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THE WEAKEST LINK? HOW HUMAN BEHAVIOR THREATENS FOOD SAFETY

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Abstract. *Despite well-developed systemic approaches, standards, and food safety legislation, numerous recalls, food fraud, and foodborne diseases persist. The human factor at organizational and operational levels causes unacceptable process deviations manifesting in critical situations. Food Safety Culture has emerged as a new paradigm addressing this challenge. This paradigm represents a critical factor ensuring food safety, quality, and hygiene in establishments. While legislative requirements and documented systems clearly define tasks, responsibilities, and procedures, practical implementation often fails due to human behavioral factors. Food safety culture, reflected in employee behavior when handling food, significantly influences product safety and public health. Research demonstrates that despite continuous education, food safety systems remain incompletely controlled due to inherent work-related human risks. Employee behavior—characterized by consistency, accuracy, and correctness in task execution—is influenced by knowledge, motivation, competence, understanding, hygienic awareness, work attitudes, job satisfaction, and resource availability. Food safety culture depends on broader organizational elements: effective HACCP-based management systems, company policy, management commitment, leadership, employee awareness, communication, work environment, and risk assessment. Contemporary approaches have evolved beyond traditional compliance-based frameworks toward comprehensive behavioral and organizational transformation strategies. Food operators increasingly implement voluntary standards beyond legislative requirements to enhance awareness and control risk factors. However, implementation varies significantly between high and low food safety culture organizations. Recent research identifies major barriers: limited resources, risk communication difficulties, and behavioral change challenges. Current trends emphasize practical implementation through digital tools, "nudging" techniques, and leadership development rather than theoretical frameworks. This evolution demonstrates shifts toward integrated technology solutions, continuous improvement processes, and evidence-based interventions addressing organizational and individual factors. Effective food safety culture requires coordinated efforts across hierarchical levels, emphasizing leadership commitment, effective communication, employee training, and systematic risk management to achieve consistent food safety practice implementation.*

Key words: *food safety, human factor, food safety culture, human behavior, nudging tools*

Introduction

Food safety represents one of the most critical public health challenges of our time. An estimated 600 million people – almost 1 in 10 people in the world – fall ill after eating contaminated food and 420,000 die every year [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 from foodborne illnesses.

The human factor: The critical vulnerability

Despite sophisticated Hazard Analysis and Critical Control Point (HACCP) systems and advanced food processing technologies, human behavior consistently emerges as the primary risk factor in food contamination incidents [4]. This vulnerability manifests across multiple stages of the food production and consumption chain.

Recently, in the scientific field of food safety assurance, topics related to food safety culture have come to the forefront, which is reflected in the behavior of employees when working with food and affects the safety, quality and hygiene of food in food establishments. Legislative requirements, system and product standards, and documented food safety assurance systems for food business operators precisely define tasks, responsibilities and work procedures for individual processes, however, in practice there are shortcomings in the implementation of these requirements and their execution. Authors indicate that this depends on the food safety culture in the company or on the behavior of people who work with food [5-7]. The behavior, which is reflected in the consistency, accuracy and correctness of performing defined tasks and work procedures, is influenced by an individual's knowledge and motivation [8], competence, understanding, level of hygienic awareness, attitude towards work, job satisfaction, self-efficacy, and temporal, human and material availability [9-11]. In a broader view, food safety culture also depends on other elements such as: effectiveness of implementation of management systems based on HACCP principles, company policy, management commitment, leadership, employee awareness, communication, work environment, resource availability, risk factor identification and risk assessment.

From past research, it is evident that the food safety assurance system, despite continuous education, is not completely controlled due to common risks associated with human nature of work [5, 10, 11]. Food safety assurance is related to the behavior of a person who handles food in a way that represents minimal risk to the

food and consequently to human health [6, 7]. Training is an important social element in this, which ensures that the necessary information is correctly understood by users [14] and used in practice [12]. It is important that food business operators ensure regular training of employees [15]. The learning process influences individual behavior to become a reliable and aware worker who conscientiously performs their tasks in the field of food safety [6, 10, 15].

Food business operators, in addition to implementing mandatory legislative requirements, also implement additional requirements defined in various national, international and private standards, with the aim of raising awareness and knowledge of their employees, better controlling risk factors when working with food, and ensuring a quality and safe product. The implementation of these requirements is voluntary and ambitious for food business operators with a high level of food safety culture, while for those with a low level of culture it is imposed. The latter has been established mainly due to changed business practices and is reflected in contract signatures with buyers who, for risk management from the perspective of food safety and quality, condition business with producers by establishing standards [9], certified by accredited institutions [16]. Some retailers have started ordering food with their own brand from certain producers, thereby transferring the responsibility for producing safe and quality food from the producer or supplier to the retailer or buyer [17]. Due to protection of their own name and brand [18], retailers for food produced under retail brand, within these standards require stricter and more comprehensive preventive measures than defined by legislation itself, thereby raising criteria for food safety assurance. This has led to in-depth research that discovers weak points due to which food production can be endangered from the perspective of quality or safety [15].

From HACCP to Food safety culture: The role of human behavior 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 [19]. This significantly affects public health [20] and defines the responsibility of food business operators, supervisory bodies and consumers [17, 21].

In the past, for a long time the belief prevailed that only microbiological risk factors were important for ensuring food safety, as microorganisms were most often recognized as the main causes of food-borne infections and/or poisoning [22], and microbiology was the main discipline that studied their growth, reproduction, survival, resistance and biofilm formation [9, 17].

Today, food-borne infections and/or poisoning still represent a significant proportion of illnesses, especially poisoning by viruses, which are increasingly coming to the forefront [2]. Reasons for this may be changed dietary and shopping habits of people, weakened immune system, more frequent consumption of food outside the home, inadequate knowledge in food preparation at home, lower degree of food processing, reduced use of preservatives, intensive farming, global food distribution, emergence of new risk factors and demographic changes [9, 10].

With the implementation of the HACCP system for food safety assurance, the control of risk factors, including chemical and physical ones, has significantly improved [23]. HACCP is a food safety assurance system based on preventive measures for preventing and controlling risk factors [24, 25]. However, other aspects must also be considered, such as food safety culture, which is manifested in employee behavior when working with food [17, 22, 25]. The HACCP system can be even more effective with certification procedures of voluntary GFSI (Global food safety initiative) group standards [9], but only if this is the goal of company policy.

Employees in food business establishments play a crucial role in ensuring food safety [26]. Some have identified demographic characteristics as reasons for errors when working with food [15, 27], lack of time, money and other resource availability [28, 29], workplace pressure [15], competence, motivation and employee satisfaction [12, 30]. 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 [5, 31, 32]. 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 [6]. This depends on elements of food safety climate from employees such as leadership, communication, commitment, risk awareness and resource availability [8, 33] and on employee competence and education level [34].

Studies have shown that the knowledge, attitude, and practices of food handlers are important factors in preventing foodborne illness [35]. 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 [36].

Appropriate leadership encourages employees to implement accompanying hygienic procedures and food safety procedures in accordance with business goals, vision and company standards. Proper communication about food safety ensures quality transfer of knowledge and information about food safety from management, through middle management to implementers who handle 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 [7]. This must take into account the factor of realistic perception of the seriousness of risk factors [26]. It happens that employees are aware of risks but do not control them for various reasons, which Griffith and colleagues [4, 7] call "optimistic bias" and "illusion of control."

De Boeck and colleagues [8, 33] 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 behavior when working with food, while the technical-managerial aspect is a reflection of the implemented food safety system in the company with existing control and activities.

Fatimah and colleagues [26] state that to improve food safety culture, it is necessary to achieve consistent implementation of food safety policy at all hierarchical levels in food companies, encourage teamwork between different departments and generations of employees, implement a reliable work evaluation system, and effectively communicate about relevant risk factors.

From compliance to culture: Modern approaches to Food safety management

The transition from compliance-based food safety systems to a genuine food safety culture reflects a paradigm shift in how organizations approach risk prevention. Traditional compliance relies on external enforcement, audits, and documentation, but these mechanisms often fail to ensure consistent behavior when direct supervision is absent. Recent studies highlight that food safety culture emphasizes shared values, internalized responsibility, and proactive engagement across all organizational levels [7]. Leadership plays a critical role in this process, as managers must move beyond "box-ticking" compliance toward fostering ownership, communication, and continuous learning [37]. Research also shows that a strong food safety culture correlates with improved hygiene behavior and reduced non-compliance, since employees are more likely to "do the right thing when no one is watching" [38]. Thus, the evolution from compliance to culture represents not only regulatory alignment but also a sustainable strategy for risk management and organizational resilience.

Pai and colleagues [37] emphasize that major barriers to establishing a positive food safety culture were identified to be limited resources, difficulties in risk communication, and difficulties in behavioral change. Nickell & Hinsz [39] and Manning [40] highlights the critical role of leadership and organizational commitment in fostering effective food safety cultures, with food safety culture transitioning from a narrow compliance-based concept to a comprehensive organisational value that is essential for ensuring food safety.

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 incredible returns such as 15 percent greater employee productivity, 26 percent decreased employee turnover, 20 percent less employee absenteeism, and 65 percent greater share prices [41].

Contemporary approaches to food safety culture increasingly focus on behavioral interventions and digital tools. A proven tool to improve frontline employee engagement in effective food safety behaviors is the concept of "nudging" [42], while regulatory bodies like the FDA are encouraging and exploring use of new digital tools and incentives that prompt desired behaviors, such as handwashing and manual temperature monitoring [43].

The evolution of food safety culture research demonstrates a shift from traditional compliance-based approaches to comprehensive behavioral and organizational transformation strategies, emphasizing the integration of technology, leadership

development, and continuous improvement processes in contemporary food safety management systems [44].

Psychological and behavioral factors in food safety

Human decision-making in food safety contexts is significantly influenced by various cognitive biases that can compromise safety outcomes [7]. 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 [26]. 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 [5].

The organizational culture within food establishments plays a crucial role in shaping individual behavior and safety outcomes [7, 8]. Environments that consistently prioritize productivity over safety often create conditions where risky behaviors become normalized, establishing systemic vulnerabilities throughout the operation [15]. 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 [28].

Traditional food safety training programs frequently fail to achieve their intended behavioral outcomes due to several fundamental limitations [5, 11]. Most conventional training approaches focus primarily on knowledge transfer rather than genuine behavior change, assuming that increased awareness will automatically translate into improved practices [14]. 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 [30]. 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 [45].

Contemporary research has identified several evidence-based solutions that address these psychological and organizational challenges more effectively [33]. Behavioral intervention strategies have shown particular promise, with nudging techniques involving environmental modifications that naturally promote safer behaviors without relying solely on conscious decision-making [41]. Social norm interventions leverage peer influence to encourage compliance by making safe behaviors more visible and socially desirable within the workplace [26]. Real-time feedback systems provide immediate monitoring and correction of unsafe practices, allowing for prompt behavioral adjustments before problems escalate [31].

Enhanced training approaches represent another critical avenue for improvement [15]. Competency-based training shifts focus from theoretical knowledge to

demonstrable skills, ensuring that participants can actually perform safety procedures correctly rather than simply understanding them conceptually [34]. Scenario-based learning utilizes realistic situations to help workers practice decision-making skills in controlled environments, building confidence and competence for real-world applications [32]. 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 [11].

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 [43]. Mobile training platforms make safety education more accessible and personalized, allowing workers to learn at their own pace and in their preferred language [41]. Predictive analytics can identify high-risk situations before contamination occurs, enabling proactive interventions rather than reactive responses to safety failures [46].

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 behaviors and safety improvements [7, 8]. These comprehensive approaches acknowledge that effective food safety culture requires addressing both individual psychological factors and broader organizational dynamics that influence behavior in complex, interconnected ways [6].

Nudge tools provide a subtle yet effective approach to improving hygiene behavior among employees in the food industry. Štefančič and Jevšnik [47] 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 behavior at all key stages of food preparation, whereas citrus scent alone had mixed effects, ranging from relaxation to distraction.

Jevšnik [48] further highlights how nudge tools—primarily priming (signs, words, scents) and affect (e.g., feelings of disgust) can influence behavioral change among food handlers. A key conclusion is that knowledge and training alone are often insufficient; nudge approaches can significantly enhance compliance with hygiene practices, even though the human factor is still often underestimated as a potential risk. This highlights that interventions targeting automatic behavior and habits can outperform those requiring deliberate decision-making.

Similarly, a systematized review [49] 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 behavior. 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 behaviors the easiest choice increases compliance and sustainability of behavioral change.

Conclusion

While humans represent the weakest link in food safety systems, they also hold the greatest potential for improvement. Food safety is a basic human right, yet billions of people worldwide remain at risk of unsafe food. Addressing human behavior requires a multifaceted approach that combines scientific understanding of behavioral psychology with practical interventions tailored to specific contexts of food science.

Success in reducing human-related food safety risks depends on moving beyond traditional training approaches toward comprehensive behavioral change strategies. This includes creating supportive organizational cultures, implementing evidence-based interventions, and recognizing that sustainable food safety improvements require addressing the complex interplay between individual knowledge, organizational systems, and social influences.

The path forward requires collaboration between food safety professionals, behavioral scientists, technology developers, and policymakers to create systems that support and enhance human performance rather than simply expecting perfection. Only through this integrated approach can we transform the weakest link into the strongest defense against foodborne illness.

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NAJSLABIJA KARIKA? KAKO LJUDSKO PONAŠANJE UGROŽAVA BEZBJEDNOST HRANE

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Sažetak. *Uprkos dobro razvijenim sistemskim pristupima, standardima i zakonodavstvu u oblasti bezbjednosti hrane, i dalje se javljaju brojna povlačenja proizvoda, prevare i bolesti prenosive hranom. Ljudski faktor na organizacionom i operativnom nivou uzrokuje neprihvatljiva odstupanja u procesima, koja se manifestuju u kritičnim situacijama.* Kultura bezbjednosti hrane *pojavila se kao novi koncept u suočavanju sa ovim izazovom. Ona predstavlja ključni faktor u osiguranju bezbjednosti, kvaliteta i higijene u prehrambenim objektima. Iako zakonski propisi i dokumentovani sistemi jasno definišu zadatke, odgovornosti i procedure, praktična primjena često izostaje zbog uticaja ljudskog ponašanja. Kultura bezbjednosti hrane, koja se ogleda u ponašanju zaposlenih prilikom rukovanja hranom, značajno utiče na bezbjednost proizvoda i javno zdravlje. Istraživanja pokazuju da, uprkos kontinuiranoj edukaciji, sistemi bezbjednosti hrane ostaju djelimično nekontrolisani zbog inherentnih ljudskih rizika vezanih za rad. Ponašanje zaposlenih – obilježeno doslјednošću, preciznošću i ispravnošću u izvršavanju zadataka – zavisi od znanja, motivacije, kompetencija, razumijevanja, higijenske svijesti, radnih stavova, zadovoljstva poslom i dostupnosti resursa. Kultura bezbjednosti hrane zavisi i od šireg organizacionog okvira: efikasnih sistema upravljanja zasnovanih na HACCP-u, politike preduzeća, posvećenosti menadžmenta, liderstva, svijesti zaposlenih, komunikacije, radnog okruženja i procjene rizika. Savremeni pristupi su se razvili izvan tradicionalnih okvira zasnovanih na usklađenosti, prelazeći ka sveobuhvatnim strategijama promjene ponašanja i organizacione transformacije. Operateri hrane sve češće primjenjuju dobrovoljne standarde, iznad zakonskih zahtjeva, kako bi unaprijedili svijest i kontrolu faktora rizika. Međutim, implementacija značajno varira između organizacija sa visoko razvijenom i onih sa niskom kulturom bezbjednosti hrane. Najnovija istraživanja ukazuju na glavne prepreke: ograničene resurse, poteškoće u komunikaciji o rizicima i izazove promjene ponašanja. Aktuelni trendovi stavljaju akcenat na praktičnu primjenu kroz digitalne alate, tehnike „gurkanja“ (*nudging*) i razvoj liderstva, umjesto na teorijske okvire. Ovaj razvoj ukazuje na pomak ka integrisanim tehnološkim rješenjima, procesima kontinuiranog unapređenja i intervencijama zasnovanim na dokazima koje obuhvataju organizacione i individualne faktore. Efikasna kultura bezbjednosti hrane zahtijeva usklađene napore na svim hijerarhijskim nivoima, sa naglaskom na posvećenost liderstva, efikasnu komunikaciju, obuku zaposlenih i sistematsko upravljanje rizicima, kako bi se obezbijedila dosljedna primjena praksi bezbjednosti hrane.*

Ključne riječi: *bezbjednost hrane, ljudski faktor, kultura bezbjednosti hrane, ljudsko ponašanje, alati za „nudging*