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SMART TECHNOLOGIES FOR FOOD SAFETY IN HOTEL AND RESTAURANT KITCHENS: A REVIEW ARTICLE

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Abstract:

In today's dynamic economy, food safety is a significant public health issue for all governments and food handling organisations around the world. It is estimated that each year up to 30% of the world's population suffers from some form of food-borne disease (WHO, 2007). As the global food supply chain is synchronising and is becoming more concise with global outreach of consumers and growing willingness to try new flavours. The concern of food safety is only growing grave roots. Further, with global challenges such as urbanisation, climate change and evolving dietary preferences. Food safety is the responsibility of every global food business entity.

Enhancing food safety is crucial for ensuring consumer protection while strengthening customer confidence. Developing benchmark requirements of food safety systems for improved cost efficiency throughout the food supply chain. Global food supply is developing within a commercial environment with an aim to source ever-cheaper food i.e. to move production to the least costly provider. Quality management systems are designed primarily to ensure compliance with third-party and retailer standards. Eliminating food contamination for the sake of the government, business organisation and consumers is crucial. Now, the need to involve technology in food safety along with the existing food safety practices is not negotiable.

Food safety management systems principally control the specific food safety hazards associated with the product and ensure compliance with food safety legislation. This paper focuses on the introduction of technological tools that can be amalgamated with existing food safety management systems for a more profound measure to eliminate even marginal risks towards food contamination while identifying the issues in organisational food safety management systems for producing safe, wholesome food.

Keywords: *Food Safety, AI, IoT, Blockchain, FSSAI, CCP*

1. Introduction:

The global status of food safety is characterised by a significant public health burden that disproportionately affects low and middle-income countries (LMICs) and even developed nations struggle with persistent outbreaks despite regulatory frameworks.(Hartantyo et al. 2023);(Kumari and Kapur 2018). World Health Organisation's (WHO) benchmark 2010 estimates, approximately **600 million people—nearly one in ten globally—fall ill** after consuming contaminated food resulting in **420,000 deaths annually**. (Yin et al. 2025;Vergis et al., 2025)

1.1 Global Status and Regional Disparities:

The burden of foodborne disease (FBD) is a major concern like infectious diseases such as malaria and tuberculosis (Kumari and Kapur 2018; Santa 2011). Children under five years of age suffer from 40% of the global FBD burden resulting in 125,000 deaths annually (Chiu et al. 2024; Gizaw 2019). In low- and middle-income countries (LMICs) across South, Southeast Asia and Sub-Saharan Africa which account for 75% of global food-related deaths (Santa 2011). Due to shifts in the diets from traditional staples to high-risk perishable foods like meat, dairy and fresh produce often straining limited safety management capacities (Kumari and Kapur 2018; Jia and Jukes 2013). the **United States** experiences an estimated **48 million illnesses**, **128,000 hospitalizations**, and **3,000 deaths** each year due to foodborne diseases are attributed to the **Centers for Disease Control and Prevention (CDC)**.Even in developed regions same issues persist: the United States sees an estimated 48 million illnesses, 128,000 hospitalisations and 3,000 deaths each year (Hook, Porter and Herzog 2018) while in the European Union, pathogens such as Salmonella and Campylobacter continue to drive the majority of human infections (Santa 2011).

1.2 Major Food Safety Concerns:

Current food safety concerns encompass biological, chemical and physical hazards while being promoted by the escalating threat of food fraud. Biological hazards are the leading cause of foodborne disease (FBD) primarily involving pathogens such as Salmonella spp., Escherichia coli, Campylobacter and Listeria monocytogenes (Vergis et al. 2025; Chiu et al. 2024; Kumari and Kapur 2018) having most outbreaks traced to animal-source foods and raw fresh produce (Santa 2011). Chemical contaminants including pesticide residues such as heavy metals (lead, cadmium, mercury) along with veterinary drug residues like antibiotics (Kamboj et al. 2020) and mycotoxins such as aflatoxins in staple crops like maize pose significant health risks (Santa 2011; Jiang et al. 2025). Physical hazards like glass, metal shards or plastic fragments present ongoing quality control challenges by risking direct injury (Onyeaka, Jalata and Mekonnen 2023). Food fraud and adulteration often economically motivated have resulted in severe issues such as the 2008 melamine milk scandal in China that impacted 300,000 infants and caused six deaths alongside issues like Sudan Red dye in spices and "gutter oil" circulation (King et al. 2017; Jia and Jukes 2013; Santa 2011).

1.3 Emerging Trends: Food Safety 4.0:

The food industry is advancing toward a proactive "zero contamination" goal by integrating cutting-edge technologies (Hartantyo et al. 2023; Food Safety and Standards Authority of India [FSSAI], 2018). Digital surveillance tools like Artificial Intelligence (AI) and Machine Learning enable rapid pathogen detection and predictive shelf-life modelling (Naseem & Rizwan, 2025; Yu et al., 2024). Blockchain and Internet of Things (IoT) sensors enhance traceability through real-time cold chain monitoring and immutable records of a product's journey for improving transparency and recall efficiency (Hartantyo et al. 2023; Bhavna et al. 2024).

2. Traditional food safety practices:

2.1. Traditional food safety management while foundational to public health, faces several critical limitations in modern, globalised food systems. Research indicates that traditional methods—primarily characterised by **prescriptive regulations, manual on-site inspections and end-product testing**—often fall short of providing the real-time and comprehensive surveillance required to prevent outbreaks. (Naseem & Rizwan, 2025). Traditional food safety checks have major weaknesses that make contamination hard to control. They can't track issues that are live while missing small problems during production, storage and shipping (Yin et al. 2025). End-of-line testing costs much more and hurts reputations far worse than upfront risk prevention (Santa 2011). Routine sampling and lab analysis create delays with incomplete checks and extra work (Yin et al. 2025).

2.2. Traditional food safety methods encounter further limitations in practical application. Microbial growth models developed in controlled laboratory settings translate poorly to the dynamic, real-world conditions of food systems (Avila-Sosa and Nevárez-Moorillón 2025). Detection remains a significant hurdle as conventional micro-extraction and analytical techniques struggle to identify contaminants introduced in the production cycle (Kamboj et al. 2020).

2.3. Traditional food safety strategies reveal key shortcomings in addressing human factors and implementation. Training staff often proves ineffective due to the assumption that knowledge dissemination automatically enhances practices (Insfran-Rivarola et al. 2020). Effective outcomes demand attention to organisational culture and human dimensions—shared values and beliefs shaping unsupervised behaviour—beyond mere training and testing (Santa 2011). Even certified establishments exhibit hygiene non-conformities while highlighting that periodic cross-sectional inspections offer only a limited view and fail to ensure consistent safety (Hartantyo et al. 2023).

3. AI in food technology:

Artificial Intelligence (AI) is revolutionising food safety governance by propelling the industry from reactive end-product testing to a proactive and whole-chain prevention and control model (Jiang et al. 2025; Naseem & Rizwan, 2025). By harnessing Machine Learning (ML), Deep Learning (DL), the Internet of Things (IoT) and Blockchain technologies: AI facilitates real-time monitoring and sophisticated risk prediction throughout the "farm-to-fork" supply chain (Yin et al. 2025).

3.1. Rapid Detection of Pathogens and Contaminants:

AI technologies markedly outperform traditional laboratory methods in the speed and accuracy of detecting food-borne hazards (Yu et al., 2024). Deep Learning techniques like Convolutional Neural Networks (CNNs) demonstrate exceptional accuracy in identifying pathogens like Salmonella and Listeria from genomic data (Naseem & Rizwan, 2025) while imaging systems paired with the **Boosting Algorithm** can increase identification of bacterial species (Yin et al., 2025). For detecting chemical residues AI-enhanced Surface-Enhanced Raman Spectroscopy (SERS) rapidly detects pesticides and veterinary drugs with Transformer-based models (Yin et al. 2025). AI fluorescence sensor arrays also enable precise heavy metal detection (lead, cadmium, mercury etc.) (Yin et al. 2025).

3.2. Predictive Analytics and Microbiology:

AI-driven predictive models empower the food industry to anticipate risks and refine safety protocols even before incidents arise (Jin et al. 2020). These systems leverage analytics from scientific literature and social media for early outbreak warnings (Naseem & Rizwan, 2025; Yu et al., 2024). Machine Learning generates advanced predictive microbiology models using current microbial behaviour data (Avila-Sosa and Nevárez-Moorillón 2025). Shelf-life prediction algorithms process storage variables like temperature and microbial activity to forecast the usability of perishables such as fish and meat (Yin et al. 2025; Naseem & Rizwan, 2025). **Machine vision and AI** are transforming production lines by automating quality control and sorting by surpassing manual inspections for consistency and precision (Yin et al., 2025).

4. IOT in food safety:

The **Internet of Things (IoT)** refers to the interconnection of various objects—such as sensors, hand-held devices and machines—via the internet or communication mediums like Wi-Fi, Bluetooth and **Radio Frequency Identification** (RFID). (Jin et al. 2020)In the context of food safety- IoT technology is a critical component of the transition from reactive, end-product testing to an end-to-end prevention-first approach. (Yu et al., 2024).

4.1. Real-Time Monitoring and Quality Control:

IoT-enabled sensors provide continuous, real-time data on environmental and product conditions throughout the supply chain: this has the potential to revolutionise food safety management (Jin et al. 2020). They track critical factors like temperature, humidity and atmospheric gases during storage and transport—essential for high-value perishables such as meat and cold-chain products. Advanced IoT systems detect spoilage through chemical signals like volatile organic compounds (VOCs) in packaging and formaldehyde in seafood (Revelou et al. 2025; Jin et al. 2020).

4.2. Enhanced Supply Chain Traceability:

IoT forms the backbone of transparent and reliable food traceability systems by enabling end-to-end visibility (Jin et al. 2020; Yin et al. 2025). Integrating GPS and RFID will track food batches' precise movement and location from origin to the consumer's table. IoT sensors capture data at critical stages—sourcing, production and transport—feeding into immutable blockchain ledgers for tamper-proof records (Yin et al. 2025). This powerful synergy establishes trusted architectures that effectively block counterfeit or substandard products from entering the market (Yin et al. 2025; Naseem & Rizwan, 2025).

5. Blockchain technology in food safety:

Blockchain technology is a transformative tool in food safety primarily utilised to create a trusted traceability architecture that ensures data immutability and enhances transparency across the entire supply chain. (Yin et al. 2025) . AI and Blockchain technologies create unchangeable, transparent records tracking every step of a product's journey while AI scans huge datasets to spot fraud or adulteration early (Yin et al. 2025; Jin et al. 2020; Naseem & Rizwan, 2025). IoT sensors monitor cold chains live with the help of AI algorithms like Boosting and RFID label scanning to speed up handling perishables during receiving and shipping (Naseem & Rizwan, 2025; Jin et al., 2020; Yin et al., 2025).

This technology illuminates complex international supply chain relationships while offering transparency absent in conventional systems (Jin et al. 2020; Naseem & Rizwan, 2025). Real-world deployments demonstrate effectiveness in tuna tracking and certification such as pork meat traceability and wine provenance verification (Jin et al. 2020).

Blockchain serves as a robust safeguard against economically motivated food fraud by establishing tamper-proof verification throughout the supply chain (Yin et al. 2025; Naseem & Rizwan, 2025). It creates immutable records of ingredients and processing steps to effectively block counterfeit or substandard products from entering circulation (Yin et al. 2025).

Blockchain dramatically accelerates food safety responses during crises by enhancing both speed and precision (White n.d.; Jin et al. 2020). In a foodborne illness outbreak, the system pinpoints contamination sources in seconds rather than days, enabling swift isolation of affected products. Targeted recalls become far more efficient as blockchain identifies precise batches while minimising unnecessary waste and limiting the outbreak's scope while protecting public health (White n.d.).

6. Smart Sensors:

Smart sensors represent a transformative leap in food safety governance through introducing a proactive and controlled Framework. (Yin et al. 2025)

6.1. Optical and Sensory Sensing Technologies:

Optical sensors provide rapid, non-invasive food analysis essential for safety monitoring. Machine vision with convolutional networks detects defects and impurities while NIRS identifies substances like liquor via molecular vibrations; hyperspectral imaging (HSI) pinpoints contamination chemically free (Jiang et al. 2025). Machine olfaction and gustation systems mimic human senses for objective and high-speed assessments. Electronic noses (E-noses) use gas arrays and AI to detect VOCs for predicting contamination. Electronic tongues (E-tongues) use electrochemical and optical sensors powered by AI to create much more accurate shelf-life predictions for products like fresh milk by surpassing traditional testing methods. (Jiang et al. 2025).

6.2. Intelligent Packaging and Biosensors:

Smart sensors embedded in packaging monitor food conditions internally to provide real-time safety alerts (Yousefi et al. 2019; Chiu et al. 2024). Time-temperature indicators track total heat exposure through colour changes or nanofiber shifts alerting when temperature history turns unsafe. Gas and humidity sensors spot packaging problems by measuring O_2, CO_2 from microbes or moisture shifts in foods using RFID humidity tags (Chiu et al. 2024; Yousefi et al. 2019). Freshness indicators target spoilage markers like Total Volatile Basic Nitrogen (TVB-N) in food packaging or pH (Chiu et al. 2024). Advanced biosensors combine biological recognition with detectors for precise pathogen sensing (Chiu et al. 2024).

7. FSSAI relevance: Schedule 4 digital compliance roadmap:

The **Food Safety and Standards Authority of India (FSSAI)** is highly relevant in the adoption of technology to modernise food safety governance. As the apex regulatory body in India, FSSAI leverages technological platforms to facilitate compliance for enhancing surveillance and engage consumers through a unified "One Nation, One Food Law" framework.(Kumari and Kapur 2018).

7.1. Digital Consumer Engagement and Transparency:

FSSAI has transitioned from traditional enforcement to technology-driven consumer empowerment through interactive platforms like the 2017 Food Safety Connect portal and app enabling feedback, queries and license verification via multiple mobile interfaces duly complemented by Food Safety Display Boards providing "360-degree assurance" (Kumari and Kapur 2018; White n.d.; Santa 2011). The authority maintains NABL-accredited laboratories nationwide under the Food Safety and Standards Act, 2006 for contaminants testing with scientific committees standardising protocols for pesticide residues, heavy metals and veterinary drugs using high-precision equipment (Santa 2011; Kumari and Kapur 2018; Food Safety and Standards Act, 2006).

FSSAI uses science data collection like big data analysis to spot new risks early and user-friendly apps to help food businesses and consumers make safer choices every day (Food Safety and Standards Act, 2006; Santa 2011).

7.2. AI and smart technologies in restaurant/hotel kitchens catch food safety issues before they happen—in real time—instead of testing after problems occur (Yu et al., 2024; Yin et al., 2025). AI-powered tools identify hazards much faster than traditional lab methods (Yin et al., 2025). These solutions address key kitchen challenges: human error, tight schedules and complex supply chains (Yin et al., 2025). IoT sensors continuously monitor temperature, humidity and gases protecting perishables like meat and dairy from bacterial growth (Djekic & Smigic, 2025; Jin et al., 2020). Automated systems track critical control points (CCPs) for instant remote diagnostics (Revelou et al., 2025).

8. Challenges Implementing AI in Hotel/Restaurant Kitchens:

AI and smart tech promise better food safety but hotel and restaurant kitchens face real hurdles—money, messy data, tech glitches and human resistance.

8.1 Economic and Financial Barriers:

AI inspection systems cost 5-8x more than basic tools while crushing small restaurants that can't afford the upgrade (Yin et al. 2025). Added on-going cloud computing bills and retrofitting old equipment breaking budgets (Naseem & Rizwan, 2025; Kudashkina et al., 2022). Blockchain supply chain tracking? Even pricier—5-8x traditional systems—needing everyone in the chain to cooperate (Yin et al. 2025; Jin et al. 2020).

8.2. Data Quality and Standardisation Issues:

Data governance challenges persist due to fragmented, non-standardised agricultural and kitchen production data that varies widely by regional processing techniques and ingredient characteristics (Yin et al. 2025). Incompatible IoT communication protocols prevent seamless device interoperability, hindering cohesive safety system integration (Jin et al. 2020). Data integrity remains critical—if initial blockchain or AI inputs at raw material receipt are inaccurate, the entire safety chain's reliability collapses (Jin et al. 2020). High-end facilities counter this through digital surveillance monitoring internet trends and social media for near real-time outbreak detection (King et al. 2017).

8.3. Tech Fails Under Kitchen Pressure:

Deep learning's "black box" nature obscures decision-making processes while leaving regulators and managers unable to explain reasons for AI safety alerts (Yin et al. 2025). High computational demands create latency issues despite kitchens' need for millisecond responses (Revelou et al. 2025) while steam, smoke and noise degrade machine vision accuracy (Jiang et al. 2025).

8.4. Human Factors:

Catering's high staff turnover and unskilled labour hinder consistent AI proficiency (Food Safety and Standards Authority of India [FSSAI], 2018). Interdisciplinary talent shortages persist—data scientists versed in kitchen hazards remain scarce (King et al. 2017). Trained workers still show "knowledge-behaviour gaps", taking shortcuts or ignoring alerts during peak rushes (Santa 2011). Technical immaturity and data entry integrity concerns—where initial inaccuracies compromise entire chains—further complicate implementation (Jin et al. 2020)

9. Research Methodology:

This review article tried to find articles related to Technological advancements in Food safety and technologies like AI, IoT, blockchain and smart sensors aiding for food safety focuses on hotel/restaurant kitchens and FSSAI compliance. Literature was searched across Scopus, PubMed, Google Scholar and government records. Research articles in the English language on relevant technology applications, kitchen case studies and FSSAI-related reviews were included for this study.

10. Conclusion:

Food safety has evolved from reactive testing to Food Safety 4.0—a proactive shield powered by AI, IoT, blockchain and smart sensors. These technologies catch contamination before it spreads by tracking every ingredient's journey and predicting risks in real time, slashing outbreaks that sicken millions yearly (WHO, 2007; Yin et al., 2025).

Yet hotel and restaurant kitchens face steep hurdles: sky-high costs crushing small businesses, messy data, glitchy tech in steamy environments and staff who ignore alerts during dinner rush (Yin et al., 2025; FSSAI, 2018). FSSAI leads India's charge with digital platforms, FoSTaC training and Schedule 4's GMP/GHP foundation—ready for tech upgrades (Food Safety and Standards Act, 2006). In future, affordable edge AI, standardised data, kitchen-proof sensors and hands-on training will unlock full potential. Governments, FSSAI and industry must collaborate—blending tech innovation with human smarts—to deliver safe food for all (Santa, 2011; Hartantyo et al., 2023).

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