International Journal of Applied Home Science
(An International Double Blind Peer Reviewed / Refereed Research Journal of Home Science)
Volume 12 (3 & 4), March & April (2025) : 158-162
Received : 21.02.2025; Revised : 07.03.2025; Accepted : 21.03.2025

REVIEW PAPER
ISSN : 2394-1413 (Print)
DOI: 10.36537/IJAHS/12.3&4/158-162

Evolving Technological Approaches To Food Safety: A Comprehensive Review

S. FATIMA BUSHRA[1] AND AJANTA NAYAK*[2]
[1]Faculty and [2]Assistant Professor
PG Department of Home Science, Shailabala Auto. Women's College, Cuttack (Odisha) India

*Corresponding Author

ABSTRACT

Food safety remains a critical global concern, increasingly challenged by the complexities of international supply chains, the emergence of new foodborne pathogens, and the need for sustainable use of natural resources. According to the World Health Organization (WHO), approximately 600 million cases of foodborne illnesses and 420,000 associated deaths occur annually, with children under the age of five accounting for 40% of the disease burden. Low- and middle-income countries bear a disproportionate share of this impact, largely due to limited infrastructure and inconsistent regulatory frameworks. Even in developed regions such as China, the United States, and the European Union, fragmented food safety systems, inadequate inspections, and variable enforcement hinder effective disease prevention. Pathogens like *Listeria monocytogenes*, *Escherichia coli* O157:H7, and *Salmonella* continue to cause severe health complications, including kidney failure, miscarriage, and neurological disorders. Addressing these challenges necessitates a proactive, unified approach integrating technological innovation and global cooperation. Emerging technologies such as biosensors and blockchain are revolutionizing food safety management. Biosensors—especially electrochemical and optical types—enable rapid, sensitive, and on-site detection of pathogens, offering a timely alternative to traditional methods that often require 3–5 days for results. Currently valued at $563 million, the biosensor market is projected to grow at a compound annual growth rate (CAGR) of 4.5%, driven by increasing applications in the food, medical, and environmental sectors. Electrochemical biosensors detect bioreceptor-analyte interactions via electrode transducers, while optical biosensors utilize techniques such as fluorescence and luminescence to identify microbial contaminants. Simultaneously, blockchain technology enhances transparency and traceability throughout the food supply chain. By recording immutable data at every stage of production and distribution, blockchain facilitates the rapid identification of contamination sources and reduces the risk of food fraud. Real-time sensor integration further enables monitoring of environmental parameters such as pH, temperature, and heavy metal concentrations in irrigation water. These technologies not only mitigate contamination risks but also reinforce consumer trust by ensuring the authenticity and safety of food products. Together, biosensors and blockchain represent a transformative step forward in ensuring global food safety and protecting public health.

Keywords: Food Safety, Biosensors, Blockchain Technology, Temperature, Traceability

INTRODUCTION

Food safety is being increasingly challenged by the global dimensions of food supply chains, the pressing need to reduce food waste, and the imperative for efficient utilization of natural resources such as clean water. It encompasses the protection of national food supply systems from the introduction, proliferation, or persistence of hazardous microbial and chemical agents (Uyttendaele *et al.*, 2016,). Food safety is embedded in food-related problems, and in proposed solutions. Despite continuous investment, the WHO estimates 23 million cases of foodborne illness and 5000 deaths in Europe every year and Europeans are not confident in the food system. Now, the circular economy aims to improve global food security through sustainable production, thus new ingredients, methods and food safety challenges. Food is unequivocally linked to non-communicable diseases, and changes are

How to cite this Article: Bushra, S. Fatima and Nayak, Ajanta (2025). Evolving Technological Approaches To Food Safety: A Comprehensive Review. *Internat. J. Appl. Home Sci.,* **12** (3 & 4) : 158-162.

needed for nutritional food safety. Emerging and re-emerging foodborne pathogens are changing the epidemiology of foodborne diseases. Additionally, some chemicals are of concern, and food is a major source of human exposure. Finally, risk communication is required for management of consumer-based foodborne hazards, yet this foodborne illness is common. We ignore food safety challenges at our peril as potential consequences of a lapse are huge; keeping the food supply safe is a never-ending task. (Slikker *et al.*, 2018)

Global Food Safety Challenges:

In 2021, a process was announced to update the WHO/FERG estimates of foodborne illness (FBI), with expected completion in 2025. These updated estimates will build upon the 2015 publication, which, based on over a decade of work, highlighted the global burden of foodborne illnesses. The 2015 estimates, using the 2010 base year, indicated that FBI from 31 major hazards caused 420,000 deaths and 600 million illnesses annually (Unnevehr, 2022). This resulted in a burden of 33 million disability-adjusted life years (DALYs), which is comparable to the global burden from tuberculosis (40 million DALYs) and malaria (66 million DALYs). The data also showed that low and middle-income countries (LMICs) in Asia and Africa, which make up 41% of the global population, accounted for 53% of FBI cases and 72% of the global DALYs lost due to FBI. Children under five, though representing just 9% of the global population, accounted for 38% of FBI cases and 40% of the DALYs lost, with unsafe food contributing to childhood stunting, further emphasizing the link between food safety and nutrition.

Challenges in India's Food Safety System:

In India, the Bihar Mid-Day Meal tragedy of 16 July 2013, in which 23 children died after consuming a contaminated school meal, highlights severe food safety failures. Meals were prepared without proper kitchen facilities, and food supplies were stored in unhygienic conditions at the teacher's residence. Despite the cook noticing signs of spoilage, including a foul smell and discoloration, no food safety measures were taken. The oil used in cooking was later found to be contaminated with pesticide, pointing to a complete breakdown in food safety standards and practices. This tragedy underscores the critical importance of enforcing food safety protocols, proper storage, and accountability in school meal schemes (Khera, 2013,).

Fragmentation in the U.S. Food Safety System:

The U.S. food safety system is highly fragmented, with multiple agencies like the USDA, FDA, and ten others sharing responsibilities. This creates inefficiencies, poor coordination, and inconsistent enforcement. The FDA inspects only about 1% of imported seafood, despite the U.S. relying heavily on food imports. The Food Safety Enhancement Act (2009) aimed to improve regulations but failed to resolve overlapping agency roles and border inspection weaknesses, leaving Americans vulnerable to foodborne illnesses.Foodborne illness is a serious public health threat. The Centers for Disease Control and Prevention (CDC) estimates that 76 million foodborne illnesses, including 325,000 hospitalizations and 5,000 deaths, occur in the United States each year (Nyachuba, 2010).

Estimated Number of Illnesses and Deaths Per Year:

Foodborne diseases have a significant public health impact in the U.S., affecting 6 to 80 million people annually, causing 9,000 deaths, and costing $5 billion. The epidemiology of these diseases is changing as new pathogens emerge and existing ones become more prevalent in different food sources. Beyond acute gastroenteritis, they can cause severe health issues—listeriosis leads to miscarriages or meningitis, toxoplasmosis causes congenital malformations, and E. coli O157:H7 is a major cause of kidney failure in children. Salmonellosis can result in invasive infections and reactive arthritis, while campylobacteriosis may lead to Guillain-Barré syndrome, a cause of paralysis. Contributing factors include demographic shifts, food industry changes, globalization, microbial adaptation, economic development, and weakened public health measures (Altekruse *et al.*, 1997).

Implementation Challenges in the EU General Food Law:

The EU General Food Law was introduced after the BSE-vCJD crisis to create a single, transparent regulatory system. While it emphasizes consumer protection, risk assessment, and food traceability, challenges remain in risk management and enforcement across EU member states. Despite being a model food law, its effectiveness depends on consistent application across different regions (Lin, 2010).

Challenges in China's Food Safety System:

China's food safety system has undergone reforms following the 2008 melamine scandal, leading to the implementation of the 2009 Chinese Food Safety Law. While the law introduced risk assessment, product recalls, and unified standards, its effectiveness largely depends on industry compliance and law enforcement. A legal framework alone is not sufficient to fully address China's food safety challenges.

Implementation Challenges in the EU General Food Law

The EU General Food Law was introduced after the BSE-vCJD crisis to create a single, transparent regulatory system. While it emphasizes consumer protection, risk assessment, and food traceability, challenges remain in risk management and enforcement across EU member states. Despite being a model food law, its effectiveness depends on consistent application across different regions (Lin, 2010).

Blockchain Technology: In Enhancing Food Safety

Biosensors have emerged as powerful analytical tools for rapid detection of foodborne pathogens, addressing the growing concern over food safety. Annually, millions of people suffer from foodborne illnesses caused by 31 major identified pathogens, with an estimated 48 million cases, 128,000 hospitalizations, and about 3,000 deaths reported each year in the United States alone (Scharff, 2012). Conventional detection methods for pathogens, which typically take 3–5 days to deliver results, have significant drawbacks, making them less effective for real-time food safety monitoring. Initially developed for clinical diagnostics, biosensors have gained prominence in the food industry due to their high sensitivity and ability to detect bacteria at an earlier stage (Rubab *et al.*, 2018). The global biosensors market was valued at approximately USD 25.1 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 7.9% from 2024 to 2030 (Grand View Research, 2024). Rapid microbial detection methods, including electrochemical and optical biosensors, allow for on-site, real-time, and multiple analyses, which are essential for detecting bacteria in perishable and semi-perishable foods. Electrochemical biosensors, which represent around 70% of the biosensor market, use electrode transducers to detect electron transfers from bioreceptor-analyte interactions, providing fast and accurate contamination data (Bunney *et al.*, 2017). Optical biosensors, on the other hand, combine biological elements with optical techniques like luminescence, fluorescence, reflectance, and absorbance to identify chemical or biological species (Thakur and Ragavan, 2013). Immunological methods, which rely on the binding of specific antibodies to antigens, enhance the ability to detect microorganisms and microbial toxins. The biosensor market, valued at approximately $563 million for pathogen detection, is expected to grow at a compounded annual growth rate (CAGR) of 4.5%, with the food-pathogen testing market projected to reach $192 million and 34 million tests by 2005 (Alocilja and Radke, 2003). Their fast, sensitive, and real-time detection capabilities make biosensors an attractive alternative to conventional methods, improving food safety and reducing the risk of contamination. Biosensors are not only transforming the food industry but also expanding their potential applications in medical, military, and environmental sectors, reinforcing their role as essential tools for rapid and reliable pathogen detection.

Identifying Contamination Sources:

Blockchain technology helps trace food products throughout the supply chain, making it easier to identify contamination sources. By recording every transaction in an immutable ledger, blockchain ensures that food products can be tracked back to their origin, allowing authorities to pinpoint contamination sources quickly (Kraken Sense, 2023). Blockchain tracing processes are triggered, and real-time monitoring data are used to trace the pollution pathway. (Lin, Y. P.)The concentrations of pH, temperature, Electrical Conductivity (EC), Cadmium (Cd), Copper ($Cu2^{+}$), Zinc (Zn), Nickel (Ni), and Lead (Pb) in irrigation water have been measured by the sensors.

Reducing Food Fraud and Counterfeit Products:

Blockchain technology has the capability of improving the safety and quality of the food supply chain around the world by offering credibility of origin and responsible authorities. Food fraud and counterfeit products pose serious risks to consumer safety and brand integrity. Blockchain prevents these issues by assigning each product a unique digital identity, ensuring authenticity and traceability. By using blockchain, food suppliers and retailers can verify the origin and authenticity of their products, reducing the prevalence of counterfeit goods in the market (Food Industry, 2023; Sri Vigna Hema and Manickavasagan, 2024).

Application of (AI) Artificial Intelligence Food Safety:

Biosensors have emerged as powerful analytical tools for rapid detection of foodborne pathogens, addressing the growing concern over food safety. Annually, millions of people suffer from foodborne illnesses caused by 31 major identified pathogens, with an estimated 48 million cases, 128,000 hospitalizations, and about 3,000 deaths reported each year in the United States alone (Scharff, 2012). Conventional detection methods for pathogens, which typically take 3–5 days to deliver results, have significant drawbacks, making them less effective for real-time food safety monitoring. Initially developed for clinical diagnostics, biosensors have gained prominence in the food industry due to their high sensitivity and ability to detect bacteria at an earlier stage (Rubab *et al.,* 2018). The global biosensors market was valued at approximately USD 25.1 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 7.9% from 2024 to 2030 (Grand View Research, 2024). Stability remains a key challenge (Zeng *et al.,* 2019). Rapid microbial detection methods, including electrochemical and optical biosensors, allow for on-site, real-time, and multiple analyses, which are essential for detecting bacteria in perishable and semi-perishable foods. Electrochemical biosensors, which represent around 70% of the biosensor market, use electrode transducers to detect electron transfers from bioreceptor-analyte interactions, providing fast and accurate contamination data (Bunney *et al.*, 2017). Optical biosensors, on the other hand, combine biological elements with optical techniques like luminescence, fluorescence, reflectance, and absorbance to identify chemical or biological species (Thakur and Ragavan, 2013). Immunological methods, which rely on the binding of specific antibodies to antigens, enhance the ability to detect microorganisms and microbial toxins. The biosensor market, valued at approximately $563 million for pathogen detection, is expected to grow at a compounded annual growth rate (CAGR) of 4.5%, with the food-pathogen testing market projected to reach $192 million and 34 million tests by 2005 (Alocilja and Radke, 2003). Their fast, sensitive, and real-time detection capabilities make biosensors an attractive alternative to conventional methods, improving food safety and reducing the risk of contamination. Biosensors are not only transforming the food industry but also expanding their potential applications in medical, military, and environmental sectors, reinforcing their role as essential tools for rapid and reliable pathogen detection.

Identifying Contamination Sources:

Blockchain technology helps trace food products throughout the supply chain, making it easier to identify contamination sources. By recording every transaction in an immutable ledger, blockchain ensures that food products can be tracked back to their origin, allowing authorities to pinpoint contamination sources quickly (Kraken Sense, 2023). Blockchain tracing processes are triggered, and real-time monitoring data are used to trace the pollution pathway (Lin *et al.*, 2020). The concentrations of pH, temperature, Electrical Conductivity (EC), Cadmium (Cd), Copper (Cu^{2+}), Zinc (Zn), Nickel (Ni), and Lead (Pb) in irrigation water have been measured by the sensors.

Reducing Food Fraud and Counterfeit Products:

Blockchain technology has the capability of improving the safety and quality of the food supply chain around the world by offering credibility of origin and responsible authorities. Food fraud and counterfeit products pose serious risks to consumer safety and brand integrity. Blockchain prevents these issues by assigning each product a unique digital identity, ensuring authenticity and traceability. By using blockchain, food suppliers and retailers can verify the origin and authenticity of their products, reducing the prevalence of counterfeit goods in the market (Food Industry, 2023; Sri Vigna Hema and Manickavasagan, 2024).

Conclusion:

Food safety remains a pressing global concern, complicated by increasingly interconnected supply chains, environmental degradation, and the emergence of new and re-emerging foodborne pathogens. Despite regulatory frameworks and continued investments, millions suffer from foodborne illnesses annually, leading to significant public health and economic burdens. Incidents like the Bihar Mid-Day Meal tragedy in India underscore the fatal consequences of lapses in safety protocols, while fragmentation in systems such as that of the United States exposes inefficiencies and enforcement challenges. Vulnerable populations, particularly in low- and middle-income countries, and children under five bear a disproportionate burden, facing higher risks of illness, stunting, and even death due to unsafe food. These multifaceted challenges, a shift toward innovative, technology-driven solutions is essential. Tools like biosensors provide rapid and sensitive detection of pathogens, blockchain technology enhances traceability, prevents food fraud, and ensures supply chain transparency, and Artificial Intelligence supports predictive risk assessment and timely decision-making. These advancements must be supported by strong policy implementation, regulatory coordination, infrastructure development, and public education. Strengthening global collaboration and accountability is vital to achieving safe, sustainable, and nutritious food systems for all. The cost of inaction is too high—food safety must be prioritized as a public health imperative.

REFERENCES

Alocilja, E.C. and Radke, S.M. (2003). Market analysis of biosensors for food safety. *Biosensors & Bioelectronics,* **18**(5–6) : 841–846.

Altekruse, S.F., Cohen, M.L. and Swerdlow, D.L. (1997). Emerging foodborne diseases. *Emerging Infectious Diseases,* **3**(3) : 285.

Bunney, T.D., Cole, A.R. and Katan, M. (2017). Phospholipase C epsilon: Linking cell signaling and disease. *Trends in Cell Biology,* **20**(10) : 563–574.

Grand View Research. (2024). *Biosensors market size, share & trends analysis report*. https://www.grandviewresearch.com

Khera, R. (2013). Mid-day meals: Looking ahead. *Economic & Political Weekly*, 12–14.

Lin, C.F. (2010). Global food safety: Exploring key elements for an international regulatory strategy. *Virginia J. Internat. Law,* **51** : 637.

Lin, Y.P., Mukhtar, H., Huang, K.T., Petway, J.R., Lin, C.M., Chou, C.F. and Liao, S.W. (2020). Real-time identification of irrigation water pollution sources and pathways with a wireless sensor network and blockchain framework. *Sensors,* **20**(13) : 3634.

Nyachuba, D.G. (2010). Foodborne illness: Is it on the rise? *Nutrition Reviews,* **68**(5) : 257–269.

Rubab, M., Shahbaz, H.M., Olaimat, A.N. and Oh, D.H. (2018). Biosensors for rapid and sensitive detection of *Staphylococcus aureus* in food. *Biosensors & Bioelectronics,* **105** : 49–57.

Scharff, R.L. (2012). Economic burden from health losses due to foodborne illness in the United States. *J. Food Protection,* **75**(1) : 123–131.

Slikker, W., Jr., Risher, J.F. and Carrington, C.D. (2018). Food safety: Emerging trends, challenges, and strategies. *Food & Chemical Toxicol.,* **111** : 460–462. https://doi.org/10.1016/j.fct.2017.12.058

Sri Vigna Hema, V. and Manickavasagan, A. (2024). Blockchain implementation for food safety in supply chain: A review. *Comprehensive Reviews in Food Science and Food Safety*, **23**(5), e70002.

Thakur, M.S. and Ragavan, K.V. (2013). Biosensors in food processing. *J. Food Sci. & Technol.,* **50** : 625–641.

Unnevehr, L.J. (2022). Addressing food safety challenges in rapidly developing food systems. *Agricultural Economics,* **53**(4) : 529–539.

Uyttendaele, M., Franz, E. and Schlüter, O. (2016). Food safety, a global challenge. *Internat. J. Environ. Res. & Public Health,* **13**(1) : 67.

Zeng, L., Peng, L., Wu, D. and Yang, B. (2019). Electrochemical sensors for food. *Nutrition in Health*.

****