https://doi.org/10.17113/ftb.64.01.26.9508 review

SI dedicated to Prof. Vladimir Mrša

Modern Food Systems Challenged by Food Safety Culture

Running title: The Impact of Food Safety Culture

Mojca Jevšnik Podlesnik[1] and Peter Raspor[2*]

[1]Department of Sanitary Engineering Research, Faculty of Health Sciences, University of Ljubljana, Slovenia
[2]Emeritus Professor of Microbiology and Biotechnology, University of Ljubljana, Slovenia

Received: 30 November 2025
Accepted: 29 January 2026

SUMMARY

Despite decades of regulatory development, standardized food safety management systems, and technological advances, foodborne outbreaks, recalls, and food fraud continue to pose significant public health and societal challenges. These persistent failures increasingly reveal systemic vulnerabilities that cannot be explained by deficiencies in legislation or formal control mechanisms alone. Instead, they highlight the critical role of human behaviour, organizational culture, and socio-technical interactions within modern, complex agri-food networks. Food safety culture has therefore emerged as a key determinant of food safety performance, linking regulatory frameworks with everyday practices in food establishments. While HACCP-based systems clearly define procedures and responsibilities, their effectiveness remains limited when behavioural consistency, leadership commitment, communication, and resource availability are weak. Research consistently shows that even well-designed systems remain insufficiently monitored when organizational alignment and behavioural adherence are lacking, allowing deviations from safe practices to persist. Contemporary

*Corresponding author:
E-mail: Peter.raspor@guest.arnes.si

approaches move beyond compliance-driven models toward cultural transformation, emphasizing leadership engagement, effective risk communication, learning-oriented environments, and evidence-based behavioural interventions. Increasingly, digital tools and real-time monitoring systems support this transition by strengthening feedback, transparency, and adaptive risk management across food systems. Strengthening food safety culture therefore requires coordinated, multi-level action that integrates governance, technology, and human-oriented approaches. Such transformation is essential not only for improving food safety outcomes but also for protecting public health, maintaining consumer trust, and enhancing the long-term resilience and sustainability of modern food systems.

Keywords: food safety; human factor; food safety culture; human behaviour; food systems; good practices

INTRODUCTION

Food safety represents one of the most critical public health challenges of our time. Foodborne diseases represent a substantial global public health burden. It is estimated that each year approximately 600 million people worldwide fall ill after consuming contaminated food, resulting in around 420,000 deaths annually. In addition to health impacts, foodborne diseases impose considerable economic and social costs, particularly in low- and middle-income countries. [*1*]. While technological advances and regulatory frameworks have significantly improved food safety systems, the human element remains the most vulnerable component in the food safety chain. In Europe, the latest data from the European Food Safety Authority (EFSA) [*2*] reveals concerning trends. In 2023, 148,181 campylobacteriosis cases were reported, marking an increase from 139,225 in 2022. After campylobacteriosis, salmonellosis was the second most reported gastrointestinal infection in humans, with 77,486 cases, compared to 65,478 cases in 2022 [*2*]. In 2023, listeriosis cases reached their highest level since 2007, while campylobacteriosis and salmonellosis remained the most frequently reported zoonotic diseases in the EU [European Centre for Disease Prevention and Control (ECDC) [*3*]. This trend is particularly concerning given Europe's aging population, as elderly individuals face higher risks of severe symptoms of foodborne illnesses. When we add chemical and physical hazards to the microbiological dimension of food safety, we face a truly multifaceted challenge for tomorrow's global food supply.

Systemic vulnerabilities

These persistent challenges expose a fundamental paradox: despite increasingly sophisticated regulatory frameworks and technological capabilities, food safety incidents continue to occur at alarming rates. This paradox reflects the complex interplay between biological hazards, including microbial adaptation and survival mechanisms, and socio-technical dynamics that characterize contemporary food systems already for some time [*4,5*] and even more intensive in since world food safety day was established [*6*]. Food safety failures rarely stem from a single cause; rather, they emerge from the intricate interplay between human behaviour, organizational culture, technological systems, and regulatory pressures. Understanding these dynamics is essential for identifying systemic vulnerabilities – the weak points where formal compliance diverges from actual practice, where communication breaks down across supply chain nodes, and where economic pressures compromise safety protocols. These vulnerabilities are not merely technical glitches to be fixed, but rather symptomatic of deeper cultural and organizational patterns that institutional frameworks alone cannot address. The evolution of food safety governance reflects this growing recognition of complexity. From the early days of command-and-control regulation focused on end-product testing, we have moved toward preventive, system-based approaches embodied in frameworks like Hazard Analysis and Critical Control Point (HACCP) system [*7*] and, more recently, risk-based verification systems that integrate transparency and sustainability principles [*8,9*].

However, the operationalization of these legislative frameworks within contemporary agri-food networks reveals significant implementation gaps. Modern food supply chains are characterized by unprecedented complexity: globalized sourcing, multiple intermediaries, rapid product turnover, and diverse stakeholder ecosystems. In this context, traditional regulatory approaches that assume linear, hierarchical control structures often prove inadequate. The challenge is no longer simply ensuring compliance with prescribed standards but rather fostering adaptive capacity and collective responsibility across decentralized, networked organizations [*10*].

This reality necessitates a fundamental shift from the institutionalization of food safety culture to genuine cultural transformation within food systems. Institutionalization – the establishment of formal policies, procedures, and compliance mechanisms – represents a necessary but insufficient condition for sustainable food safety. True cultural transformation requires moving beyond procedural compliance toward the internalization of food safety values at all organizational levels, the development of proactive rather than reactive mindsets, and the creation of learning cultures that continuously adapt to emerging risks. This transformation must bridge the gap between the "work-as-imagined" in regulations and procedures and the "work-as-done" in actual food handling

environments, addressing the socio-technical realities that create systemic vulnerabilities while operationalizing food safety principles in ways that resonate with the distributed, networked nature of contemporary agrifood systems [*11*].

FROM INSTITUTIONALIZATION OF FOOD SAFETY CULTURE TO CULTURAL TRANSFORMATION IN FOOD SYSTEMS

Despite sophisticated HACCP systems and advanced food processing technologies, human behaviour consistently emerges as the primary risk factor in food contamination incidents [*12*]. This vulnerability manifests across multiple stages of food production and consumption chains often connected to different attitudes specific to different professions along food production chains [*13*]. For more than two decades, the food industry has operated under the paradigm of comprehensive supply chain oversight, captured in slogans such as "From farm to fork" and "From stable to table" [*14*]. However, structural and political changes have not adequately supported the essence of this development. The persistent gap between regulatory ambition and operational reality reveals a fundamental truth: institutional frameworks alone cannot guarantee food safety [*15*]. Despite assurances from proponents of structured systems that technical controls would suffice, operational challenges were evident from early implementation phases [*16, 17, 18*].

The most crucial element remains and will continue to be - the human factor, with all its rational and emotional characteristics that dictate behaviour in practical circumstances at each step of food production, processing, distribution, preparation, and delivery. This recognition marks a critical shift from viewing food safety culture as merely an institutional requirement to understanding it as a dynamic, lived reality that must be actively cultivated and sustained [*19*].

The emergence of food safety culture as a critical research domain

The emergence of food safety culture reflects a broader shift from purely technical and compliance-based approaches toward the recognition of human and organizational factors as central determinants of food safety performance [*13,20,21*]. This conceptual transition has recently been formalized within the European regulatory framework through Commission Regulation (EU) 2021/382, which amended Regulation (EC) No 852/2004 by explicitly introducing food safety culture as a mandatory component of food business operations [*8*].

By requiring food business operators to establish, maintain, and provide evidence of an appropriate food safety culture, the regulation represents a significant regulatory milestone. It moves beyond traditional hazard control and documentation toward expectations related to leadership

commitment, employee awareness, communication, and shared responsibility for food safety outcomes [*22,23,24*]. Importantly, the regulation acknowledges that formal food safety management systems alone are insufficient if they are not supported by consistent behaviours and organizational alignment in everyday practice [*15,25*].

However, while Regulation (EU) 2021/382 provides regulatory legitimacy to the concept of food safety culture, it deliberately leaves its operationalization open to interpretation. The absence of prescriptive criteria, standardized indicators, or validated assessment tools places responsibility for implementation largely on food business operators and competent authorities. This regulatory flexibility allows context-specific adaptation but also introduces challenges related to consistency, monitoring, and enforcement across diverse food systems [*11,26*].

Consequently, regulation reinforces the need for interdisciplinary approaches that integrate regulatory compliance with behavioural science, organizational learning, and leadership practices [*27,28*]. Food safety culture thus emerges not merely as a regulatory requirement, but as a dynamic socio-technical construct linking governance frameworks with human behaviour and organizational performance.

The behavioural dimension of food safety is complex and multifaceted

The consistency, accuracy, and correctness with which employees perform defined tasks and work procedures are influenced by multiple interacting factors: individual knowledge and motivation [*12*], competence levels, understanding of food safety principles, hygienic awareness, attitude towards work, job satisfaction, self-efficacy, and the availability of temporal, human, and material resources [*29, 30, 31*]. In a broader organizational view, food safety culture also depends on the effectiveness of HACCP-based management system implementation, company policy, management commitment and leadership quality, employee awareness levels, communication patterns, work environment characteristics, resource availability, and the processes of risk factor identification and assessment. In this context, risk management must remain dynamically responsive to a rapidly evolving global environment marked by continual emergence of new challenges and conflicts [*25*]. This requirement reflects not transient concern but an enduring, structural challenge [*32*].

The persistent challenge: from knowledge to practice

Past research clearly demonstrates that, despite continuous education efforts, food safety assurance systems remain insufficiently monitored and imperfectly controlled due to inherent risks associated with the human nature of work [*33,30,31*]. This reveals a critical distinction between knowing what should be done and consistently doing it. Food safety assurance is fundamentally

related to how individuals who handle food behave in ways that represent minimal risk to food products and, consequently, to human health [*22,20*].

Training represents an important social element in bridging this knowledge-practice gap, ensuring that necessary information is correctly understood by users [*34*] and effectively applied in practice [*35*]. Food business operators must ensure regular, ongoing training of employees [*36*]. However, training alone is insufficient. The learning process must influence individual behaviour to create reliable and aware workers who conscientiously perform their food safety tasks [*22,30,36*]. This transformation from trained employee to intrinsically motivated food safety practitioner represents the essence of cultural change [*25*].

FROM COMPLIANCE TO CULTURE: THE EVOLUTION OF FOOD SAFETY STANDARDS

Food business operators today navigate a complex landscape of requirements that extends far beyond mandatory legislative compliance. In addition to legal obligations, many organizations implement additional requirements defined in various national, international, and private standards [*37*]. These voluntary commitments aim to raise employee awareness and knowledge, better control risk factors when working with food, and ensure quality and safe products [*38*].

However, the voluntariness of these enhanced standards reveals an important cultural division. For food business operators with a high level of food safety culture, implementing these standards represents an ambitious, self-motivated pursuit of excellence. For those with a low level of culture, implementation is often imposed externally. This external imposition has emerged primarily due to changed business practices and power dynamics within food supply chains, manifested in contractual requirements where buyers condition business relationships with producers on establishing certified standards [*29,39,40*].

The rise of private label products has further complicated this landscape

Some retailers now order food products under their own brands from specific producers, effectively transferring the responsibility for producing safe and quality food from the producer or supplier to the retailer or buyer [*41*]. To protect their reputation and brand equity [*42*], retailers often require stricter and more comprehensive preventive measures for private label products than legislation itself mandates, thereby raising the bar for food safety assurance across their supply chains. This market-driven elevation of standards has catalyzed in-depth research to discover weak points that could endanger food production from quality or safety perspectives [*36*].

The institutionalization paradox

This evolution of standards and requirements creates a paradox: the very institutionalization of food safety culture through proliferating standards, certifications, and audits may inadvertently undermine the development of genuine cultural transformation [*43*].

When food safety culture becomes primarily a matter of documented compliance - checkbox exercises, audit preparation, and certification maintenance it risks becoming disconnected from the daily lived experience of food handlers and the intrinsic values that should guide their behaviour [*44*].

Genuine cultural transformation requires moving beyond this institutionalized approach. Organizations must shift from extrinsic motivation, such as avoiding penalties and passing audits, to intrinsic motivation characterized by personal commitment to food safety. This transformation also demands moving from procedural compliance to adaptive expertise that enables employees to respond effectively to novel situations. Furthermore, companies need to transition from top-down enforcement approaches to distributed ownership of food safety outcomes across all organizational levels. Finally, organizations must evolve from static documentation systems to dynamic learning systems that continuously improve and adapt to changing circumstances. The challenge facing contemporary food systems is therefore not simply implementing more rigorous standards or conducting more frequent audits but rather fostering authentic cultural change that embeds food safety values deeply within organizational DNA and individual professional identity. This transformation must bridge the persistent gap between "work-as-imagined" in regulations and standards and "work-as-done" in the messy realities of daily food handling operations [*23,21*]. This paradox is one that the European Union is actively attempting to address through intensive educational initiatives aimed at strengthening the competencies of professionals working within governmental food safety structures across Member States [*45,46*].

The role of human behaviour in food safety

Food legislation provides a legal framework for implementing regulations designed to guide and manage risks and ensure food safety throughout the entire food chain [*47*]. This significantly affects public health [*48*] and defines the responsibility of food business operators, supervisory bodies and consumers [*41,49*].

Today, food-borne infections and/or poisoning still represent a significant proportion of illnesses, particularly viral foodborne diseases, which are increasingly coming to the forefront [*24*]. Contributing factors include the development of novel food products designed to meet consumer

demand for innovation, often based on traditional substrates but produced, handled, or consumed in new ways that introduce additional safety challenges [*50*].

Foodborne viral infections remain a significant public health concern due to interacting with changes in food systems and consumption practices. Evidence shows that viruses are increasingly associated with minimally processed and ready-to-eat foods, traditional raw materials used in novel product formats, and consumption contexts that limit the effectiveness of conventional control measures. These risks are amplified by globalized food supply chains, increased consumption of food prepared outside the home, reduced use of preservatives, demographic shifts toward more vulnerable populations, and persistent gaps in food handling knowledge at the household level, allowing foodborne viruses to persist despite existing controls [*51*].With the implementation of the HACCP system for food safety assurance, the control of risk factors, including chemical and physical ones, has significantly improved [*52*]. HACCP is a food safety assurance system based on preventive measures for preventing and controlling hazard factors [*53,54*]. However, other aspects must also be considered, such as food safety culture, which is manifested in employee behaviour when working with food [*41,24,54*]. The HACCP system can be even more effective with certification procedures of voluntary Global food safety initiative [GFSI] group standards [*29*], but only if these systems are embedded within company policy and translated into well-organized daily practices in food establishments [*55*] as well as in food handling practices at home [*56*].

Employees in food business establishments play a crucial role in ensuring food safety [*57*]. Some have identified demographic characteristics as reasons for errors and mistakes when working with food [*36,58*], lack of time, money and other resource availability [*59,60*], workplace pressure [*36*], competence, motivation and employee satisfaction [*35,61*]. Observation of employees working with food has shown that employees demonstrate sufficient knowledge about food safety assurance and included standards, but it is not necessarily the case that they always work this way in practice [*33,62,63*]. Therefore, it is very important in food companies to establish a high level of food safety culture that influences the correct implementation of work procedures [*22*]. This depends on elements of food safety climate from employees such as leadership, communication, commitment, risk awareness and resource availability [*64,65*] and on employee competence and education level [*66*].

Studies have shown that the knowledge, attitude, and practices of food handlers are important factors in preventing foodborne illness [*67*]. However, research consistently reveals significant gaps between theoretical knowledge and practical application. Food handlers may understand basic food safety principles but fail to implement them consistently due to time pressure, inadequate resources, or complacency [*68*] and language barriers.

Appropriate leadership encourages and guide employees to implement accompanying hygienic measures and food safety procedures in accordance with business goals, vision and company standards. Proper communication about food safety ensures transfer of practices and knowledge as well as all relevant information about food safety from management, through middle management to implementers who handle operational tasks with food. Commitment to food safety contributes to raising the values of all employees and their conviction about the correctness of food safety procedures, which must be in accordance with company policy and goals [*20*]. This must consider the factor of realistic perception of the seriousness of risk factors [*57*]. It happens that employees are aware of risks but do not control them for various reasons, which Griffith *et al.* [*20*] call "optimistic bias" and "illusion of control."

De Boeck *et al.* [*64*] believe that food safety culture consists of two conceptual aspects, namely human and technical-managerial, which ultimately result in safe and quality food. The human aspect includes two levels, namely organizational and individual. The human aspect is an interaction of food safety climate elements that is manifested in employee behaviour when working with food, while the technical-managerial aspect reflects the implemented food safety system in the company with existing control and activities [*65*].

Fatimah *et al.* [*57*] argue that strengthening food safety culture requires consistent implementation of food safety policies across all hierarchical levels, fostering collaboration between departments and generations of employees, establishing a reliable system for evaluating work performance, and ensuring effective communication about relevant risk factors. Such risk factors have been identified not only at the level of declarations [*69*], but also within legislation and regulatory frameworks, as well as in the practical, day-to-day realities of food handling environments [*70*].

Psychological and behavioural factors in food safety

Human decision-making in food safety contexts is significantly influenced by various cognitive biases that can compromise safety outcomes [*20*] what is well observed during food safety days [*71*]. Optimism bias leads individuals to believe that foodborne illness happens to others rather than themselves, creating a false sense of security that may result in neglecting proper safety protocols [*57*]. This psychological tendency is compounded by familiarity bias, where people assume that familiar foods are inherently safe regardless of how they are handled or processed. Additionally, the availability heuristic causes individuals to overestimate the risks of highly publicized food safety incidents while simultaneously underestimating more common but less newsworthy risks, leading to misallocated attention and resources in safety management [*33*].

The organizational culture within food establishments plays a crucial role in shaping individual behaviour and safety outcomes [*20,64*]. Environments that consistently prioritize productivity over safety often create conditions where risky behaviours become normalized, establishing systemic vulnerabilities throughout the operation [*36*]. When organizations fail to demonstrate genuine commitment to food safety through their policies, resource allocation, and daily practices, employees are more likely to adopt shortcuts and compromise safety standards, particularly under time pressure or when facing competing priorities [*59*].

Traditional food safety training programs frequently fail to achieve their intended behavioural outcomes due to several fundamental limitations [*33,31*]. Most conventional training approaches focus primarily on knowledge transfer rather than genuine behaviour change, assuming that increased awareness will automatically translate into improved practices [*34,72*]. These programs often lack practical application opportunities that would allow participants to practice new skills in realistic settings, and they typically fail to address workplace-specific challenges that employees face in their daily operations [*61*]. Furthermore, many training programs do not adequately account for cultural and linguistic diversity among workers, potentially excluding important segments of the workforce from effective safety education [*73*].

Contemporary research has identified several evidence-based solutions that address these psychological and organizational challenges more effectively [*65*]. Behavioural intervention strategies have shown promise, with nudging techniques involving environmental modifications that naturally promote safer behaviours without relying solely on conscious decision-making [*74*]. Social norm interventions leverage peer influence to encourage compliance by making safe behaviours more visible and socially desirable within the workplace [*57*]. Real-time feedback systems provide immediate monitoring and correction of unsafe practices, allowing for prompt behavioural adjustments before problems escalate [*62*].

Enhanced training approaches represent another critical avenue for improvement [*36*]. Competency-based training shifts focus from theoretical knowledge to demonstrable skills, ensuring that participants can perform safety procedures correctly rather than simply understanding them conceptually [*66*]. Scenario-based learning utilizes realistic situations to help workers practice decision-making skills in controlled environments, building confidence and competence for real-world applications [*63*]. Continuous reinforcement through regular refresher training and ongoing competency assessments helps maintain high safety standards over time rather than allowing skills to deteriorate after initial training [*31*].

Technology integration offers additional opportunities to strengthen food safety culture through digital monitoring systems that provide automated temperature and time tracking, reducing reliance on manual processes prone to human error [*75*]. Mobile training platforms make safety education more accessible and personalized, allowing workers to learn at their own pace and in their preferred language [*74*]. Predictive analytics can identify high-risk situations before contamination occurs, enabling proactive interventions rather than reactive responses to safety failures [*76*].

Finally, organizational culture development requires sustained commitment to leadership visibility in supporting safety priorities, creating systems that empower employees to report safety concerns without fear of retaliation, and implementing recognition programs that reward safe behaviours and safety improvements [*20,64*]. These comprehensive approaches acknowledge that effective food safety culture requires addressing both individual psychological factors and broader organizational dynamics that influence behaviour in complex, interconnected ways [*22*].

Nudge tools provide a subtle yet effective approach to improving hygiene behaviour among employees in the food industry. Štefančič and Jevšnik [*77*] conducted a case study in a retirement home, testing the effectiveness of different nudges such as storytelling about foodborne outbreaks, a thermometer image, citrus scent, and citrus scent combined with a sign on hygiene criteria. The findings show that storytelling alone had little effect, while the thermometer image significantly improved compliance with critical control points. The citrus scent combined with a sign markedly improved behaviour at all key stages of food preparation, whereas citrus scent alone had mixed effects, ranging from relaxation to distraction.

Behavioural economics research further demonstrates how nudge tools based on priming (e.g. signs, words, sensory cues) and affective triggers can influence behavioural change among food handlers. A consistent finding is that knowledge-based training alone is often insufficient to ensure sustained compliance, whereas nudge-based interventions can significantly enhance hygiene behaviour by targeting automatic responses and habitual practices. This highlights that interventions shaping choice architecture and reducing cognitive load may outperform approaches that rely primarily on deliberate decision-making [*78,79*].

Similarly, a systematized review [*80*] found that priming nudges (sensory or verbal cues), affective salience nudges (emotional triggers like disgust or appeal), messenger nudges (social norm framing), and default nudges (pre-set safer/healthier options) consistently improved food choice behaviour. Importantly, priming was effective in most cases, demonstrating the power of subtle environmental signals in shaping everyday hygiene and food-related practices. These insights underline the psychological principle that reducing cognitive load and making safe or desired

behaviours the easiest choice increases compliance and sustainability of behavioural change. In addition to classical psychological and behavioural determinants such as knowledge, attitudes, leadership, and organisational climate, contemporary organisational practice increasingly recognises the role of operational philosophies and emerging technologies in shaping employee behaviour and motivation. Lean manufacturing, with its emphasis on continuous improvement and respect for people, has been shown to influence organisational culture, employee engagement, and motivational dynamics by embedding efficiency-oriented and participatory behaviours in everyday work practices [*81*].

More recently, the integration of digital technologies—particularly Artificial Intelligence (AI)—into Lean-oriented organisations has introduced new psychological and behavioural dynamics that may affect employee performance and motivation. Empirical evidence suggests that AI adoption within Lean systems can enhance employee engagement when AI-enabled tools are perceived as supportive of human decision-making, autonomy, and skill utilisation [*82*]. In such contexts, AI may reduce repetitive workload, improve role clarity, and strengthen perceived competence, all of which are well-established drivers of motivation and performance.

However, the behavioural and psychological effects of AI are not uniformly positive. When AI is perceived as a mechanism of surveillance, control, or a threat to job security, it may increase stress, resistance, and demotivation among employees. Recent studies on AI-enabled job characteristics highlight that the impact of AI on employee well-being and performance depends strongly on implementation strategies, transparency, and the extent to which human-centred principles are maintained [*83*]. These findings suggest that both Lean Manufacturing and AI should be considered important contextual factors that interact with traditional psychological and behavioural determinants, particularly in organisational settings where employee behaviour plays a critical role in safety-related performance.

FROM LEGISLATION TO CONTEMPORARY AGRI-FOOD NETWORK OPERATIONALIZATION

The paradigm shift: from compliance to culture

The transition from compliance based food safety systems to a genuine food safety culture reflects a fundamental paradigm shift in how organizations approach risk prevention. This shift is not merely conceptual but represents a response to the changing nature of food systems themselves—from linear, hierarchical production chains to complex, networked ecosystems of suppliers, processors, distributors, and retailers [*27*]. Traditional compliance relies on external enforcement, audits, and documentation, mechanisms rooted in command-and-control regulatory models that

assume direct oversight and hierarchical authority structures. However, these mechanisms often fail to ensure consistent behaviour when direct supervision is absent, particularly in the distributed, multi-nodal environments characteristic of contemporary agri-food networks [*84*].

Recent studies highlight that food safety culture emphasizes shared values, internalized responsibility, and proactive engagement across all organizational levels [*20*]. In networked food systems, this cultural dimension becomes even more critical, as food safety outcomes depend not only on individual organizational performance but on collective coordination across multiple autonomous actors [*43*]. Leadership plays a critical role in this process, as managers must move beyond "box-ticking" compliance toward fostering ownership, communication, and continuous learning [*85*]. Research also shows that a strong food safety culture correlates with improved hygiene behaviour and reduced non-compliance, since employees are more likely to "do the right thing when no one is watching" [*28*]. Thus, the evolution from compliance to culture represents not only regulatory alignment but also a sustainable strategy for risk management and organizational resilience in increasingly complex supply chain environments.

Barriers and enablers in cultural transformation

Translating legislative intent into operational reality across contemporary agri-food networks faces significant structural challenges. Pai *et al.* [*85*] emphasize that major barriers to establishing a positive food safety culture include limited resources, difficulties in risk communication, and challenges in behavioural change. These barriers are amplified in networked settings where information must flow across organizational boundaries, where resource constraints vary dramatically between large retailers and small suppliers, and where cultural norms and practices differ across geographic and organizational contexts [*84*].

Nickell and Hinsz [*86*] and Manning [*87*] highlight the critical role of leadership and organizational commitment in fostering effective food safety cultures, noting that food safety culture has transitioned from a narrow compliance-based concept to a comprehensive organizational value essential for ensuring food safety. However, in contemporary agri-food networks, leadership must operate at multiple scales: within individual organizations, across supply chain partnerships, and at the network level where collective governance mechanisms shape behaviour [*88*]. This multi-level leadership challenge requires new forms of coordination and shared accountability that transcend traditional buyer-supplier relationships [*89*].

Contemporary trends: investment, technology and behavioural science

Current trends indicate that senior leadership commitment and investment in creating a food safety culture that prioritizes food safety and quality remains paramount for 2024 and beyond. The emphasis has shifted toward practical implementation rather than theoretical frameworks, with organizations recognizing that companies with better training and workforce development experience substantial returns: 15 percent greater employee productivity, 26 percent decreased employee turnover, 20 percent less employee absenteeism, and 65 percent greater share prices [*74*]. These metrics demonstrate that food safety culture is not merely an ethical or regulatory imperative but a strategic business advantage in competitive food markets.

Contemporary approaches to food safety culture increasingly focus on behavioural interventions and digital tools that enable operationalization at scale across distributed networks. A proven tool to improve frontline employee engagement in effective food safety behaviours is the concept of "nudging" [*48,90,91*], behavioural interventions that guide choices without restricting options [*78*]. In networked food systems, digital platforms enable nudging interventions to be deployed consistently across multiple sites and organizations, creating standardized behavioural scaffolding even in the absence of direct supervision [*79*]. Regulatory bodies like the FDA are encouraging and exploring use of new digital tools and incentives that prompt desired behaviours, such as handwashing and manual temperature monitoring [*75*].

The digitalization of food safety management represents a critical bridge between legislative frameworks and network-level operationalization. Digital traceability systems, real-time monitoring technologies, blockchain-based verification, and data analytics platforms create new possibilities for transparency, accountability, and rapid response across complex supply chains. These technologies enable traditional legislation and compliance mechanisms could not: visibility into "work-as-done" rather than merely "work-as-documented," early warning systems that detect emerging risks before they become incidents, and feedback loops that support continuous learning across network participants [*92,93*].

System level determinants of food safety culture

The evolution of food safety culture research demonstrates a shift from traditional compliance-based approaches to comprehensive behavioural and organizational transformation strategies, emphasizing the integration of technology, leadership development, and continuous improvement processes in contemporary food safety management systems [*91*]. However, the operationalization of these strategies in contemporary agri-food networks requires additional dimensions beyond individual organizational culture [*94*]. As contemporary agri-food systems grow increasingly

interconnected, the effective implementation of food safety culture initiatives can no longer rely solely on transformations within individual organizations. Instead, it requires a broader systems perspective that recognizes the interaction between organizational culture and governance structures, information flows, and adaptive capacities across the wider supply network. In this context, several additional dimensions emerge as critical for translating food safety culture principles into practice across complex, interdependent food-system structures.

Network-level governance mechanisms must complement organizational-level culture by establishing shared norms, mutual expectations, and collective accountability across supply chain participants. These mechanisms include collaborative standard-setting processes, joint auditing mechanisms, and shared investment in food safety infrastructure that benefits all network members [*95*].

Information architecture must enable transparent communication and knowledge sharing across organizational boundaries to address critical vulnerabilities in the food supply chain. Food safety incidents often result from information asymmetries or communication failures between supply chain nodes, and digital platforms combined with standardized data protocols can effectively mitigate these vulnerabilities [*96*].

Adaptive capacity must be distributed throughout the network rather than concentrated in the hands of a few powerful actors. Small and medium enterprises, which form the backbone of many food supply chains, require targeted support and resources to implement food safety culture initiatives that are commensurate with their capabilities and operational contexts.

Regulatory frameworks themselves must evolve to recognize and actively support network-level approaches to food safety. Traditional food safety legislation focuses primarily on individual business operators, but contemporary regulation must facilitate collaborative governance arrangements, incentivize information sharing across organizational boundaries, and create enabling conditions for collective learning throughout the supply chain [*97*].

The challenge of operationalizing food safety culture in contemporary agrifood networks thus extends beyond implementing standards or deploying technologies within individual organizations. It requires fundamentally rethinking how food safety is governed, monitored, and improved across complex, dynamic systems where risks emerge from interactions between multiple actors, technologies, and environments. This network-oriented approach represents the next frontier in the evolution from legislation to lived practice in food safety assurance [*43*].

Table 1 summarizes key short-term and long-term actions needed to strengthen food safety culture across seven critical organizational domains. Short-term measures focus on establishing basic

behavioural expectations, communication clarity, and initial cultural diagnostics, while long-term actions emphasize systemic integration, leadership development, and data-driven organizational learning. Together, these measures illustrate how food safety culture evolves from operational compliance toward a mature, strategically embedded organizational capability.

COMPILATION OF CURRENT FOOD SAFETY MANAGEMENT PERSPECTIVE

The role of food safety culture in shaping risks within modern food systems, while humans represent the weakest link in food safety systems, they also hold the greatest potential for improvement. This paradox encapsulates the central challenge facing contemporary food safety governance: how to transform individual human vulnerability into collective systemic resilience. Accordingly, food safety must be understood not only as a technical and regulatory domain but also as a fundamentally social and cultural phenomenon shaped by collective behaviours, organizational dynamics, and the broader context in which food systems operate [*43,98*].

Food safety is a fundamental human right, yet billions of people worldwide remain at risk of unsafe food. The persistent gap between regulatory ambition and food safety outcomes evidenced by rising foodborne illness rates even in highly regulated environments demonstrates that traditional approaches cantered on compliance and technical controls are necessary but insufficient.

Addressing human behaviour in food safety requires moving beyond the reductionist view of humans as error-prone components to be controlled, toward recognizing people as adaptive agents whose behaviour emerges from complex interactions between individual characteristics, organizational cultures, technological systems, and socio-economic pressures [*43,99*]. This requires a multifaceted approach that combines scientific understanding of behavioural psychology with practical interventions tailored to the specific contexts of food production, processing, and distribution. Critically, it demands acknowledging the socio-technical nature of food safety failures: incidents rarely result from isolated human errors but from systemic vulnerabilities where organizational pressures, resource constraints, communication breakdowns, and cultural norms create conditions in which errors become likely or inevitable. Empirical evidence supports this systems-oriented perspective, demonstrating that lower maturity of food safety culture is associated with higher costs of quality, reflecting inefficiencies, rework, and failure-related losses that stem from underlying organizational and cultural weaknesses rather than individual misconduct [*101*].

Food practices emerge from culture, history and human behaviour; technical controls alone don’t guarantee safety. Modern systems must therefore treat the human/social side as core, not peripheral [*43,91*].

From institutionalization to transformation

Success in reducing human-related food safety risks depends on moving beyond the institutionalization of food safety culture - the establishment of formal policies, standards, and compliance mechanisms toward genuine cultural transformation. As this analysis has shown, the proliferation of food safety standards, certifications, and audit requirements may paradoxically undermine authentic cultural change when they become ends in themselves rather than embedding food safety values deeply within organizational practice and professional identity [*11*].

Genuine transformation requires creating supportive organizational cultures that foster intrinsic motivation rather than relying solely on external enforcement, implementing evidence-based behavioural interventions that recognize the context-specific nature of food handling work, developing adaptive expertise that can respond to novel situations rather than merely procedural compliance, and establishing learning systems that bridge the persistent gap between "work-as-imagined" in regulations and "work-as-done" in actual operational environments [*25*].

This transformation must recognize that sustainable food safety improvements require addressing the complex interplay between individual knowledge and competence, organizational systems and leadership, technological capabilities and constraints, and the broader social, economic, and regulatory influences that shape behaviour across supply chains [*62*].

There is a persistent gap between knowledge and safe behaviour among food handlers. Our surveys and studies repeatedly show that knowledge, attitudes and self-reported practices do not always align - training alone often fails to change daily behaviour without cultural support [*33,30,31,36*].

Operationalizing culture in networked food systems

The challenge of cultural transformation is further complicated by the networked nature of contemporary agrifood systems. Food safety outcomes increasingly depend not only on individual organizational performance but on collective coordination across multiple autonomous actors: farmers, processors, distributors, retailers, and food service operators, each operating under different pressures, resources, and cultural contexts. Traditional regulatory frameworks designed for hierarchical, linear production chains prove inadequate for governing these complex, dynamic networks. Operationalizing food safety culture in this context requires multi-level interventions: network level governance mechanisms that establish shared norms and collective accountability across supply chain participants; information architectures that enable transparent communication

and knowledge sharing across organizational boundaries; distributed adaptive capacity that supports small and medium enterprises in implementing food safety improvements appropriate to their contexts; and evolved regulatory frameworks that facilitate collaborative governance and create enabling conditions for collective learning rather than focusing solely on individual compliance [*97,100*].

The digital transformation of food safety management through traceability systems, real-time monitoring, data analytics, and behavioural nudging platforms offers unprecedented opportunities to operationalize food safety culture at scale across distributed networks. However, technology alone cannot create culture; digital tools must be designed and deployed in ways that support rather than undermine human agency, expertise, and intrinsic motivation [*90*].

Food-safety culture is multidimensional and measurable, but complex. Research on dimensionality demonstrates that culture comprises several factors [leadership, communication, risk awareness, resources, routines] and that measurement requires rigorous, context-specific tools [*101*].

Modern food system trends increase the cultural challenge

Contemporary food systems are undergoing rapid transformation driven by globalization, digitalization, and changing consumption patterns. These developments have fundamentally altered how food is produced, processed, distributed, and consumed, increasing both structural complexity and behavioural demands across the food chain. Globalized sourcing and extended supply chains reduce direct oversight, increase heterogeneity in practices and standards, and amplify coordination challenges between geographically and culturally diverse actors. As a result, food safety increasingly depends on shared values, consistent behaviours, and effective communication across organizational and national boundaries rather than on centralized control alone [*75,100*].

At the same time, digital transformation has introduced new operational models such as e-commerce platforms, home delivery services, cloud kitchens, and so-called “virtual restaurants,” where food is prepared, handled, and distributed outside traditional, physically co-located establishments. These models often involve fragmented responsibilities, high staff turnover, algorithm-driven work organization, and limited face-to-face supervision, all of which place additional strain on the development and maintenance of food safety culture. In such contexts, formal procedures and documentation may exist, but their consistent enactment relies heavily on employees’ internalized commitment to food safety principles [*85,100,101*].

Further challenges arise from the introduction of novel ingredients, alternative proteins, minimally processed foods, and innovative processing technologies, which may outpace existing

regulatory frameworks and organizational learning processes. When technological and market innovation advances faster than cultural adaptation, gaps emerge between “work-as-imagined” in food safety systems and “work-as-done” in daily operations. These gaps heighten the risk that safety practices become inconsistent, especially under economic pressure, time constraints, and competitive delivery models [*26,100*].

Together, these trends significantly increase the need for robust and adaptive food safety cultures that can function effectively under conditions of uncertainty, decentralization, and rapid change. Rather than relying solely on compliance mechanisms, contemporary food systems require cultures that support shared responsibility, learning, and resilience across firms and throughout the supply chain, enabling safe practices to be sustained even when traditional supervisory and regulatory controls are limited [*26*,*102,100*].

The path forward: integrated approaches for systemic resilience

The path forward requires collaboration between food safety professionals, behavioural scientists, technology developers, and policymakers to create systems that support and enhance human performance rather than simply expecting perfection. This integrated approach must address several critical priorities that span research, practice, policy, and technology.

Research and practice must focus on understanding and addressing systemic vulnerabilities by examining the organizational, technological, and economic conditions that make errors likely rather than merely attributing failures to individual human inadequacy [*26,100*]. This shift in perspective recognizes that human error is often a symptom of deeper systemic issues that require structural solutions.

Investment in workforce development must go beyond basic food safety training to cultivate professional identity, adaptive expertise, and genuine ownership of food safety outcomes among employees. The evidence demonstrates that such investments yield substantial returns in productivity, employee retention, and overall business performance, proving that food safety culture is not merely an ethical imperative but also a strategic competitive advantage [*85*].

Regulatory innovation must complement existing legislative frameworks with enabling mechanisms that support learning, collaboration, and continuous improvement across food system networks. This includes creating safe spaces for reporting and learning from near misses without fear of punishment, incentivizing transparency and information sharing between supply chain partners, and recognizing that adaptive capacity is as important as procedural compliance in ensuring food safety [*43*].

Technological development must prioritize human-cantered design principles that enhance rather than replace human judgment in critical decision-making processes. Technology should support the development of adaptive expertise rather than deskilling workers through excessive automation, and it must create effective feedback loops that facilitate continuous learning and improvement [*65*].

Addressing food safety culture requires confronting uncomfortable truths about power, resource allocation, and responsibility distribution within food systems. Research on food safety culture determinants consistently demonstrates that behaviour is shaped not only by individual knowledge and attitudes but also by broader organizational, economic, and contextual conditions. Small producers and frontline workers, who often operate with limited resources and decision-making power, may therefore carry disproportionate responsibility for food safety outcomes while simultaneously facing economic pressures that constrain their ability to prioritize safety over productivity. Genuine cultural transformation thus requires moving beyond individual-level behaviour change to address the structural conditions and systemic inequalities that fundamentally shape food safety practices across the system [*101*].

The challenge of transforming food safety culture is ultimately a challenge of transforming food systems themselves: from compliance-focused, hierarchical structures toward learning-oriented, networked ecosystems characterized by shared values, collective accountability, and distributed resilience. Only through this systemic transformation can we move beyond treating humans as the weakest link to recognizing and cultivating their potential as the adaptive, intelligent foundation of food safety assurance [Table 2]. In doing so, we transform not only how we prevent foodborne illness but how we understand agri-food chain through the relationship between people, organizations, technology, and the complex systems that feed the world.

Table 2 presents a set of key performance indicators [KPIs] that enable systematic monitoring and incremental improvement of food safety culture. These indicators capture critical dimensions such as reporting transparency, behavioural compliance, leadership engagement, and the effectiveness of communication and training. Together, they provide organizations with quantifiable metrics that support evidence-based decision-making and strengthen food-safety culture both internally and across the supply chain.

CONCLUSIONS

Modern food systems are increasingly complex, globalized, and technologically dynamic, making food-safety culture a central pillar for ensuring safe food from farm to fork. This review, synthesizing research aligned with international authorities (EFSA, FAO, FDA, GFSI, WHO),

demonstrates that contemporary food safety depends not solely on technical controls but equally on human behaviour, organizational values, and shared responsibility.

A consistent understanding emerges across global literature: even the most advanced HACCP-based systems can fail when individuals do not internalize safe practices, communicate risks effectively, or operate within supportive leadership structures. A persistent gap between knowledge and behaviour remains evident, underscoring the critical need for continuous, context-adapted education and sustained leadership engagement.

The multidimensional nature of food safety culture encompassing attitudes, communication, risk perception, resource allocation, and social norms require systematic measurement, management, and improvement. Contemporary challenges including globalization, supply chain complexity, outsourcing, and e-commerce amplify the necessity for cultural alignment across all food system actors.

Building and sustaining robust food-safety culture represents not merely best practice but a strategic imperative for 21st century food systems. As global megatrends intensify and food systems continue to evolve, sustained safety can only be achieved through the deliberate integration, continuous monitoring, and adaptive improvement of both technical controls and cultural dimensions across every stage of production and supply networks. Only through this holistic approach can the global food supply remain safe, resilient, and trustworthy for future generations.

ACKNOWLEDGMENTS

MJP and PR would like to express their gratitude to the many students and colleagues at the University of Ljubljana who contributed to the realization of numerous studies over the past 20 years. They are colleagues, and there are friends. Some of them remain with us forever. Professor Vladimir Mrša united both of these roles in our decades of collaboration. I believe that a part of what we achieved together has been shared with the broader community for a better tomorrow.

FUNDING

We are grateful for the financial support provided by Slovenian Research Agency research (core funding No. P3-0388) and European funding agencies, which made the research reviewed in this publication possible.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The manuscript is original. No part of the manuscript has been published before, nor is any part of it under consideration for publication in another journal.

AUTHORS' CONTRIBUTION

M. Jevšnik Podlesnik was responsible for the conception of the study and the writing of the original draft of the manuscript. P. Raspor contributed to the critical revision of the manuscript and approved the final version to be published. Both authors have read and agreed to the published version of the manuscript.

ORCID ID

Mojca Jevšnik Podlesnik https://orcid.org/0000-0001-6166-0983
Peter Raspor https://orcid.org/0000-0001-5499-3157

REFERENCES

1. World Health Organization. (2024). Food safety. World Health Organization. Available from: https://www.who.int/news-room/fact-sheets/detail/food-safety
2. European Food Safety Authority (EFSA). The European Union One Health 2023 zoonoses report. EFSA J. 2024;22(12):e9106. https://doi.org/10.2903/j.efsa.2024.9106
3. European Centre for Disease Prevention and Control (ECDC). Zoonotic diseases on the rise in EU: listeriosis cases hit highest level since 2007. ECDC News. 2024 Dec 10. Available from: https://www.ecdc.europa.eu/en/news-events/zoonotic-diseases-rise-eu-listeriosis-cases-hit-highest-level-2007.
4. Rabbinge R, Raspor P. Foreword 2. In: Rabbinge R, Linnemann AR, editors. European food systems in a changing world: forward look. Strasbourg: European Science Foundation; Brussels: COST Office; 2009. p. 4.
5. European Cooperation in Science and Technology (COST). European food systems in a changing world: forward look. Strasbourg: European Science Foundation; Brussels: COST Office; 2009. 4 p. ISBN 2-912049-96-2.
6. Raspor P. Codex Alimentarius and its faces. In: Raspor P, editor. Food standards safe lives: 5th World Food Safety Day 2023. Ljubljana: European Declaration on Food, Technology and Nutrition Network; 2023. p. 13-8. ISBN 978-961-95942-2-3.

7. Raspor P, Ambrožič M, Jevšnik Podlesnik M. Food chain safety management systems: the impact of good practices. In: Yanniotis S, Taoukis P, Stoforos N, Karathanos V, editors. Advances in food process engineering research and applications. Food Engineering Series. Boston (MA): Springer; 2013. p. 607-25. https://doi.org/10.1007/978-1-4614-7906-2_30

8. European Commission. Commission Regulation (EU) 2021/382 of 3 March 2021 amending Annexes to Regulation (EC) No 852/2004 of the European Parliament and of the Council on the hygiene of foodstuffs as regards food safety culture, allergen management and redistribution of food. Off J Eur Union. 2021;L74:3-5. Available from: https://eur-lex.europa.eu/eli/reg/2021/382/oj

9. Malik S, Krishnaswamy K, Mustapha A. Hazard analysis and risk-based preventive controls (HARPC): current food safety and quality standards for complementary foods. Foods. 2021;10(9):2199. https://doi.org/10.3390/foods10092199

10. Su IH, Wu L, Tan KH. The future of the food supply chain: a systematic literature review and research directions towards sustainability, resilience, and technology adoption. J Digit Econ. 2023;2:303-16. https://doi.org/10.1016/j.jdec.2024.03.001

11. Raspor P, Jevšnik Podlesnik M, Ambrožič M. Food safety systems. In: Selamat J, Iqbal SZ, editors. Food safety: basic concepts, recent issues, and future challenges. Springer; 2016. p. 3-31. https://doi.org/10.1007/978-3-319-39253-0_1

12. Griffith CJ, Livesey KM, Clayton DA. Food safety culture: the evolution of an emerging risk factor? Br Food J. 2010a;112(4):426-38. https://doi.org/10.1108/00070701011034439

13. Raspor P. Food and nutrition as permanent challenge. In: Raspor P, Mrša V, editors. Food, nutrition and environment: positions in Central European space. Zagreb: Croatian Academy of Engineering; 2022. p. 9-18. ISBN 978-953-7076-30-6.

14. Raspor P. Total food chain safety: how good practices can contribute? Trends Food Sci Technol. 2008;19:405-12. https://doi.org/10.1016/j.tifs.2007.08.009

15. Jevšnik Podlesnik M, Bobnar S, Sraka M, Raspor P. Food safety culture among food handlers in Slovenia. Acta Microbiol Bulg. 2021;37(1):10-21.

16. Ambrožič M, Božič T, Jevšnik Podlesnik M, Cook N, Raspor P. Compliance of proposed Codex Alimentarius guidelines for virus management with principles of good practice. Acta Aliment. 2011;40(3):364-75. https://doi.org/10.1556/AAlim.40.2011.3.7
17. Ambrožič M, Kukec A, Jevšnik Podlesnik M, Smole Možina S, Raspor P. Food safety expertise among professional food handlers and consumers related to foodborne viruses: case Slovenia. Sanitarno Inženirstvo. 2016;10(1):4-19.
18. Jevšnik Podlesnik M, Bauer M, Zore A, Raspor P. Hygienic status of small and medium sized food enterprises during adoption of HACCP system. Int J Food Sci Technol Nutr. 2007;1(1):95-113.
19. Zabukošek M, Jevšnik Podlesnik M, Maletič M. Analysis of dimensionality of food safety culture: an empirical examination of a Slovenian food processing company. Sanitarno Inženirstvo. 2016;10(1):20-34. Available from: http://journal.institut-isi.si/wp-content/uploads/2017/01/SI-110-2016-Zabukosek-Jevsnik-Maletic.pdf.
20. Griffith CJ, Livesey KM, Clayton DA. The assessment of food safety culture. Br Food J. 2010b;112(4):439-56. https://doi.org/10.1108/00070701011034448
21. Raspor P. Sampling, management of samples and sample preparation. In: BTSF - Food Testing, training course on microbiology; 2016 Feb 18; Brussels, Belgium. 2016.
22. Yiannas F. Food safety culture: creating a behavior-based food safety management system. New York (NY): Springer; 2009.
23. De Boeck E, Jacxsens L, Bollaerts M, Vlerick P. Food safety climate in food processing organizations: development and validation of a self-assessment tool.Trends Food Sci Technol. 2015;46(2):242-51. https://doi.org/10.1016/j.tifs.2015.09.006
24. Behrens JH, Vedovato GM, Cervato-Mancuso AM, Bastos DHM. Social representations of safety in food services. Food Res Int. 2015;74:324-28. https://doi.org/10.1016/j.foodres.2015.05.024
25. Raspor P. Faces of foods on the world of food systems. Acta Aliment. 2006;35(3):247-9.
26. Chen da Cunha DT, Stedefeldt E, Luning PA, Prates CB, Zanin LM. Food safety culture as a behavioural phenomenon shaping food safety. Curr Opin Food Sci. 2025;63:101305. https://doi.org/10.1016/j.cofs.2025.101305

27. Marsden T, Banks J, Bristow G. Food supply chain approaches: exploring their role in rural development. Sociol Ruralis. 2000;40(4):424-38. https://doi.org/10.1111/1467-9523.00158

28. Yiannas F. Food safety = behavior: 30 proven techniques to enhance employee compliance. New York (NY): Springer; 2015.

29. Griffith CJ. Food safety: where from and where to? Br Food J. 2006;108(1):6-15. https://doi.org/10.1108/00070700610637599

30. Jevšnik Podlesnik M, Kirbiš A, Grebenc S, Jamnikar Ciglenečki U, Ovca A, Kavčič M. Food safety knowledge among professional food handlers in Slovenia: the results of a nation-wide survey. Foods. 2023;12(14):2735. https://doi.org/10.3390/foods12142735

31. Jevšnik Podlesnik M, Raspor P. The human factor as a trigger of food safety culture within food networks: the review. Acta Microbiol Bulg. 2020;36(4):115-31.

32. Redmond EC, Griffith CJ, Slader J, Humphrey TJ. Microbiological and observational analysis of cross contamination risks during domestic food preparation. Br Food J. 2004;106(8):581-97. https://doi.org/10.1108/00070700410553585

33. Clayton DA, Griffith CJ, Price P, Peters AC. Food handlers' beliefs and self-reported practices. Int J Environ Health Res. 2002;12(1):25-39. https://doi.org/10.1080/09603120120110031

34. Jevšnik M, Hlebec V, Raspor P. Food safety knowledge and practices among food handlers in Slovenia. Food Control. 2008;19(12):1107-18. https://doi.org/10.3390/foods12142735

35. Ko WH. The relationships among professional competence, job satisfaction and career development confidence for chefs in Taiwan. Int J Hosp Manag. 2015;44:10-9. https://doi.org/10.1016/j.ijhm.2011.12.004

36. Raspor P, Jevšnik Podlesnik M, Kirbiš A, Raspor Lainšček P, Ambrožič M. Food safety between Scylla and Charybdis - between the European Food Safety Authority and the consumer. Medicinski Razgledi Suppl. 2012;51(Suppl 6):25-33.

37. Jevšnik Podlesnik M, Hlebec V, Raspor P. Meta-analysis as a tool for barriers identification during HACCP implementation to improve food safety. Acta Aliment. 2006;35(3):319-53. https://doi.org/10.1556/aalim.35.2006.3.9

38. Henson S, Humphrey J. The impacts of private food safety standards on the food chain and on public standard-setting processes. Food Policy. 2010;35(2):178-86. https://doi.org/10.1016/j.foodpol.2009.12.009

39. Manning L. The influence of organizational culture on food safety. Br Food J. 2018;120(6):1323-1339. https://doi.org/10.1108/BFJ-01-2018-0006

40. Griffith CJ. Food safety in catering establishments. In: Farber JM, Todd ECD, editors. Safe handling of foods. New York (NY): Marcel Dekker; 2000. p. 235-56.

41. Manning L. Food safety and brand equity. Br Food J. 2007;109(7):496-510. https://doi.org/10.1108/00070700710761491

42. Raspor P, Jevšnik Podlesnik M. Food supply chains vs food supply nets. In: Nedović V, Raspor P, Lević J, Tumbas Šaponjac V, editors. Emerging and traditional technologies for safe, healthy and quality food. Springer; 2016. p. 9-32. https://doi.org/10.1007/978-3-319-24040-4_2

43. Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO). Strengthening food safety governance for complex supply chains: a One Health approach. FAO and WHO; 2020. Available from: https://www.fao.org/one-health/areas-of-work/food-safety/en

44. A culture of food safety: a position paper from the Global Food Safety Initiative. V1.0, 4 Nov 2018. The Consumer Goods Forum; 2018. Available from: https://www.mygfsi.com/wp-content/uploads/2019/09/GFSI-Food-Safety-Culture-Full.pdf

45. Raspor P. Expert knowledge elicitation: training coordinator for BTSF initiative, course 8 - evidence collection, management and integration; 2025 Feb 3-7; Rome, Italy. 2025.

46. Wilson AM, Meyer SB, Webb T, Henderson J, Coveney J, McCullum D, Ward PR. How food regulators communicate with consumers about food safety. Brit Food J. 2015;117(8):2129-142. https://doi.org/10.1108/BFJ-12-2014-0419

47. Antle JM. Benefits and costs of food safety regulation. Food Policy. 1999;24(6):605-23.

48. Chapman B, Eversley T, Fillion K, MacLaurin T, Powell D. Assessment of food safety practices of food service food handlers (risk assessment data): testing a communication intervention (evaluation of tools). J Food Prot. 2010;73(6):1101-7. https://doi.org/10.4315/0362-028X-73.6.1101

49. Nordhagen S, Lee J, Onuigbo-Chatta N, Okoruwa A, Monterrosa E, Lambertini E, Pelto GH. What is safe and how much does it matter? Food vendors' and consumers' views on food safety in urban Nigeria. Foods. 2022;11(2):225. https://doi.org/10.3390/foods11020225

50. Bozkurt H, Phan-Thien K, van Ogtrop F, Bell T, McConchie R. Viruses in foods: occurrence, transmission, and control. Compr Rev Food Sci Food Saf. 2021;20(2):1379-414. https://doi.org/10.1111/1541-4337.12721

51. Mattison K, Sebunya TK, Shukla A, Cook N. Foodborne viruses: an overview of transmission, persistence, and control strategies. Annu Rev Food Sci Technol. 2023;14:201-24. https://doi.org/10.1146/annurev-food-060721-023458

52. Ropkins K, Beck AJ. Evaluation of worldwide approaches to the use of HACCP to control food safety. Trends Food Sci Technol. 2000;11(1):10-21. https://doi.org/10.1016/S0924-2244(00)00036-4

53. Redmond EC, Griffith CJ. Consumer perceptions of food safety risk, control and responsibility. Appetite. 2005;43(3):309-13. https://doi.org/10.1016/j.appet.2004.11.006

54. De Boeck E, Jacxsens L, Bollaerts M, Uyttendaele M, Vlerick P. Interplay between food safety climate, food safety management system and microbiological hygiene in farm butcheries and affiliated butcher shops. Food Control. 2016;65:78-91. https://doi.org/10.1016/j.foodcont.2016.01.014

55. Yeargin TA, Gibson KE, Fraser AM. New approach to food safety training: a review of a six-step knowledge-sharing model. J Food Prot. 2021;84(11):1852-64. https://doi.org/10.4315/JFP-21-146

56. Jevšnik Podlesnik M, Pirc L, Ovca A, Šantić M, Raspor P, Godič Torkar K. A multimethod study on kitchen hygiene, consumer knowledge and food handling practices at home. Processes. 2022;10(10):2104. https://www.mdpi.com/2227-9717/10/10/2104

57. Fatimah UZAU, Strohbehn CH, Arendt SW. An empirical investigation of food safety culture in onsite foodservice operations. Food Control. 2014;46:255-63. https://doi.org/10.1016/j.foodcont.2014.05.029

58. Sneed J, Strohbehn C. Trends impacting food safety in retail foodservice: implications for dietetics practice. J Am Diet Assoc. 2008;108(7):1170-7. https://doi.org/10.1016/j.jada.2008.04.012

59. Howells AD, Roberts KR, Shanklin CW, Pilling VK, Brannon LA, Barrett BB. Restaurant employees' perceptions of barriers to three food safety practices. J Am Diet Assoc. 2008;108(8):1345-9. https://doi.org/10.1016/j.jada.2008.05.016

60. Manning L, Soon JM. Developing food safety competence: integrating education, training and organisational learning. Food Control. 2022;134:108720. https://doi.org/10.1016/j.foodcont.2022.108720

61. Strohbehn Strohbehn C, Sneed J, Paez P, Meyer J. Hand washing frequencies and procedures used in retail food services. J Food Prot. 2008;71(8):1641-50. https://doi.org/10.4315/0362-028X-71.8.1641

62. Webb M, Morancie A. Food safety knowledge of foodservice workers at a university campus by education level, experience, and food safety training. Food Control. 2015;50:259-64. https://doi.org/10.1016/j.foodcont.2014.09.002

63. Strohbehn C, Shelley MC, Arendt S, Correia AP, Meyer J, Ungku Fatimah UZA, Jinhyun J. Retail foodservice employees' perceptions of barriers and motivational factors that influence performance of safe food behaviors. Food Prot Trends. 2014;34(3):139-50.

64. De Boeck E, Jacxsens L, Goubert H, Uyttendaele M. Ensuring food safety in food donations: case study of the Belgian donation/acceptation chain. Food Res Int. 2017;100(Pt 2):137-49. https://doi.org/10.1016/j.foodres.2017.08.046

65. da Cunha DT, Prates CB, Canuto IG, Stedefeldt E, Luning PA, Zanin LM. The relationship of food safety culture elements: a serial mediation model. Food Control. 2025;169:111022. https://doi.org/10.1016/j.foodcont.2024.111022

66. Smigic N, Djekic I, Martins ML, Rocha A, Sidiropoulou N, Kalogianni EP. The level of food safety culture in food establishments in three European countries. Food Control. 2016;63:187-94. https://doi.org/10.1016/j.foodcont.2015.11.017

67. Ncube F, Kanda A, Chijokwe M,Mabaya G, Nyamugure T. Food safety knowledge, attitude and practices of restaurant food handlers in a lower-middle-income country. Food Sci Nutr. 2020;8:1677-87. https://doi.org/10.1002/fsn3.1454

68. Clayton DA, Griffith CJ. Efficacy of an extended theory of planned behaviour model for predicting caterers' hand hygiene practices. Int J Environ Health Res. 2008;18(2):83-98. https://doi.org/10.1080/09603120701358424

69. Raspor P. The European declaration on food, technology and nutrition: editorial. Acta Aliment. 2009;38(1):3-7. https://doi.org/10.1556/aalim.38.2009.1.2

70. Canuto IG, Montezano de Carvalho IM, Buarque PR, Soon-Sinclair JM, Stedefeldt E, Zanin LM, da Cunha DT. Does physical structure drive food safety behaviors of food handlers? A broken window theory perspective. Food Control. 2025;178:111464. https://doi.org/10.1016/j.foodcont.2025.111464

71. Raspor P. Safety, food security and health. In: Raspor P, editor. World Food Safety Day 2020: 2nd Conference on World Food Safety Day 2020, Ljubljana, 8 June 2020. Ljubljana: National Council of the Republic of Slovenia; Administration for Food Safety, Veterinary and Plant Protection; 2020. p. 11-4. Available from: http://eftndeclaration.aaeuropae.org/LinkClick.aspx?fileticket=kTmraCvOFIM%3d&tabid=310

72. Yeargin TA, Gibson KE, Fraser AM.New approach to food safety training: a review of a six-step knowledge-sharing model. J Food Prot. 2021;84(11):1852-64. https://doi.org/10.4315/JFP-21-146

73. Lee HK, Abdul Halim H, Thong KL, Chai LC. Assessment of food safety knowledge, attitude, self-reported practices, and microbiological hand hygiene of food handlers. Int J Environ Res Public Health. 2017;14(1):55. https://doi.org/10.3390/ijerph14010055

74. Zheng M, Bai L, Liu C, Gong S. Improving household food safety through combining nudge strategies with knowledge-based intervention: the effectiveness and mechanism. Food Control. 2025;168:110923. https://doi.org/10.1016/j.foodcont.2024.110923

75. Sartoni M, Semercioz Oduncuoglu AS, Guidi A, Annosi MC, Luning PA. Towards digitalisation of food safety management systems - enablers and constraints. Food Control. 2025;168:110952. https://doi.org/10.1016/j.foodcont.2024.110952

76. Ovca A, Jevšnik Podlesnik M, Raspor P. Curriculum analysis of food safety competences at elementary and upper-secondary level of formal education inside food-related programmes in Slovenia. J Food Sci Educ. 2018;17(2):33-71. https://doi.org/10.1111/1541-4329.12136

77. Štefančič V, Jevšnik M. Nudge tools for improving hygiene behavior among food handlers: case study. J Food Saf. 2020;40(5):e12836. https://doi.org/10.1111/jfs.12836

78. Jevšnik M. Nudge tools: are they effective to improve hygiene behavior of food handlers? J Food Technol Preserv. 2021;5(3):1-4.

79. Soon JM, Wallace CA. Behavioural economics in food safety: nudging consumers and food handlers toward safer practices. Food Control. 2020;108:106847. https://doi.org/10.1016/j.foodcont.2019.106847

80. Lindstrom KN, Tucker JA, McVay M. Nudges and choice architecture to promote healthy food purchases in adults: a systematized review. Psychol Addict Behav. 2023;37(1):87-103. https://doi.org/10.1037/adb0000892

81. Iranmanesh M, Zailani S, Hyun SS, Ali MH, Kim K. Impact of lean manufacturing practices on firms' sustainable performance: lean culture, process innovation and employee engagement. Int J Prod Econ. 2019;214:102-14. https://doi.org/10.1016/j.ijpe.2019.03.016

82. Tortorella GL, Fogliatto FS, Cauchick-Miguel PA, Kurnia S, Jurburg D. Artificial intelligence adoption in lean manufacturing systems: impacts on employee engagement and job characteristics. Int J Prod Res. 2025;63(2):1-18. https://doi.org/10.1080/00207543.2024.2321987

83. Zhong RY, Newman ST, Huang GQ, Lan S. Artificial intelligence-enabled job characteristics and employee well-being: the role of human-centred implementation. Int J Prod Econ. 2025;259:108846. https://doi.org/10.1016/j.ijpe.2024.108846

84. Bánáti D, Jevšnik Podlesnik M, Nyambayo I, Bogueva D, Stanley NL. Consumer perception of food safety in Europe. In: Bogueva D, Marinova D, Raphaely T, Schmidinger K, editors. Consumer perceptions and food. Singapore: Springer; 2024. p. 415-55. https://doi.org/10.1007/978-981-97-7870-6_21

85. Pai AS, Jaiswal S, Jaiswal AK. A comprehensive review of food safety culture in the food industry: leadership, organizational commitment, and multicultural dynamics. Foods. 2024;13(24):4078. https://doi.org/10.3390/foods13244078

86. Nickell GS, Hinsz VB. Applying the theory of planned behavior to understand workers' production of safe food. Eur J Work Organ Psychol. 2023;39(2):89-100. https://doi.org/10.5093/jwop2023a10

87. Manning L. The influence of organizational subcultures on food safety management. J Mark Channels. 2017;24(3-4):180-9. https://doi.org/10.1080/1046669X.2017.1393235

88. Trienekens J, Zuurbier P. Quality and safety standards in the food industry, developments and challenges. Int J Prod Econ. 2008;113(1):107-22. https://doi.org/10.1016/j.ijpe.2007.02.050

89. Havinga T. Private regulation of food safety by supermarkets. Law Policy. 2006;28(4):515-33. https://doi.org/10.1111/j.1467-9930.2006.00237.x

90. Mlakar T, Mihelič Zajec A, Jevšnik Podlesnik M. Use of a nudge tool for improving hand hygiene in a nursing team in home for elderly people: case study. Sanitarno Inženirstvo. 2017;11(1):33-46. Available from: https://journal.institut-isi.si/wp-content/uploads/2018/04/SI-111-2017-Mlakar-Mihelic-Zajec-Jevsnik.pdf.

91. Hadzikadic V, Grazia D, Luning PA. Digital environments and behavioural interventions: integrating nudging in food safety management systems. Food Control. 2024;162:108080. https://doi.org/10.1016/j.foodcont.2024.108080

92. Rogerson M, Parry GC. Blockchain: case studies in food supply chain visibility. Supply Chain Manag. 2020;25(5):601-14. https://doi.org/10.1108/SCM-08-2019-0300

93. Vasileiou, M., Kyrgiakos, L.S., Kleisiari, C. et al. Digital Transformation of Food Supply Chain Management Using Blockchain: A Systematic Literature Review Towards Food Safety and Traceability. Bus Inf Syst Eng (2025). https://doi.org/10.1007/s12599-025-00948-0

94. Manning L, Soon JM. Building strategic resilience in the food supply chain. Br Food J. 2016;118(6):1477-93. https://doi.org/10.1108/BFJ-10-2015-0350

95. Henson S, Humphrey J. Understanding the complexities of private standards in global agri-food chains as they impact developing countries. J Dev Stud. 2010;46(9):1628-46. https://doi.org/10.1080/00220381003706494

96. Trienekens JH, Wognum PM, Beulens AJM, van der Vorst JGAJ. Transparency in complex dynamic food supply chains. Adv Eng Inform. 2012;26(1):55-65. https://doi.org/10.1016/j.aei.2011.07.007

97. García Martinez M, Fearne A, Caswell JA, Henson S. Co-regulation as a possible model for food safety governance: opportunities for public-private partnerships. Food Policy. 2007;32(3):299-314. https://doi.org/10.1016/j.foodpol.2006.07.005

98. Jevšnik Podlesnik M, Raspor P. Food safety knowledge and behaviour among food handlers in catering establishments: a case study. Br Food J. 2022;124(10):3293-307. https://doi.org/10.1108/BFJ-09-2020-0795

99. Raspor P, Jevšnik Podlesnik M. Good nutritional practice from producer to consumer. Crit Rev Food Sci Nutr. 2008;48(3):276-92. https://doi.org/10.1080/10408390701326219

100. Soon JM, Saguy IS. Food safety challenges in the era of globalization, digital transformation, and evolving food systems. Trends Food Sci Technol. 2023;139:58-70. https://doi.org/10.1016/j.tifs.2023.05.004

101. Nyarugwe SP, Linnemann A, Hofstede GJ, Fogliano V, Luning PA. Determinants for conducting food safety culture research. Trends Food Sci Technol. 2016;56:77-87. https://doi.org/10.1016/j.tifs.2016.07.015

102. Spagnoli P, Defalchidu L, Vlerick P, Jacxsens L. The relationship between food safety culture maturity and cost of quality: an empirical pilot study in the food industry. Foods. 2024;13(4):571. https://doi.org/10.3390/foods13040571

Table 1. Short-term vs. long-term actions for strengthening food safety culture

Element (7 key areas)	Short-term actions (1–4 years)	Long-term actions (5–10 years)
1. Leadership and commitment	Managers model safe behavior daily; ensure resources and clear expectations.	Build leadership development programs; embed food safety culture into strategic governance and accountability systems.
2. Communication and awareness	Standardize internal communication; clarify rules, reminders, and visual cues; align messages with suppliers.	Develop global communication frameworks across multicultural supply chains; embed two-way communication practices.
3. Training and competency	Provide frequent, task-specific micro-trainings focused on behaviour, not just knowledge.	Create long-term competency frameworks supported by behavioural science; integrate digital learning ecosystems.
4. Behaviour and workplace practices	Address immediate gaps between knowledge and actual behaviour; introduce simple behaviour checklists.	Implement continuous behaviour monitoring, coaching, and incentives; build a culture where safe behaviour is habitual.
5. Reporting and transparency	Introduce non-punitive reporting of near misses and unsafe acts to increase openness.	Develop a mature learning organization where reporting data is analyzed and used to predict and prevent failures.
6. Assessment and monitoring	Use basic culture surveys, interviews, and observations to identify weak points.	Integrate culture Key Performance Indicators (KPIs) into audits and certifications; adopt digital, real-time monitoring tools and analytics.
7. Supply-Chain Alignment and Systems Integration	Define clear expectations for suppliers, contractors, cloud kitchens, gig workers.	Build harmonized international standards and fully integrated food-safety culture requirements across global supply chains.

Table 2. Based on key performance indicators (KPIs) which would be of great help for increment improvements to food safety culture

KPI	What it measures	Why it matters
1. Near miss reporting rate	Number of near misses reported per month/employee.	Indicates openness, trust, and a non-punitive reporting culture. Higher reporting usually means stronger culture.
2. Training completion and competency score	Percentage of staff completing required food-safety training and passing competency checks.	Measures not only attendance but actual understanding and application of safe practices.
3. Leadership walkthrough frequency	Number of documented food safety leadership observations/engagements per week or month.	Shows visible leadership commitment and reinforces safe behaviour.
4. Behaviour compliance score	Percentage compliance observed during hygiene, PPE, handwashing, and CCP-related behaviour checks.	Directly reflects whether everyday actions match food-safety expectations.
5. Corrective action closure time	Average time from identifying an issue to resolving it.	Demonstrates responsiveness, accountability, and operational discipline.
6. Internal communication effectiveness	Percentage of employees who report understanding food-safety messages (via short surveys or pulse checks).	Measures clarity, consistency, and reach of safety communication.
7. Supplier/contractor food-safety culture compliance	Percentage of suppliers meeting or exceeding defined culture-related requirements (audits, behaviour standards, reporting).	Ensures food safety culture extends across the entire supply chain, not just inside the company.