



The role of artificial intelligence (AI) in foodborne disease prevention and management—a mini literature review

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Academic Editor: Zhaohui Gong, Ningbo University, China

Received: September 9, 2025 **Accepted:** September 24, 2025 **Published:** October 21, 2025

Cite this article: Maritschnik S, Benka B, Aoun A, Richter L, Chakeri A, Brait V, et al. The role of artificial intelligence (AI) in foodborne disease prevention and management—a mini literature review. *Explor Digit Health Technol.* 2025;3:101167. <https://doi.org/10.37349/edht.2025.101167>

Abstract

The World Health Organization (WHO) estimates that unsafe food is responsible for 600 million cases and over 400,000 deaths annually. Traditional outbreak investigations are often time-consuming, inefficient, and limited by the quality and timeliness of available data. The integration of artificial intelligence (AI), such as machine learning, offers innovative approaches to improve the accuracy, speed, and efficiency of foodborne disease surveillance and outbreak detection. We conducted a mini review of the published literature and explored the potential applications of AI in foodborne disease prevention and control. Key areas explored included predictive analytics, food supply chain monitoring, public health surveillance, and laboratory-based investigations. AI-based predictive models support improved monitoring of environmental risk factors, better management of food supply chains, and more timely detection and prevention of contamination and outbreaks. We also described several challenges related to the integration of AI in food safety systems, including data quality, regulatory frameworks, and ethical considerations. By integrating advanced AI-driven methods, the future of food safety promises greater efficacy and equity in public health.

Keywords

foodborne outbreak, artificial intelligence, outbreak control, outbreak investigation process



Introduction

Foodborne outbreak investigations and surveillance used to rely on conventional methodologies such as manual data collection, laboratory testing, and epidemiological analysis. These approaches are often time-consuming, resource-intensive, and limited by the quality and timeliness of data.

Recent advancements in technology, such as machine learning, natural language processing, and whole genome sequencing, offer innovative solutions to overcome these challenges and enhance food safety [1]. In 2021, there was a notable increase in reported cases of zoonotic diseases and foodborne outbreaks compared to 2020, although the overall number of cases remained lower than pre-pandemic figures [2]. Given the risk of rising cases, timely surveillance and effective outbreak investigation remain critical to the prevention and control of foodborne diseases [2]. These activities are primarily conducted by public health agencies staffed with professionals skilled in epidemiology, food safety, nutrition, and laboratory sciences. Collaboration across subnational, national, and international levels enhances the effectiveness of these efforts [3]. Prior to the COVID-19 pandemic, foodborne outbreak investigations and surveillance largely relied on conventional methodologies (e.g., manual data collection, laboratory testing, and epidemiological analysis), which were often time-consuming, not always cost-effective, and sometimes limited by the scale and speed of data processing.

Today, the realm of foodborne disease surveillance and outbreak investigations is evolving in complexity. This includes the disciplines of genomics and bioinformatics, especially after the adoption of advanced technologies such as whole genome sequencing [1]. Also, there is a shift in food production, distribution, and consumption patterns, which demand a multidisciplinary approach, which is driven by a complex number of factors that are sometimes interconnected, such as urbanization, environmental factors, climate change [4], and the scarcity of human resources. Therefore, it is critical to provide adequate training and support to the workforce for effective surveillance and management of outbreaks [3], even in high-income countries.

Furthermore, prompt detection and intervention in cases of foodborne disease outbreaks are vital not only for stopping ongoing outbreaks but also for preventing potential future outbreaks, thereby decreasing the overall occurrence of foodborne diseases. In this paper, we discuss the potential role of artificial intelligence (AI) in enhancing four key areas of foodborne disease prevention and management: predictive analytics, supply chain monitoring, public health surveillance, and laboratory investigations.

Methods

We conducted a mini review of the literature to explore the role of AI in the context of foodborne diseases. The literature search was performed using PubMed and Google Scholar. We used a combination of keywords and Medical Subject Headings (MeSH) terms related to two main concepts: “foodborne diseases” and “artificial intelligence”. Articles were selected based on their relevance to AI applications in the prevention, detection, and management of foodborne disease outbreaks, including outbreak investigations and food safety. We included articles published in English and applied no exclusions for the date of publication. No time scope was used.

The four emerging themes included: 1) general predictive models; 2) the introduction of AI in the food supply chain; 3) the role of AI in enhancing public health surveillance; and 4) AI can be used for foodborne outbreak laboratory investigations (Table 1).

General predictive models

With the emergence of AI, there is increasing interest in using predictive models [5]. This provides a number of tools that can assist farmers in monitoring environmental factors such as weather, temperature, water usage, and soil quality [5]. Ensuring food safety is central to achieving sustainable food security [6], which includes the monitoring of hazards, including biological (e.g., bacteria, viruses, and parasites), chemical (e.g., heavy metals, pesticides, and mycotoxins), and physical (e.g., metal particles, glass fragments) [7]. These hazards can pose a risk of contamination and eventually unsafe food production for

Table 1. Summary of AI applications in food safety and foodborne outbreak prevention.

Applications of AI	Opportunities	Considerations
1) Predictive models for food safety and security Monitoring environmental factors (weather, water, soil, temperature); hazard prediction (biological, chemical, physical); early warning systems; forecasting contamination risks	Anticipate and prevent risks; enhance food chain monitoring; support sustainable food security; enable climate change adaptation strategies	Require high-quality historical data; complex modeling; dependent on data sharing and standardization
2) AI in the food supply chain Digitalization of production data; tracing, monitoring, inspection; supervised and unsupervised learning for anomaly detection; outbreak source identification	Faster and more accurate outbreak detection; real-time risk prediction; improved supply chain transparency	Risks of AI hallucinations; reliance on robust data infrastructure; interpretability of models
3) Public health surveillance Linking syndromic surveillance to causative agents; anomaly detection via image recognition (hygiene, handwashing); prediction of outbreak risks and spread	Early detection and intervention; prevent large-scale exposures; support rapid public health response	Under-reporting and misreporting; potential misclassification by AI; need for human oversight
4) Laboratory investigations Spectra-based analysis; hyperspectral imaging; bacterial strain differentiation (antibiotic resistance, virulence, host specificity); modeling bacterial growth	Rapid pathogen detection (hours vs. days); automation of labor-intensive tasks; improved accuracy; adaptable across food types	Workforce readiness; need for interdisciplinary expertise; high upfront costs

consumers, with a serious risk to human and animal health [7]. Also, one of the core elements of food safety measures is to forecast and prevent future risks [8, 9]. Therefore, ensuring food safety throughout the entire food chain, by controlling and monitoring food safety, is crucial through early warning systems [10]. Machine learning algorithms can be trained on historical data and build analytical models [11], which can be used to forecast, predict, and prevent future threats to food safety, including outbreaks [8].

Moreover, it is worth noting the potential threat of climate change to food security globally: The risk of hunger, which is one of the impediments to sustainable development cited by the United Nations. Machine learning can play a role in the agricultural supply chain, which includes pre-production, production, processing, and distribution [12].

The introduction of AI in the food supply chain

In recent years, a proportion of the food production industry has introduced AI [13], which has enhanced the digitalization of data during the food production processes, tracing, monitoring, and inspection. Therefore, AI has emerged as a pivotal technology in this regard. Hereby, the digitalized data can be used by other AI algorithms to identify patterns that might be overlooked through a manual analysis, and can potentially predict potential outbreak sources and spread with higher accuracy and speed (although such a process can lead to hallucination with the current versions of AI). In addition, AI models could be trained to match consumption patterns to food exposure from persons who fell ill during an outbreak [14]. Also, AI can be used to compile large qualitative data collected during the outbreak's interview process [15]. Utilization of these models could facilitate the rapid detection of the source of foodborne contamination, which is crucial for food safety and would lead to less foodborne illness overall [14].

For example, the different machine learning-related models can be trained on historical contamination data to predict the probability of contamination during the process of the supply chain. It includes supervised learning to identify anomalies in production line data or unsupervised learning to detect unusual patterns indicative of potential risks. Such an approach, when combined with real-time monitoring, has the potential to do early detection of contamination, which can lead to more efficient response strategies [5, 13].

The role of AI in enhancing public health surveillance

Machine learning can be used to increase our ability to predict foodborne illness etiologies, geographical spread, and potential outbreak risks [16]. Models, such as anomaly detection using image recognition, can

be used to assess hygiene practices (for example, analysing handwashing techniques, evaluating food safety, and predicting contamination risk); however, these models should be used with caution, as AI systems can have errors in their reading capabilities [17]. Also, supervised learning can link syndromic surveillance to the causative agents—Although the methods for outbreak detection require overcoming the risk of under-reporting and incorrect reporting [18].

Hence, the acceleration in such predictions can help public health agencies in early interventions, which would prevent the population from being exposed to contaminated food and, eventually, prevent larger outbreaks [19].

AI can be used for foodborne outbreak laboratory investigations

Spectra-based analysis and hyperspectral imaging have the potential to identify, rapidly (in a few hours instead of 24–72 hours for pathogen detection and strain identification) and with precision, bacteria in environmental samples, which is crucial for food safety, and therefore in outbreak investigations [20]. As well, it can assist in differentiating bacterial strains and understanding their resistance to antibiotics, host specificity, and virulence. Furthermore, machine learning can model how bacteria grow and interact within populations, offering insights that can streamline the time, resources, and expertise needed for comprehensive food safety analysis and decision-making [20].

The rapid collection of image data and advances in imaging technology make AI ready for commercial use and integration into food safety testing systems. It can potentially be adapted to various food types and conditions, contributing to a more sophisticated understanding and control of foodborne pathogens. This integration of AI is essential, given the complex nature of pathogen detection and characterization and the need for a capable workforce. Especially as traditional labor-intensive methods face the challenges of workforce attrition [6], machine learning facilitates the automation of many laboratory processes.

To be able to enhance the utility of AI, the following strategies are needed: i) enhancing data sharing agreements among all stakeholders, using strict data privacy regulatory measures and an ethical framework [21], ii) fostering multi-disciplinary partnerships, and iii) promoting education in data science, software engineering, and design thinking for food safety professionals [16].

Governance considerations: AI is a form of technology meant to enable health systems towards the betterment of health [22]. Although AI is not a fully autonomous system, it has the tendency to make independent decisions, which raises concerns regarding the theme of accountability for the related outcomes [21]. Policy makers regulate AI in a reactive fashion, i.e., instead of generating full laws, they produce framework guidelines that outline the AI-related policies [22]. In general, the European Union (EU) is considered a pioneer in developing a blueprint for the international community on how to proceed with AI regulations [20]. This includes protecting the rights of individuals to the utility of AI, and establishing a standardized definition of an AI system [22]. Additionally, AI tends to be cost-effective when compared to the traditional approach of using a microbiology laboratory facility [20, 23]. Finally, AI-assisted approaches tend to detect bacterial classification at a higher accuracy [20].

Challenges

The utility of AI, e.g., machine learning, has its own limitations as well. We list them under the following categories (Table 2):

Table 2. Summary of challenges in applying AI to food safety.

Challenge	Implication
A) Data integrity and model performance	
• Dependence on high-quality, reliable data	• Poor data quality reduces the accuracy and reliability of AI predictions
• Need for external validation of AI models	• Models may fail under new conditions without validation
• Scalability of AI solutions to large and evolving	

Table 2. Summary of challenges in applying AI to food safety. *(continued)*

Challenge	Implication
datasets	• Scalability is essential for adapting to growing and diverse food safety datasets
• Learning from pre-existing data may perpetuate biases	• Bias can result in inequitable decision-making and compromised food safety evaluations
• Risk of biased training data leading to unfair or inaccurate outcomes	
B) System integration and operational feasibility	
• Incompatibility with legacy food safety infrastructure	• Technical barriers delay deployment in real-world food systems
• High costs and complex regulatory standards hinder adoption	• Cost and regulatory hurdles limit adoption, especially in low-resource settings
• Environmental burden of AI systems (energy use, e-waste)	• Sustainability concerns must be addressed to avoid unintended harms
C) Ethics, transparency, and trust	
• “Black box” nature of AI decisions limits interpretability	• Lack of transparency undermines trust and compliance
• Risks to data privacy and security	• Privacy violations erode consumer confidence
• Need for informed consent in the collection of personal or health-related data	• Ethical safeguards and accountability frameworks are essential for responsible AI deployment

- 1) Data integrity and model performance challenges, which are related to the quality, reliability, and scalability of data:
 - i) Data quality is crucial in food safety, because it affects each of the performance and accuracy of AI and machine learning models;
 - ii) The need for data validation, by testing AI models on external datasets [24];
 - iii) The scalability of AI solutions to manage large databases and adaptation to changing conditions can be a challenge. The needs of food safety evolve as the volume of data increases; therefore, AI needs to be agile to meet the needs of different scenarios of new types of data [25];
 - iv) Machine learning, as a subset of AI, learns from experiences [26] and preexisting data to train its models, so it can be used for new data [26], which implies that data quality is crucial [27];
 - v) Bias in AI technology can lead to unfair or unjust outcomes. For example, biased data used in AI models’ training can have inaccurate predictions. This can affect certain groups in an unjust fashion, including decision-making on product quality and evaluations of suppliers [28].
- 2) System integration and operational feasibility, which include the logistical/practical impediments in deploying AI into the current food system, including legacy infrastructure, resources, and compliance:
 - i) Integrating AI with existing food systems can be complex due to incompatibility with the traditional systems [28];
 - ii) Adoption of AI-related technologies, due to either high costs or complex regulatory frameworks and standards [29];
 - iii) The utility and deployment of AI, including the technologies needed for data collection, can have an effect on the environment, including energy consumption and electronic waste.
- 3) Ethics, transparency, and trust, which include safeguarding rights and ensuring the ethical deployment of AI in food safety contexts:
 - i) The AI algorithms tend to be perceived as “black boxes”, which means the decision-making process is not fully interpretable. Lack of transparency makes it impossible to understand the rationale behind AI decisions. The transparency is crucial to increase trust and compliance with processes [30];

- ii) Ethical considerations, such as data privacy and informed consent, are essential for accountability [31]. The use of AI includes the collection of data from various sources (e.g., consumer feedback or health-related information) in the food safety process. Mismanagement or unauthorized access of this data is a potential risk for privacy violations, which can lead to the loss of consumer trust [25];
- iii) Informed consent is required before the collection of personal data. This is a crucial ethical principle to be considered [26].

Conclusions

In this review, we summarized the enablers and impediments of using AI in food safety (Table 3).

Table 3. Highlights/take-home message.

Take home messages
• AI highlights real-time surveillance and automation of food safety tasks • High-quality data and transparent algorithms are essential for trustworthy outcomes • Scalable infrastructure and strong digital data management are key to adaptation • Current challenges include privacy risks and system integration barriers • Public-private collaborations accelerate responsible adoption • AI complements, rather than replaces, human expertise in food safety decision-making

AI has the potential to transform real-time surveillance and the automation of complex tasks; yet, the success of its implementation depends on high-quality datasets, transparent algorithm design, and scalable infrastructure.

There are some potential challenges to utilizing AI in public health, as current algorithms may not be sufficiently advanced to ensure the resolution of complex tasks. However, initiating the shift from traditional, manual methods to AI-driven approaches will provide an efficient and more accurate potential for safeguarding public health. Advancements in digital data management, alongside innovative solutions for data privacy, are paving the way for the increased adoption of AI. With continued digital upskilling of the staff and strategic industry collaborations, AI is set to become a crucial decision-support asset in food safety, complementing human expertise.

Finally, investing in training staff on AI and ethical governance is considered a strategic investment to ensure that AI becomes a trusted, equitable, and sustainable decision-support tool that complements and enhances public systems.

Abbreviations

AI: artificial intelligence

Declarations

Author contributions

SM and ZEK: Conceptualization, Investigation, Writing—original draft, Writing—review & editing. BB, LR, AC, ACR, MMDC: Investigation, Writing—review & editing. AA: Investigation, Writing—original draft, Writing—review & editing. VB and AN: Writing—review & editing. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

Funding

Not applicable.

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