

Research Paper

Food Safety Governance and Risk Communication in the Global Food Supply Chain: A Conceptual Review of Regulatory Frameworks and Best Practices

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Abstract

Global food supply chains have become increasingly complex, necessitating robust governance frameworks and effective risk communication strategies to ensure food safety and protect public health. This conceptual review examines the multilayered architecture of food safety governance, spanning international, regional, and national regulatory frameworks, with particular emphasis on the role of the Codex Alimentarius Commission, the World Health Organization (WHO), and the Food and Agriculture Organization (FAO) in harmonizing standards and facilitating trade. The review synthesizes current literature to identify key governance mechanisms, including risk-based regulation, Hazard Analysis and Critical Control Points (HACCP), and food safety management systems, while critically analyzing persistent challenges such as capacity deficits, fragmented surveillance systems, and trade-policy tensions. Risk communication emerges as a critical component of effective governance, requiring evidence-based, audience-tailored approaches that leverage digital technologies and foster stakeholder engagement. The analysis reveals that successful food safety governance depends on integrating scientific risk assessment with transparent communication, public-private collaboration, and adaptive regulatory frameworks. Emerging trends including digitalization, blockchain traceability, artificial intelligence, and One Health approaches offer promising pathways for strengthening global food safety systems. This review contributes to the literature by providing a comprehensive synthesis of regulatory frameworks and best practices, identifying critical gaps, and

proposing directions for future research and policy development in food safety governance and risk communication.

Keywords: Food Safety Governance, Risk Communication, Regulatory Frameworks, Codex Alimentarius, HACCP, Global Supply Chain.

1. Introduction

The globalization of food supply chains has fundamentally transformed the landscape of food safety governance, creating unprecedented challenges for regulators, industry stakeholders, and consumers worldwide. Modern food systems are characterized by extensive international trade, complex multi-tier supply networks, and diverse production practices that span multiple jurisdictions and regulatory regimes (Lin et al., 2022; Nguyen et al., 2022). This complexity has amplified the potential for food safety incidents to cascade across borders, affecting millions of consumers and generating significant economic and public health consequences (Fortin, 2023). The imperative to ensure safe food for consumers everywhere while facilitating fair trade practices has driven the development of sophisticated governance frameworks and risk communication strategies at international, regional, and national levels. Food safety governance encompasses the institutional arrangements, regulatory mechanisms, standards, and coordination processes through which governments, international organizations, and private actors manage food safety risks throughout the supply chain (Albisinni, 2023). At its core, effective governance requires the integration of scientific risk assessment, evidence-based risk management, and transparent risk communication, the three pillars of the risk analysis framework promoted by the Codex Alimentarius Commission since the 1990s (Yamada, 2022). However, the implementation of these principles varies considerably across jurisdictions, reflecting differences in regulatory capacity, political priorities, economic development, and cultural contexts (Ng et al., 2022).

Risk communication has emerged as a critical yet often underutilized component of food safety governance. Beyond the technical aspects of hazard identification and control, effective governance depends on the ability to communicate risks clearly and credibly to diverse audiences, including policymakers, industry operators, healthcare professionals, and consumers (Duru, 2023). The evolution of digital technologies and social media has both expanded the opportunities for risk communication and introduced new challenges related to misinformation, public trust, and

stakeholder engagement (Smith et al., 2021). Understanding how to leverage these tools while maintaining scientific integrity and regulatory credibility represents a key frontier in contemporary food safety governance. The purpose of this conceptual review is to synthesize current knowledge on food safety governance and risk communication in global supply chains, with specific objectives to: (1) map the multilayered architecture of international, regional, and national regulatory frameworks; (2) identify persistent challenges and gaps in current governance systems; (3) analyze best practices in food safety management and their implementation across different contexts; (4) examine risk communication strategies and their effectiveness in supporting governance objectives; and (5) explore emerging trends and future directions for strengthening food safety systems. This review draws on recent scholarly literature published between 2020 and 2024, focusing on conceptual frameworks, comparative analyses, and evidence-based recommendations that can inform policy development and practice.

The structure of this paper reflects a systematic progression from foundational governance frameworks through operational challenges and best practices to forward-looking innovations. Section 2 examines the multilayered regulatory architecture, beginning with international standard-setting bodies and extending to regional and national systems and private sector initiatives. Section 3 critically analyzes the key challenges confronting contemporary food safety governance, including capacity deficits, supply chain complexity, and trade tensions. Section 4 synthesizes best practices in food safety management, emphasizing risk-based approaches, HACCP systems, traceability mechanisms, and collaborative governance models. Section 5 focuses specifically on risk communication strategies, examining evidence-based frameworks, stakeholder engagement, and crisis communication. Section 6 explores emerging trends including digitalization, One Health approaches, and regulatory equivalence. The paper concludes with a synthesis of key findings and recommendations for future research and policy development.

2. Regulatory Frameworks and Governance Structures

2.1 International Governance Architecture

The international governance of food safety is anchored in a multilateral framework centered on the Codex Alimentarius Commission (CAC), established jointly by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) in 1963 (Titus, 2023). As the

preeminent international standard-setting body for food safety, Codex has developed a comprehensive collection of standards, codes of practice, guidelines, and recommendations that serve dual purposes: protecting consumer health and ensuring fair practices in international food trade (Das et al., 2020). With 188 member countries representing over 98% of the global population, Codex provides the scientific and regulatory foundation for harmonizing food safety measures across diverse national contexts (Heilandt et al., 2024). The legitimacy and influence of Codex standards derive significantly from their incorporation into the World Trade Organization's (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). Article 3.1 of the SPS Agreement mandates that WTO members base their sanitary and phytosanitary measures on international standards where they exist, explicitly referencing Codex standards for food safety (Yamada, 2022). This linkage between Codex and the WTO creates a powerful incentive for countries to align their national regulations with international standards, as measures consistent with Codex are presumed to be necessary for health protection and compliant with WTO obligations (Bittisnich, 2023). Conversely, measures that deviate from Codex standards may face scrutiny in trade disputes and require scientific justification to avoid being deemed unnecessary barriers to trade (Wearne et al., 2024).

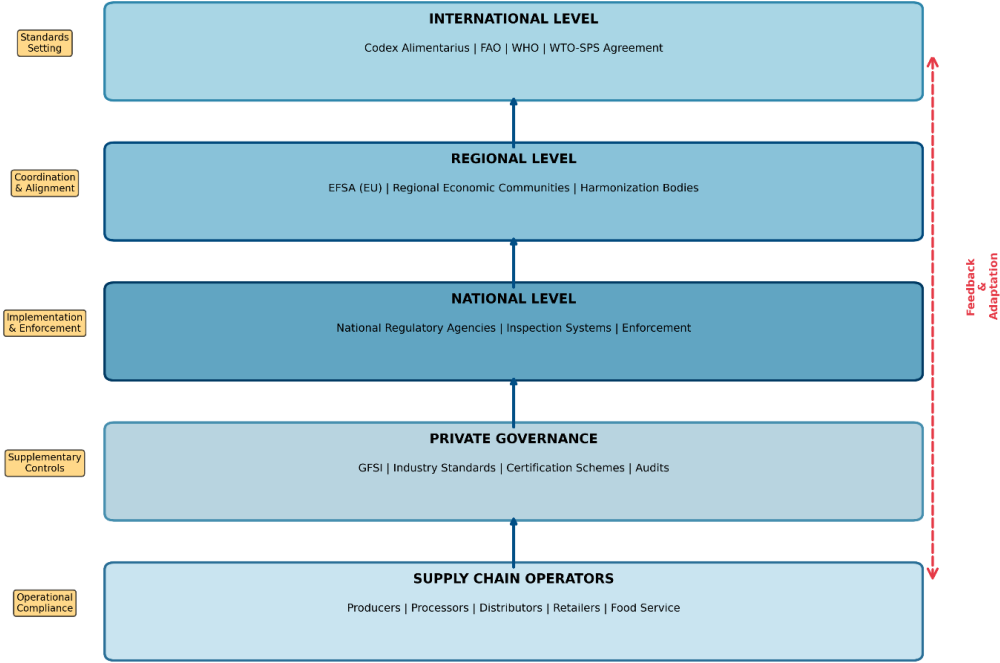


Figure 1. Global Food Safety Governance architecture

Note. Multilayered Architecture of Global Food Safety Governance– Placeholder for flowchart showing relationships between international bodies (Codex/FAO/WHO/WTO), regional agencies, national regulators, and private sector schemes

The Codex system operationalizes the risk analysis framework through a clear institutional separation between risk assessment and risk management functions. Independent scientific advisory bodies, including the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the Joint FAO/WHO Meeting on Pesticide Residues (JMPR), and expert consultations on microbiological hazards, conduct rigorous risk assessments that provide the scientific foundation for Codex standards (Petrenko et al., 2021). These expert bodies function as risk assessors, while Codex committees and the Commission itself serve as risk managers, translating scientific evidence into practical standards and guidelines (Yamada, 2022). This separation is designed to ensure that standard-setting decisions are grounded in the best available science while remaining responsive to legitimate policy considerations and stakeholder input. Beyond Codex, the FAO and WHO play essential roles in building capacity for food safety governance, particularly in developing countries. These organizations provide technical assistance, training programs, and guidance documents that help national authorities implement international standards and strengthen their food control systems (Fortin, 2023). The International Food Safety Authorities Network (INFOSAN), coordinated by WHO and FAO, facilitates rapid information exchange during food safety emergencies, enabling coordinated responses to transboundary incidents (Duru, 2023). This network exemplifies the shift toward collaborative, real-time governance mechanisms that complement traditional standard-setting processes.

2.2 Regional and National Regulatory Systems

While international standards provide a harmonized foundation, the implementation and enforcement of food safety measures occur primarily at regional and national levels, where regulatory systems exhibit considerable diversity in structure, capacity, and approach (Ng et al., 2022). Regional bodies such as the European Food Safety Authority (EFSA) in the European Union play pivotal roles in coordinating risk assessment, providing scientific advice, and harmonizing regulatory approaches across member states (Heppner et al., 2022). EFSA's model of centralized scientific assessment combined with decentralized enforcement by national competent authorities represents one approach to balancing harmonization with subsidiarity in food safety

governance. Comparative analyses of national food safety systems reveal significant variations in institutional architecture and regulatory philosophy. Ng et al. (2022) examined risk assessment systems in China, Australia/New Zealand, Canada, and the United States, identifying key differences in stakeholder cohesiveness, capacity for hazard identification, and alignment with international standards. Their analysis highlighted that while all four systems incorporate risk-based approaches, China faces particular challenges in building capacity for robust risk assessment and achieving stakeholder coordination comparable to more established systems. These findings underscore that adopting international standards requires not only regulatory alignment but also substantial investments in scientific infrastructure, human resources, and institutional coordination.

Canada's Safe Food for Canadians Act and associated regulations, implemented in 2019, illustrate efforts to streamline and modernize national food safety frameworks (Charlebois et al., 2021). This reform consolidated multiple regulatory instruments into a unified framework, strengthened preventive controls, and enhanced traceability requirements across the food supply chain. However, Charlebois et al. (2021) noted that even in a well-resourced jurisdiction like Canada, significant challenges remain in ensuring consistent implementation, maintaining surveillance capacity, and keeping pace with evolving food technologies and trade patterns. Their review emphasized the need for continuous improvement and adaptation in national food safety systems, even those considered international benchmarks. The harmonization of national standards with Codex recommendations varies considerably across countries and product categories. Lee et al. (2021) documented Korea's systematic efforts to align its food safety management policies with Codex guidelines, particularly in risk analysis frameworks and standards development. Korea has actively participated in Codex standard-setting, leading the development of six international standards for traditional foods including Kimchi and Gochujang. This case illustrates how countries can leverage international standard-setting processes to gain recognition for culturally significant foods while simultaneously strengthening their domestic food safety systems through alignment with global best practices.

2.3 Private Sector Governance Mechanisms

The complexity and global reach of modern food supply chains have driven the emergence of private sector governance mechanisms that complement and, in some cases, substitute for official

regulatory controls (Film, 2023). The Global Food Safety Initiative (GFSI), established in 2000 by food industry leaders, represents the most prominent example of private sector-led governance. GFSI has evolved from a benchmarking organization focused on harmonizing food safety audits into a comprehensive platform that delivers strategic outcomes in regulatory affairs, capability building, and stakeholder engagement (Film, 2023). By benchmarking recognized certification programs against a unified framework, GFSI reduces audit duplication, facilitates regulatory compliance, and builds trust throughout supply chains. The relationship between private governance schemes and public regulation is complex and multifaceted. On one hand, private standards often exceed minimum regulatory requirements, driving continuous improvement in food safety management practices and creating competitive advantages for certified suppliers (Nguyen et al., 2021). GFSI-benchmarked schemes such as BRC, IFS, FSSC 22000, and SQF have become de facto requirements for accessing major retail and food service markets, particularly in Europe and North America. On the other hand, the proliferation of private standards can create barriers for small and medium enterprises and suppliers in developing countries who lack the resources to achieve certification (Film, 2023).

The ethylene oxide incident in sesame seeds, which triggered extensive product recalls across the European Union between 2020 and 2021, illustrates both the strengths and limitations of hybrid public-private governance models (Kowalska et al., 2022). Private sector testing and auditing played a crucial role in identifying the scope and depth of contamination, complementing official regulatory controls. However, the incident also revealed gaps in coordination between private certification schemes and public surveillance systems, highlighting the need for more integrated approaches to food safety governance. Kowalska et al. (2022) argued that reflexive governance supported by emerging technologies such as blockchain could enhance the effectiveness of public-private collaboration by improving data sharing, traceability, and incident response capabilities. The integration of private standards with public regulation raises important questions about accountability, transparency, and equity in food safety governance. While private schemes can drive innovation and efficiency, they also introduce concerns about regulatory capture, conflicts of interest, and the potential for standards to serve protectionist rather than public health objectives (Albisinni, 2023). Effective governance requires clear delineation of roles and responsibilities,

mechanisms for regulatory oversight of private certification bodies, and safeguards to ensure that private standards complement rather than undermine public health objectives.

3. Challenges and Gaps in Current Food Safety Systems

3.1 Capacity and Harmonization Deficits

Despite decades of international standard-setting and capacity-building efforts, significant disparities persist in the ability of national food safety systems to implement risk-based regulation and meet international standards (Ng et al., 2022). These capacity deficits manifest in multiple dimensions, including scientific infrastructure for risk assessment, laboratory capabilities for hazard detection and monitoring, human resources with specialized expertise, and institutional coordination mechanisms. Charlebois et al. (2021) emphasized that even in developed countries with well-established food safety systems, maintaining adequate capacity requires continuous investment and adaptation to address emerging hazards, new technologies, and evolving supply chain configurations. The challenge of capacity building is particularly acute in developing countries, where resource constraints, competing policy priorities, and limited technical expertise constrain the ability to implement comprehensive food safety controls (Eruaga, 2024). These limitations have direct consequences for public health, as foodborne diseases disproportionately affect populations in low- and middle-income countries. Moreover, capacity deficits create barriers to international trade, as countries unable to demonstrate equivalence with importing country requirements face market access restrictions and reduced competitiveness (Wearne et al., 2024). The literature consistently emphasizes that addressing capacity gaps requires sustained international cooperation, targeted technical assistance, and long-term investments in education, infrastructure, and institutional development.

Harmonization of food safety standards, while a central objective of the Codex system, remains incomplete and uneven across countries and product categories. Zhao (2023) analyzed patterns of convergence and divergence in global food law, identifying persistent tensions between the push for international harmonization and the pull of national sovereignty and policy autonomy. Countries may legitimately adopt more stringent standards than Codex recommendations based on domestic risk assessments, consumer preferences, or precautionary principles. However, divergent standards can fragment markets, increase compliance costs for international traders, and create

opportunities for regulatory arbitrage. Achieving an appropriate balance between harmonization and flexibility represents an ongoing challenge for global food safety governance.

3.2 Supply Chain Complexity and Fragmentation

The extensive outsourcing and geographic dispersion that characterize contemporary food supply chains create fundamental challenges for hazard identification, control, and traceability (Nguyen et al., 2022). Multi-tier supply networks involving numerous intermediaries, processors, and distributors across multiple jurisdictions complicate efforts to maintain visibility and accountability throughout the chain. This complexity is compounded by the increasing prevalence of e-commerce in food trade, which introduces new actors and distribution channels that may fall outside traditional regulatory frameworks (Bittisnich, 2023). The COVID-19 pandemic further exposed vulnerabilities in global food supply chains, disrupting logistics, straining inspection resources, and highlighting the need for more resilient governance systems. Fragmentation in surveillance and data sharing represents a critical gap in current food safety systems. Kowalska et al. (2022) documented how the ethylene oxide incident revealed disconnects between private testing programs, third-party audits, and official control systems, complicating efforts to assess the full scope of contamination and coordinate recall actions. The absence of interoperable data systems and standardized information-sharing protocols limits the ability of regulators and industry to detect emerging risks, trace contaminated products, and implement targeted interventions. Addressing this fragmentation requires investments in digital infrastructure, development of data standards, and establishment of governance frameworks that facilitate secure and timely information exchange while protecting proprietary business information.

The literature emphasizes that managing food safety in complex global supply chains requires moving beyond traditional border inspection and end-product testing toward integrated, systems-based approaches that embed controls throughout the production and distribution process (Nguyen et al., 2021). This shift necessitates greater collaboration between public and private actors, enhanced traceability mechanisms, and risk-based allocation of regulatory resources to focus on the highest-risk nodes in supply networks. However, implementing such approaches at scale remains challenging, particularly for products sourced from regions with limited regulatory capacity or transparency.

3.3 Trade-Sovereignty Tensions

The intersection of food safety regulation with international trade creates inherent tensions between countries' sovereign right to protect public health and their obligations to avoid unnecessary barriers to trade (Fink, 2023). While the SPS Agreement and Codex standards provide a framework for balancing these objectives, disputes frequently arise over the scientific justification for measures that deviate from international standards, the appropriate level of protection, and the application of precautionary principles in the face of scientific uncertainty. Fink (2023) argued that harmonization efforts, while reducing trade barriers, can impose regulatory costs and constrain the ability of governments and communities to pursue novel or more stringent approaches to food safety based on domestic values and risk perceptions. The regulatory costs of developing and implementing international standards extend beyond direct compliance expenses to include opportunity costs associated with foregone policy alternatives and potential impacts on domestic producers (Fink, 2023). Small-scale producers and processors may face disproportionate burdens in meeting international standards designed primarily for large-scale industrial operations, potentially leading to market consolidation and reduced diversity in food systems. These equity concerns are particularly salient in developing countries, where stringent import requirements in major markets can exclude producers who lack the resources to achieve certification, even when their products pose no greater food safety risk than certified alternatives.

Wearne et al. (2024) examined the underutilization of regulatory deference and equivalence mechanisms as a missed opportunity for facilitating trade while respecting national regulatory autonomy. Codex has developed guidance on equivalence concepts and procedures for recognizing that different regulatory approaches can achieve comparable levels of food safety protection. However, implementation of equivalence agreements remains limited, reflecting concerns about regulatory sovereignty, administrative complexity, and the challenges of assessing comparability across diverse regulatory systems. Expanding the use of equivalence mechanisms could reduce trade barriers and compliance costs while preserving countries' flexibility to tailor food safety measures to their specific contexts and priorities.

4. Best Practices in Food Safety Management

4.1 Risk-Based Regulation and Risk Analysis

Risk-based regulation has emerged as the dominant paradigm in contemporary food safety governance, reflecting a shift from prescriptive, one-size-fits-all rules toward flexible, science-driven approaches that allocate resources according to the magnitude and likelihood of food safety hazards (Kumar et al., 2024). The risk analysis framework, comprising risk assessment, risk management, and risk communication, provides the conceptual foundation for this approach. Risk assessment involves the systematic evaluation of hazards, exposure pathways, and potential health consequences using the best available scientific evidence (Yamada, 2022). Risk management translates these scientific findings into practical control measures, considering not only health protection but also feasibility, costs, and stakeholder input. Risk communication ensures that information flows transparently among scientists, regulators, industry, and the public throughout the process (Duru, 2023). The implementation of risk-based regulation requires robust scientific capacity for hazard identification and characterization, exposure assessment, and risk characterization. Yamada (2022) emphasized that effective risk assessment depends on high-quality data on hazard occurrence, consumption patterns, and dose-response relationships—data that are often incomplete or uncertain, particularly for emerging hazards and vulnerable populations. Addressing these data gaps through targeted surveillance, research, and international collaboration represents a critical priority for strengthening risk-based governance. Moreover, risk assessment must be conducted with transparency and independence to maintain credibility and public trust, necessitating clear institutional separation between assessment and management functions.

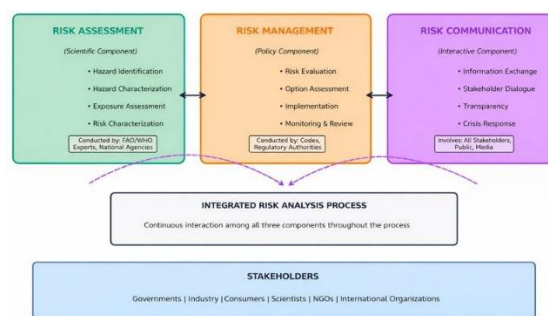


Figure 2. Risk Analysis Framework in Food Safety Governance

Risk-based approaches enable more efficient allocation of regulatory resources by focusing intensive controls on the highest-risk products, processes, and establishments while applying lighter-touch oversight to lower-risk activities (Eruaga, 2024). This prioritization is particularly important given the resource constraints facing most food safety authorities and the impossibility of inspecting every food product or establishment. However, implementing risk-based regulation requires sophisticated information systems for risk profiling, performance monitoring, and adaptive management, capabilities that remain underdeveloped in many jurisdictions. The literature emphasizes that transitioning to risk-based systems is a long-term process requiring sustained investment in data infrastructure, analytical capacity, and organizational change management.

4.2 HACCP and Food Safety Management Systems

Hazard Analysis and Critical Control Points (HACCP) represents the cornerstone of preventive food safety management, providing a systematic methodology for identifying hazards, establishing critical control points, setting critical limits, and implementing monitoring and corrective action procedures (Kumar et al., 2024). Originally developed for the U.S. space program in the 1960s, HACCP has been codified in Codex guidelines and incorporated into regulatory requirements and private standards worldwide. The strength of HACCP lies in its focus on prevention rather than end-product testing, its adaptability to diverse food operations, and its emphasis on continuous monitoring and improvement. The implementation of HACCP and broader food safety management systems (FSMS) has been extensively documented as a best practice for ensuring food safety across global supply chains (Nguyen et al., 2021). Systematic literature reviews demonstrate that certified FSMS, when properly implemented and maintained, significantly reduce food safety incidents and improve compliance with regulatory requirements. However, the effectiveness of HACCP depends critically on prerequisite programs (including Good Manufacturing Practices, sanitation, and supplier controls), management commitment, employee training, and verification procedures. Nguyen et al. (2021) emphasized that FSMS implementation is not a one-time event but an ongoing process requiring continuous improvement, adaptation to changing hazards and technologies, and integration with broader quality management systems.

The proliferation of FSMS standards and certification schemes has created both opportunities and challenges for global food safety governance. ISO 22000, FSSC 22000, and GFSI-benchmarked

schemes provide internationally recognized frameworks that facilitate trade and build confidence among supply chain partners (Film, 2023). However, the multiplicity of standards can create confusion, increase costs, and disadvantage smaller operators who lack resources for certification. Efforts to harmonize and mutually recognize different FSMS schemes, such as those undertaken by GFSI, represent important steps toward reducing duplication while maintaining high standards. The literature suggests that the future evolution of FSMS will increasingly incorporate digital technologies for real-time monitoring, data analytics for predictive risk management, and integration with traceability systems.

4.3 Traceability and Digital Technologies

Traceability, the ability to track food products and their ingredients through all stages of production, processing, and distribution, has become a fundamental requirement for effective food safety management in globalized supply chains (Ayeni et al., 2024). Robust traceability systems enable rapid identification of contamination sources during incidents, targeted recalls that minimize economic losses and consumer exposure, and verification of supplier compliance with food safety requirements. The literature emphasizes that traceability is not merely a technical capability but a governance mechanism that creates accountability, deters fraud, and builds consumer confidence in food safety systems. Digital technologies are transforming the possibilities for food traceability and supply chain transparency. Blockchain technology offers the potential for immutable, distributed ledgers that record transactions and product movements across supply chains, creating unprecedented visibility and reducing opportunities for fraud or falsification (Eruaga, 2024). Internet of Things (IoT) sensors enable real-time monitoring of temperature, humidity, and other critical parameters during storage and transport, providing early warning of conditions that could compromise food safety. Artificial intelligence and machine learning algorithms can analyze vast datasets to identify patterns, predict risks, and optimize control strategies (Ayeni et al., 2024). These technologies are moving from pilot projects to operational deployment, though widespread adoption faces barriers including implementation costs, interoperability challenges, and concerns about data security and privacy.

The ethylene oxide incident analyzed by Kowalska et al. (2022) illustrated both the value and limitations of current traceability systems. While traceability enabled identification of affected products and facilitated recalls, the process was complicated by incomplete records, multiple

intermediaries, and lack of interoperability between different tracking systems. The authors argued that next-generation traceability systems incorporating blockchain and other digital technologies could significantly enhance incident response capabilities, but only if accompanied by governance frameworks that mandate participation, ensure data quality, and protect confidential business information. The literature suggests that realizing the full potential of digital traceability requires not only technological innovation but also regulatory mandates, industry standards, and public-private collaboration to create interoperable, end-to-end systems.

4.4 Public-Private Collaboration Models

The complexity of global food supply chains and the limitations of purely regulatory approaches have driven the evolution of collaborative governance models that leverage the capabilities and resources of both public and private actors (Film, 2023). Public-private partnerships in food safety take multiple forms, including information sharing networks, joint surveillance programs, co-regulatory arrangements, and multi-stakeholder initiatives for capacity building and standard development. These collaborations recognize that industry possesses detailed knowledge of supply chains, technologies, and operational practices that regulators cannot replicate, while government retains essential functions of standard-setting, enforcement, and protection of public interest. The Global Food Safety Initiative exemplifies the potential of industry-led collaboration to drive continuous improvement in food safety practices while complementing regulatory oversight (Film, 2023). GFSI's benchmarking of certification schemes has created a common language and framework for food safety management across diverse supply chains and geographies, reducing audit duplication and facilitating market access for certified suppliers. Beyond benchmarking, GFSI has evolved to address capacity building, particularly in developing countries, and to create dialogue between industry and regulators on implementation of Codex standards and emerging food safety challenges. This evolution reflects recognition that effective governance requires not only standards and audits but also sustained investment in knowledge sharing, training, and institutional development.

The ethylene oxide incident demonstrated how private sector testing and auditing can complement official controls in detecting and responding to food safety problems (Kowalska et al., 2022). Company testing programs identified contamination that might have escaped detection through routine regulatory surveillance, while private audit data helped define the scope of affected

products. However, the incident also revealed coordination challenges and the need for more systematic integration of private and public data streams. Kowalska et al. (2022) proposed reflexive governance models that would formalize public-private collaboration, establish protocols for data sharing during incidents, and leverage emerging technologies to create more transparent and responsive food safety systems. The literature emphasizes that successful public-private collaboration requires clear governance frameworks that define roles, responsibilities, and accountability mechanisms (Eruaga, 2024). Concerns about regulatory capture, conflicts of interest, and the potential for private standards to serve commercial rather than public health objectives necessitate safeguards including regulatory oversight of certification bodies, transparency in standard-setting processes, and mechanisms for stakeholder input. When properly structured, public-private partnerships can enhance the effectiveness, efficiency, and legitimacy of food safety governance by combining regulatory authority with industry expertise and resources.

5. Risk Communication Strategies in Food Safety Governance

5.1 Evidence-Based Communication Frameworks

Risk communication has evolved from a peripheral concern to a central pillar of food safety governance, recognized as essential for building public trust, enabling informed decision-making, and supporting effective risk management (Heppner et al., 2022). The European Food Safety Authority has been at the forefront of developing evidence-based approaches to risk communication, emphasizing the need to ground communication strategies in systematic audience analysis, behavioral science, and evaluation of communication effectiveness. Heppner et al. (2022) outlined a framework for evidence-based risk communication that integrates audience research, message testing, channel selection, and impact assessment throughout the communication process. Effective risk communication requires understanding the diverse information needs, risk perceptions, and communication preferences of different audience segments (Smith et al., 2021). EFSA has identified distinct audience clusters for EU food safety risk communication, including policymakers, risk managers, media, healthcare professionals, educators, and various consumer segments. Each cluster requires tailored content strategies, communication channels, and engagement approaches. For example, communication with policymakers emphasizes scientific evidence and policy implications, while consumer communication focuses on practical guidance and addresses emotional and cultural dimensions of food risk perceptions. This audience-centered

approach contrasts with traditional one-size-fits-all communication that often fails to resonate with intended recipients or achieve behavioral change objectives.

Table 1. Evidence-Based Risk Communication Process

Step	Title	Key Activities
1	Planning	- Define objectives - Identify stakeholders
2	Audience	- Segment audiences - Assess perceptions
3	Messaging	- Evidence-based - Clear & accessible
4	Channels	- Traditional media - Digital/social media
5	Delivery	- Coordinate timing - Multi-channel release
6	Monitoring	- Track reach - Assess understanding
7	Evaluation & Feedback	- Measure effectiveness - Gather feedback - Identify improvements

The integration of behavioral science insights into risk communication represents an important evolution in food safety governance. Research on risk perception demonstrates that public responses to food safety information are shaped not only by objective hazard characteristics but also by factors including trust in information sources, perceived control, familiarity with hazards, and media framing (Duru, 2023). Effective communication must address these psychological and social dimensions, not merely transmit technical information. This requires communication professionals with expertise in social science, message design, and stakeholder engagement—capabilities that remain underdeveloped in many food safety authorities. Smith et al. (2021) emphasized that building these capabilities requires sustained investment in training, recruitment

of communication specialists, and organizational cultures that value communication as a core function rather than an afterthought.

5.2 Stakeholder Engagement and Transparency

Transparency in risk assessment and decision-making processes has become a fundamental expectation in contemporary food safety governance, driven by demands for accountability, concerns about regulatory capture, and recognition that public trust depends on openness (Petrenko et al., 2021). Codex and regional authorities have implemented various transparency mechanisms, including public consultations on draft standards, publication of scientific opinions and supporting data, and stakeholder participation in advisory committees. However, the literature identifies persistent challenges in achieving meaningful transparency, including the technical complexity of risk assessments, the volume of information generated, and tensions between transparency and protection of confidential business information. Stakeholder engagement extends beyond transparency to encompass active participation of diverse actors in risk assessment, risk management, and communication processes (Eruaga, 2024). Multi-stakeholder approaches recognize that effective food safety governance requires input from industry, consumer organizations, academic researchers, and civil society, each bringing distinct perspectives, expertise, and legitimacy. Structured engagement mechanisms, such as advisory committees, public consultations, and multi-stakeholder platforms, can improve the quality of risk assessments by incorporating diverse knowledge sources, enhance the legitimacy and acceptability of risk management decisions, and build shared understanding of food safety challenges and trade-offs.

The literature emphasizes that meaningful stakeholder engagement requires more than token consultation; it demands genuine dialogue, responsiveness to input, and clear explanation of how stakeholder contributions influenced decisions (Duru, 2023). This is particularly important when risk management decisions involve value judgments or trade-offs that extend beyond purely scientific considerations. For example, decisions about acceptable risk levels, the application of precautionary principles, or the balance between food safety and other objectives (such as nutrition, sustainability, or cultural food practices) inherently involve societal values that cannot be resolved through science alone. Transparent articulation of these value dimensions and inclusive deliberation about them can enhance the legitimacy of governance decisions even when stakeholders disagree about outcomes.

5.3 Crisis Communication and Incident Response

Food safety incidents, from localized outbreaks to transboundary contamination events, test the effectiveness of risk communication systems and can have lasting impacts on public trust and market confidence (Kowalska et al., 2022). Crisis communication during incidents requires rapid dissemination of accurate information to protect public health, coordination among multiple agencies and jurisdictions, management of media attention, and maintenance of credibility under conditions of uncertainty and evolving information. The literature identifies several best practices for crisis communication, including pre-established communication protocols, designated spokespersons with appropriate training, proactive rather than reactive communication, acknowledgment of uncertainty, and consistent messaging across agencies and jurisdictions. The ethylene oxide incident illustrated the complexity of crisis communication in globalized food supply chains involving multiple countries, regulatory authorities, and private actors (Kowalska et al., 2022). Effective response required coordination between EU member states, communication with industry about testing and recall procedures, and public messaging about health risks and product identification. Challenges included managing public anxiety about a relatively unfamiliar contaminant, addressing inconsistencies in risk assessment approaches across jurisdictions, and maintaining transparency about the scope and evolution of the incident. The authors emphasized that crisis communication effectiveness depends not only on communication skills but also on the underlying governance infrastructure, including surveillance systems for early detection, traceability for rapid source identification, and established relationships among regulatory authorities and industry.

Digital and social media have fundamentally altered the landscape of crisis communication, creating both opportunities and challenges for food safety authorities (Smith et al., 2021). Social media enables rapid, direct communication with large audiences and real-time monitoring of public concerns and misinformation. However, it also accelerates the spread of inaccurate information, amplifies emotional responses, and creates expectations for immediate official responses that may be difficult to meet during evolving incidents. Smith et al. (2021) argued that food safety authorities must develop digital communication capabilities, including social media monitoring, rapid response protocols, and strategies for countering misinformation while maintaining scientific credibility. This requires not only technical skills but also organizational

agility and willingness to engage in more informal, conversational communication styles appropriate to digital platforms.

6. Emerging Trends and Future Directions

6.1 Digitalization and Technological Innovation

The digital transformation of food systems represents one of the most significant trends shaping the future of food safety governance. Beyond the traceability applications discussed earlier, digital technologies are enabling new approaches to hazard detection, risk prediction, and regulatory oversight (Ayeni et al., 2024). Whole genome sequencing of foodborne pathogens allows precise identification of contamination sources and detection of outbreak clusters that would be missed by traditional methods. Predictive analytics using machine learning can identify high-risk establishments or products based on historical data, inspection results, and environmental factors, enabling more targeted allocation of regulatory resources. Remote sensing and satellite imagery can monitor environmental conditions relevant to food safety, such as water quality in aquaculture areas or agricultural practices in crop production regions. The integration of these technologies into food safety governance faces multiple challenges, including high implementation costs, requirements for specialized expertise, concerns about data security and privacy, and regulatory lag in adapting oversight frameworks to new technologies (Ayeni et al., 2024). The literature emphasizes that realizing the potential of digital technologies requires not only technical innovation but also governance frameworks that address data ownership, access, and use; standards for interoperability and data quality; and mechanisms for ensuring that technological capabilities do not exacerbate inequalities between well-resourced and resource-constrained actors. Public-private partnerships may play important roles in developing and deploying digital food safety technologies, but must be structured to ensure that public health objectives remain paramount.

Artificial intelligence and automation are beginning to transform food safety management at the operational level, from automated monitoring systems in food processing facilities to AI-powered inspection tools that can detect contamination or quality defects more rapidly and consistently than human inspectors (Eruaga, 2024). These technologies promise to enhance the effectiveness and efficiency of food safety controls, but also raise questions about validation, accountability, and the

appropriate balance between automated systems and human judgment. The literature suggests that the adoption of AI in food safety will be gradual and will require careful attention to validation, transparency in algorithmic decision-making, and maintenance of human oversight for critical decisions.

6.2 One Health and Systems Approaches

The One Health concept, recognizing the interconnections among human, animal, and environmental health, is gaining traction as a framework for food safety governance, particularly for zoonotic diseases and antimicrobial resistance (Nguyen et al., 2022). Many foodborne pathogens originate in animal populations or environmental reservoirs, and effective control requires interventions across the entire food chain from primary production through consumption. One Health approaches emphasize cross-sectoral collaboration among human health, veterinary, agricultural, and environmental authorities; integrated surveillance systems that track hazards across domains; and recognition that food safety interventions must consider broader ecological and sustainability implications. Implementing One Health approaches in food safety governance requires overcoming significant institutional and disciplinary barriers. Food safety authorities typically focus on post-harvest controls and may have limited engagement with agricultural production practices, animal health programs, or environmental management. Nguyen et al. (2022) argued that effective One Health governance requires new institutional arrangements that facilitate cross-sectoral coordination, integrated data systems that enable tracking of hazards across domains, and workforce development to build capacity for interdisciplinary collaboration. The COVID-19 pandemic has heightened awareness of the importance of One Health approaches and may catalyze investments in the infrastructure and coordination mechanisms needed to operationalize this concept.

Systems thinking more broadly offers valuable perspectives for addressing the complexity and interconnectedness of contemporary food safety challenges (Albisinni, 2023). Rather than focusing narrowly on individual hazards or control points, systems approaches examine the relationships, feedback loops, and emergent properties of food systems as wholes. This perspective can reveal unintended consequences of interventions, identify leverage points for systemic change, and support more holistic approaches to food safety that consider interactions with nutrition, sustainability, and equity objectives. However, translating systems thinking into practical

governance tools and decision-making frameworks remains an ongoing challenge requiring further research and experimentation.

6.3 Regulatory Deference and Equivalence

The development of international standards and guidance on regulatory deference and equivalence represents an important but underutilized mechanism for facilitating trade while respecting national regulatory autonomy (Wearne et al., 2024). Equivalence recognizes that different regulatory approaches can achieve comparable levels of food safety protection, allowing countries to accept imports subject to exporting country controls that differ from but are equivalent to importing country requirements. Codex has developed detailed guidance on equivalence concepts, procedures for equivalence assessment, and principles for equivalence agreements. However, implementation remains limited, with few countries having established systematic frameworks for equivalence assessment or concluded comprehensive equivalence agreements.

Wearne et al. (2024) argued that expanded use of equivalence mechanisms could yield significant benefits for global food security and trade facilitation, particularly for developing countries seeking to access international markets. Equivalence agreements can reduce compliance costs by eliminating the need for exporters to meet multiple, potentially conflicting regulatory requirements. They can also support capacity building by focusing attention on outcomes (achieving equivalent levels of protection) rather than prescriptive compliance with specific regulatory approaches. However, equivalence assessment is technically demanding, requiring detailed understanding of both regulatory systems, robust data on their performance, and mechanisms for ongoing monitoring and verification. The literature identifies several barriers to wider adoption of equivalence mechanisms, including concerns about regulatory sovereignty, administrative complexity and resource requirements for equivalence assessment, lack of trust between regulatory authorities, and political sensitivities around accepting foreign regulatory oversight (Wearne et al., 2024). Addressing these barriers requires sustained diplomatic engagement, technical cooperation to build mutual understanding of regulatory systems, and development of practical tools and guidance for equivalence assessment. Regional trade agreements and bilateral partnerships may provide frameworks for piloting equivalence approaches and building the experience and confidence needed for broader application. The literature suggests that equivalence represents an important frontier for evolving food safety

governance toward more flexible, outcome-oriented approaches that can accommodate regulatory diversity while maintaining high levels of protection.

7. Conclusion

This conceptual review has examined the multilayered architecture of food safety governance in global supply chains, analyzing regulatory frameworks, persistent challenges, best practices, and emerging trends. The analysis reveals that effective food safety governance depends on the integration of multiple elements: science-based risk assessment, transparent risk communication, adaptive regulatory frameworks, public-private collaboration, and technological innovation. International standard-setting through Codex Alimentarius provides essential harmonization and facilitates trade, but implementation varies considerably across jurisdictions reflecting differences in capacity, priorities, and contexts. Persistent challenges including capacity deficits, supply chain complexity, fragmented surveillance systems, and trade-sovereignty tensions constrain the effectiveness of current food safety systems. Addressing these challenges requires sustained investments in scientific infrastructure, human resources, and institutional coordination; development of interoperable data systems and traceability mechanisms; and governance frameworks that balance harmonization with flexibility for national adaptation. The literature emphasizes that strengthening food safety governance is not a one-time reform but an ongoing process of learning, adaptation, and improvement in response to evolving hazards, technologies, and supply chain configurations.

Best practices in food safety management center on risk-based regulation, HACCP and food safety management systems, robust traceability, and collaborative governance models that leverage both public authority and private sector capabilities. However, the effectiveness of these practices depends critically on implementation quality, organizational capacity, and enabling governance frameworks. The proliferation of private standards and certification schemes has driven improvements in food safety practices but also created challenges related to costs, complexity, and equity. Future evolution of food safety governance will likely involve greater integration of public and private systems, supported by digital technologies that enable real-time data sharing and enhanced transparency. Risk communication has emerged as a critical yet often underutilized component of food safety governance. Evidence-based communication frameworks that

incorporate audience analysis, behavioral science insights, and systematic evaluation can enhance the effectiveness of risk communication in supporting informed decision-making and building public trust. Stakeholder engagement and transparency are essential for the legitimacy of governance decisions, particularly when those decisions involve value judgments that extend beyond purely scientific considerations. Crisis communication during food safety incidents requires pre-established protocols, coordination among multiple actors, and digital communication capabilities to manage rapidly evolving information environments.

Emerging trends including digitalization, One Health approaches, and regulatory equivalence mechanisms offer promising pathways for strengthening food safety governance. Digital technologies enable new capabilities for traceability, risk prediction, and regulatory oversight, but their adoption requires addressing challenges related to costs, interoperability, data governance, and equity. One Health approaches recognize the interconnections among human, animal, and environmental health and call for cross-sectoral collaboration and integrated surveillance systems. Equivalence mechanisms could facilitate trade and support capacity building by focusing on outcomes rather than prescriptive regulatory approaches, but their wider adoption requires overcoming technical, political, and institutional barriers. Several priorities emerge from this review for future research and policy development. First, there is a need for more systematic evaluation of the effectiveness of different governance approaches, risk communication strategies, and technological interventions in achieving food safety outcomes. Much of the current literature is descriptive or conceptual; rigorous empirical research on what works, for whom, and under what conditions would strengthen the evidence base for policy decisions. Second, research is needed on how to design and implement governance frameworks that effectively integrate public and private systems, leverage digital technologies, and operationalize One Health approaches. Third, attention should focus on equity dimensions of food safety governance, including how to ensure that standards and technologies do not create barriers for small-scale producers and suppliers in developing countries.

Fourth, there is a need for research on risk communication effectiveness, including how to tailor messages for diverse audiences, counter misinformation, and use digital platforms effectively while maintaining scientific credibility. Fifth, research should examine the political economy of food safety governance, including how power relationships, economic interests, and institutional

dynamics shape standard-setting, implementation, and enforcement. Finally, research is needed on the governance implications of emerging food technologies, including novel foods, alternative proteins, and gene-edited crops, which may challenge existing regulatory frameworks and require new approaches to risk assessment and management. Food safety governance in global supply chains requires sophisticated, adaptive systems that integrate scientific risk assessment, transparent communication, collaborative partnerships, and technological innovation. While significant progress has been made in developing international standards and strengthening national systems, persistent challenges and emerging trends demand continued evolution of governance frameworks and practices. The literature reviewed here provides a foundation for understanding current approaches and identifying priorities for future development, but also highlights the need for ongoing research, experimentation, and learning to address the complex and dynamic challenges of ensuring safe food in an interconnected world.

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