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EMERGING TRENDS IN FOOD SAFETY AND QUALITY MANAGEMENT (2025)

Original Research

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ABSTRACT

Background: Foodborne diseases remain a critical global public health concern, responsible for approximately 600 million illnesses and 420 000 deaths annually. Between 2020 and 2025, food safety and quality management have been reshaped by regulatory reforms, technological innovation, and One Health considerations. These changes reflect a shift from reactive control measures toward proactive, data-driven approaches that emphasize prevention, transparency, and resilience.

Objective: This review aims to synthesize recent developments in food safety and quality (FSQ) management from 2019 to 2025, examining regulatory frameworks, emerging technologies, and global health priorities to inform clinical practice, policy, and future research directions.

Main Discussion Points: Five converging themes emerge from the literature. First, regulatory frameworks—including Codex CXC 1 (2020 revision), ISO 22000:2018, GFSI Benchmarking Requirements v2024, FSSC 22000 v6, and the FDA's FSMA 204 rule—are increasingly aligned around food safety culture, allergen control, environmental monitoring, and traceability. Second, genomics-driven surveillance, particularly whole-genome sequencing and quasi-metagenomics, has enhanced outbreak detection and source attribution. Third, digital innovations such as IoT-enabled cold chain monitoring, blockchain, and digital twins are strengthening transparency and recall efficiency. Fourth, advances in smart packaging and biosensor technologies are enabling real-time monitoring of food quality and spoilage. Finally, One Health priorities—including antimicrobial resistance mitigation, climate change resilience, and food fraud prevention—are expanding the scope of FSQ systems beyond traditional hazard control.

Conclusion: Recent progress highlights a decisive move toward integrated, preventive, and technology-enabled FSQ systems. While the evidence underscores significant benefits, methodological variability, limited large-scale validation, and resource constraints remain barriers to global implementation. Future research should focus on standardization, multicenter evaluations, and strategies to enhance adoption in resource-limited settings to ensure equitable improvements in food safety and public health.

Keywords: Food Safety; Quality Management; HACCP; ISO 22000; GFSI; FSSC 22000 v6; FSMA 204; Traceability; Whole Genome Sequencing; Metagenomics; IoT; Blockchain.

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INTRODUCTION

Food safety has emerged as one of the most pressing global public health concerns, with unsafe food causing an estimated 600 million illnesses and 420 000 deaths every year, resulting in nearly 33 million disability-adjusted life years (DALYs) lost worldwide (1). Children under five years of age bear a disproportionate share of this burden, accounting for approximately 125 000 deaths annually, underscoring the vulnerability of this population (1,2). Beyond the human cost, unsafe food imposes staggering economic consequences, particularly in low- and middle-income countries (LMICs), where annual losses in productivity and medical expenses approach US$110 billion. Compounding this challenge is the growing problem of food fraud, estimated at US$10–15 billion annually, with some reports suggesting figures as high as US$40 billion, creating not only economic losses but also hidden risks to consumer health (2,3). These figures demonstrate both the magnitude of the problem and the urgency for comprehensive and harmonized approaches to food safety. The international regulatory landscape has evolved considerably over the past five years, with multiple frameworks converging on common expectations of stronger food safety culture, allergen control, environmental monitoring, and digital traceability. Codex Alimentarius updated its General Principles of Food Hygiene in 2020, sharpening the interface between good hygiene practices (GHP) and hazard analysis and critical control points (HACCP), while emphasizing allergen control and environmental monitoring (4). ISO 22000:2018 provided a systems-based approach that integrates the Plan-Do-Check-Act cycle across organizational levels and aligns with other management standards, facilitating its adoption in diverse industries (5). Private schemes benchmarked against the Global Food Safety Initiative (GFSI) have responded to the 2024 revision of benchmarking requirements by raising expectations for allergen management validation and food safety culture (6). Likewise, FSSC 22000 Version 6, mandatory from April 2024, expanded its scope to trading and brokering activities, reinforced requirements for allergen and environmental monitoring, and introduced provisions on food defense, fraud mitigation, and food loss and waste reduction (7). In parallel, regulatory agencies such as the U.S. Food and Drug Administration (FDA) have finalized the Food Safety Modernization Act (FSMA) traceability rule, requiring the documentation of key data elements (KDEs) and critical tracking events (CTEs) to enable faster recalls. While originally slated for 2026, the FDA proposed an extension to July 2028 to facilitate industry compliance, without diluting substantive requirements (8). Collectively, these frameworks illustrate a trajectory towards integrated, preventive, and technology-driven systems of food safety management.

Genomic surveillance has simultaneously transformed outbreak detection and attribution. Whole genome sequencing (WGS) has replaced pulsed-field gel electrophoresis in public health networks such as CDC PulseNet, allowing precise strain discrimination and earlier detection of outbreak clusters (9). Quasi-metagenomic approaches now enable direct sequencing of enriched or raw food and environmental samples, avoiding culture isolation while capturing strain-level and antimicrobial resistance data (10). Integration of harmonized data and metadata across jurisdictions, through initiatives such as PulseNet International and EFSA/ECDC One Health reports, has strengthened cross-border analytics, though resource limitations continue to pose challenges (11). Embedding such genomic approaches within environmental monitoring, supplier verification, and bioinformatics capacity building offers a pathway to proactive food safety systems. Alongside genomics, digital technologies aligned with Industry 4.0 are reshaping traceability and quality management. Internet-of-Things (IoT) sensors now enable continuous monitoring of temperature, humidity, and handling shocks, improving cold chain integrity and informing dynamic first-in-first-out (FIFO) decisions (12). Blockchain applications, particularly when integrated with IoT and digital twins, have demonstrated potential for enhancing data immutability, recall speed, and supply chain transparency, although challenges remain in governance, interoperability, and cost scalability (13). Practical roadmaps emphasize starting with high-risk commodities—such as ready-to-eat foods, fresh produce, and seafood—and gradually onboarding suppliers into permissioned ledger systems supported by standardized data contracts (14). Despite advances, gaps remain in ensuring equitable implementation across geographies, balancing technological adoption with cost and capacity, and translating regulatory requirements into operational reality. This study is therefore designed to critically examine the emerging trends in food safety and quality management, with a focus on regulatory convergence, genomics-driven surveillance, and digital traceability tools, while assessing their implications for global health and food system resilience. The objective is to evaluate how these evolving strategies can be integrated into practice to reduce the burden of foodborne illness, strengthen consumer protection, and advance public health outcomes worldwide.

Regulatory & standards landscape (2020–2025)

Over the past five years, global food safety governance has undergone notable transformation. International and national regulatory bodies, as well as private certification schemes, have aligned their requirements around shared priorities, including the promotion of food safety culture, enhanced allergen management, strengthened environmental monitoring, and the integration of digital traceability systems. This convergence reflects recognition that foodborne risks are increasingly complex, transboundary, and intertwined with broader sustainability and public health challenges.

Codex General Principles of Food Hygiene (CXC 1 1969, Rev. 2020)

The 2020 revision of the Codex General Principles of Food Hygiene (CXC 1) marked a significant milestone. It formalized "food safety culture" as a core element of food safety management, underscoring the need for leadership commitment and worker engagement throughout the food chain. The updated text also clarified the interface between prerequisite programs (GHPs) and hazard analysis and critical control points (HACCP), supporting a more coherent and risk-based approach. Importantly, the revision placed new emphasis on allergen management and environmental monitoring, reflecting the growing recognition of these hazards in food safety incidents worldwide.

ISO 22000:2018 (FSMS)

In parallel, the ISO 22000:2018 standard consolidated its role as a global benchmark for food safety management systems. By embedding the Plan–Do–Check–Act (PDCA) cycle at both the organizational and operational levels, ISO 22000 emphasized continuous improvement and adaptability in food businesses. The integration of prerequisite programs (PRPs), operational prerequisite programs (OPRPs), and critical control points (CCPs) into a unified framework also aligned ISO 22000 with the high-level structure of other management system standards such as ISO 9001 (quality management) and ISO 14001 (environmental management). This alignment facilitates harmonization across business management systems, supporting efficiency and cross-functional collaboration.

GFSI Benchmarking Requirements v2024

The Global Food Safety Initiative (GFSI) updated its Benchmarking Requirements in 2024, further tightening global expectations. Key changes included the introduction of systematic validation requirements for allergen management, an expanded emphasis on food safety culture with explicit terminology, and more rigorous expectations for scheme governance and sanction mechanisms. These requirements prompted major certification programs such as BRCGS, SQF, and FSSC to undergo re-benchmarking against the new framework, driving consistency across third-party assurance models while ensuring alignment with Codex CXC 1 and the updated ISO 22003-1:2022 requirements.

FSSC 22000 Version 6 (mandatory audits from 1 Apr 2024; upgrade window to 31 Mar 2025)

The publication of FSSC 22000 Version 6 has introduced significant structural and technical changes. The scope of certification has been expanded to cover trading and brokering activities, while food chain categories have been realigned in accordance with ISO 22003-1. New elements include mandatory requirements on food safety and quality culture (clause 2.5.8), enhanced allergen management systems, and strengthened expectations for environmental monitoring. The standard also incorporates explicit provisions on food defense, food fraud vulnerability assessments, and food loss and waste reduction, reflecting broader sustainability and consumer trust concerns.

FDA FSMA Traceability Rule (Section 204)

In the United States, the Food and Drug Administration (FDA) finalized the Food Safety Modernization Act (FSMA) Traceability Rule in November 2022. Initially scheduled for compliance by January 2026, the FDA announced in March 2025 an intention to extend compliance deadlines by 30 months, shifting the effective date to July 2028. Despite this delay, the substantive requirements remain intact. The rule mandates the documentation of Key Data Elements (KDEs) and Critical Tracking Events (CTEs) for commodities on the Food Traceability List, with the goal of accelerating outbreak detection and recall efficiency.

Regulatory takeaway: Across both public and private frameworks, the period between 2020 and 2025 has seen a distinct shift from reactive control measures towards proactive, preventive, and culturally embedded food safety systems. The alignment of Codex, ISO, GFSI, FSSC, and FSMA underscores a shared vision of harmonized standards, with digital traceability and allergen/contaminant monitoring as central pillars.

Genomics driven surveillance and analytics

The maturation of genomics has reshaped foodborne disease surveillance by providing higher-resolution tools for pathogen detection and source attribution. This transformation reflects both technological advances in sequencing and increasing global collaboration on data sharing.

Whole genome sequencing (WGS)

Since 2020, public health agencies worldwide, including the U.S. Centers for Disease Control and Prevention (CDC) through its PulseNet network, have transitioned from pulsed-field gel electrophoresis (PFGE) to whole genome sequencing (WGS) for routine outbreak investigations. WGS enables single-nucleotide resolution of microbial genomes, enhancing the ability to link dispersed cases into outbreak clusters, trace contamination back to sources, and monitor the emergence of antimicrobial resistance determinants (9). This level of discrimination has shortened outbreak detection timelines and improved the effectiveness of recalls.

(Quasi)metagenomics

Beyond isolate-based sequencing, quasi-metagenomic approaches—sequencing directly from enriched or raw samples—have advanced substantially between 2020 and 2025. These methods enable detection of pathogens at the strain level without requiring pure culture isolation, which is especially valuable for organisms that are slow-growing, unculturable, or masked by dominant flora. Advances in long-read sequencing platforms and bioinformatics pipelines have improved the ability to reconstruct genomes, detect virulence genes, and identify antimicrobial resistance (AMR) markers from complex food and environmental matrices.

Data ecosystems

The success of genomic surveillance depends on harmonized data infrastructures. Initiatives such as PulseNet International and the European Food Safety Authority (EFSA)/European Centre for Disease Prevention and Control (ECDC) One Health surveillance reports have promoted the integration of metadata standards and cross-jurisdictional data sharing. These efforts have facilitated real-time outbreak detection across borders. Nevertheless, resource constraints, data governance issues, and unequal sequencing capacity across regions remain significant challenges, with some reports in 2025 noting scaled-back surveillance coverage in U.S. FoodNet due to funding pressures.

Practice implications

The integration of WGS and metagenomics into food safety programs offers clear benefits for early detection and precise identification of contamination events, particularly in ready-to-eat (RTE) food categories and high-risk environments such as low-moisture or high-hygiene processing facilities. To maximize value, organizations should establish validated sampling protocols, define actionable thresholds (e.g., multilocus sequence typing or average nucleotide identity criteria), and allocate resources for bioinformatics capacity. Participation in national or regional genomic networks will also be critical to ensure interoperability and collaborative response.

Digital traceability and Industry 4.0

Technological innovation is increasingly central to modern food safety strategies. The convergence of IoT, blockchain, and data-driven predictive analytics offers the potential to enhance transparency, responsiveness, and efficiency across supply chains.

IoT + cold chain/quality telemetry

Low-power, wireless sensors capable of measuring temperature, humidity, and shock are now deployed across transport and storage environments. These devices allow real-time monitoring of critical parameters, enabling dynamic first-in–first-out (FIFO) decisions, early detection of cold chain breaches, and more accurate shelf-life prediction. Such capabilities are especially valuable for perishable commodities like seafood, dairy, and fresh produce, where minor deviations in handling conditions can precipitate significant food safety risks.

Blockchain enabled traceability

Blockchain-based systems have emerged as a promising tool for secure, immutable recording of supply chain data. Peer-reviewed studies published between 2023 and 2025 highlight blockchain's capacity to enhance transparency, improve recall speed, and provide trusted, tamper-resistant records when integrated with IoT and digital twins. Nevertheless, several challenges remain unresolved, including data quality assurance, interoperability across platforms, and the financial burden of implementation. Governance models that balance transparency with confidentiality are still under development.

Practical blueprint

A pragmatic roadmap for digital traceability emphasizes prioritization and scalability. Organizations are encouraged to begin with high-risk product categories—such as RTE meals, fresh produce, and seafood—that are frequently implicated in outbreaks and targeted by FSMA 204 traceability requirements. Mapping critical tracking events and key data elements across the supply chain provides a foundation for implementing permissioned blockchain ledgers, which can be further strengthened by integration with IoT sensor data via standardized APIs. Phased onboarding of suppliers, supported by clear data-sharing agreements and exception management dashboards, has been proposed as a practical path to scale.

Smart packaging, rapid tests, and biosensors

In addition to digital platforms, physical technologies embedded in packaging are advancing rapidly. Intelligent packaging systems now incorporate colorimetric and fluorometric freshness indicators, RFID and NFC tags, and printed biosensors capable of detecting specific spoilage metabolites such as total volatile basic nitrogen (TVB-N), pH shifts, and volatile organic compounds. The integration of these tools with cloud-connected readers provides both manufacturers and consumers with real-time information on food quality and safety. Recent reviews from 2024–2025 highlight significant progress in the use of nanomaterials, which improve sensor sensitivity, specificity, and environmental sustainability. Nevertheless, challenges remain around material safety, regulatory approval, and consumer acceptance, necessitating careful piloting before large-scale deployment.

One Health priorities reshaping FSQ

The One Health framework—emphasizing the interconnectedness of human, animal, and environmental health—has become increasingly central to food safety strategies. Between 2020 and 2025, three key issues have dominated discussions: antimicrobial resistance, climate change, and food fraud.

Antimicrobial resistance (AMR)

Reports from WHO's Global Antimicrobial Resistance Surveillance System (GLASS) and joint EFSA/ECDC assessments consistently demonstrate high levels of resistance among zoonotic pathogens such as *Salmonella* and *Campylobacter* (6). These findings reinforce the need for reduced use of critically important antimicrobials in food-producing animals, alongside robust biosecurity and hygiene measures across the supply chain.

Climate change

Climate change has emerged as a significant driver of food safety risks. FAO and EFSA analyses indicate that rising temperatures and altered precipitation patterns are expanding the geographical range of foodborne pathogens and toxin-producing fungi, increasing the prevalence of mycotoxins and enhancing the suitability of coastal waters for *Vibrio* proliferation. Furthermore, climate-related disruptions to supply chains and power infrastructure elevate the risk of temperature abuse in perishable products. Integrating climate risk into HACCP reassessments and investing in resilient infrastructure, such as backup cold storage, have been identified as essential adaptation strategies.

Food fraud

Food fraud, particularly the adulteration of high-value commodities, continues to pose economic and public health challenges. The European Medicines Agency (EMA) and other bodies have highlighted the persistent vulnerabilities in global supply chains. Emerging tools, including isotopic analysis and omics-based authenticity testing, coupled with systematic vulnerability assessments (VACCP), are recommended to strengthen fraud prevention. Contractual requirements and supplier monitoring systems remain critical to mitigating intentional adulteration risks.

Technology readiness and pitfalls

While the adoption of genomics and digital traceability holds transformative potential, recent literature highlights the importance of careful implementation. Whole genome sequencing and metagenomics are now considered mature technologies for outbreak detection, yet they require significant investment in laboratory infrastructure, trained personnel, and bioinformatics support (9). For blockchain and IoT applications, the principal obstacles remain interoperability, scalability, and the reliability of input data; without standardized data governance, the integrity benefits of distributed ledgers may be undermined. Similarly, intelligent packaging technologies, despite rapid advancements in sensor design, face regulatory scrutiny over the safety of nanomaterials and the practical challenges of adoption in diverse markets.

Overall, the period between 2020 and 2025 has seen remarkable convergence of regulatory frameworks, rapid expansion of genomics-driven surveillance, and the emergence of Industry 4.0 technologies in food safety. Yet significant disparities in infrastructure, cost barriers, and regulatory harmonization remain, highlighting the need for sustained investment, capacity building, and cross-sector collaboration to realize the promise of safer, more transparent food systems.

Table: Comparative snapshot of major frameworks (2025)

Topic	Codex CXC 1 (2020)	ISO 22000:2018	GFSI BMR v2024	FSSC 22000 v6	FSMA 204 (Traceability)
Food safety culture	Introduced/strengthened	Implicit via leadership/communication	Explicit emphasis and terminology	Mandatory plan (2.5.8)	N/A
Allergen control	Expanded guidance	Requirements via PRPs	Systematic validation focus	Enhanced allergen mgmt.	N/A
Environmental monitoring	Reinforced	Risk-based within PRPs/OPRPs	Expected via scheme criteria	Strengthened, documented	Facility-specific for FTL foods (indirect)
Food defense & fraud	Reinforced	Context-dependent	Reinforced	Explicit requirements	N/A
Traceability	Principle-based	Clause 8.3	Alignment push	Requirements + supplier controls	KDE/CTE mandatory for FTL; digital records

CRITICAL ANALYSIS AND LIMITATIONS

The body of evidence published between 2019 and 2025 demonstrates substantial progress in regulatory alignment, genomics-based surveillance, and digital traceability within food safety systems. However, a critical appraisal of the literature reveals several important limitations that temper the strength and generalizability of these findings. One of the most notable constraints is the predominance of descriptive or case-based reports rather than large, controlled studies. For example, much of the published evidence on blockchain pilots in fresh produce and seafood supply chains derives from small demonstration projects with limited participants and narrow geographic scope. While these pilots suggest improvements in recall precision and consumer trust, they do not provide robust longitudinal data on cost-effectiveness or long-term scalability (15). Similarly, reports of whole genome sequencing (WGS) applications in outbreak investigations—such as multi-state *Listeria* events—highlight reductions in detection time, but these are often retrospective analyses with small sample numbers and without appropriate comparators (16). The lack of randomized controlled trials or large multicenter prospective evaluations limits the ability to draw firm conclusions about the universal effectiveness of these technologies. Methodological variability is another challenge. Genomics-based studies often employ different sequencing platforms (short-read versus long-read), bioinformatic pipelines, and thresholds for defining genetic relatedness. This heterogeneity complicates cross-study comparisons and introduces the potential for misclassification bias in outbreak attribution or antimicrobial resistance (AMR) detection (17). Similarly, research on smart packaging and biosensors demonstrates promising sensitivity to spoilage indicators such as volatile organic compounds, yet validation protocols vary considerably, making it difficult to assess reproducibility or performance under real-world conditions (18).

Potential sources of bias also warrant attention. Surveillance reports from networks such as PulseNet or EFSA/ECDC provide critical insights into pathogen prevalence and AMR trends but often rely on convenience samples from participating laboratories. This raises the possibility of selection bias, as data may underrepresent low-resource regions or specific food categories. In addition, many food fraud vulnerability assessments in the literature focus on high-profile commodities, leaving gaps in knowledge about lower-value but widely consumed products that may also pose safety risks (19). Publication bias is another concern. Studies reporting successful implementation of digital traceability or rapid diagnostic tools are more likely to be published than those describing failures, delays, or cost overruns. This creates an overly optimistic picture of technological readiness and underestimates the practical barriers encountered during deployment. Reports of IoT-enabled cold chain monitoring, for instance, frequently emphasize reduced temperature excursions and waste, but there is limited systematic evidence on the sustainability of these systems or their performance across diverse climatic and infrastructural contexts (20). Finally, questions of generalizability remain largely unresolved. Many of the reviewed frameworks and technologies have been piloted in high-income countries with robust regulatory oversight and technical infrastructure. In low- and middle-income countries, where the burden of foodborne disease is greatest, implementation may be hampered by limited resources, fragmented supply chains, and gaps in laboratory or digital capacity (21). The recent indication that parts of the U.S. FoodNet surveillance network were scaled back due to resource constraints highlights how even high-income countries face challenges in sustaining comprehensive monitoring (22). In sum, while the literature from 2020 to 2025 reflects important advances, its reliance on case studies, methodological heterogeneity, potential biases, and limited geographical scope underline the need for more rigorous, standardized, and globally inclusive research. Without addressing these limitations, the translation of emerging technologies and regulatory frameworks into universally effective food safety and quality management systems may remain uneven.

IMPLICATIONS AND FUTURE DIRECTIONS

The synthesis of recent evidence on food safety and quality management between 2020 and 2025 carries several important implications for clinical practice, regulatory policy, and future research. At the clinical level, the increasing adoption of whole genome sequencing (WGS) and metagenomic tools has the potential to transform patient care. More precise and rapid identification of pathogens implicated in foodborne outbreaks allows clinicians to deliver targeted treatments earlier, thereby reducing morbidity and mortality associated with infections such as *Salmonella* and *Listeria* (21). The enhanced ability of genomic methods to detect antimicrobial resistance genes also informs antimicrobial stewardship strategies, enabling clinicians to avoid ineffective therapies and preserve the efficacy of last-line antimicrobials (22). Furthermore, intelligent packaging and real-time cold chain monitoring systems provide actionable information on food quality at the point of consumption, which could indirectly reduce clinical burden by decreasing the likelihood of patients being exposed to contaminated products (23). In terms of policy and guideline development, the convergence of major frameworks—including Codex Alimentarius (CXC 1, 2020 revision), ISO 22000:2018, GFSI Benchmarking Requirements v2024, and FSSC 22000 Version 6—offers an opportunity to harmonize global expectations. For regulators and policymakers, the incorporation of food safety culture, allergen management, and environmental monitoring into normative standards sets a new baseline for industry compliance and accountability (24,25). At the national level, the implementation of the FDA's FSMA Traceability Rule, even with its extended compliance timeline to 2028, underscores the strategic importance of digital recordkeeping and standardized key data elements for effective recall management (26). Clinical and public health practitioners stand to benefit from these policy shifts, as improved traceability and data sharing facilitate more timely recognition of foodborne outbreaks and more precise identification of contaminated products. There remains, however, a pressing need for guidance on integrating genomics into routine surveillance, defining acceptable thresholds for metagenomic detection, and embedding climate resilience considerations into hazard analysis and critical control point (HACCP) systems (17,18).

Several research gaps persist. The majority of published work remains concentrated in high-income countries, limiting generalizability to low- and middle-income regions that bear a disproportionate share of the global foodborne disease burden (9). Methodological inconsistencies in genomic analyses, particularly the use of diverse sequencing platforms and bioinformatics pipelines, create challenges for comparing findings across studies and jurisdictions (2,7). Evidence on the economic and operational feasibility of blockchain-enabled traceability and smart packaging is still emerging, with many projects limited to pilot scale and lacking rigorous cost–benefit evaluation (10). Additionally, the long-term impact of enhanced food safety culture initiatives on clinical outcomes remains insufficiently quantified, despite regulatory emphasis on this dimension. Future research should prioritize well-designed, multicenter prospective studies that can provide robust evidence on the effectiveness of WGS, metagenomics, and digital traceability in reducing the incidence and severity of foodborne disease. Randomized controlled trials, while challenging in food safety contexts, could be employed to evaluate specific interventions such as allergen control validation protocols or smart packaging systems in controlled settings. Longitudinal studies are essential to assess how sustained improvements in food safety culture influence compliance, outbreak frequency, and ultimately patient outcomes. In the domain of digital traceability, comparative effectiveness studies should investigate the performance, interoperability, and cost implications of blockchain and IoT platforms across diverse supply chains. For One Health-related priorities, integrated surveillance research that captures data from human, animal, and environmental reservoirs is critical to mapping transmission pathways and designing holistic interventions (8,9). Overall, the literature between 2020 and 2025 highlights a decisive shift toward proactive, technology-enabled, and culturally embedded approaches to food safety. Translating these advances into clinical benefit will depend on rigorous validation, clear international guidance, and investments that bridge capacity gaps across regions. Future work should emphasize interdisciplinary collaboration, standardization of methodologies, and evaluation of real-world impact, ensuring that innovations meaningfully contribute to reducing the global burden of foodborne disease.

CONCLUSION

The evolving landscape of food safety and quality management between 2020 and 2025 reflects a clear transition from reactive controls toward proactive, integrated, and technologically enabled systems. Regulatory frameworks such as Codex CXC 1 (2020), ISO 22000:2018, GFSI Benchmarking Requirements v2024, FSSC 22000 v6, and the FDA's FSMA 204 rule are increasingly aligned in emphasizing food safety culture, robust allergen and environmental monitoring, and interoperable traceability mechanisms. Concurrently, scientific advances in whole-genome sequencing, metagenomics, and digital technologies including IoT-based cold chain monitoring and blockchain traceability have expanded the capacity for earlier detection, more precise outbreak attribution, and faster recalls. However, the current evidence base is constrained by methodological variability, limited scale of pilot studies, and underrepresentation of low- and middle-income regions, which raises questions about the generalizability and long-term sustainability of these innovations. To maximize their impact, food safety professionals should prioritize embedding validated genomic tools into routine surveillance, strengthening supplier digital integration, and incorporating smart packaging and resilience planning into standard practice. Future research must move beyond descriptive case studies toward multicenter, prospective evaluations and harmonized methodological frameworks, ensuring that the growing momentum in regulatory and technological innovation translates into tangible reductions in the global burden of foodborne disease.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Usama Aslam*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Esha Aslam	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Shahbaz*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published

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