https://doi.org/10.17221/130/2025-CJFS

Modern advanced food safety and smart traceability systems

Aslihan Tüğen[1]*, *Louiza Belkacemi*[2]

[1]*Department of Food Engineering, Afyon Kocatepe University Institute of Sciences, Afyonkarahisar, Türkiye*

[2]*Laboratory of Agricultural, Agri-food Production Techniques and Sustainable Development, Higher School of Agronomy of Mostaganem, Mostaganem, Algeria*

**Corresponding author: asl.tugen@gmail.com*

Citation: Tüğen A., Belkacemi L. (2026): Modern advanced food safety and smart traceability system. Czech J. Food Sci., 44: 265–281.

Abstract: This systematic review article aimed to examine the effects of digitalisation in the field of food safety and traceability on applications and the challenges encountered in the context of the food industry. The decentralised structure of blockchain technology prevents forgery in records. It has been determined that tools such as IoT sensors and Radio Frequency Identification (RFID) facilitate quality control and logistic processes, ensure consumer trust, savings and cost reduction in logistics and supply. High investment and energy costs make it difficult to use these technologies. The incompatibility of regulatory policies and standards in different countries is a factor that makes difficult to create a global food traceability ecosystem. Despite all these challenges, blockchain and IoT technologies are expected to contribute more to food safety and traceability applications in the future.

Keywords: food fraud; food law; digitalisation; blockchain; Internet of Things; RFID; digital food monitoring

Food fraud poses significant public health risks. In 2008, milk contaminated with melamine in China caused illness in over 50 000 infants and six deaths. Scandals such as the discovery of horse meat in beef in 2013 and fipronil in eggs in 2017 attracted global attention (European Council 2019). Often, such incidents stem not only from individual or institutional errors but also from systemic weaknesses in globalised food supply chains, such as fragmented data flows, limited transparency, and delayed source tracing. Poor verification tools, such as manipulations in food shipment documents and invoices, necessitate a review of quality control processes and monitoring systems. The complex nature of food processes, including supply, and the rapid recall requirements have clearly demonstrated the inadequacy of traditional supply systems in providing real-time tracking and global circulation. The 2011 *Escherichia coli* outbreak in Germany was initially attributed to imported Spanish cucumbers due to delays in traceability systems, but it was later determined to have originated from vegetable sprouts from Egypt. This incident demonstrated that failure to conduct real-time tracing can lead to delayed detection of public health risks and increased economic losses (Creydt and Fischer 2019). Such incidents have demonstrated a greater need for real-time source identification and traceability systems that provide immutable data records.

Regulatory frameworks have begun to be established with the aim of developing real-time, immutable, recorded traceability systems for food supply systems,

https://doi.org/10.17221/130/2025-CJFS

and end-to-end traceability throughout the entire process has been emphasised. The European Union defined its food safety policies with the General Food Law adopted in 2002. This policy adopts an integrated approach covering all stages from animal feed to food production, processing, storage, transportation, and import and export processes. In this way, traceability of all food products produced and sold in the European Union from 'farm to fork' is ensured, and consumers are provided with the opportunity to obtain information about the content of their food (European Commission 2014). In the US, standardisation in practices has been introduced with the Food Safety Modernisation Act, and additional record-keeping obligations have been added to the food tracing section (Yiannas 2018). The complexity and fragmentation of modern food supply chain networks hinder the development of strong traceability mechanisms. Technologies such as blockchain enable traceability in supply chains by matching food products with digital identifiers, including growing conditions, batch numbers, and expiration dates. In this way, consumers can learn the ecological footprint of their food, surplus distribution can be directed, and food waste can be prevented. The inability to change records makes it possible to identify the source of foodborne diseases and provides a solution for counterfeiting (Antonucci et al. 2019). However, the same literature also notes that traceability performance is shaped not only by technical design but by interoperability, governance capacity, and the feasibility of implementation at scale.

It is stated that food safety and traceability, as the basic elements of the modern food chain, are of critical importance in terms of consumer health, transparency of production processes, and trust in food (WHO 2019). The globalising food supply chain facilitates the delivery of food produced in different geographies and with various processing techniques to the consumer, but parallelly it increases the risk of foodborne illness (FAO 2019). In addition, the stages during food production make it even more necessary to establish effective monitoring, auditing, and retrospective control mechanisms during the production process (ISO 22000:2018). As processes lengthen during supply, all stages become fragmented. Safety-related activities lead to integrated process operation of production systems, going beyond a single production line, and becoming dependent on monitoring, auditing, and control mechanisms. In this way, food safety focuses on preventing physical, chemical, and biological hazards that may arise during the production, processing, storage, and distribution of food products. Within the scope of food safety management, systems such as Hazard Analysis and Critical Control Points (HACCP) are widely used for hazard analysis and identification of critical control points. HACCP aims to identify and control food safety hazards through a systematic approach and to ensure that food reaches the consumer safely (EC 2014).

On the other hand, in ensuring food safety, not only the production stage but also the entire chain extending from raw materials to the end consumer should be taken into account (Bosona and Gebresenbet 2013). It has been stated that what is important here is the effective and holistic implementation of traceability systems, and it has been deemed important to quickly identify errors or sources of contamination (WHO 2019). In this context, traceability has been defined as recording each stage of a product in the supply chain and reviewing these records retrospectively when necessary (Aung and Chang 2014). Traceability technologies generally include labelling, barcoding, radio frequency identification (RFID), and blockchain-based systems, which have been talked about more in recent years. Labelling and barcoding technologies have enabled the rapid and cost-effective reading of essential information such as product identification, batch number, production location, and harvest/consumption dates. RFID systems provide real-time location, temperature, and humidity tracking in storage, transportation, and retail processes through contactless data transfer via radio waves. While these tools improve visibility, they may also introduce trade-offs (e.g. sensor reliability and cybersecurity risks for IoT/RFID; scalability and energy demands for blockchain) that directly affect system-level performance.

Blockchain-based traceability applications make it difficult to change information by storing all records in the production process in a decentralised ledger and ensure that all critical data about food is shared transparently (Galvez et al. 2018). At the same time, the literature increasingly frames blockchain as a governance layer that is most effective when paired with reliable data capture and clear institutional rules, rather than as a standalone solution. Despite numerous literature reviews on food safety and traceability, the research has remained superficial, emphasising the need to establish technological infrastructure or legal frameworks. Studies have consistently lacked holistic and comparative perspectives on systems, and how these systems enhance transparency, sustainability, and consumer safety has been overlooked. More specifically,

https://doi.org/10.17221/130/2025-CJFS

existing reviews often prioritise categorisation over cross-study comparison, leaving contradictions (e.g. transparency-driven trust gains versus context-dependent adoption) and system trade-offs insufficiently synthesised.

Traceability systems not only facilitate emergency response to food-related public health threats but also allow consumers to share information about the origin, quality, and sustainability of products. In this way, the demand for innovative approaches is increasing due to increased competition and trust in the food sector (Bigliardi and Galati 2013). In fact, many countries and international organisations are making regulations and establishing standards on food safety. In particular, the ISO 22000:2018 standard provides a global framework for food safety management systems and represents a common approach. In the EU, food safety directive 178/2002 offers a preventive approach and establishes the legal framework for traceability standards (EC 2021). The WHO and FAO contribute to the process by publishing continuous traceability guidelines and strategy plans related to food safety (FAO 2019; WHO 2019). In this context, it has been determined that the standards and regulatory frameworks valid in the international food market standardise the practices of countries and ensure the smooth supply of food and the protection of public health.

This study was prepared to examine the research conducted on food traceability and safety between 2021 and 2025, focusing on smart technologies, supply chain transparency, and consumer protection. The research on smart traceability obtained was classified under eight categories and evaluated in terms of its technology, scalability, and limitations.

MATERIALS AND METHODS

Research focus. The development of digital technologies and their increasing use in industrial applications have fundamentally changed decision-making processes related to production, cost, efficiency, and hazards, particularly in food supply chains, through the use of smart technologies (blockchain-based monitoring and control, IoT sensor networks) in food safety and traceability. This research aims to examine the latest developments in the use of smart technologies in food safety within the food industry. In this context, studies on blockchain-based systems, Internet of Things (IoT) sensor networks, RFID technologies, biosensors, and AI-powered monitoring tools were evaluated using a systematic review method. Rather than providing a purely descriptive overview of technologies, the review adopts a comparative and system-oriented perspective, assessing how different technological approaches perform in relation to empirical evidence strength, technological maturity, scalability potential, and reported limitations. The findings of the resulting documents were assessed from a comparative and holistic perspective. The study attempts to address decision-making processes, implementation barriers, interoperability challenges, regulatory constraints, and cost-benefit balances that are often not sufficiently addressed in the current literature. By explicitly examining these dimensions, the study aims to move beyond technology-centered narratives and to evaluate smart traceability systems as socio-technical configurations embedded in institutional and operational contexts.

Data sources and analyses. In line with the research objective, comparisons were made to determine the advantages and limitations of using different technological applications in food supply systems, and the role of transparency, efficiency, and compliance in decision-making processes in food safety and traceability systems was evaluated. In this context, literature published between 2021 and 2025, covering the period when technologies such as blockchain and IoT-based traceability systems began to be used and become widespread in the food sector. A total of 51 studies met the inclusion criteria. To ensure transparency and avoid duplication, each study was assigned to a single primary indexing source based on journal indexation. Accordingly, 28 studies were indexed in the Web of Science Core Collection, 20 in Scopus, and 3 were published in journals indexed only in Google Scholar and not covered by major citation databases.

The research required studies to focus on digital, smart, or technology-oriented traceability systems such as blockchain, IoT, RFID, biosensors, and artificial intelligence-based approaches; empirical studies, systematic reviews, and application-oriented case studies with clearly and detailedly reported methodologies and findings were included to increase analytical robustness. Conference abstracts, editorial articles, opinion pieces, and non-peer-reviewed publications; studies not directly related to the agri-food sector; and purely theoretical articles without an applied or evaluative component were not accepted. Articles for which the full text was not accessible were not included in the study. Access to the research material consisted of documents obtained using specific keywords such as 'food safety' AND

https://doi.org/10.17221/130/2025-CJFS

Table 1. References materials

Category	Aim	Method	Results	References
Data integrity, immutability and auditability	strengthening post-COVID food chain transparency and immutability	design of blockchain-based distributed ledger system	blockchain ensures tamper-proof audit trails and significantly improves food safety governance	Iftekhar and Cui (2021)
	designing an IoT–blockchain architecture for agricultural traceability	IoT sensor-gateway-blockchain system design	IoT sensors enable real-time data capture blockchain preserves data integrity	Guo et al. (2021)
	developing a smart-contract–enabled agricultural traceability model	smart contract development	smart contracts automate validation and improve supply chain efficiency	Wang et al. (2021)
	enhancing traceability and quality in the dairy sector	blockchain supply chain modelling	immutable cold-chain records increase dairy product safety	Khanna et al. (2022)
	applying blockchain to livestock traceability	implementation analysis	blockchain improves efficiency, credibility, and safety across livestock chains	Patel et al. (2023)
	applying blockchain to cherry supply chains	case study	blockchain strengthens traceability between farmers, wholesalers, and retailers	İndap and Tanyaş (2023)
	systematically reviewing blockchain-based food traceability	systematic review	transparency is widely improved, while interoperability remains a major limitation	Lv et al. (2023)
	enhancing traceability and quality in the dairy sector	blockchain supply chain modelling	immutable cold-chain records increase dairy product safety	Singh et al. (2023)
	reviewing blockchain applications in food safety	literature review	blockchain enhances authenticity and safety scalability remains a concern	Duan et al. (2024)
	improving national food security through blockchain	soft system methodology	blockchain increases transparency in public distribution systems	Gupta and Shankar (2024)
	designing a blockchain-based restaurant food monitoring system	system development + validation	transparency and trust improve across restaurant supply chains	Yele and Litoriya (2024)

RFID – radio frequency identification; EOSIO – open-source blockchain protocol; ISS – information systems success model; TPB – theory of planned behaviour; SEM – structural equation modelling; SC – supply chain

https://doi.org/10.17221/130/2025-CJFS

Table 1. To be continued...

Category	Aim	Method	Results	References
Real-time monitoring and sensor -based verification	digitising supply chains using IoT sensors (RFID, temperature–humidity sensors, optical sensors)	IoT–RFID + big-data framework	real-time monitoring improves freshness, safety, and accuracy of traceability	Zheng et al. (2021)
	evaluating RFID performance in fisheries	systematic review	RFID enhances traceability and trust in highly perishable seafood chains	Rahman et al. (2021)
	implementing IoT systems in food industry traceability	system development	IoT significantly enhances transparency and safety	Lin et al. (2022)
	optimising traceability via IoT	machine-learning classifier algorithms	IoT improves detection of operational errors and enhances efficiency	Wei et al. (2023)
	designing IoT traceability architecture	system component analysis	operational efficiency and data flow improved	Mehannaoui et al. (2023)
	metrological traceability in food analytics	comprehensive review	rapid point-of-need testing strengthens real-time monitoring	Mattarozzi et al. (2023)
	real-time pesticide monitoring	field testing	environmental sensors provide low-cost, real-time detection	Radogna et al. (2022)
	improving wheat quality traceability	processing-chain analysis	traceability highlights critical quality-loss stages	Nadimi et al. (2023)
Hybrid and integrated traceability architecture	developing IoT–blockchain systems for food safety	hyperledger simulation	integrity is strengthened and erroneous data minimised	Balamurugan et al. (2022)
	developing a blockchain–IoT framework for smart cities	EOSIO-based solution	lower latency and higher reliability achieved in urban food traceability	Tripathi et al. (2023)
	integrating AI–IoT–blockchain for food authenticity	comprehensive review	AI–IoT–blockchain synergy boosts automation, fraud detection, and real-time monitoring	Liu et al. (2025)
	assessing smart traceability technologies	synthesis review	smart technologies enhance visibility of critical control points	Yu et al. (2022)

https://doi.org/10.17221/130/2025-CJFS

Table 1. To be continued...

Category	Aim	Method	Results	References
Consumer trust, adoption and behavioural dynamics	identifying drivers of consumer adoption of blockchain food traceability	structural modelling using ISS + TPB	trust, perceived usefulness, and ease of use strongly influence adoption	Lin et al. (2021)
	evaluating blockchain's impact on retailer–consumer trust	experimental consumer modelling	retailer credibility and consumer confidence increase through blockchain-enabled transparency	Garaus and Treiblmaier (2021)
	understanding societal cognition toward blockchain in food safety	digital text mining + Tobit regression	perceptions are shaped by advantages, cost expectations, and policy clarity	Hong et al. (2021)
	evaluating organic food traceability and consumer trust	survey + PROCESS Macro	traceability is a trust signal enhancing perceived product integrity	Guanqi and Husnain (2022)
	seafood traceability information preferences	experimental survey + conditional logit	consumers prioritise safety and quality claims	Hoque et al. (2022)
	identifying factors influencing consumer adoption of blockchain	SEM + segmentation	incentives, low complexity, and consumer expertise are adoption drivers	Wang and Scrimgeour (2023)
	consumer valuation of traceability	meta-analysis of 72 studies	consumers show rising willingness to pay for traceable products	Tran et al. (2024)
Fraud detection, authenticity and quality assurance	applying molecular markers for traceability	DNA/protein marker analysis	molecular tools enable high-precision authentication	Fanelli et al. (2021)
	applying metabolomics to food authenticity	review of metabolomics approaches	metabolite profiling improves fraud detection	Li et al. (2021)
	authenticating EVOO	chemical marker review	reliable markers enhance authenticity and fraud detection	Lozano-Castellón et al. (2022)
	examining privacy barriers in blockchain traceability	literature review	privacy–efficiency trade-offs limit widespread adoption	Lei et al. (2022)
	biosensors for food safety	systematic review	biosensors deliver rapid, sensitive contaminant detection	Meliana et al. (2024)
	electrochemical sensors	technical review	real-time, high-sensitivity food monitoring capability improved	Sakthivel et al. (2024)
Supply chain efficiency, logistics and recall performance	assessing downstream traceability and recall performance	recall dataset analysis (2007–2013)	downstream traceability improves recall speed and reduces costs	Hall and Johnson-Hall (2021)
	developing traceability -integrated decision tools	logistics case study	multi-source data integration improves distribution decisions	Gallo et al. (2021)
	optimising supply chain strategies for safety	Stackelberg game model	traceability investment increases safety while reallocating incentives	Ma et al. (2022)
	traceability technology adoption in supply chains	three-tier SC model	adoption improves efficiency but changes pricing structures	Dong et al. (2023)

https://doi.org/10.17221/130/2025-CJFS

Table 1. To be continued...

Category	Aim	Method	Results	References
Regulatory, institutional and policy alignment	understanding traceability adoption in aquatic markets	game-theoretic modelling + market surveys	higher inspection intensity strongly increases adoption	Jin et al. (2021)
	identifying global traceability trends	Scopus-based bibliometric analysis	significant increase in traceability research post-2014	Sinha et al. (2021)
	consumer-centric traceability for tomatoes	consumer & stakeholder analysis	consumer preferences guide successful traceability implementation	Anastasiadis et al. (2021)
	factors influencing Chinese farmers' participation	SEM + logistic regression	social influence and supporting infrastructure drive participation	Li et al. (2021)
	reviewing EU food safety policy frameworks	legal–policy analysis	EU regulations strengthen safety but reveal internal implementation gaps	Tankosić et al. (2022)
	impact of policy mixes on doption	empirical study	diverse regulatory tools increase traceability investment	Zhou et al. (2022)
	authentication methods in Europe	systematic review	automatic verification techniques increasingly adopted	Dimitrakopoulou and Vantarakis (2023)
Adoption barriers, scalability and inclusiveness	evaluating India's food traceability system	national survey	lack of awareness is the central barrier to adoption	Rao et al. (2022)
	assessing Malawi beef chain traceability	field research	traceability gaps create public health risks	Kumvenji et al. (2022)
	designing voluntary traceability for Agriculture 4.0	framework + case study	enhances transparency and compliance in organic chains	Latino et al. (2022)
	nanotechnology in traceability	review	nano-sensors provide micro-level monitoring and enhanced detection	Aggarwal and Idrishi (2023)

https://doi.org/10.17221/130/2025-CJFS

'traceability', 'blockchain' AND ('food safety' OR 'food traceability'), 'IoT' OR 'RFID' OR 'smart technologies' AND 'food supply chain', 'digital traceability' AND 'food fraud', 'artificial intelligence' OR 'biosensors' AND 'food authenticity'. The categorisation and information regarding the obtained documents are summarised in Table 1.

This study was conducted in line with the PRISMA guidelines (Moher et al. 2009). In the literature review conducted between 2021 and 2025, 70 documents were accessed. After removing 5 duplicate records, 65 documents were included in the screening phase. In the eligibility stage, 60 documents that could be accessed in full text were evaluated, and 8 of them were not included in the study. Among the excluded studies, 4 documents were outside the scope of the research, 2 documents did not meet the criteria for publication date, 1 document was theoretical in nature, and 1 document did not contain sufficient findings. As a result, 51 documents were included in the final analysis. The flow diagram showing the document selection process is presented in Figure 1.

As illustrated in Figure 1, the studies included in this review were examined through a systematic literature synthesis. Following the study selection process, relevant information was extracted from each article and qualitatively analysed to identify recurring themes related to the benefits and challenges of digital traceability systems. The analysis focused on key dimensions such as traceability performance, food safety outcomes, supply chain transparency, regulatory compliance, and implementation constraints. Evidence reported in the reviewed studies was comparatively synthesised to evaluate how different digital technologies contribute to fraud prevention, contamination control, and risk management within food supply systems. This approach enabled an integrated assessment of current research trends and existing limitations in smart food safety and traceability solutions.

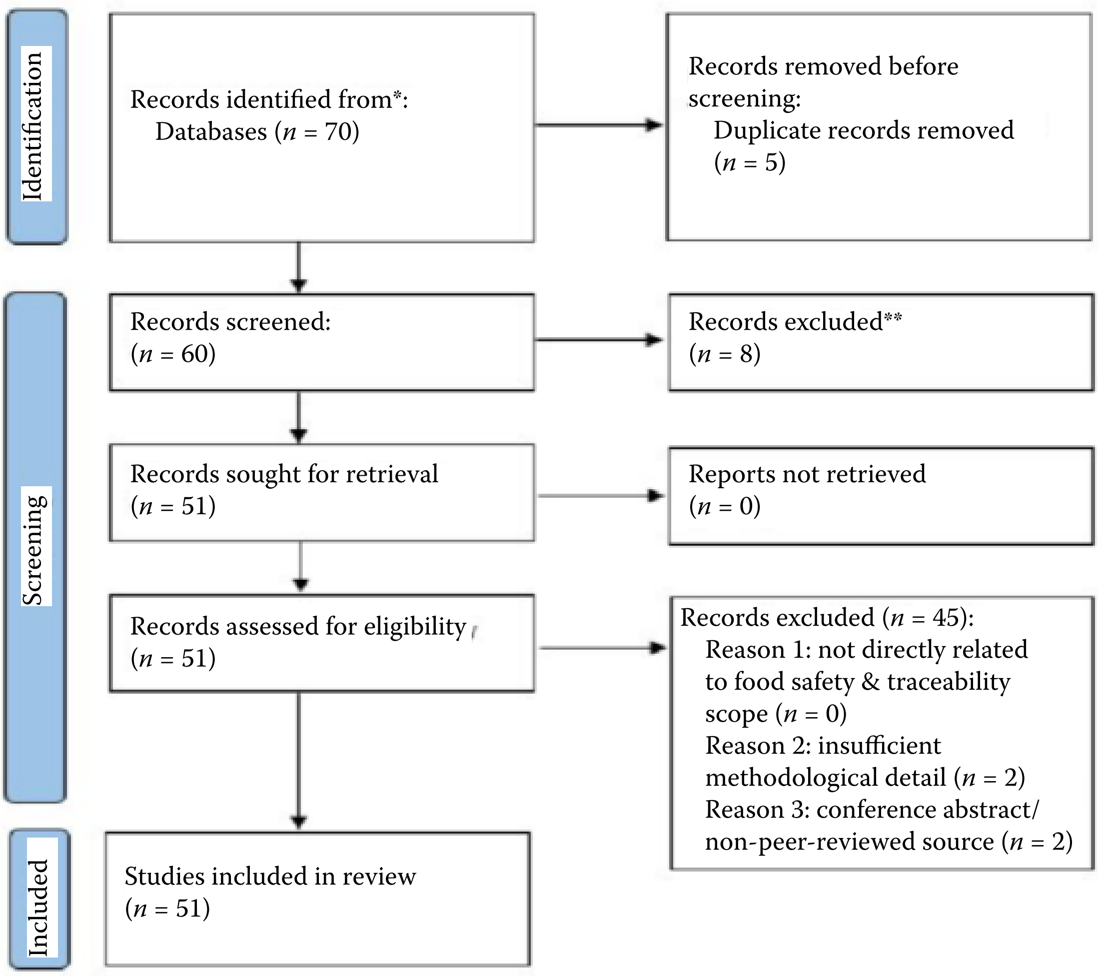

Figure 1. Prisma diagram

https://doi.org/10.17221/130/2025-CJFS

RESULTS AND DISCUSSION

Consumers are becoming increasingly aware of food safety, quality, and transparency in the supply chain. According to IFIC's (2019) Food and Health Survey, 60% of consumers say they find it difficult to determine the environmental sustainability of the food they buy, while 63% say their choices would change if they had more information. While taste continues to be the most decisive factor in food and beverage choices, consumers' trust in the brand and knowledge of product ingredients also have a significant impact. Furthermore, 45% of consumers see government agencies as the most reliable source of information on food recalls. These data show that consumers tend to make more informed choices about food (IFIC 2019). Rather than indicating a uniform behavioural shift, these findings suggest that transparency-driven decision-making is conditional on the credibility, accessibility, and interpretability of traceability information provided to consumers. However, empirical evidence suggests that increased information availability alone does not uniformly translate into trust or behavioural change; consumer response is mediated by institutional credibility and perceived usefulness of traceability information (Garaus and Treiblmaier 2021; Hong et al. 2021).

Globalisation, the food supply chain must be inspected at every stage, and risks must be anticipated, identified, and intervened. In this context, continuous monitoring methods supported by internet-based communication, wireless identification (RFID), and sensor technologies are being developed to ensure internal and external control (Aung and Chang 2014; Galvez et al. 2018). Furthermore, processes such as good manufacturing practices (GMP, GHP), Hazard Analysis and Critical Control Points (HACCP), ISO 22000:2018, and Total Quality Management (TQM) are improving the quality of food safety in production (Bosona and Gebresenbet 2013; Bigliardi and Galati 2013). Nevertheless, several studies emphasise that these management systems primarily address preventive control at the process level and remain insufficient for end-to-end traceability without digital verification and real-time data integration (Islam and Cullen 2021; Qian et al. 2022).

The 51 studies evaluated within the scope of the research were primarily assessed based on publication numbers by year, publication trends, geographical distribution, traceability technologies used, application areas, and types of reported outputs. These studies were published between 2021 and 2025 and met the inclusion criteria. The distribution of classification categories by year is presented in Figure 2.

According to Figure 2, there has been a significant concentration of research in the smart food traceability literature since 2021; the period between 2021 and 2023 is the most intense in terms of both the number and thematic diversity of studies. During this period, the 'Data Integrity, Immutability, and Auditability' category has been particularly dominant, with blockchain-based systems beginning to play a central role in food safety governance. This dominance reflects a prioritisation of record security and auditability over system-wide performance metrics such as scalability, inclusiveness, and cost efficiency (Lv et al. 2023; Duan et al. 2024).

The Real-Time Monitoring and Sensor-Based Verification category showed a significant increase in 2022 and 2023, indicating the increasing adoption of IoT, RFID, and sensor-based solutions in operational trace-

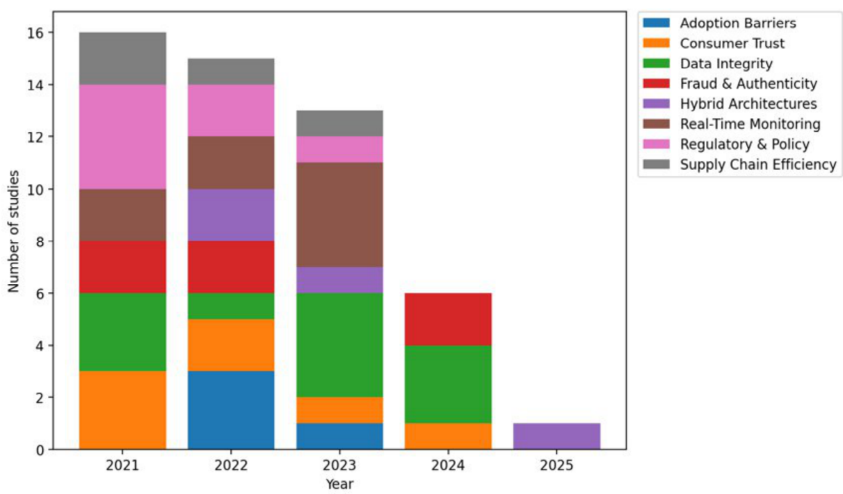

Figure 2. Yearly distribution of publications on smart food safety and traceability systems between 2021 and 2025

https://doi.org/10.17221/130/2025-CJFS

ability. Comparative analysis indicates a clear trade-off: while IoT- and RFID-based systems significantly enhance responsiveness and early warning capacity (Rahman et al. 2021; Zheng et al. 2021), their outputs remain vulnerable to calibration errors, data loss, and manipulation unless combined with secure validation mechanisms (Lei et al. 2022; Mattarozzi et al. 2023).

In parallel, studies under the heading 'Hybrid and Integrated Traceability Architectures' gained visibility, especially after 2022. A paradigm shift from single technologies to multi-layered and integrated architectures has been identified in the literature. Despite their conceptual superiority, most hybrid-system studies rely on pilot-scale applications, simulations, or framework proposals, limiting empirical evidence on scalability and long-term operational performance (Balamurugan et al. 2022; Yu et al. 2022; Tripathi et al. 2023).

Studies in the consumer trust, adoption, and behavioural dynamics category show a stable distribution between 2021 and 2024. Results across these studies are partially inconsistent: while blockchain-enabled transparency has been associated with increased willingness to pay and perceived product integrity (Garaus and Treiblmaier 2021; Tran et al. 2024), other studies demonstrate that adoption is strongly mediated by regulatory clarity, institutional trust, and user familiarity with technology (Lin et al. 2021; Wang and Scrimgeour 2023). The categories of Fraud Detection, Authenticity and Quality Assurance, and Regulatory, Institutional and Policy Alignment were found to be represented in publications with a limited number of studies and were considered as complementary elements. This relative underrepresentation suggests that material verification methods and governance frameworks are often treated as auxiliary components rather than as integral elements of traceability system design (Fanelli et al. 2021; Dimitrakopoulou and Vantarakis 2023). Geographical distribution of the studies included in the systematic review is presented in Table 2.

As shown in Table 2, the majority of studies originate from Asia and Europe, with these two regions accounting for more than two-thirds of the total publications. This concentration is attributed to increasing regulatory pressures in the areas of food safety and traceability, high technological investment capacity, and complex supply chain structures in these regions. Regional comparison reveals divergent research emphases: Asian studies predominantly focus on technological robustness and data immutability (Guo et al. 2021; Iftekhar and Cui 2021), whereas European studies more frequently examine consumer trust, governance, and policy compliance (Anastasiadis et al. 2021; Tankosić et al. 2022). Asian countries focused on data integrity, immutability and auditability, and real-time monitoring categories; while in Europe, consumer trust, behavioural dynamics, and fraud and authenticity categories stood out. European-based studies focus more on the impact of transparency on consumer perception, trust, and willingness to pay, rather than technological infrastructure. North America follows Asia and Europe, with studies predominantly focusing on con-

Table 2. Geographical distribution of the studies included in the systematic review (*n*)

Category	Asia	Europe	North America	Africa	Oceania	Multi-regional/global	Total
Data integrity, immutability and auditability	5	4	1	0	0	1	11
Real-time monitoring and sensor-based verification	3	3	1	1	0	0	8
Hybrid and integrated traceability architectures	2	1	0	0	0	1	4
Consumer trust, adoption and behavioural dynamics	2	3	1	0	0	1	7
Fraud detection, authenticity and quality assurance	1	3	0	0	0	2	6
Supply chain efficiency, logistics and recall performance	1	1	1	1	0	0	4
Regulatory, institutional and policy alignment	3	1	1	0	0	1	6
Adoption barriers, scalability and inclusiveness	1	0	1	1	2	0	5
Total	18	16	7	3	2	5	51

https://doi.org/10.17221/130/2025-CJFS

sumer trust, recall effectiveness, and regulatory compliance. The concentration on adoption barriers, inclusivity, and supply chain vulnerabilities in countries such as Africa and Oceania is thought to stem from technological capacity deficiencies, infrastructure problems, and awareness levels. Indeed, studies that identify problems such as accessibility and applicability are concentrated in these countries. Multi-regional studies have shown that governance issues such as hybrid systems, fraud, and policy alignment, as well as global integration and interoperability, are evaluated. Analytical comparison of smart food safety and traceability approaches is presented in Table 3.

Table 3 indicates that research on smart food safety and traceability has evolved along several analytical lines rather than being confined to a single technological trajectory. Nevertheless, this diversity does not yet reflect a fully balanced system-oriented perspective. While technological feasibility and data security dominate the literature, issues related to scalability, inclusiveness,

Table 3. Analytical comparison of smart food safety and traceability approaches

Category	Dominant technology focus	Number of studies (*n*)	Share (%)	Empirical evidence level*	Technological maturity	Scalability potential	Key analytical implication
Data integrity, immutability and auditability	blockchain, smart contracts, distributed ledgers	11	21.6	medium–high	medium	medium	strong auditability and transparency; scalability and energy efficiency remain limiting factors
Real-time monitoring and sensor-based verification	IoT, RFID, environmental & process sensors	8	15.7	high	high	high	operationally mature backbone for traceability; requires secure validation to ensure data trust
Hybrid and integrated traceability architectures	blockchain + IoT ± AI	4	7.8	low–medium	low–medium	medium	highest theoretical system-level performance; limited empirical validation
Consumer trust, adoption and behavioural dynamics	blockchain interfaces, transparency tools, consumer analytics	7	13.7	medium	medium	medium	trust gains are conditional on regulation, institutional credibility, and user literacy
Fraud detection, authenticity and quality assurance	biosensors, molecular, chemical authentication methods	6	11.8	high	high	low–medium	high-precision authentication; cost and field scalability constrain widespread adoption
Supply chain efficiency, logistics and recall performance	traceability-enabled SC models, logistics analytics	4	7.8	medium	medium	medium	demonstrated recall and efficiency gains; system-wide evaluations remain limited
Regulatory, institutional and policy alignment	policy instruments, governance frameworks, compliance tools	6	11.8	medium	medium	low–medium	regulatory coherence is a key enabling factor; fragmentation limits scalability
Adoption barriers, scalability and inclusiveness	cost–benefit analyses, modular & nano-enabled systems	5	9.8	low	low	low–medium	structural barriers persist for SMEs and developing regions
Total		51	100				

RFID – radio frequency identification; SC – supply chain; SMEs – small and medium-sized enterprises; *empirical evidence level was assigned by the authors from the number and design of the included studies

https://doi.org/10.17221/130/2025-CJFS

and economic feasibility receive comparatively limited attention, pointing to a disconnect between technical development and real-world implementation capacity (Kumvenji et al. 2022; Rao et al. 2022).

A substantial proportion of the studies focus on data integrity, immutability, and auditability (21.6%, n = 11), primarily through blockchain-based solutions such as smart contracts and distributed ledger technologies. This emphasis highlights that safeguarding records and ensuring transparency remain central concerns. Real-time monitoring and sensor-based verification follow as the second most frequent research area (15.7%, n = 8), underscoring the practical importance of IoT and RFID technologies in operational traceability, quality assurance, and early risk identification within food supply chains.

Research addressing consumer trust, adoption, and behavioural dynamics (13.7%, n = 7), together with studies examining regulatory, institutional, and policy alignment (11.8%, n = 6), suggests a growing awareness that the effectiveness of traceability systems is shaped by more than technical infrastructure alone. These studies collectively point to the influence of regulatory clarity, institutional credibility, and stakeholder acceptance in determining whether traceability technologies are meaningfully adopted and trusted in practice.

In contrast, relatively few studies address hybrid and integrated traceability architectures (7.8%, n = 4) or explicitly evaluate supply chain efficiency, logistics performance, and recall effectiveness (7.8%, n = 4). This limited representation implies that multi-technology integration and comprehensive assessments of system-level performance are still emerging areas of research. Similarly, the modest focus on adoption barriers, scalability, and inclusiveness (9.8%, n = 5) indicates that the challenges faced by small-scale producers and actors in developing regions have not yet been systematically explored, which tempers claims of a fully realised system-wide transformation. Synthesised analytical evaluation of smart food safety and traceability research is presented in Table 4.

As presented in Table 4, the 51 studies included in this systematic review are organised into eight thematic categories, offering a structured overview of both prevailing research directions and underexplored areas in smart food safety and traceability. The distribution of these studies suggests that the literature is shaped by an interplay of technological development, behavioural responses, and governance frameworks, rather than by technological innovation alone.

A dominant share of the literature concentrates on data integrity, immutability, and auditability, underscoring the central role attributed to secure data management in contemporary traceability research. Blockchain-based systems are widely reported to enhance transparency, accountability, and the reliability of audit trails across diverse food supply chains, including agriculture, dairy, livestock, and food service sectors (Iftekhar and Cui 2021; Guo et al. 2021; Wang et al. 2021). Empirical evidence further indicates that smart contracts can streamline verification and compliance procedures, thereby improving operational efficiency (Wang et al. 2021). In cold chain-dependent systems, particularly within dairy and livestock supply chains, immutable data records have been associated with improved product safety and quality assurance, as well as strengthened coordination among supply chain actors (Khanna et al. 2022; Patel et al. 2023; İndap and Tanyaş 2023). At the same time, a growing body of work cautions that blockchain solutions, when applied in isolation, remain insufficient to address the scale, complexity, and heterogeneity of global food systems, with persistent challenges related to energy demand, interoperability, and scalability (Lv et al. 2023; Singh et al. 2023; Duan et al. 2024).

The second most prominent research stream concerns real-time monitoring and sensor-based verification, highlighting the operational importance of IoT, RFID, and environmental sensing technologies. Continuous data generation through these systems has been shown to improve freshness control, safety monitoring, and traceability accuracy, particularly in perishable food supply chains (Rahman et al. 2021; Zheng et al. 2021). Several studies further demonstrate that integrating IoT infrastructures with machine learning–based classification and anomaly detection enhances transparency and reduces process-related errors (Lin et al. 2022; Wei et al. 2023). Advances in point-of-need testing and environmental sensors have also strengthened early warning capabilities by enabling rapid contaminant detection and real-time risk assessment (Radogna et al. 2022; Mattarozzi et al. 2023). Despite their relatively high operational maturity, these systems remain dependent on complementary governance and data validation mechanisms to ensure long-term reliability and user trust (Mehannaoui et al. 2023).

A notable proportion of the reviewed studies addresses consumer trust, adoption, and behavioural dynamics, alongside regulatory, institutional, and policy alignment. This trend reflects an increasing recognition that the effectiveness of traceability systems is closely

https://doi.org/10.17221/130/2025-CJFS

Table 4. Synthesised analytical evaluation of smart food safety and traceability research

Category	Evidence synthesis	Methodological strength	Key trade-offs & limitations	System-level interpretation
Data integrity, immutability and auditability	blockchain-based systems consistently enhance transparency, auditability, and tamper resistance across food supply chains	medium–high (case studies, pilots, sectoral applications)	scalability constraints, high energy consumption, interoperability issues	strong governance and accountability layer, insufficient alone for full system integration
Real-time monitoring and sensor-based verification	IoT and RFID technologies significantly improve early warning capacity and operational traceability, especially in perishable foods	high (field applications, industrial deployment)	sensor reliability, cybersecurity risks, data manipulation potential	operational backbone of traceability systems, requires secure validation mechanisms
Hybrid and integrated traceability architectures	integrated blockchain–IoT–AI architectures offer the highest theoretical system performance	low–medium (conceptual, simulations, pilots)	high complexity, limited real-world validation, cost barriers	high future potential, but currently limited system-wide impact
Consumer trust, adoption and behavioural dynamics	transparency generally increases trust and willingness to pay, but effects are context-dependent	medium (surveys, experiments, SEM)	adoption mediated by regulation, institutional trust, digital literacy	social and institutional factors are decisive for effectiveness
Fraud detection, authenticity and quality assurance	biosensors and molecular methods provide high-precision authentication and fraud detection	high (laboratory and applied studies)	high cost, limited field scalability, integration challenges	critical complementary layer rather than standalone solution
Supply chain efficiency, logistics and recall performance	traceability investments reduce recall time and economic losses	medium (model-based and recall data analyses)	limited cross-sector evaluation, secondary research focus	demonstrated operational benefits, underexplored at system scale
Regulatory, institutional and policy alignment	regulatory coherence strongly shapes adoption and performance of traceability systems	medium (policy analysis, empirical studies)	fragmented regulations, uneven enforcement	key enabling or constraining factor for scalability
Adoption barriers, scalability and inclusiveness	SMEs and developing regions face disproportionate adoption barriers	low (exploratory, case-based)	infrastructure gaps, financing constraints, low awareness	highlights structural inequity in global traceability adoption

RFID – radio frequency identification; SEM – structural equation modelling; SMEs – small and medium-sized enterprises

linked to social acceptance and governance capacity. Research consistently identifies perceived benefits, trust, and ease of use as key drivers of consumer adoption, particularly in the context of blockchain-enabled traceability (Garaus and Treiblmaier 2021; Lin et al. 2021). In addition, empirical findings indicate that regulatory clarity and institutional credibility significantly shape consumer perceptions, influencing willingness to pay for traceable products in markets such as organic food and seafood (Guanqi and Husnain 2022; Hoque et al. 2022; Wang and Scrimgeour 2023; Tran et al. 2024). Policy-oriented analyses further emphasise that audit rigor, information-sharing mechanisms, and supportive regulatory environments are decisive factors in facilitating adoption, while also revealing coordination gaps within existing food safety governance structures (Anastasiadis et al. 2021; Jin et al. 2021; Zhou et al. 2022; Dimitrakopoulou and Vantarakis 2023).

https://doi.org/10.17221/130/2025-CJFS

In contrast, research focusing on supply chain efficiency, logistics performance, recall effectiveness, and hybrid or integrated traceability architectures remains comparatively limited. Available evidence suggests that traceability systems can shorten recall times, reduce operational losses, and improve coordination across logistics networks; however, comprehensive system-level evaluations and cross-sector comparisons are still scarce (Hall and Johnson-Hall 2021). Studies exploring multi-source data integration and advanced supply chain modelling indicate that combining traceability data with optimisation and game-theoretic approaches may redirect incentives toward preventive food safety investments, yet these approaches are rarely validated at scale (Gallo et al. 2021; Ma et al. 2022; Dong et al. 2023). Emerging evidence from hybrid architectures integrating IoT, blockchain, and artificial intelligence points to superior performance in terms of data integrity, real-time monitoring, and error reduction, positioning such systems as promising next-generation solutions, albeit with increased complexity and cost considerations (Balamurugan et al. 2022; Yu et al. 2022; Tripathi et al. 2023; Liu et al. 2025).

The limited representation of the adoption barriers, scalability, and inclusiveness categories stems from the fact that implementation challenges, particularly for small-scale manufacturers, small and medium-sized enterprises (SMEs), and developing regions, remain unresolved. Rao et al. (2022) and Kumvenji et al. (2022) indicates that lack of awareness, limited technical capacity, and high implementation costs have a disproportionate impact on developing regions and small-scale actors. Indeed, awareness gaps and inadequate infrastructure are considered the main obstacles to traceability adoption (Kumvenji et al. 2022; Rao et al. 2022). Voluntary, modular, and nano-supported traceability systems offer scalable and inclusive solutions, especially for organic and small-producer-dominated supply chains, thus positively contributing to adoption processes (Latino et al. 2022; Aggarwal and Idrishi 2023). This finding tempers claims of system-level transformation and indicates that current smart traceability solutions primarily benefit technologically and institutionally mature supply chains rather than providing universally scalable models (Latino et al. 2022; Aggarwal and Idrishi 2023).

CONCLUSION

Digital technologies, replacing traditional control systems to prevent safety, disease risk, and fraud in the food process, have made supply chains real-time and transparent. The decentralised nature of blockchain systems prevents record alterations and prevents counterfeiting. The study concludes that data integrity, immutability, and auditability of blockchain-based applications are dominant research priorities in the literature. Real-time monitoring provided through IoT, RFID, and sensor-based technologies is described as the operational backbone of traceability; its importance is particularly highlighted in increasing early warning capacity, quality control, and transparency in perishable food supply chains. However, hybrid and fully integrated applications remain relatively limited, and the field continues its transition towards holistic systems that combine secure data verification, continuous monitoring, and intelligent analytics. Beyond technical infrastructure, consumer trust, behavioural adoption, and regulatory compliance have emerged as critical elements determining the effectiveness of traceability systems and are gaining increasing importance. However, technological development alone is insufficient without corporate credibility, regulatory consistency, and stakeholder acceptance. Geographical differences show that Asia and Europe are leading in technological and regulatory innovation, while scalability, inclusivity, and infrastructure issues pose disproportionate challenges for developing regions and SMEs. The most effective traceability mechanisms are achieved in integrated and hybrid systems equipped with governance frameworks and inclusive design principles; these systems are proactive, transparent, and hold a significant position in terms of sustainability.

REFERENCES

Aggarwal D., Idrishi R. (2023): Nanotechnology applications for food traceability. In: Sharma A., Vijayakumar P.S., Prabhakar E.P.K., Kumar R. (eds.): Nanotechnology Applications for Food Safety and Quality Monitoring. Cambridge, Academic Press: 457–472.

Anastasiadis F., Apostolidou I., Michailidis A. (2021): Food traceability: A consumer-centric supply chain approach on sustainable tomato. Foods, 10: 543.

Antonucci F., Figorilli S., Costa C., Pallottino F., Raso L., Menesatti P. (2019): A review on blockchain applications in the agri-food sector. Journal of the Science of Food and Agriculture, 99: 6129–6138.

Aung M.M., Chang Y.S. (2014): Traceability in a food supply chain: Safety and quality perspectives. Food Control, 39: 172–184.

https://doi.org/10.17221/130/2025-CJFS

Balamurugan S., Ayyasamy A., Joseph K.S. (2022): IoT-Blockchain driven traceability techniques for improved safety measures in food supply chain. International Journal of Information Technology, 14: 1087–1098.

Bigliardi B., Galati F. (2013): Models of adoption of open innovation within the food industry. Trends in Food Science & Technology, 30: 16–26.

Bosona T., Gebresenbet G. (2013): Food traceability as an integral part of logistics management in food and agricultural supply chain. Food Control, 33: 32–48.

Creydt M., Fischer M. (2019): Blockchain and more – Algorithm driven food traceability. Food Control, 105: 45–51.

Dimitrakopoulou M.E., Vantarakis A. (2023): Does traceability lead to food authentication? A systematic review from a European perspective. Food Reviews International, 39: 537–559.

Dong L., Jiang P., Xu F. (2023): Impact of traceability technology adoption in food supply chain networks. Management Science, 69: 1518–1535.

Duan K., Onyeaka H., Pang G., Meng Z. (2024): Pioneering food safety: Blockchain's integration in supply chain surveillance. Journal of Agriculture and Food Research, 18: 101281.

EC (2014): Food Safety. Brussels, European Commission. Available at: https://commission.europa.eu/strategy-and-policy/food-safety_en

EC (2021): Regulation (EC) No. 178/2002 Laying Down the General Principles and Requirements of Food Law: Consolidated Version March 27, 2021. Brussels, European Commission. Available at https://eur-lex.europa.eu/eli/reg/2002/178/2021-03-27

European Council (2019): Safe and Transparent Food Chain: Provisional Agreement on Availability and Independence of Scientific Studies. Brussels, European Council. Available at https://www.consilium.europa.eu/en/press/press-releases/2019/02/12/safe-and-transparent-food-chain-provisional-agreement-on-availability-and-independence-of-scientific-studies/

Fanelli V., Mascio I., Miazzi M.M., Savoia M.A., De Giovanni C., Montemurro C. (2021): Molecular approaches to agri-food traceability and authentication: An updated review. Foods, 10: 1644.

FAO (2019): The Future of Food Safety: There Is No Food Security Without Food Safety. Rome, FAO and WHO.

Gallo A., Accorsi R., Goh A., Hsiao H., Manzini R. (2021): A traceability-support system to control safety and sustainability indicators in food distribution. Food Control, 124: 107866.

Galvez J.F., Mejuto J.C., Simal-Gandara J. (2018): Future challenges on the use of blockchain for food traceability analysis. Trends in Analytical Chemistry, 107: 222–232.

Garaus M., Treiblmaier H. (2021): The influence of blockchain-based food traceability on retailer choice: The mediating role of trust. Food Control, 129: 108082.

Guanqi Z., Husnain M. (2022): Assessing the role of organic food supply chain traceability on food safety and consumer wellbeing: A mediated-moderation investigation. Frontiers in Psychology, 13: 1073376.

Guo J., Cengiz K., Tomar R. (2021): An IoT and blockchain approach for food traceability system in agriculture. Scalable Computing: Practice and Experience, 22: 127–137.

Gupta R., Shankar R. (2024): Managing food security using blockchain-enabled traceability system. Benchmarking: An International Journal, 31: 53–74.

Hall D.C., Johnson-Hall T.D. (2021): The value of downstream traceability in food safety management systems: An empirical examination of product recalls. Operations Management Research, 14: 61–77.

Hong W., Mao J., Wu L., Pu X. (2021): Public cognition of the application of blockchain in food safety management – Data from China's Zhihu platform. Journal of Cleaner Production, 303: 127044.

Hoque M.Z., Akhter N., Chowdhury M.S.R. (2022): Consumers' preferences for the traceability information of seafood safety. Foods, 11: 1675.

IFIC (2019): 2019 Food and Health Survey. Washington, D.C., IFIC. Available at https://ific.org/research/2019-food-and-health-survey/

Iftekhar A., Cui X. (2021): Blockchain-based traceability system that ensures food safety measures to protect consumer safety and COVID-19 free supply chains. Foods, 10: 1289.

İndap Ş., Tanyaş M. (2023): Blockchain applications for traceability and food safety in agri-food supply chain: Cherry product application. Journal of Enterprise Information Management, 38: 1327–1353.

Islam S., Cullen J.M. (2021): Food traceability: A generic theoretical framework. Food Control, 123: 107848.

Jin C.Y., Levi R., Liang Q., Renegar N., Zhou J.H. (2021): Food safety inspection and the adoption of traceability in aquatic wholesale markets: A game-theoretic model and empirical evidence. Journal of Integrative Agriculture, 20: 2807–2819.

Khanna A., Jain S., Burgio A., Bolshev V., Panchenko V. (2022): Blockchain-enabled supply chain platform for Indian dairy industry: Safety and traceability. Foods, 11: 2716.

Kumvenji D.C.E., Chamba M.V.M., Lungu K. (2022): Effectiveness of food traceability system in the supply chain of local beef and beef sausages in Malawi: A food safety perspective. Food Control, 137: 108839.

Latino M.E., Menegoli M., Lazoi M., Corallo A. (2022): Voluntary traceability in food supply chain: A framework

https://doi.org/10.17221/130/2025-CJFS

leading its implementation in Agriculture 4.0. Technological Forecasting and Social Change, 178: 121564.

Lei M., Xu L., Liu T., Liu S., Sun C. (2022): Integration of privacy protection and blockchain-based food safety traceability: Potential and challenges. Foods, 11: 2262.

Li D., Zang M., Li X., Zhang K., Zhang Z., Wang S. (2020): A study on the food fraud of national food safety and sample inspection of China. Food Control, 116: 107306.

Li L., Paudel K.P., Guo J. (2021a): Understanding Chinese farmers' participation behavior regarding vegetable traceability systems. Food Control, 130: 108325.

Li S., Tian Y., Jiang P., Lin Y., Liu X., Yang H. (2021b): Recent advances in the application of metabolomics for food safety control and food quality analyses. Critical Reviews in Food Science and Nutrition, 61: 1448–1469.

Lin X., Chang S.C., Chou T.H., Chen S.C., Ruangkanjanases A. (2021): Consumers' intention to adopt blockchain food traceability technology towards organic food products. International Journal of Environmental Research and Public Health, 18: 912.

Lin S., Shi Q., Zhou N. (2022): Construction of a traceability system for food industry chain safety information based on Internet of Things technology. Frontiers in Public Health, 10: 857039.

Liu Z., Yu X., Liu N., Liu C., Jiang A., Chen L. (2025): Integrating AI with detection methods, IoT, and blockchain to achieve food authenticity and traceability from farm-to-table. Trends in Food Science and Technology, 158: 104925.

Lozano-Castellón J., López-Yerena A., Domínguez-López I., Siscart-Serra A., Fraga N., Sámano S., López-Sabater C., Lamuela-Raventós R.M., Vallverdú A., Pérez M. (2022): Extra virgin olive oil: A comprehensive review of efforts to ensure its authenticity, traceability, and safety. Comprehensive Reviews in Food Science and Food Safety, 21: 2639–2664.

Lv G., Song C., Xu P., Qi Z., Song H., Liu Y. (2023): Blockchain-based traceability for agricultural products: A systematic literature review. Agriculture, 13: 1757.

Ma J., Chen J., Liu Y. (2022): Research on optimization of food supply chain considering product traceability recall and safety investment. Managerial and Decision Economics, 43: 3953–3972.

Mattarozzi M., Laski E., Bertucci A., Giannetto M., Bianchi F., Zoani C., Careri M. (2023): Metrological traceability in process analytical technologies and point-of-need technologies for food safety and quality control: Not a straightforward issue. Analytical and Bioanalytical Chemistry, 415: 119–135.

Mehannaoui R., Mouss K.N., Aksa K. (2023): IoT-based food traceability system: Architecture, technologies, applications, and future trends. Food Control, 145: 109409.

Meliana C., Liu J., Show P.L., Low S.S. (2024): Biosensor in smart food traceability system for food safety and security. Bioengineered, 15: 2310908.

Moher D., Liberati A., Tetzlaff J., Altman D.G., PRISMA Group (2009): Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Annals of Internal Medicine, 151: 264–269.

Nadimi M., Hawley E., Liu J., Hildebrand K., Sopiwnyk E., Paliwal J. (2023): Enhancing traceability of wheat quality through the supply chain. Comprehensive Reviews in Food Science and Food Safety, 22: 2495–2522.

Patel A.S., Brahmbhatt M.N., Bariya A.R., Nayak J.B., Singh V.K. (2023): Blockchain technology in food safety and traceability concern to livestock products. Heliyon, 9: e16526.

Qian J., Dai B., Wang B., Zha Y., Song Q. (2022): Traceability in food processing: Problems, methods, and performance evaluations – A review. Critical Reviews in Food Science and Nutrition, 62: 679–692.

Radogna A.V., Latino M.E., Menegoli M., Prontera C.T., Morgante G., Mongelli D., Giampetruzzi L., Corallo A., Bondavalli A., Francioso L. (2022): A monitoring framework with integrated sensing technologies for enhanced food safety and traceability. Sensors, 22: 6509.

Rahman L.F., Alam L., Marufuzzaman M., Sumaila U.R. (2021): Traceability of sustainability and safety in fishery supply chain management systems using radio frequency identification technology. Foods, 10: 2265.

Rao E.S., Shukla S., Rizwana (2022): Food traceability system in India. Measurement: Food, 5: 100019.

Sakthivel K., Balasubramanian S., Chang-Chien G.P., Wang S.F., Ahammad, Billey W., Platero J., Soundappan T., Sekhar P. (2024): Advances in electrochemical sensors: Improving food safety, quality, and traceability. ECS Sensors Plus, 3: 020605.

Singh A., Gutub A., Nayyar A., Khan M.K. (2023): Redefining food safety traceability system through blockchain: Findings, challenges and open issues. Multimedia Tools and Applications, 82: 21243–21277.

Sinha A., Priyadarshi P., Bhushan M., Debbarma D. (2021): Worldwide trends in the scientific production of literature on traceability in food safety: A bibliometric analysis. Artificial Intelligence in Agriculture, 5: 252–261.

Tankosić J.V., Puvača N., Giannenas I., Tufarelli V., Ignjatijević S. (2022): Food safety policy in the European Union. Journal of Agronomy, Technology and Engineering Management, 5: 712–717.

Tran D., Schouteten J.J., Gellynck X., De Steur H. (2024): How do consumers value food traceability? – A meta-analysis. Food Control, 162: 110453.

Tripathi A.K., Akul Krishnan K., Pandey A.C. (2023): A novel blockchain and Internet of Things-based food traceability

https://doi.org/10.17221/130/2025-CJFS

system for smart cities. Wireless Personal Communications, 129: 2157–2180.

Wang L., Xu L., Zheng Z., Liu S., Li X., Cao L., Li J., Sun C. (2021): Smart contract-based agricultural food supply chain traceability. IEEE Access, 9: 9296–9307.

Wang O., Scrimgeour F. (2023): Consumer adoption of blockchain food traceability: Effects of innovation-adoption characteristics, expertise in food traceability and blockchain technology, and segmentation. British Food Journal, 125: 2493–2513.

Wei Z., Alam T., Al Sulaie S., Bouye M., Deebani W., Song M. (2023): An efficient IoT-based perspective view of food traceability supply chain using optimized classifier algorithm. Information Processing & Management, 60: 103275.

WHO (2019): World Health Statistics 2019: Monitoring health for the SDGs, Sustainable Development Goals. Geneva, WHO. Available at https://www.who.int/publications/i/item/9789241565707

Yele S., Litoriya R. (2024): Blockchain-based secure dining: Enhancing safety, transparency, and traceability in food consumption environment. Blockchain: Research and Applications, 5: 100187.

Yiannas F. (2018): A new era of food transparency powered by blockchain. Innovations: Technology, Governance, Globalization, 12: 46–56.

Yu Z., Jung D., Park S., Hu Y., Huang K., Rasco B.A., Wang S., Ronholm J., Lu X., Chen J. (2022): Smart traceability for food safety. Critical Reviews in Food Science and Nutrition, 62: 905–916.

Zheng M., Zhang S., Zhang Y., Hu B. (2021): Construct food safety traceability system for people's health under the Internet of Things and big data. IEEE Access, 9: 70571–70583.

Zhou J., Jin Y., Liang Q. (2022): Effects of regulatory policy mixes on traceability adoption in wholesale markets: Food safety inspection and information disclosure. Food Policy, 107: 102218.

Received: August 6, 2025
Accepted: July 1, 2026
Published online: August 7, 2026