the Food Industry

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Abstract

Food safety is essential to our survival and well-being. The intricacy and sophistication of today's food systems necessitate upholding the strictest food safety regulations and employing state-of-the-art technologies to shield consumers from foodborne illness while lowering the possibility that food companies will suffer millions of dollars in recall expenses and potential harm to their brand. This review paper explores the burgeoning integration of artificial intelligence (AI) in the food industry, focusing on its applications in various domains. The study encompasses the utilization of machine learning (ML), deep learning (DL), computer vision, and image processing techniques. The review provides a holistic overview of AI's transformative impact on the food sector's production and quality control processes. The paper searches through the specific applications of AI in dairy products, meat products, fruits, vegetables, and bakery items. Each category examines the role of ML and DL algorithms, highlighting their efficacy in optimizing production efficiency, quality assurance, and supply chain management. Computer vision and image processing techniques are explored for their ability to enhance product inspection and quality control, ensuring compliance with industry standards.

Keywords: Artificial intelligence, machine learning, deep learning, food quality

1 Introduction

A healthy diet is essential for human health. Natural products have long been used as food, but to meet consumer demand, they are being processed (Zhou et al., 2019). Not only is food safety vital for the food industries, but it is also essential forthe health of humans. Therefore, the food industry should have a fast and reliable detection method.These traditional methods, such as gas chromatography (GC), high-performance liquid chromatography (HPLC), and polymerase chain reaction (PCR), are time-consuming, laborious, and costly.

We must develop precise, quick, consistent, and nondestructive food and quality evaluative techniques to meet the demand for high-quality food. Although these noninvasive techniques have numerous privileges, some dare remain (Lin et al., 2023).The type of food, its compositions, nutrients, and processing methods are all crucial considerations for a healthy diet. The eating habits of the people are different from region to region. Knowing food attributes (such as type, composition, nutrients, and processing methods) is essential for inspecting the quality and safety of food for consumers worldwide(Zhou et al., 2019).As living standards rise and technological advancement increases the importance of food quality, food industries adapt to new technologies for improvement.Because the population is growing and consumer expectations and awareness of food quality are growing, the food industry now requires quick and absolute analytical techniques to meet consumer demand. Food hygiene and health concern food safety. Food safety means providing quality food to prevent foodborne illness or ensuring that food does not contain microbial, chemical, or physical contaminants during transportation, preparation, and storage and does not cause diseases. Sometimes, there is confusion between food safety and security, but both terms havedistinct meanings. Food safety means health and accessibility of food that does not cause illness to the person who consumes the food(Chen & Yu, 2022).

More than 200 diseases are caused by food that contains harmful bacteria, viruses, parasites, and chemicals. According to the Food and Agriculture Organization (FAO), unwholesome food kills 2 million people each year, the majority are children. Many studies have shown that new threats to food safety are constantly emerging, such as environmental changes, food production, distribution, and threats from emerging pathogens and antimicrobial food resistance.As the food safety system becomes more globalized, it must be strengthened. As the food industry expands, so does the use of hormones, antibiotics, pesticides, and additives, which cause congenital anomalies and cancer, particularly in children. As the food supply becomes more globalized, increased attention to the food safety system is required(Chen & Yu, 2022).Foodborne disease outbreaks and subsequent recalls are causing havoc in the food industry. Consider the recent E. coli outbreaks and salmonella found in chicken nuggets.These issues can potentially be lethal and expensive to the food industry financially and in terms of fame.The cost of recall varies and depends on many other factors.

Still, the average number allows for the understanding that such recalls affect individual organizations and the entire food industry (Kudashkina et al., 2022).Electronic noses, computer vision, spectroscopy, and other modern techniques have been widely used to find food attributes of food. With the help of these new technologies, we can decrease disease outbreaks(Zhou et al., 2019).Artificial intelligence is a popular technology in various industries, including healthcare, finance, education, transportation, and marketing media. Although it was not used in the early days of the food industry, it is not an exception. Compared to traditional methods available to the industry, AI in the food sector has expanded reliable, objective, profitable, non-destructive, and practical techniques (P. Sharma & Sharma, n.d.). There are many branches of AI, but machine learning and deep learning are widely used in the food industry.Deep learning is a powerful technology gaining traction in agriculture, medical science, robotics, health care, human action recognition, speech recognition, etc. Deep learning has many advantages, such as learning data representations, transfer learning, and dealing with large amounts of data; additionally, deep understanding can achieve better performance and higher precision (Zhou et al., 2019).

Machine learning is a cost-effective alternative to traditional procedures. Because it can solve high-level problems, machine learning as a part of artificial intelligence is considered adequate, and it has achieved fair performance in various research areas. Because ML algorithms are experimental, they can gradually learn rules and identify patterns from large datasets without being specificallyprogrammed. The use of ML to process datasets assembled by the above-mentioned non-destructive technologies allows us to recognize and distinguish the interrelationships in specific characteristics that affect food quality. This can also facilitate observation into the interrelationship in these featuresbetter to understand dormant impacts on the quality and safety of food. As a result, combining noninvasive techniques with advanced ML has become more of a common trend in device defense reactions than in production mechanization (Lin et al., 2023).

2 AI-enabled technologies inthe food industry

2.1 Machine Learning

In recent years, advanced technology such as artificial intelligence, machine learning, and automation have become commonplace in food safety and quality. Automation is combined with artificial intelligence to predict crop yield.

AI is used for food product classification in conjunction with automation, such as image processing technologies, sensor technologies, and robotics (Karanth et al., 2023).Machine learning is a subpart of AI. Machine learning uses data to identify text and image patterns to make statistical decisions (P. Sharma & Sharma, n.d.). Machine learning is capable of identifying and analyzing customer demands. Essentially, ML gathers and combines knowledge from random datasets so that the output of such algorithms functions as a computer program capable of completing specific tasks. ML is primarily concerned with developing algorithms to study and estimate data rather than relying on constant programming instructions. Machine learning is divided into four categories: supervised learning, unsupervised learning, reinforcement learning, and representation learning. Supervised learning: Prediction for the unobserved points is done with supervised learning(Thapa et al., 2023).

The model is compared to an expert system in supervised learning.The input and output events are known in supervised learning. It learns from the input and output provided, and the output is produced only if the input is known the next time(Anwar et al., 2023). Unsupervised learning: It also makes predictions for the unobserved points. Unsupervised machine learning takes only datasets as input and then uses data points to identify specific patterns. It divides the data into groups. Unlabeled data is used in unsupervised machine learning.Reinforced learning: It is an interaction between the program and the environment. Reinforcement learning is based on a price and penalty scheme. An agent acquires by interacting with the environment, and for each correct decision made, the agent receives rewards, while performing incorrectly results in penalties (Anwar et al., 2023).

Representation Learning: In this, a raw data set is fed to the machine, and a classification model is found; this is also known as feature learning (Thapa et al., 2023).Machine learning is used in decision-making, reducing the cost of sensory evaluation and improving corporate strategies. Machine learning has demonstrated its ability to forecast sales and the amount of food waste produced (Thapa et al., 2023).Risk assessment is a decision-making tool in many fields, including the food industry. For example, salmonella species prefer ambient temperature, but some sediments can withstand high temperatures. Because there are differences in subtypes for different species in such cases, the data is extensive, so we use mathematical and statistical models to assess the risk. Accessors try incorporating genetic information into the modeling framework through machine learning to reduce uncertainty in modeling food safety risks.

This supervised learning technology predictsdisease severity caused by pathogens such as salmonella and listeria based on genome sequencing data. The author was able to extrapolate the food-borne clinical cases of listeriosis using whole genome multi-locus sequence typing(Karanth et al., 2023).

2.2 Deep Learning

Deep learning is a branch of machine learning. It uses ANN (Artificial Neural Network) to mimic the human brain. It is used in various fields, such as speech and object recognition(P. Sharma & Sharma, n.d.). It is built on a deep hierarchy of layers that solve complex problems. It increases the capacity of supervised and unsupervised learning algorithms for solving real-life complex problems by adding different processing (Sadiku et al., 2020). Deep learning is a type of representation learning that refines multilevel representations. Machine learning is active in many fields, but for analyzing raw natural data, traditional machine learning techniques must be exaggerated by manual feature extraction methods (Zhou et al., 2019).

With the help of deep learning, we can solve complex problems very quickly. If adequate data is available, then deep learning demonstrates the classification task. Deep learning is used in food category recognition, like quality detection of fruits and vegetables, calorie estimation, etc. CNN includes components like convolution layers, pooling layers, fully connected layers, etc.

It is one of the famous models in the research area. How CNN describes the classification problem is shown in Figure 1. Convolution layers are built by rules that will be optimized according to the problems.

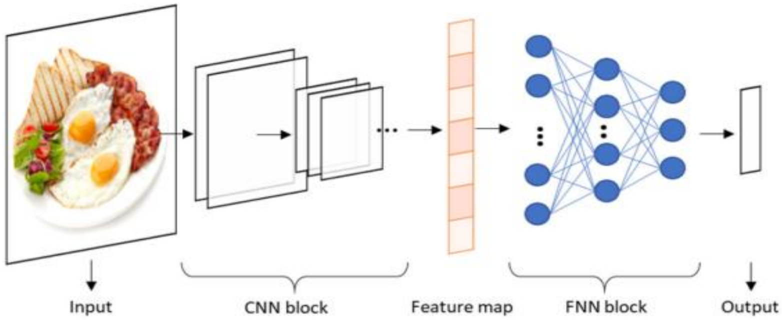

Figure 1 CNN structure for image classification

Sensory evaluation plays an essential role in food quality. That is why researchers are attracted to and willing to put more effort into this field in predicting sensory characteristics and eating environments. By using traditional data processing methods like PLSR, SVM, and Neural Networks, some researchers tried to find the relation between catering hedonic data and food sensory parameters. The sensory characteristics of food have a significant impact on diet. Some advanced technologies are used to predict food sensory data and its physical and chemical parameters. The traditional machine learning techniques are arranged to establish the relationship between texture and sensory characteristics and food's physicochemical parameters. Research on sensory characteristics is stuck on traditional data analysis methods, including image feature extraction, statistical analysis, etc. The deep learning method is hardly used for feature mining(Zhou et al., 2019).For better understanding, we take the example of apple classification by deep learning. Apple is a fruit with plentiful nutrients in it. That is why we say an apple daily keeps a doctor away. It is used in the treatment of joint pain, is suitable for losing weight, and is also used in the prevention ofasthma and cancer. Types of apples are classified using a dataset in deep learning.

In deep learning, the CNN (Convolution Neural Network) recognizesthe type of apple with the computer vision. Here, supervised learning makes predictions that require an arrangement of the dataset. Unsupervised learning uses data that is not classified but allows the method to respond to data without support (Addanki et al., 2022).

2.3 Computer Vision

Computer vision consists of image acquisition and image processing. It is a technique through which an artificial system can be constructed. It is now employed in quality detection in the food sector. It is also employed in grading different fruits (Sadiku et al., 2020).There are various applications of computer vision in sorting and quality detection. Because of increased consumer awareness, the quality assessment of fruits and vegetables is increasing.In 2012, Intaravanne, Sumriddetchkajorn, and Nukeaw used a smartphone to classify ripening levels in bananas, in which they assessed the 2D spectral analysis. In this research, they examined the 2d images of bananas with the help of UV rays and white light and sorted the bananas as ripe, overripe, and immature.

Based on the spectral method, banana ripeness is successfully classified(Intaravanne et al., 2012). In 2018 (Aquino et al.) developed a technique to count berries in cluster images. The application that is manually operated for this purpose is called Vitisberry(Aquino et al., 2018).In 2016, Das et al. developed a smartphone-based spectrophotometer. With the help of this spectrophotometer, we can monitor the fruit's ripeness. For this, they use the sample's chlorophyll spectra and measure the sample's chlorophyll with the help of a spectrophotometer. Then, the results are compared with the benchtop spectrophotometer(Das et al., 2016).

Computer vision is usedin picking, processing, and packaging. The scanner, used on the conveyor belt, uses computer vision to check the quality of fruits. AII-defected and oversized fruits are rejected by computer vision. Computer vision also helps to predict the temperature, mixing speed, and adding components at a time. It also monitors the color and density of the ketchup, as it is an essential parameter in the ketchup. It requires more human resources and time to carry out this task earlier. Also, the probability of inferior quality products was higher in manual work.Computer vision plays an essential role in packaging. It checks whether the bottle is filled correctly or not and whether it is clean. The camera and sensor capture digital pictures for this task, as shown in Fig 2.(S. Sharma, Bisoyee, et al., 2021).

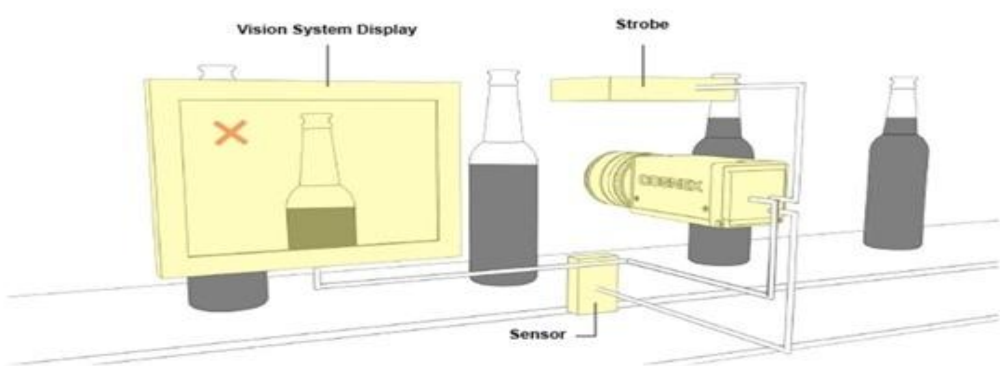

Figure 2: Scanning and Elimination of bottle by computer vision.

Meat and meat-based products are popular products in many countries. As it is a popular product, the quality of these products is essential. Recently, the smartphone-based image processing method, which assesses meat quality, has been introduced. In 2019, Hosseinpour, Ilkhchi, and Aghbashlo developed an app to predict the tenderness of beef samples.

For this, various image processing algorithms are used. This algorithm eliminates the uncontrolled condition and gives a proper final result. It is also able to predict the texture analysis in fresh meat. An artificial neural network assesses the correlation between instrumental data and processed image features. The findings of Hosseinpour, Ilkhchi, and Aghbashlo say that the app can predict beef's tenderness from its image(Amani et al., 2022).

2.4 Image Processing

Image processing is a part of the computer vision. Here, the main stages involved in image processing are described. Image processing is used for classification, quality recognition, and identification of various properties. The basic steps for image processing are imaging, pre-processing, image segmentation, representation, explanation, recognition, and interpretation (Technischeet al.& Institute of Electrical and Electronics Engineers, n.d.). Ultrasound, X-rays, and other devices use sensors to create digital images. Proper lighting is necessary for a proper image, which means different lamps and X-rays are used. In Pre-processing,different techniques are used to increase image quality. The IP system segregates the image into parts. After segregation, one analyzes the size and shape, and another determines texture and defect. For representation, the selection of image display depends upon the application—recognition, and interpretation are done using a neural network for quality analysis(Chen & Yu, 2022).

3 Application of AI-enabled technologies in different food sectors

3.1 Artificial Intelligence in Dairy Products.

Milk contains a lot of protein, fat, carbohydrate, minerals, and vitamins. As it is nutritious and highly consumed by children, particularly vegetarians, its demand is high. However, because of increasing demand, the vendors focus on making money, not on people's health, by adulterating milk. This adulterant can cause severe health issues(Anwar et al., 2023).

In dairy processing plants, raw milk acceptance will depend upon its microbial load. Different adulterants decreasethe count of microorganisms(Jeong et al., 2015). E-Nose is used to detect adulterants like formalin, sodium hypochlorite, and hydrogen peroxide. Various types of equipment are used for the detection of adulterants. They (Tohidi et al., 2018a) did one experiment in which eight levels of hydrogen peroxide, eight levels of formalin, and seven levels of sodium hypochlorite were tested. The accuracy is nearer to 92% for each adulterant(Tohidi et al., 2018). In one study conducted in 2018, an E-nose was used to detect various levels of different oils and fats mixed with pure ghee. It was first heated at 40-50^0 Celsius (Ayari et al., 2018). Electric noses, with the help of AI and ML, access the database of dangerous odors and find the infection and pollution. It plays a good role in food quality and safety (Mohd Ali et al., 2020).Milk is perishable, so high-quality equipment is needed for high-quality requirements, and the maintenance cost of this high-quality equipment is higher. However, because of some innovations in dairy products, the degree of hygiene has increased, and the shelf life of these perishable food products and the maintenance costs have decreased(S. Sharma, Bisoyee, et al., 2021). Milk gets spoiled easily if we do not refrigerate it properly. To avoid spoilage, a system with wireless sensors must be used with AI (M, 2012). Milking of cows is one of the time-consuming tasks and also requires more human resources. In 1999, Europe developed the automatic milking machine. Later, it was introduced by the US (Sandey et al., n.d.). The electronic tag is fitted to the cow, making it easy for the robot to identify them. The milking cups are attached to the teats after the milking cups get disconnected. Later, before exit, the disinfectant was sprayed on the cow (Sandey et al., n.d.). One of the findings describes that heat stress is one of the reasons for the collapse of milk production. This data was collected using a back propagation neural network. We can decrease this stress by sprinkling water on cattle's bodies(S. Sharma, Bisoyee, et al., 2021).

For the detection of E. coli in yogurt in 2018, Zeinhom, Wang, Sheng, et al. discovered a smartphone-based fluorescence device. In this experiment, they added a certain quantity of E. coli into the sample and captured images of it with the help of Image J software. In this, the fluorescence image converts intothe intensity of fluorescence. The obtained values were then compared with the microplate reader. Both results do not vary much, so a new device was developed to detect food pathogens(Amani et al., 2022).The linear layer design is used to anticipateprocessed cheese's shelf life, and the expiry date is controlled using the multiple regression model (S. Sharma, Bisoyee, et al., 2021). The computer vision system and multispectral CVS check the products' apparent quality(Chauhan et al., 2017).

3.2 Artificial Intelligence in Meat and Meat Products

Meat is famous worldwide for its taste and nutritional profile, as we know it is a good source of protein (Rahmati et al., 2016). Suppliers mix low-priced meat with expensive meat to gain profits. Because of these adulterations, food quality and safety areessential(Rohman, 2019).

In 2022, Huang and Gu performed an experiment using the E-nose to collect data on adulterated meat. In this experiment, the beef is adulterated with the pork. First, the fat tissues are removed and then minced for 1 minute in a blender. The framework used in the quantitative detection of meat adulteration is 1DCNN-RFR, combined with a one-dimensional convolutional neural network (1DCNN) and a random forest regressor (RFR).The effectiveness of this framework is compared with the other four models, but this model performed well compared to the other models used for adulteration of meat (Huang & Gu, 2022). The study, accompanied by Feyzioglu and Taspinar (2023), identified the freshness of beef cuts using an E-nose. In this, the beef quality is classified into four classes. The analysis of variance method (ANOVA) is used to determine active features within the data set. However, they were selected through ANOVA to classify three active features. Machine learning methods were utilized. The results show 98.8% accuracy for KNN and 98.6% for LR(Feyzioglu&Taspinar, 2023).

For removing the carcass of sheep, both men and machines are required; the man will perform the slitting and cutting for the remaining things,and machines are used. Intelligent packaging technology is used to detect spoilage in seafood stored under various conditions. Hierarchical cluster analysis (HCA), principal components analysis (PCA), and partial least squares regression analysis (PLS) are applied as experimental techniques, and for spoilage maker identification, PLS was selected. A fuzzy logic system is used to solve meat quality and microbial estimation usinga component fuzzifier and fuzzified. Machine vision will contribute better to quantifyingthe visual appearance of meat (S. Sharma, Gahlawat, et al., 2021).

Meat and aquatic products come under the category of perishable products. For them, a rapid, nondestructive quality detection method is required. For this purpose, spectral sensing is combined with the TML (Lin et al., 2022). In 2020,Anderssen et al. proved that combining HSI with the PSLR model accurately predicts moisture loss in frozen and thawed cod. Genetic algorithms are permitted in developed hyperspectral models (Anderssen et al., 2020). A spectrophotometer is used to scan food such as meat and meat products with a single scan. It can assess the multiple attributes of the product. Deep multilayered ANN predicts microbial and fungal contamination (Ellis et al., 2002). For differentiating the chicken and turkey, the spectroscopic data is analyzed with the genetic algorithm in which the AI is used to detect adulteration (Ellis et al., 2005).In 2019, Yao et al. worked on a portable system that monitors the pH of pork meat. In this system, the hyperspectral scanner and smartphone are linked together.

It also has a white LED lamp to cast light upon the sample while capturing the image. After that, the image is analyzed to compute the reflected spectra.The pH of the meat sample is measured using a pH meter, and models between the pH value and the establishment of image processing data are done using support vector regression. The accuracy of the result is good, so it is the potential method for predicting pH in pork meat (Yao et al., 2019). CIS(Computer imaging system) is used in the meat industry for quality characteristics in fresh beef, like sensitivity towards contaminants, meat color, and PH. The contaminants in chicken and poultry are detected using the hyperspectral imaging system. It can detect 140 carcasses per minute (Chen & Yu, 2022).

3.3 Artificial Intelligence in Fruits and Vegetables

Vegetables and fruits are important in the diet as they contain essential nutrients for human health. However,improper handling during storage in inappropriate conditions causes the loss of fruits and vegetables, and various microorganisms attack this, hurting consumers' health (Zhou et al., 2019).Intelligent refrigeration is an advanced refrigerator that can give information about the content and age of the product. In this refrigerator, the input is given in the form of images, then it processes the input given, and the microprocessor displays the output. In this refrigerator, the shelf life count is also maintained. It sorts the vegetables based on maturity weight, size, etc. The accuracy is up to 96.55% for this refrigerator. Automatic visual inspection uses infrared color and ultraviolet images for sorting the fruits. It sorts 15 fruits per second(S. Sharma, Bisoyee, et al., 2021).

In image processing, machine vision is a tool to detect the quality of the product based on consumer demand. The contamination on the apple surface is detected using machine vision in this fluorescence imaging, and multidimensional algorithms are used. They use a pair of red-purple linear lights to detect infected parts of the apple. This system is used for the prevention of foodborne diseases and to reduce the risk. Infrared imaging with a high correlation coefficient detects the moisture content, firmness, softness, and the fruit’s pH(Chen & Yu, 2022). In 2020, C. Zhang et al. found the total phenolic content of flavonoids and anthocyanin in black goji berries using the CNN model and Deep learning with infrared hyperspectral imaging. They got good results from this experiment (Zhang et al., 2020).Quality assessment of various fruits and vegetables, including their ripening defects and damage, can be done with the help of 3D structure images as they give in-depth information on the sample conditions.

This has another advantage, such as the chlorophyll component in plants for photosynthesis. With its help, smartphone-based spectroscopy gets proper indicators; this is a good idea given by the author for expanding the technique's usability (Amani et al., 2022). Sorting of fruits and vegetables is done in every food industry related to fruits and vegetables. It consumes so much time as well as human resources. If we use advanced technology like AI and ML, it will reduce the production cost very effectively. The solution for sorting and peeling used by TOMRA says that they recover up to 5-10% in production. To reduce the waste while sorting the potatoes, the system uses Near-infrared spectroscopy lasers and X-rays with photographic cameras to analyze the vegetables(P. Sharma & Sharma, n.d.).

3.4 Artificial intelligence in Bakery products

Various automated systems, like food quality sensors, which convert food properties into electrical signals, are now used in the bakery industry. With the help of these signals, various quality parameters are determined. The smart ovens are there in the bakery industry. Because of the advances in the bakery industry, baking operations are easy and less time-consuming; intelligent control systems provide adequate baking conditions and increase product performance (S. Sharma, Bisoyee, et al., 2021).Kondakci et. Al discusses many advanced control strategies we can apply in baking, fermentation, and dairy processes(P. Sharma & Sharma, n.d.).

For making bread, it goes through several processes. The yeast is inoculated into the dough for the making of bread. If any of the steps are not performed properly, it hampers the quality of the bread(Addanki et al., 2022). The sensors control the rheological properties of the sourdough and dough. It also controls the dough's acidity, smell, temperature, humidity, and weight. This is the automated controlled system in robotics technology. The quality checking of bread requires one hour, while the whole baking process requires 3 hours from starting to packaging. To check the quality of the bread, first, we cut the bread, and a camera is used to check the inner portion of the bread. The sensors for food quality detection convert food properties into electrical signals(Addanki et al., 2022).

4 Conclusion

This paper discussed the conspicuousness of AI in the food industry and its various applications. AI is necessary for the future of the food industry. There are so many misconceptions about AI in people's minds. One of the most common misconceptions is that AI will replace humans and they will lose their jobs, but that is not the thing; supervision is needed to conduct the operation with the help of AI. As described by different researchers in the above paper, food quality and product safety will improve with the help of machine learning, deep learning, computer vision, etc. It causes decrement in the outbreaks of foodborne diseases. Image processing is used to detect the different pathogens in food. It takes less time than the other traditional methods. The various kinds of applications of machine learning, deep learning computer vision, and image processing in various sectors like milk and dairy, meat and meat products, fruits and vegetables, and bakery sector are discussed in the paper.

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