https://dergipark.org.tr/tr/pub/food
OPEN ACCESS JOURNAL

ISSN 2667-5803

FHTI Journal of Food Health and Technology Innovations
December Vol 7, No 15 (2024)

DergiPark AKADEMİK

Review Article

ARTIFICIAL INTELLIGENCE IN THE FOOD INDUSTRY

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Abstract Nutrition is vital for human survival. It is essential to reduce food waste, streamline the supply chain, and improve food logistics, delivery, and safety. Artificial intelligence and machine learning significantly contribute to achieving these objectives. Artificial Intelligence (AI) refers to the development of intelligent systems capable of doing activities that typically require human intelligence. In the food industry, it is seen that solution tools such as ANN (Neural Network), Fuzzy Logic and Genetic Algorithm are widely used in solving problems and performing their analyses. Artificial intelligence has been employed in food science and technology for classification, process modeling and optimization, quality control of food, prediction of dough rheological properties, classification of wine based on anthocyanin content, forecasting the maximum or minimum temperature attained in a sample post-pressurization, determining the time required for thermal re-equilibration in high-pressure food processing systems, and classifying fruits and vegetables according to their morphological characteristics. This article discusses artificial intelligence applications in the food industry and manufacturing.

Keywords: Artificial İntelligence, Food ındustry, Food Engineering

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Introduction

Artificial intelligence (AI) comprises technologies replicating human intellect, enabling computers to emulate human cognition and behavior for autonomous learning, reasoning, planning, and decision-making. The essence of artificial intelligence encompasses machine learning (ML), deep learning, natural language processing, computer vision, and additional technologies applicable across diverse sectors and industries (4). The term 'big data' denotes a vast and varied assemblage of data, usually produced by numerous sensors or mobile devices, extracted from the internet and other origins, encompassing organized and unstructured data, including text, photos, and videos. These data collections are typically defined by high velocity, high volume, and high dimensionality, necessitating storage, processing, and analysis through specialized technologies, commonly known as 'big data technologies.' In the food industry, big data analytics can forecast market demand, enhance the supply chain, elevate food safety and quality, and provide enterprises with additional opportunities and competitive benefits (4,17,31,52,56).

Artificial intelligence significantly contributes to food science and industry by enhancing the efficiency of cleaning-in-place (CIP) systems, managing supply chains (33), developing new products aligned with consumer preferences, categorizing fresh produce, ensuring food quality (42,47,50,58,69), controlling processes (45,70), processing images (29,69), evaluating sensory attributes such as odor and flavor (2), and, crucially, conserving time and resources (9). It has also recently grown to include predictions about keeping an eye on food safety and illnesses that come from eating (9,36,42,47,65,70). Machine learning positively influences sales of fast-moving consumer goods, particularly perishable food products, enhancing supply chain efficiency, profitability, and consumer accessibility (60).

Application in food industry

The role of artificial intelligence in these challenges is to assist both in overcoming these difficulties and in creating, diversifying and improving products (Figure 1) (43).

Applications of artificial intelligence in the food industry are expressed in the following areas (43):

- ✓ Sales forecasting. Artificial intelligence can track customer preferences and purchases to predict sales.
- ✓ Predicting consumer preferences and purchasing methods by tracking customer emotions on social media processes and analyzes data to sort their posts and label them as positive, negative or neutral.
- ✓ Improvement of food products. Many food brands are improving their product offerings by using artificial intelligence and deep learning technologies to create flavor combinations that will be popular with consumers.
- ✓ Inventory forecasting. Artificial intelligence can provide accurate guidance for better market analysis.
- ✓ This will facilitate pricing, inventory forecasts and more accurate planning.
- ✓ Supply chain improvement. Food safety regulations are becoming more and more stringent, requiring full transparency in supply chain management for food industry businesses. The need for AI-driven supply chain tracking can optimize the supply chain to increase enterprise profitability.
- ✓ Sorting for quality assurance. Sorting is one of the most labor-intensive operations in the production process. It can be facilitated with the help of artificial intelligence. This will contribute to increased productivity, reduced scrap and higher quality.
- ✓ Food security. The food industry is faced with the challenge of meeting the increased demand for food, due to the growing world population, climate change, decreasing areas of agricultural land, etc.
- ✓ Food safety. With artificial intelligence, practices that are not in line with the corporate policy for healthy and safe production can be identified.

Table 1 shows the areas where AI and ML can be implemented in the food industry to enhance food quality while keeping up with the food industry's problems. These are not the only applications of AI; they can also improve food processing, storage, and transportation. Intelligent technology, such as robots and drones, can also help reduce packaging costs. It will also help with food delivery work fulfillment in hazardous areas and the provision of high-quality items (24,31,32).

Data collection and analysis divide the food industry into four categories, as shown in Figure 2.

The first category is smart farming. AI has various significant uses in food, such as soil monitoring, robocropping, and predictive analysis(32).

Smart transportation constitutes the second category. The transportation sector is evolving due to artificial intelligence. It has been utilized across various industries, including automobiles, trains, ships, and aircraft, as well as in optimizing traffic flow. It possesses the potential to transform the food industry and all modes of transportation, enhancing their safety, environmental sustainability, intelligence, and efficiency. Artificial intelligence-assisted autonomous mobility may mitigate human error, a significant factor in road accidents. Nonetheless, there are tangible risks linked to these scenarios, including unintended consequences and potential exploitation, such as cyberattacks and biased transit decisions.In addition to ethical concerns, there are further implications for employment about the accountability of artificial intelligence for decisions made in the absence of human oversight (31,32).

The third category includes smart processing. Artificial intelligence (AI) is attracting the attention of businesses across all sectors and industries, including food processing and handling (FP and H). AI exerts both direct and indirect impacts on the FP and H sectors. It indirectly aids farmers in weather forecasting, allowing them to generate superior raw materials for food processing companies, hence minimizing costs related to product sorting. Artificial intelligence assists transportation companies in minimizing shipping prices, hence lowering transportation costs for food manufacturing enterprises. In all circumstances, it aids FP and H firms in reducing revenue (32).

The final category of financial inclusion is intelligent distribution and consumption. The name signifies the intended application of agricultural products in FI. Machine learning (ML) can effectively address challenges such as optimizing delivery routes, managing raw material supply, predicting demand for particular food items, and enhancing logistics planning. Machine learning can help with distribution problems by determining where the delivery person should be based on current or expected traffic conditions and then telling them the best way to get there in real-time. Numerous applications in the food service industry today aid in forecasting the quantity and type of food orders, along with the associated inventory. (32).

Statistical analyses of visitor traffic and the required food products over time can utilize the data. The data are put together by combining information from past customer interactions, like their meal preferences, habits, and complaints, with details about what goods were available then (32).

AI in food enzymes development

Artificial intelligence has demonstrated significant efficacy in examining the links between enzyme structure and function. AI is anticipated to facilitate the simulation of the most complex reactions executed by process-aid enzymes in food processing. This presents a significant benefit over traditional approaches employed to enhance these enzymes, which account for a restricted number of parameters and fail to consider the actual food processing environment (5).

Wang et al. (66) have recently examined the advantages of AI-assisted design and engineering of enzymes for food processing applications. The substantially reduced computing time is A primary benefit

of AI in food enzyme engineering. Significantly less time and resources are utilized than conventional physical approaches while potentially providing extensive knowledge that aids in innovative product development.

AI in precision fermentation

AI-driven methodologies have garnered significant interest recently in the domain of industrial microbiology. AI techniques provide a significantly accelerated comprehension of the optimal modifications to implement in the microbial genome to enhance the yield of a desired chemical. AI tools facilitate the editing and customization of microbes for the synthesis of specific chemicals required in the food business, while also assisting in the storage and manipulation of extensive data sets generated from the integration of experimental and in silico studies. Currently, numerous food organizations are concentrating on this emerging technology to address the expanding variety of food demands (5).

AI in food safety and food toxicity

Food safety is crucial to human survival and health. AI is used in food supply chain management, quality control, sorting, and hygiene. Food fraud was predicted by a Bayesian network model (MedISyss-FF) developed by the European Union's Rapid Alert System for Food and Feed (7). In contrast, the U.S. FDA (Food and Drug Administration) has used AI to develop a model for predicting aflatoxin to help identify low- and high-risk seafood sourcing (18). Similarly, a study conducted in Taiwan by Chang et al. (8) describes the development of an automated alarm system for food safety. Microbial toxins and toxic chemicals are significant factors contributing to food safety risks. The methodologies currently used to detect such risks are costly and time-consuming. Integrating AI and machine learning software into the conventional methods used for assessing food toxicity has led to significant improvements in the rapidity and cost-effectiveness of food analyses to detect toxic compounds of both chemical and biological origins. Managing large datasets enabled by AI tools allows one to detect and classify poisonous compounds rapidly and efficiently. In this context, the chemical migration from package to food can also represent the risk of food toxicity (5).

Wang et al. (66) have developed an AI-based system that addresses these issues by utilizing a mix of data related to chemical properties, material type, food category, and temperature. The rapidity of AI-driven methodologies facilitates the examination of deleterious compounds throughout all critical phases of food production. The varied shapes and sizes of food items often hinder the advancement of AI-based food sorting and packaging. Once implemented, AI can enhance decision-making and automation, resulting in rapid, efficient, and hygienic operations, among other benefits. TOMRA and TensorFlow are two leading AI technologies that employ a combination of high-resolution cameras, laser technology, X-ray systems, and infrared spectroscopy. Product sorting efficiency has reportedly risen by around 90% due to these strategies (34).

AI in food pathogen microbiology

Artificial intelligence and machine learning are discovering crucial uses in food pathogen microbiology. Microbial infections in food can lead to food poisoning or deterioration. In traditional laboratories, food samples are examined for pathogens by isolating contaminants on agar plates, thereafter undergoing biochemical analysis. These procedures are inefficient and frequently hindered by the difficulty to isolate bacteria using the growth media accessible in ordinary laboratories. AI applications can significantly decrease detection time and enhance sensitivity (5).

Lupolova et al. (38) demonstrated that AI-based techniques can ascertain host specificity and zoonotic potential of species such as Salmonella enterica and Escherichia coli, which is of significant relevance to public health.

Wang et al. (64) utilized an AI-based technology platform to identify bacterial growth in under 3 hours and accurately

classify over 80% of bacterial kinds within about 8 hours, resulting in a time savings of over 12 hours compared to traditional approaches. Artificial intelligence is facilitating the deployment of technologies and tools for food safety, enabling the swift and precise identification of adulterations and microbial contaminants. This includes hyperspectral imaging (HSI), which integrates traditional imaging with spectroscopy (23), and innovative electronic devices like electronic noses (ENs), which are automated detectors of odors or microbial growth that amalgamate chemical sensor arrays with a pattern recognition system (20).

AI in precision nutrition

Precision nutrition synthesizes genetic, metagen omic, metabolomic, physiopathological, behavioral, and sociocultural factors to comprehend metabolism and human well-being, facilitating the implementation of health interventions (37). This signifies a developing subject within the field of food biotechnology. Gut bacteria and dietary components exhibit a mutually reliant relationship. Gut microorganisms convert food components into metabolites that affect and modulate the host's immunological and metabolic responses, while dietary components determine the type and functional characteristics of the gut microbes. These exchanges are often intricate and highly individualized. AI serves as a potent instrument for analyzing extensive datasets and conducting thorough studies to formulate dietary guidelines aimed at mitigating disease onset and progression (14). Artificial intelligence is increasingly employed to analyze gut microbiota and utilize the findings to develop diagnostic and therapeutic interventions for critical diseases. AI algorithms are adept in establishing correlations among nutrition, health, and dietary behaviors (13).

Artificial intelligence techniques in food engineering

In the food industry, it is seen that solution tools such as ANN (Neural Network), Fuzzy Logic and Genetic Algorithm are widely used in solving problems and performing their analyses.

Artificial neural networks (ann)

One of the most studied subjects within the scope of artificial intelligence science is artificial neural networks. ANNs are systems that learn the relationships between events from examples and then make decisions using the information they have learned about examples they have never seen (44).

In order to increase quality and control capacities in the food industry, modeling of multivariate data obtained from computer imaging analysis, electronic nose and electronic tongue analysis is successfully applied in analysis applications using artificial neural networks, fuzzy logic and genetic algorithm processes (15,55,67). In studies on dairy farming (19,25,30), in a study on the shelf life of yoghurts (55), in modelling the heat treatment applied to canned foods (22), in a study to determine the temperatures and the time required to reach thermal equilibrium in foods processed in high-pressure food processes (62), in modelling the drying of tomatoes (41), in a study to determine the correlation between the farinographic properties of dough and the protein content of flour, wet gluten, sedimentation value and falling number (46), in the sun drying of foods (63), in the Biomass Generation with Artificial Neural Network in Industrial Baker's Yeast Fermentation It has been used in the classification of whole corn kernels by separating them from broken ones (35), in the determination of rheological properties of dough (48), in the classification of wines by determining anthocyanin contents (27), in the evaluation of heat processes in foods, in the estimation of heat conductivity according to apparent porosity, temperature and moisture content in foods, in the infrared spectrometry (NIRS) in yogurt fermentation (11), in the modeling of process according to galactose, lactate and lactose contents with artificial neural networks with the data obtained from the measurements with electronic nose (electronicnose-en) and bioreactor probes (68), in the estimation of the freezing time of food products (40), in the characterization and classification of some teas (12), in the

determination of physical properties of oat varieties (59), and in the classification of durum wheat varieties (61) they have achieved success using artificial neural networks.

Fuzzy logic

Fuzzy Logic is a mathematical discipline. In daily life, people solve problems by making decisions using linguistic qualifiers that are not fully defined and numerical (such as cold, slightly cold, lukewarm, hot, very hot, etc.). The reason why people can control some systems better than machines is based on the fact that people have the ability to make decisions using some information that cannot be expressed with certainty (uncertain). In Fuzzy Logic, approximate thinking is used instead of thinking based on definite values (54,56).

Fuzzy Logic provides the opportunity to be used in areas such as clustering, classification, product grading, product design in foods. In the food industry, it is used in biochemical processes that are highly nonlinear and difficult to control, and in the control of bacterial growth with biochemical reactors (26).

Fuzzy logic modeling is used in applications in cooking pressing processes in cheese making (26), estimation of frying time in foods (49), classification of apples according to their hardness levels (53), classification of tomatoes according to their quality criteria (28), classification of pizza (57), assessment of food safety (1), pH control in food production (10), use as a preservative in essential oils and fruit juices (6), modeling of kefir production (3), optimization opportunities in the dairy industry (16) have used.

Genetic algorithm

Genetic Algorithms (GA) are search algorithms based on natural selection and natural genetic mechanisms (21). GA was first studied by John Holland in 1975, and in the last thirty years, successful applications have been made in many areas from scheduling to network optimization to find solutions to difficult optimization problems. GA, which is quite successful in capturing global optima without getting stuck in local optima, does not require special mathematical analysis for optimization problems. The user can easily code the problem without having in-depth mathematical and algorithm knowledge. Due to this feature, GA is used in areas such as process modeling in foods, product design, control of storage systems, and estimation of product yield (21). Application of genetic algorithm and adaptive network based fuzzy inference systems for parameter optimization and estimation in drying of foods was used to determine sensory properties of fast foods.

Conclusion

In conclusion, artificial intelligence and machine learning can be utilized along the entire farm-to-fork continuum. This include forecasting climate change, agricultural yields, meteorological patterns, precipitation conditions, soil quality assessment, optimal seed selection and planting techniques, as well as the management of dairy farms for animals and poultry. Additionally, it encompasses the administration and repurposing of several waste categories. The algorithms demonstrate efficacy in the manufacturing phases of food products, functional foods, and nutraceuticals, encompassing formulation, sensory evaluation, industrial processing, analytical testing, nutrient content evaluation, packaging, storage, and food supply chain management, while ensuring food quality and safety. Furthermore, it encompasses food distribution, customer delivery, pleasure with consumption, and the evaluation of how food or alternative medicine intake influences human health, both physically and psychologically. It involves monitoring food consumption quantities, caloric values, efficacy, dietary control, and facilitation through prospective artificial intelligence techniques. The capabilities of artificial intelligence-based approaches and technologies facilitate the prediction and regulation of food-related crystallization

processes, ultimately improving both processes and products. The implementation of artificial intelligence, machine learning, and associated technologies establishes a promising intelligent cycle, encompassing agriculture and nutrition, which are integral to the fundamental human necessity of food.

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Table.1. Application of AI and ML in FI.

Area	AI and ML techniques
Food security management	(i) ANN (ii) Data mining (iii) Data analysis (iv) Intelligent optimisation techniques
Food quality management	(i) Genetic algorithm (ii) Predictive models (iii) Tree decisionfimaking
Food production	(i) ANN (ii) Decision tree (iii) Gaussian mixture models (iv) Data mining
Food logistics	(i) ABS techniques (ii) Robot programming (iii) Simulated annealing (iv) Automated planning
Food supply chain	(i) Bayesian network (ii) Stochastic simulation (iii) ANN (iv) Fuzzy logic
Food processing industry	(i) Decision fimaking data analytics (ii) Predictive models (iii) Forecasting models of AI and ML

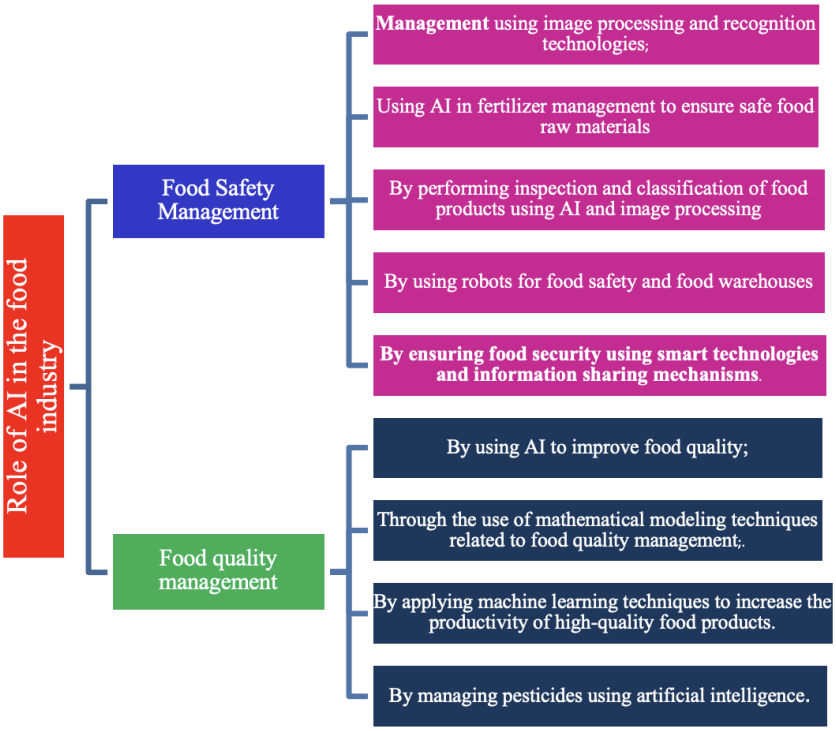

Fig. 1. Role of AI in the food industry

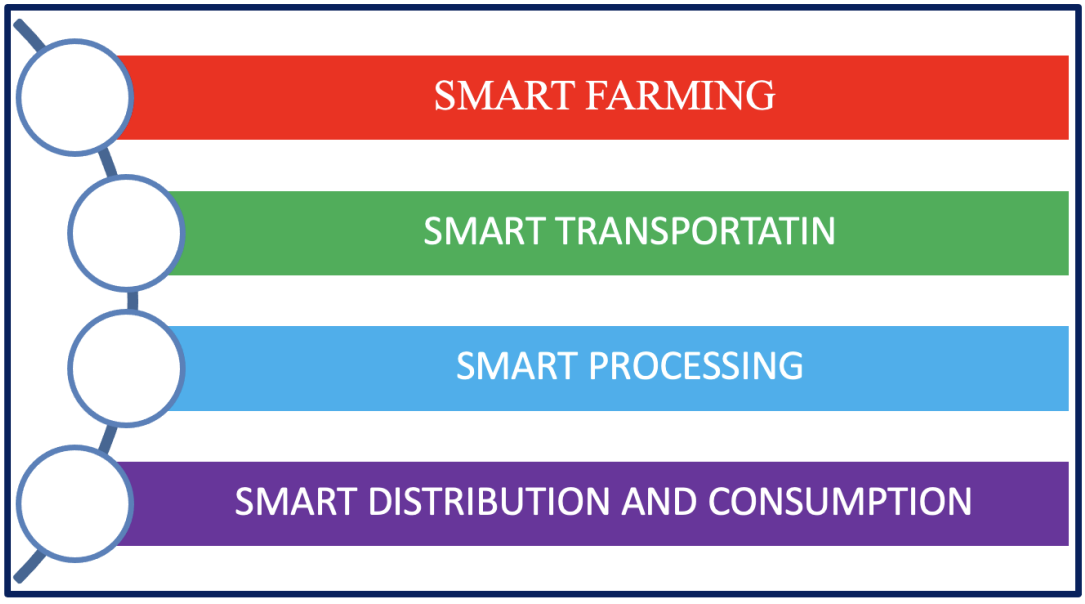

Figure. 2.Categorization food industry