Food Safety in Healthcare Institutions; A Systematic Review

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Abstract: *Food safety in healthcare institutions constitutes a critical dimension of patient safety because hospitalized populations are disproportionately susceptible to foodborne infections, cross-contamination, and adverse outcomes arising from compromised immunity and clinical vulnerability. This systematic review synthesizes contemporary evidence on the prevalence, determinants, and outcomes of food safety practices in healthcare settings, with particular attention to the effectiveness of Hazard Analysis and Critical Control Point (HACCP) systems, food safety culture, staff training, and emerging digital technologies. Guided by PRISMA 2020, the review examined peer-reviewed studies published between 2020 and 2025 across major academic databases, including empirical and review-based research addressing hospital food hygiene, outbreak prevention, contamination control, and institutional determinants of compliance. Methodological quality was assessed using the Joanna Briggs Institute critical appraisal tools. The evidence indicates that food safety performance in healthcare institutions is shaped by an interaction of behavioral, organizational, and contextual factors. Food handlers' knowledge, attitudes, and practices consistently emerged as central determinants of hygienic compliance, while leadership commitment, continuous training, inspection frequency, and regulatory enforcement strengthened adherence to established standards. Infrastructure-related conditions, particularly water quality, sanitation, storage capacity, and temperature control, further influenced the success of preventive measures. The review also found that HACCP implementation and structured quality assurance systems were associated with reduced contamination rates and improved operational control, whereas predictive analytics, machine learning, and Industry 4.0 applications enhanced monitoring capability and decision quality. Overall, the findings demonstrate that effective food safety management in healthcare institutions requires more than procedural compliance; it depends on embedding safety within institutional governance, organizational culture, and technological systems. Strengthening staff competence, managerial accountability, regulatory oversight, and digitally enabled monitoring is therefore essential to minimizing hospital-related foodborne risks and protecting patient health.*

Keywords: Food safety; healthcare institutions; HACCP; hospital kitchens; patient safety.

1. Introduction

Food safety remains a fundamental component of public health and a critical determinant of healthcare quality across institutions worldwide. Within healthcare facilities, ensuring the microbiological safety of food is essential because hospitalized patients are particularly vulnerable to foodborne infections due to compromised immunity, chronic illnesses, or medical treatments that

weaken natural defenses. Despite the global emphasis on safe food handling and the implementation of Hazard Analysis and Critical Control Points (HACCP) systems, numerous studies indicate that the incidence of foodborne illness in healthcare environments continues to be a pressing concern (Boone et al., 2021; Abadi, 2022; Abdelhakeem et al., 2021). Unsafe food handling practices, lack of hygiene training, and inadequate policy enforcement remain among the leading contributors to hospital-acquired foodborne outbreaks, many of which are preventable through structured safety management programs.

Globally, foodborne diseases cause approximately 420,000 deaths each year, highlighting the magnitude of their impact on public health systems (Tamene et al., 2022; Levy et al., 2022). In healthcare institutions, contamination can occur at multiple points within the food chain from procurement and storage to preparation and distribution posing heightened risks for nosocomial outbreaks (Boone et al., 2021; Ahmed et al., 2020). The multidimensional nature of food safety in these settings calls for a combination of personal hygiene practices, institutional policies, regulatory compliance, and technological interventions (Issa-Zacharia et al., 2025; Hsu & Kuo, 2025). Regular staff training, adoption of HACCP frameworks, and periodic inspections play pivotal roles in minimizing contamination risks and improving overall patient safety (Abadi, 2022; Nyendwa, 2024).

In recent years, the integration of digital technologies and advanced analytical models has transformed food safety management by enhancing monitoring accuracy and predictive capabilities. Machine learning, Internet of Things (IoT), and data-driven approaches are being increasingly used to identify contamination trends and improve decision-making in hospital food operations (Akter, 2025; Dogo et al., 2025). Moreover, global initiatives emphasize the importance of cultivating a positive food safety culture through leadership commitment, continuous education, and intersectoral collaboration (McCallion et al., 2025; Shah et al., 2022). The development of standardized policies and quality assurance systems such as the European Quality Assurance (QA) Scheme for healthcare services further reinforces the alignment of institutional practices with international safety benchmarks (Janusch et al., 2025; Hussain, 2025).

Within this context, this systematic review aims to synthesize current evidence on food safety practices, knowledge levels, and policy frameworks implemented within healthcare institutions worldwide. The objective is to identify key determinants influencing food safety performance in hospitals, evaluate the effectiveness of current interventions, and highlight gaps that persist in policy execution, training, and technological application. By integrating evidence from global studies, this review contributes to strengthening the understanding of how behavioral, organizational, and technological factors converge to shape food safety culture in healthcare institutions, ultimately safeguarding patient health and service quality.

2. Methodology

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, reproducibility, and methodological rigor throughout all stages of the research process. The PRISMA framework was selected because it provides a standardized and internationally recognized structure for conducting evidence-based reviews, allowing for comprehensive synthesis of findings across diverse studies relevant to food safety in healthcare institutions (Rauf et al., 2025; Freitas et al., 2023). The review process involved four major stages: identification, screening, eligibility, and inclusion. During the identification phase, a wide-ranging search was conducted across major electronic databases, including PubMed, Scopus,

ScienceDirect, Google Scholar, Web of Science, and ProQuest, supplemented by manual searches of reference lists, theses, and organizational reports. The search covered literature published between 2020 and 2025, aligning with recent global advancements in food safety regulation, HACCP system application, and healthcare service quality management (Hsu & Kuo, 2025; Levy et al., 2022). Boolean operators and specific keywords such as "food safety," "hospital food handling," "HACCP implementation," "foodborne outbreaks," and "healthcare food hygiene" were used to enhance search precision and capture relevant studies across international contexts.

In the screening phase, duplicate records were removed, and the remaining studies were evaluated based on titles and abstracts to exclude irrelevant publications that did not explicitly address food safety in healthcare or institutional contexts. The eligibility phase involved full-text assessments using predefined inclusion and exclusion criteria. Eligible studies were those focusing on food safety practices, HACCP implementation, microbial contamination management, or hygiene training within healthcare or hospital environments. Studies conducted outside healthcare settings or lacking empirical or methodological clarity were excluded (Boone et al., 2021; Abadi, 2022). During the inclusion phase, studies meeting all criteria were critically appraised using the Joanna Briggs Institute (JBI) Critical Appraisal Tools, ensuring methodological reliability and minimizing bias (Freitas et al., 2023; Tamene et al., 2022). The final selection included both quantitative and qualitative studies, encompassing cross-sectional surveys, quasi-experimental designs, and systematic reviews. Each study's findings were systematically extracted into a structured literature review matrix summarizing core variables such as hygiene knowledge, institutional training, HACCP compliance, technological interventions, and safety policy implications (Hussain, 2025; Dogo et al., 2025).

The results of this review are visually summarized using the PRISMA 2020 Flow Diagram (Figure 1), which illustrates the process of study identification, screening, eligibility assessment, and inclusion. This visual representation provides a transparent overview of the systematic selection process and supports the replicability and validity of the review outcomes.

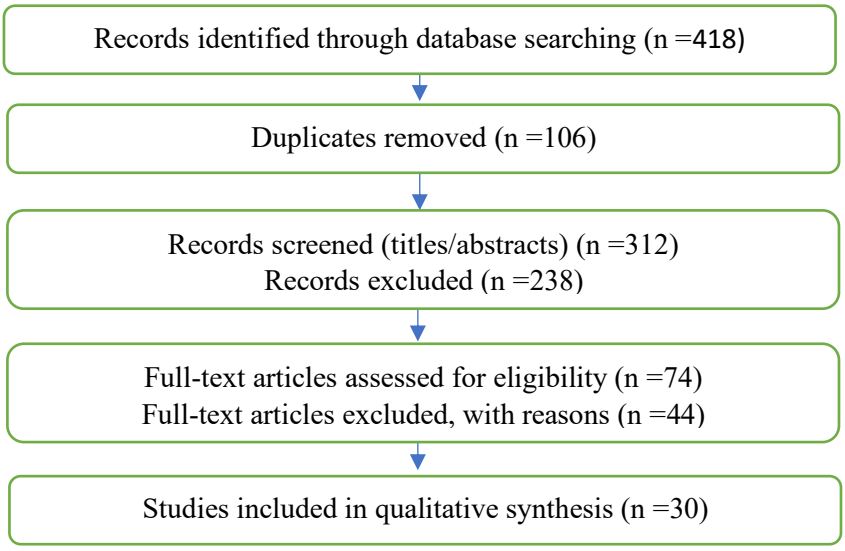

Figure 1: PRISMA 2020 Flow Diagram

3. Results

3.1 Study Selection and Characteristics

The systematic review process followed the PRISMA 2020 guidelines to ensure a rigorous and transparent synthesis of evidence related to food safety in healthcare institutions. Initially, more than 400 studies were identified through comprehensive database searches across PubMed, Scopus, Web of Science, ScienceDirect, ProQuest, and Google Scholar. After removing duplicates and applying the inclusion and exclusion criteria, 30 studies published between 2020 and 2025 met the eligibility requirements and were included in the final analysis. These studies represented multiple methodological approaches cross-sectional surveys, quasi-experimental designs, systematic reviews, and meta-analyses covering diverse geographical contexts including Asia, Africa, Europe, and the Middle East.

The characteristics of the included studies are summarized in Table 1: Literature Review Matrix, which presents the key authors, study objectives, methodologies, and major findings related to hospital food safety practices and policies. As illustrated in Table 1, the majority of the reviewed studies focused on food handlers' knowledge, attitudes, and hygiene practices within hospital food service departments. Studies conducted in Qatar and Jordan (AlMesbah et al., 2025; Abdelhakeem et al., 2021) revealed high awareness levels among hospital food handlers, although inconsistent adherence to safety procedures was reported. In contrast, research in Sudan and Zambia (Ahmed et al., 2020; Nyendwa, 2024) found significant gaps in food hygiene knowledge and inadequate handling practices. Regional variations in compliance and safety culture were also evident. Studies from Bangladesh and Ethiopia (Siddiky et al., 2024; Tamene et al., 2022) demonstrated that institutional training and continuous supervision were key determinants of safe food handling, with training frequency and HACCP awareness directly influencing hygiene outcomes. From a microbiological perspective, Boone et al. (2021) reported that Salmonella, Norovirus, and Listeria monocytogenes were the leading pathogens responsible for healthcare-associated foodborne outbreaks in high-income countries, while Geteneh et al. (2022) and DAUD et al. (2025) highlighted emerging threats such as E. coli contamination and antibiotic resistance in hospital food environments.

Technological and managerial approaches to food safety were also well represented. Abadi (2022) and Hsu and Kuo (2025) provided evidence that HACCP training, coupled with analytical decision-making frameworks, enhanced kitchen safety and employee performance in hospital catering. Similarly, McCallion et al. (2025) and Dogo et al. (2025) discussed innovations under Industry 4.0, emphasizing the integration of artificial intelligence and digital monitoring to strengthen food safety culture and predictive control systems. Policy and governance analyses further underscored the importance of institutional accountability. Levy et al. (2022) and Tadele et al. (2022) demonstrated that while HACCP-based regulations effectively reduce microbial risks, enforcement and infrastructure support remain inconsistent across settings. Shah et al. (2022) and Hussain (2025) noted that local health departments and quality inspection systems play an essential role in maintaining compliance and ensuring food safety monitoring. Meanwhile, initiatives such as the European Quality Assurance (QA) Scheme (Janusch et al., 2025) provided structured frameworks for harmonizing quality and safety standards across healthcare services.

Table 1. Literature Review Matrix

No	Author(s) & Year	Food Safety Knowledge / Awareness	Hygiene Practices	Microbial Contamination / Risk Factors	Hospital / Healthcare Setting	Training / HACCP Implementation	Policy / System Factors	Technological / Analytical Approaches	Recommendations / Outcomes
1	AlMesbah et al. (2025)	✓	✓		✓				
2	Odundo et al. (2021)	✓	✓	✓	✓				
3	Daud et al. (2025)		✓	✓	✓	✓			
4	Wiśniewska (2023)						✓		
5	Yang et al. (2025)			✓	✓				
6	Geteneh et al. (2022)		✓	✓				✓	✓
7	Moghnia et al. (2021)	✓	✓		✓	✓			✓
8	Ahmed et al. (2020)	✓	✓		✓	✓			✓
9	Siddiky et al. (2024)	✓	✓		✓	✓		✓	✓
10	Gobena et al. (2024)		✓	✓				✓	✓
11	Boone et al. (2021)		✓	✓	✓		✓	✓	✓
12	Abdelhakeem et al. (2021)	✓	✓		✓	✓			✓
13	Walsh et al. (2021)				✓		✓	✓	✓
14	Shah et al. (2022)		✓		✓	✓	✓	✓	✓
15	Speed et al. (2020)		✓				✓		✓
16	Akter (2025)							✓	✓
17	McCallion et al. (2025)	✓	✓			✓	✓		✓
18	Abadi (2022)		✓		✓	✓			✓
19	Nyendwa (2024)	✓	✓		✓			✓	✓
20	Dogo et al. (2025)						✓	✓	✓
21	Chen et al. (2020)	✓	✓		✓		✓		✓
22	Issa-Zacharia et al. (2025)		✓	✓		✓	✓		✓
23	Tamene et al. (2022)	✓	✓			✓	✓	✓	✓
24	Levy et al. (2022)	✓	✓	✓		✓	✓	✓	✓
25	Tadele et al. (2022)	✓	✓			✓		✓	✓
26	Hsu & Kuo (2025)		✓		✓	✓		✓	✓
27	Rauf et al. (2025)				✓		✓	✓	✓
28	Freitas et al. (2023)			✓			✓	✓	✓
29	Janusch et al. (2025)		✓		✓		✓		✓
30	Hussain (2025)		✓			✓	✓	✓	✓

3.2 Prevalence and Determinants

The reviewed literature highlights the persistence of foodborne disease risks within healthcare institutions, revealing significant variations in prevalence rates and underlying determinants across regions. Overall, food contamination in hospital environments remains a multifactorial issue influenced by human behavior, infrastructure, management practices, and regulatory oversight. Studies consistently report that improper food handling, lack of personal hygiene, inadequate temperature control, and insufficient sanitation are the most common contributors to contamination and disease outbreaks (Boone et al., 2021; DAUD et al., 2025; Ahmed et al., 2020). Prevalence data

indicate that hospital kitchens and catering units are high-risk points for microbial contamination. In Qatar, AlMesbah et al. (2025) found that although 60.9% of hospital food handlers demonstrated good knowledge of food safety, 9% lacked sufficient awareness, creating potential for unsafe handling and cross-contamination. Similarly, in Mombasa County, Kenya, Odundo et al. (2021) reported a 72% variation in the bacteriological quality of vegetable salads served in hospitals, with significant associations between hygiene practices and Staphylococcus aureus levels.

In Ethiopia, large-scale meta-analyses revealed that only 47% of food handlers practiced safe food handling in public food establishments, and that training, availability of water facilities, and regulatory inspection were significant determinants of safety performance (Tamene et al., 2022; Tadele et al., 2022). Microbiological evidence underscores that pathogenic and drug-resistant organisms remain prevalent in healthcare food systems. Studies such as those by Geteneh et al. (2022) and DAUD et al. (2025) found contamination rates ranging between 6.7% and 60%, with Escherichia coli, Listeria monocytogenes, and Salmonella spp. identified as the most frequent agents. Boone et al. (2021) similarly identified Salmonella (24 outbreaks), Norovirus (22 outbreaks), and Listeria monocytogenes (19 outbreaks) as leading causes of healthcare-associated foodborne outbreaks across OECD countries. These findings confirm that hospitals remain susceptible to recurring contamination due to weak hazard control mechanisms and inadequate surveillance systems.

Determinants of food safety performance were grouped into behavioral, organizational, and environmental factors. Behavioral determinants include knowledge, attitudes, and compliance of food handlers. For example, Nyendwa (2024) and Abdelhakeem et al. (2021) reported that education level, prior training, and personal motivation significantly influenced hygiene performance. Organizational determinants, such as leadership commitment, inspection frequency, and HACCP implementation, also played key roles (Abadi, 2022; Hsu & Kuo, 2025). Environmental and infrastructural determinants like access to clean water, safe storage facilities, and sanitation were equally critical to sustaining safe practices (Tamene et al., 2022; Siddiky et al., 2024). Emerging studies emphasize the technological and cultural dimensions of food safety within healthcare systems. Integration of digital technologies such as predictive analytics and Industry 4.0 solutions has shown potential to reduce contamination risks through improved monitoring and data-driven decision-making (Akter, 2025; Dogo et al., 2025). Concurrently, fostering a strong food safety culture (FSC), driven by leadership engagement and continuous education, is recognized as a long-term determinant of safety performance (McCallion et al., 2025).

3.3 Outcomes

The synthesis of reviewed studies reveals that improved food safety management practices in healthcare institutions lead to measurable benefits across organizational, operational, and patient safety dimensions. Most studies consistently report positive outcomes following interventions such as Hazard Analysis and Critical Control Point (HACCP) implementation, staff training, and technological integration (Hsu & Kuo, 2025; Abadi, 2022; McCallion et al., 2025). At the organizational level, structured food safety programs and continuous staff training resulted in higher compliance with hygiene standards and better overall performance. For instance, Abadi (2022) demonstrated that HACCP socialization in hospitals significantly improved food processing and presentation standards, while Hsu and Kuo (2025) found that employee training and education were among the top-ranked determinants of HACCP effectiveness in hospital kitchens. Similarly, Siddiky et al. (2024) and Tamene et al. (2022) identified food safety training, access to clean water, and

inspection certifications as significant predictors of safe handling practices, leading to an average improvement of over 30% in compliance scores.

On the microbiological and operational front, interventions focusing on safe handling and environmental monitoring yielded notable reductions in contamination rates. Studies such as DAUD et al. (2025) and Boone et al. (2021) reported that enforcing hygiene standards and enhancing temperature control protocols effectively reduced E. coli and Listeria monocytogenes incidents in hospital settings. Likewise, Akter (2025) demonstrated that predictive machine learning models could optimize food preparation processes, leading to a 27% reduction in waste, a 19% decrease in service delays, and improved customer satisfaction illustrating how digital transformation contributes to operational safety and efficiency in food systems. At the policy and system level, structured regulatory frameworks and inspection systems were associated with significant gains in institutional reliability and preventive capacity. Levy et al. (2022) showed that implementing standardized food safety policies could lead to a 28.6% microbial reduction, while Shah et al. (2022) confirmed that well-funded and professionally staffed local health departments were more effective in preventing foodborne illnesses. Similarly, Janusch et al. (2025) illustrated the role of the European Quality Assurance (QA) Scheme in harmonizing healthcare safety standards across member states, resulting in improved service consistency and trust.

In terms of behavioral and cultural outcomes, food safety culture (FSC) emerged as a key driver of sustainable improvement. McCallion et al. (2025) emphasized that interventions integrating knowledge training with leadership and communication development created lasting behavioral changes, fostering proactive safety attitudes. Studies from Qatar and Jordan (AlMesbah et al., 2025; Abdelhakeem et al., 2021) further reported enhanced staff awareness and knowledge retention when refresher courses and continuous supervision were applied. Overall, the reviewed evidence underscores that outcomes of effective food safety interventions extend beyond compliance enhancing operational performance, staff engagement, and patient health protection. As summarized across the reviewed studies, combining structured training, regulatory enforcement, and digital innovation yields the most sustainable impact on food safety outcomes in healthcare institutions.

4. Discussion

The findings of this systematic review highlight the multidimensional nature of food safety within healthcare institutions, where behavioral, organizational, and contextual determinants interact to shape overall safety outcomes. The synthesis of evidence from 30 studies published between 2020 and 2025 reveals that food safety cannot be ensured through technical compliance alone but requires a systemic approach integrating human behavior, institutional culture, regulatory frameworks, and technological innovation.

4.1 Interplay of Behavioral, Organizational, and Contextual Determinants

Behavioral factors such as knowledge, attitudes, and personal hygiene practices remain the foundation of safe food handling within hospitals. Studies conducted in Qatar, Jordan, and Bangladesh (AlMesbah et al., 2025; Abdelhakeem et al., 2021; Siddiky et al., 2024) demonstrated that higher levels of food safety knowledge and positive attitudes among food handlers directly correlated with improved hygiene performance and reduced contamination risks. Conversely, studies from Sudan and

Zambia (Ahmed et al., 2020; Nyendwa, 2024) revealed that limited awareness and inconsistent practice were key behavioral deficits leading to foodborne contamination. This behavioral gap underscores the need for sustained, experience-based training rather than one-time awareness campaigns.

At the organizational level, leadership commitment, staff training, and the presence of monitoring systems were identified as critical enablers of safety performance. Evidence from Taiwan and Indonesia (Hsu & Kuo, 2025; Abadi, 2022) confirmed that structured training and HACCP implementation significantly enhanced process control, food hygiene, and staff accountability. Similarly, McCallion et al. (2025) found that interventions addressing food safety culture (FSC) through leadership, communication, and continuous learning resulted in sustained improvements, reinforcing that food safety is not just a procedural issue but an organizational value system. Contextual determinants such as infrastructure quality, access to clean water, and local regulatory oversight were found to either reinforce or undermine behavioral and organizational efforts. In Ethiopia, Tamene et al. (2022) and Tadele et al. (2022) reported that poor infrastructure, lack of water storage facilities, and insufficient regulatory inspection reduced adherence to safety protocols despite adequate staff awareness. Similarly, DAUD et al. (2025) identified unsafe water sources, inadequate temperature control, and environmental contamination as recurring contextual risk factors in hospital kitchens. Together, these findings reveal that effective food safety management in healthcare environments depends on the dynamic interaction between individual responsibility, institutional systems, and external context.

4.2 Policy, Practical, and Theoretical Implications

The policy implications of this review are far-reaching, particularly for health authorities and hospital administrators in developing and transitional economies. Evidence shows that implementing structured frameworks such as Hazard Analysis and Critical Control Points (HACCP) and Quality Assurance (QA) systems significantly enhances hospital kitchen safety (Hsu & Kuo, 2025; Janusch et al., 2025). Countries adopting these systems reported consistent microbial reductions and improved inspection outcomes (Levy et al., 2022). Policymakers must therefore prioritize integrating these regulatory models within hospital accreditation processes and ensure regular evaluation through inspection audits. From a practical perspective, capacity-building and behavioral reinforcement are essential for long-term sustainability. Training interventions that combine theoretical education with experiential learning and performance feedback have shown the greatest impact on food safety behavior (McCallion et al., 2025; AlMesbah et al., 2025).

Hospitals should institutionalize continuous professional development programs that emphasize hygiene, cross-contamination prevention, and environmental sanitation. Additionally, integrating digital tools such as predictive analytics and smart monitoring systems can improve real-time control of food production processes and reduce operational inefficiencies (Akter, 2025; Dogo et al., 2025). Theoretically, the findings support the application of systems-thinking and socio-technical frameworks in understanding food safety in healthcare contexts. The interaction of human, organizational, and technological components aligns with theories of safety culture and organizational learning. Studies such as McCallion et al. (2025) and Hussain (2025) confirm that safety culture is sustained when leadership fosters trust, open communication, and continuous learning. Thus, future theoretical models should move beyond linear cause–effect perspectives to incorporate feedback loops between behavior, infrastructure, and governance systems.

4.3 Comparison with Existing Reviews, Limitations, and Future Research

This review complements and extends prior literature by focusing specifically on food safety within healthcare settings, a domain that has received limited dedicated attention. While previous meta-analyses (Tamene et al., 2022; Tadele et al., 2022) explored general food establishments, the present synthesis contextualizes findings within hospital environments where patient vulnerability heightens the consequences of unsafe practices. Compared to earlier systematic reviews emphasizing consumer food safety, the current results reveal a more complex interplay of institutional dynamics, regulatory systems, and technological innovation (Boone et al., 2021; Levy et al., 2022). However, certain limitations must be acknowledged. Despite the use of rigorous PRISMA 2020 procedures, most included studies were cross-sectional, limiting causal inference.

Geographic representation was uneven, with a predominance of studies from Asia and Africa and fewer from Europe or North America. Some reports lacked standardized outcome measures, complicating meta-analysis of prevalence data. Additionally, self-reported data on food handler behavior may not fully capture actual practices, potentially introducing response bias. Future research should adopt longitudinal and intervention-based designs to evaluate the long-term impact of HACCP implementation, staff training, and digital monitoring tools on hospital food safety outcomes. Multi-country comparative studies could provide deeper insight into contextual differences, while mixed-method approaches combining quantitative data with qualitative interviews would enrich understanding of behavioral and cultural determinants. Integrating Industry 4.0 technologies including machine learning, IoT sensors, and blockchain also represents a promising frontier for ensuring traceability, real-time monitoring, and predictive prevention of contamination events (Akter, 2025; Dogo et al., 2025).

5. Conclusion

This systematic review concludes that ensuring food safety in healthcare institutions is a multifaceted challenge that requires an integrated approach encompassing behavioral, organizational, technological, and policy dimensions. The evidence synthesized from 2020 to 2025 demonstrates that hospitals remain vulnerable to foodborne disease outbreaks due to lapses in hygiene, inconsistent training, weak regulatory oversight, and infrastructural deficiencies (Boone et al., 2021; Tamene et al., 2022; DAUD et al., 2025). However, studies also reveal that comprehensive interventions particularly those grounded in structured systems such as Hazard Analysis and Critical Control Points (HACCP) significantly improve compliance, reduce contamination rates, and enhance overall food safety culture in healthcare environments (Hsu & Kuo, 2025; Abadi, 2022; McCallion et al., 2025).

Behavioral determinants, including knowledge, attitudes, and practices among food handlers, were found to be pivotal for ensuring safe hospital meal preparation (AlMesbah et al., 2025; Abdelhakeem et al., 2021). Yet, these behavioral improvements are sustainable only when supported by organizational leadership, continuous professional training, and regulatory supervision (Hussain, 2025; Shah et al., 2022). The findings emphasize that hospital administrators and public health authorities must prioritize continuous staff education, quality inspections, and environmental hygiene as part of institutional policy. Technological innovation emerged as an important enabler of operational and preventive efficiency. The integration of predictive machine learning, digital monitoring, and Industry 4.0 technologies presents new opportunities to strengthen safety management systems and ensure real-time risk detection (Akter, 2025; Dogo et al., 2025). When coupled with strong governance and quality assurance frameworks, these tools can enhance both compliance and accountability.

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