Biotechnological Journal of Environmental Microorganisms "BJEM"

Biotechnological Journal of Environmental Microorganisms(BJEM) 2(8) 2024 439-447

A Review of the Application of Artificial Intelligence in Identifying Pathogenic Bacteria in the Food Industry

Arman Moradi[1], Amirhossein Khorramian[2], Golnoosh Moradabasi[3], Mohammad Faezi Ghasemi[1*]

[1]Department of Microbiology,Faculty of Basic Sciences,Lahijan Branch, Islamic Azad University,Lahijan,Iran
[2]Department of Microbiology, Ardabil Branch, Islamic Azad University, Ardabil, Iran
[3]Department of Cellular and Molecular Biology, Faculty of Basic Sciences, Lahijan Branch, Islamic Azad University, Lahijan, Iran

Received: 27 February 2024/ Revised:20 March 2024/Accepted: 29 March 2024

Abstract

Foodborne illnesses caused by harmful bacteria are a major global concern that poses a threat to public health. Traditional detection techniques are frequently time-consuming, labor-intensive, and perhaps inaccurate. The food industry can benefit from the use of artificial intelligence (AI) for the quick, precise, and automated detection of these microorganisms. Foodborne illnesses caused by harmful bacteria are a major public health concern worldwide. Traditional methods for identifying these bacteria are often time-consuming, costly, and may be inaccurate. The food industry can leverage artificial intelligence (AI) to quickly, accurately, and automatically identify these microorganisms. Machine learning (ML) methods such as support vector machines, random forests, and nearest neighbors are used in this context. AI models are capable of identifying pathogens like *Salmonella Listeria*, and *E. coli* with accuracy rates of over 90%. AI facilitates automation and non-destructive testing, which minimizes human labor and errors. Integrating AI with sensor networks makes it possible to monitor food production in real time. The difficulties include securing high-quality datasets, enhancing model transparency, establishing uniform procedures, and securing regulatory approval. Ongoing research aims to solve these problems by developing better data sharing, explainable AI, and standards.

Key words: Artificial Intelligence , Pathogenic Bacteria , Food Industry, deep learning , Public health

* Corresponding Author: E-mail: mfaezi@iau.ac.ir

doi:10.71886/bioem.2024.1216365

Introduction

Artificial Intelligence is a branch of computer science that develops systems and algorithms that can perform tasks similar to human intelligence, such as learning, reasoning, pattern recognition, and decision-making. By simulating human cognitive processes, this technology enables the automation of complex decision-making and has been able to create significant developments in a wide range of scientific and industrial fields. In scientific research, artificial intelligence is divided into several different categories, including machine learning, deep learning, natural language processing, and expert systems. Machine learning, using self-learning algorithms, is able to discover hidden patterns in large and complex data and provide accurate predictions. Deep learning, as a subset of machine learning, has the ability to identify and analyze very complex and multidimensional data using multilayer artificial neural networks. Natural language processing also allows machines to understand human language and automatically analyze and interpret scientific texts and textual data(Shan et al., 2021). In addition, expert systems, by utilizing specialized knowledge and defined rules, are able to make intelligent and accurate decisions in specific areas. In the field of food microbiology, artificial intelligence plays a vital and growing role, enabling the improvement of the quality and safety of food products. Using advanced machine learning algorithms and image processing techniques, it is possible to quickly and accurately identify pathogenic and spoilage microorganisms, which helps reduce detection time and prevent widespread contamination. Also, artificial intelligence models are able to predict spoilage processes based on environmental, chemical and microbial data and help to better manage the food supply chain and storage. The use of expert systems and deep learning in analyzing data from laboratory experiments and smart sensors automates quality control processes and reduces human errors. In addition to these applications, artificial intelligence in analyzing genomic and proteomic data of microorganisms provides a more accurate understanding of metabolic pathways and pathogenic mechanisms, which can lead to the development of new methods of prevention and treatment in the field of food hygiene(Ma et al., 2023). On the other hand, artificial intelligence, with its capabilities for analyzing large and complex data, allows researchers to identify new behavioral patterns of microorganisms and better understand the interactions between various environmental and microbial factors. This knowledge can provide sustainable and efficient solutions to preserve the shelf life of food and reduce its waste. In general, artificial intelligence, as a transformative tool, covers a wide range of applications in food microbiology, and its role in improving safety, quality, and innovation in the food industry is expected to become more prominent with further advances(Onyeaka et al., 2024). Therefore, continuous research and development of artificial intelligence technologies in this field are of great importance in order to achieve efficient and cost-effective solutions to solve complex microbiological challenges in food. Artificial Intelligence is a branch of computer science that develops systems and algorithms that are capable of performing tasks similar to human intelligence, such as learning, reasoning, pattern recognition, and decision-making(Kumar et al., 2024). This technology, by simulating human cognitive processes, enables the automation of complex decision-making and has been able to create significant developments in a wide range of scientific and industrial fields. In scientific research, artificial intelligence is divided into several different categories, including machine learning, deep learning, natural language processing, and expert systems. Machine learning, using self-learning algorithms, is able to discover hidden patterns in large and complex data and provide accurate predictions. Deep learning, as a subset of machine learning, is able to identify and analyze very complex and multidimensional data using multilayer artificial neural networks. Natural language processing also allows machines to understand human language and automatically analyze and interpret scientific texts and text data(Sharma & Tharani, 2024). In addition, expert systems are able to make intelligent and accurate decisions in specific areas by using specialized knowledge and defined rules. In the field of food microbiology, artificial intelligence plays a vital and growing role, enabling improvements in the

quality and safety of food products. Using advanced machine learning algorithms and image processing techniques, it is possible to quickly and accurately identify pathogenic and spoilage microorganisms, which helps reduce detection time and prevent widespread contamination. Artificial intelligence models can also predict spoilage processes based on environmental, chemical, and microbial data, helping to better manage the food supply chain and storage(Deng et al., 2025). The use of expert systems and deep learning in analyzing data from laboratory tests and smart sensors automates quality control processes and reduces human errors. In addition to these applications, AI in the analysis of microbial genomic and proteomic data provides a more detailed understanding of metabolic pathways and pathogenic mechanisms, which can lead to the development of new methods of prevention and treatment in the field of food hygiene(Yu et al., 2025). On the other hand, AI, with its capabilities of analyzing large and complex data, allows researchers to identify new behavioral patterns of microorganisms and better understand the interactions between various environmental and microbial factors. This knowledge can provide sustainable and efficient solutions to preserve the shelf life of food and reduce its waste. In general, AI, as a transformative tool, covers a wide range of applications in food microbiology and is expected to play an increasingly important role in improving safety, quality and innovation in the food industry with further advances(Deng et al., 2025). Therefore, continuous research and development of artificial intelligence technologies in this field is of great importance in order to achieve efficient and cost-effective solutions to solve complex microbiological challenges in food.

Literature Review

AI technologies combined with optical imaging have enabled the identification of bacteria at the early stages of growth, i.e. the microcolony stage, in less than 3 hours. This advancement has dramatically reduced the typical time required for bacterial identification. For example, the YOLOv4 algorithm has performed very well in identifying *Escherichia coli* among other foodborne bacteria, with an average accuracy of 94% and a false negative rate of less than 10% in contaminated samples(Ma et al., 2023).

On the other hand, deep learning-based models have been developed for the automated detection of foodborne pathogens, achieving impressive accuracy rates of between 90% and 100% for several common pathogens. In addition to reducing dependence on expert human resources, these technologies minimize the percentage of errors caused by microscopic evaluation (Chen et al., 2024). Artificial intelligence (AI) is playing a major role in identifying biofilm-forming pathogens, which have become a major challenge to treat due to their resistance to antimicrobial drugs. The application of machine learning and image processing techniques in this field has made significant progress in identifying these agents at different levels, not only increasing diagnostic capabilities but also clarifying the path of preventive measures, Despite the transformative potential of AI in pathogen detection, significant challenges remain, such as the need for high-quality datasets and the development of models that can be better interpreted. In addition, the integration of AI in the field of food safety must also carefully consider ethical and regulatory implications in order to gain consumer trust and fully comply with food safety standards(Mishra et al., 2024). Artificial intelligence systems are able to quickly and accurately detect infections, including new and drug-resistant strains, by analyzing complex data from diverse sources such as genetic sequencing and microscopic images(Zhang et al., 2024). AI-based AST methods significantly reduce the time required to determine drug susceptibility while simultaneously improving the speed and accuracy of laboratory testing(Elshafei, 2024). AI-based AST methods significantly reduce the time required to determine drug susceptibility while simultaneously improving the speed and accuracy of laboratory testing(Zhang et al., 2024). A team of researchers at the Institute of Microbiology of the Chinese Academy of Sciences has developed an innovative technology for identifying single-celled microbes . The technology combines Raman spectroscopy and artificial intelligence, which can identify pathogens with an average accuracy of 95.64%, and the process can be completed in just 5 minutes. The research explores the use of AI-based machine learning in various fields, including image analysis

, genome sequencing data analysis, and natural language processing, to identify pathogens. It is also emphasized that AI can improve the accuracy and speed of diagnosis, facilitate faster identification and personalized treatments, and play an important role in enhancing public safety and health(Gao & Liu, 2024).

The various forms of artificial intelligence

Artificial Intelligence is a set of technologies and algorithms that allow machines and computer systems to perform functions similar to human intelligence, such as learning, reasoning, pattern recognition, and decision-making. In various sciences, especially in scientific research, AI is divided into several major types, each with its own characteristics and applications. One common classification is the division of AI into Weak AI or Limited AI, which is designed to perform specific and limited tasks and operations and performs very effectively in this field, such as voice assistants and image recognition programs(Razavian et al., 2020). In contrast, Strong AI or General AI, is a concept that refers to systems that have the ability to understand, learn, and perform any intellectual task at a level equal to or beyond that of humans; this type of AI is currently theoretical and has not yet been implemented.Technically, artificial intelligence in scientific research usually includes several key subfields: machine learning, deep learning, natural language processing, and expert systems. Machine learning refers to algorithms that have the ability to learn from data and improve performance without explicit programming, and is widely used in many fields, including scientific data analysis(Liu et al., 2021). Deep learning is a subset of machine learning that uses multilayer neural networks to identify complex patterns and extract high-level features. These models have been particularly successful in analyzing images, complex genetic data, and natural language. Natural language processing allows systems to understand human language and automatically process and analyze scientific texts and linguistic data(Abu-El-Ruz et al., 2025). Expert systems also provide intelligent decisions and solutions in specific fields based on specialized knowledge and defined rules. These different types of AI, with their unique capabilities, play a very important role in various sciences, including medicine, biology, physics, and especially food microbiology, and have accelerated the research and development process in these fields. As a result, a detailed familiarity with these types of AI and the capabilities of each will pave the way for their more effective and targeted application in scientific research(Pannu, 2015). Figure 1 illustrates the types of artificial intelligence in the research world.

Fundamentals of Artificial Intelligence in Microbiology

Artificial intelligence (AI), with machine learning (ML) at its core, is driving a profound shift in microbiology. These advanced computational technologies provide robust analytical tools capable of handling the complexity and high dimensionality of microbial datasets. By facilitating the detailed analysis of genomic, proteomic, and phenotypic information, AI enables critical applications such as precise microbial identification, prediction of antibiotic resistance, and functional characterization of microbial communities. Its ability to integrate diverse data sources while detecting intricate patterns significantly surpasses traditional statistical methods, enhancing diagnostic precision and accelerating scientific breakthroughs. Examples of this impact include ML approaches like convolutional neural networks (CNNs) and random forests, which have successfully classified microbial species from metagenomic data and predicted resistance phenotypes based on genetic indicators. These innovations are crucial in addressing pressing public health concerns, including the emergence of multidrug-resistant pathogens. Additionally, AI-driven models provide tools for real-time surveillance of microbial dynamics in both clinical and environmental contexts, enabling timely interventions and tailored therapeutic solutions. As AI continues to merge with high-throughput experimental platforms, it holds the promise of advancing our understanding of microbial ecology, evolution, and disease mechanisms(Tsitou et al., 2024).Figure 2 shows a schematic of Fundamentals of Artificial Intelligence in Microbiology.

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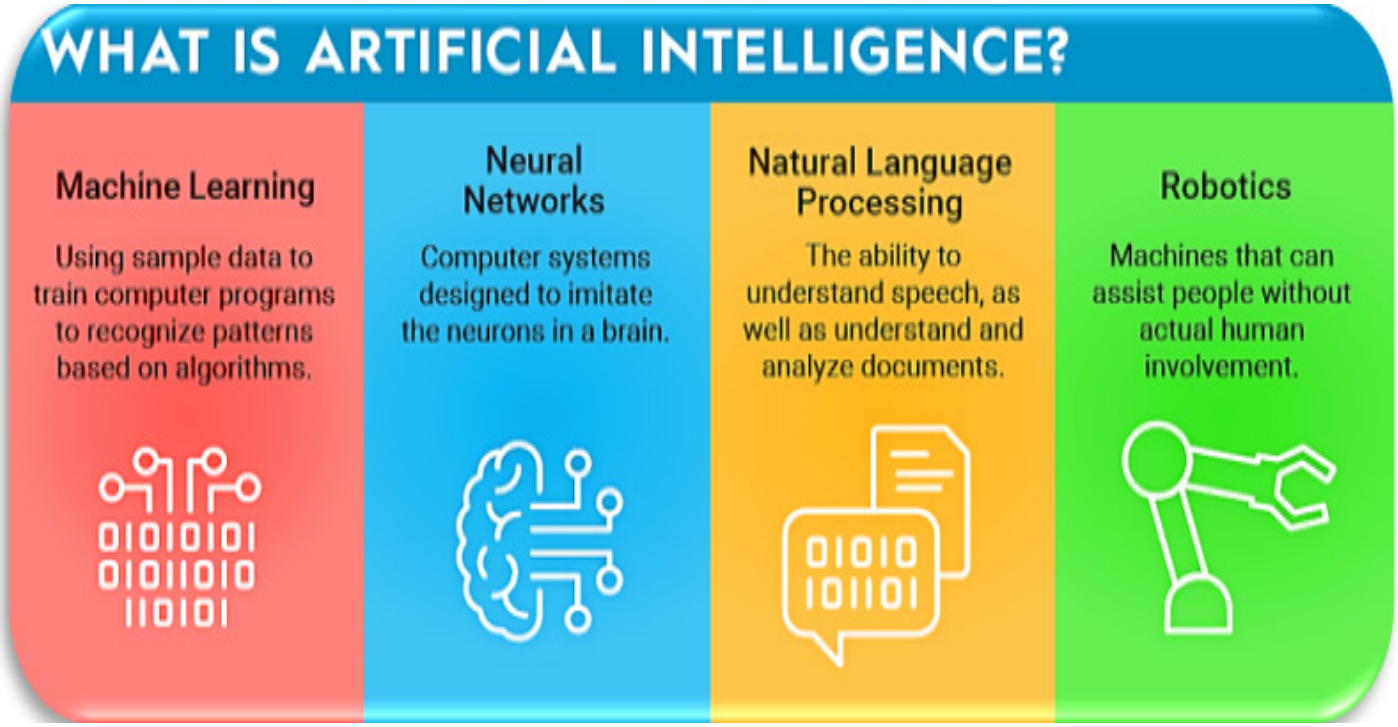

Figure 1: The four main branches of artificial intelligence include machine learning, neural networks, natural language processing, and robotics, each with its own methods and applications, which have paved the way for the development of intelligent technologies in various sciences. These technologies enable machines to learn from data, recognize patterns, understand human language, and perform a variety of tasks automatically(Chen et al., 2023).

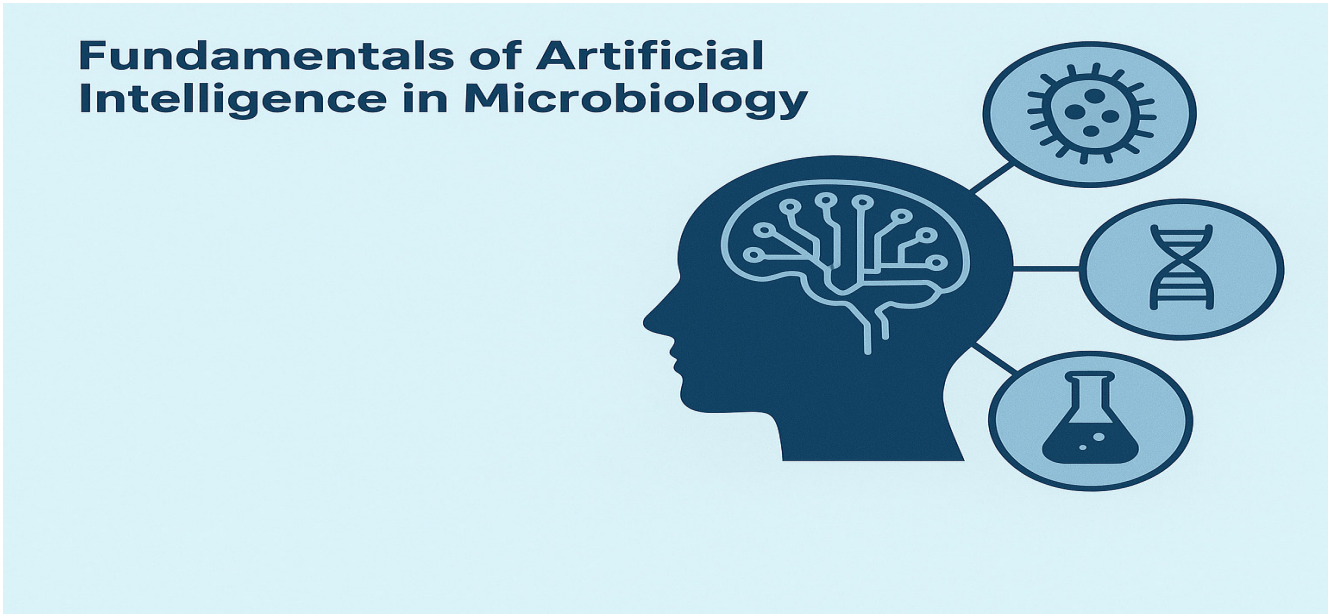

Figure 2: Schematic representation of AI applications in microbiology

Application of artificial intelligence in the food industry

In recent years, Artificial Intelligence (AI) has emerged as one of the most advanced and transformative technologies in the food industry. By utilizing machine learning algorithms, deep learning, neural networks, and big data processing, this technology has been able to improve production processes, quality control, safety, and supply chain management. The use of AI in the food industry not only increases productivity but also helps reduce food waste, optimize resources, and ensure the health and quality of the final product(Kumar et al., 2021). One of the most important applications of AI in the food industry is quality control. Machine learning-based systems, using advanced sensors and cameras, are able to accurately detect appearance abnormalities, microbial and chemical contamination, and even product quality changes at different stages of production and packaging. This helps reduce human errors and increase inspection accuracy. For example, the use of spectroscopic methods combined with deep learning allows for non-destructive detection of food freshness and quality, which plays a key role in reducing waste. In addition, artificial intelligence plays a prominent role in optimizing production processes(Mavani et al., 2022). Optimization algorithms can ensure optimal conditions such as temperature, time, and pressure for the production of food products to improve the quality of the final product and reduce energy consumption. Robots and automated systems based on artificial intelligence are also used in the production line to perform cutting, packaging, and product handling operations with high speed and accuracy, which increases productivity and reduces costs. In the field of supply chain management, artificial intelligence, with the help of real-time data and advanced analytics, enables tracking products from origin to consumer and enables optimal warehousing and distribution management by predicting potential problems. AI-based technologies also help maintain optimal transportation conditions, such as temperature and humidity, so that healthy, high-quality food products reach consumers(Wang et al., 2024). Other new applications of AI in the food industry include machine perception, including machine vision and electronic noses, which play a role in sensory evaluation of products and can evaluate important parameters such as smell, color, and shape. In addition to increasing the accuracy of quality assessment, these technologies allow testing in situations where humans cannot be present(Addanki et al., 2022).

Application of Artificial Intelligence in Cookie Making

Artificial intelligence in the cookie industry, as a new technology, plays a significant role in improving quality, optimizing the production process, reducing waste, and increasing productivity. Using advanced machine learning and machine vision algorithms, cookie factories can perform quality control accurately and automatically and quickly identify problems such as appearance abnormalities, texture changes, and product defects. This capability ensures that the final products have a uniform and acceptable quality that brings consumer satisfaction. In addition to quality control, artificial intelligence is also used in optimizing the composition of raw materials and cookie formulations. By analyzing a variety of data from different experiments and consumer preferences, intelligent models can suggest optimal combinations that, in addition to maintaining the desired taste and flavor, reduce production costs and improve health properties. Advanced AI systems are also involved in designing smart packaging, which protects the quality of cookies throughout the distribution chain with real-time information on storage conditions. Finally, the use of AI in supply chain management and production planning helps increase efficiency and reduce product delivery times. Accurate demand forecasting allows factories to manage their production more efficiently and avoid large warehouses and resource depletion. In this way, AI, as an advanced tool, can move the cookie industry towards smart, sustainable and quality processes and enhance its competitive position in the global market(Jeong et al., 2025; Stevance, 2021).

Application of artificial intelligence in fruit juice production

Artificial intelligence in the fruit juice industry, as a new and advanced tool, plays a key role in

in improving product quality, optimizing the production process and increasing consumer satisfaction. This technology is able to provide better and more accurate formulations by analyzing complex data on the chemical composition of fruits, consumer tastes and process parameters, which results in the production of juices with uniform taste and stable quality. The use of machine learning algorithms and computer vision in quality control allows for the accurate identification of defects and contamination at different stages of production, thus reducing waste and increasing productivity. Another important application of artificial intelligence in this industry is demand forecasting and intelligent supply chain management(Aniama, 2021). By analyzing historical sales data, seasonal factors, weather conditions and market trends, intelligent models are able to predict demand with high accuracy, which helps to plan production and distribution more optimally and prevent product waste. AI also plays an important role in designing smart packaging and improving the user experience, which can maintain product quality over time and provide useful information to the consumer(Gonzalez Viejo et al., 2019). In addition, AI accelerates research and development processes, allowing the development of new flavors and products with less time and cost. Through user preference analysis and predictive algorithms, brands can offer personalized products tailored to specific market needs. In this way, AI plays an effective role as a strong driver of innovation in the juice industry, improving quality, reducing costs, and increasing customer satisfaction(Mohammadi & Minaei, 2019).

Application of Artificial Intelligence in Dairies

As a new technology, it plays a very effective role in improving product quality, optimizing production processes and increasing productivity. By using machine learning algorithms and advanced data analysis techniques, dairies are able to accurately monitor and analyze data related to milk production, quality control of protein products and the health status of raw materials. This technology prevents waste of resources by quickly identifying anomalies and problems in processes and optimizes the production process(De Vries et al., 2023). One of the important applications of artificial intelligence in dairies is automatic quality control of products, which, by using machine vision and advanced sensors, identifies possible defects and contamination in products step by step and prevents the supply of defective products to the market. Also, predictive algorithms, by analyzing historical production and sales data, significantly contribute to better supply chain management and demand forecasting. In addition, AI plays a key role in managing energy and resource consumption in the dairy production process, helping to reduce costs and protect the environment by optimizing various parameters(Jeong et al., 2022). AI-based automated systems in production lines perform operations such as filling, packaging, and labeling with high accuracy and speed, which increases quality and reduces human errors. Finally, the use of AI in dairies leads to increased production flexibility, reduced downtime, and improved product health and safety. As a strategic tool, this technology paves the way for the sustainable development and progress of the dairy industry and creates a smart future for this industry(Figure 3).

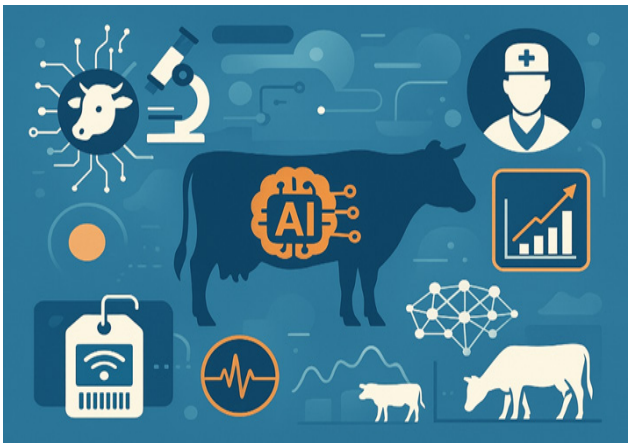

Figure 3: Demonstrate advanced applications of artificial intelligence in animal husbandry and livestock production, including individual identification, disease diagnosis, growth assessment, and environmental management using machine learning algorithms, neural networks, and machine vision. These technologies help improve health, productivity, and product quality in the livestock industry(Bao & Xie, 2022).

Conclusion

By providing accurate tools for rapid identification of microbial contamination and improving hygiene monitoring, AI has significantly improved the safety and quality of food products,

including bakery, juice, and dairy products. By accelerating quality control processes and reducing the risk of contamination, this technology has found an important place in improving public health and increasing consumer confidence in the food industry.

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