# Investigating barriers to the adoption of digital tools for supporting Food Safety Management System (FSMS) audits based on insights from literature and stakeholders' perspectives

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# Executive summary


**Background description**

The assurance of food safety continues to be a key issue throughout global supply chains, especially since food companies are increasingly being asked to prove compliance to Food Safety Management Systems (FSMS). Audits play a critical role in verifying FSMS effectiveness. However, traditional auditing has some challenges such as time constraints, subjectivity, as well as logistically oriented complexities. Against this background, Industry 4.0 technologies such as IoT, AI, blockchain, and cloud-based platforms has attracted interest as potential tools to support and digitalize FSMS auditing processes. Despite the increasing applicability, their use adoption remains limited. Technological and management-based barriers vary considerably across different stakeholders such as auditors, certification bodies, scheme owners, as well as auditees. However, a structured and in-depth investigation into these barriers across stakeholder perspectives is still lacking.

**Research aim and questions**

The aim of this study is to explore technological and management barriers in adoption of digital tools and technologies for FSMS auditing from stakeholder`s perspectives. The study focuses on three main themes. The identification of digital tools and technologies and their functionality for auditing FSMS, technological and management barriers in adoption of them according to the relevant literature, and the existing practice as well as the perceived issues from the perspectives of the stakeholders who are involved in auditing processes.

**Research methodology**

A qualitative approach was applied to examine the study aim in depth. First, a semi-systematic literature review was conducted to explore from 27 recent publications on digital tools and technologies relevant to FSMS audits, as well as to synthesize most-referred technological and management barriers. The review was supported by a focused set of 13 appraisal questions, and transparent methods of selection, extraction, and thematic coding of the data. Second, semi-structured interviews were carried out with selected stakeholder group members such as auditors, auditees, certification bodies, as well as scheme owners. The interview transcripts were then analysed thematically to search for recurring concepts, enabling a basis for comparison to be made with the findings of the literature, and practice-based insights into issues in the real world.

**Main findings**

The literature review identified 10 digital tools relevant to FSMS auditing, with the Internet of Things (IoT), artificial intelligence (AI), blockchain, and digital audit platforms emerging as the most prominent. These technologies primarily enhance audit processes by facilitating real-time monitoring, ensuring secure traceability, enabling data analytics, and automating compliance-related tasks. Technological barriers frequently cited include system

interoperability issues, cybersecurity risks, poor connectivity, and inadequate infrastructure. Managerial barriers encompass resistance to organisational change, insufficient digital literacy and training, limited leadership commitment, and unclear regulatory guidance. Insights from expert interviews corroborated many of these findings while also highlighting context-specific nuances. Although participants generally recognised the potential value of digital tools, concerns were raised regarding usability, increased data entry workload, and misalignment between technological capabilities and the practical requirements of audits as barriers.

**Conclusion and recommendations**

This study concludes that while digital technologies offer considerable promise in advancing FSMS auditing practices, their widespread adoption remains hindered by persistent technological and managerial barriers. Successful adoption of digital tools and technologies in FSMS audits requires coordinated efforts among stakeholders. It has included the establishment of interoperability standards, investment in IT infrastructure, and the provision of context-specific training initiatives. Furthermore, regulatory bodies and scheme owners must offer clearer, authoritative guidance on the validity and reliability of digital audit outputs.

Strategic alignment, effective resource allocation, and sustained stakeholder engagement are essential to facilitate a successful digital transition in audit practices. Future research should investigate sector-specific approaches to address these barriers and assess the long-term effectiveness of digital tools in improving audit quality and ensuring food safety compliance.

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# List of abbreviations

AI: Artificial Intelligence

IoT: Internet of Things

FSMS: Food Safety Management Systems

HACCP: Hazard Analysis and Critical Control Point

EU: European Union

DESI:  Digital Economy and Society Index

T-M:  Technological and managerial

SMEs: Small and Medium-sized Enterprises

GFSI: Global Food Safety Initiative

CBs: Certification bodies

CCPs: Critical control points

I4.0: Industry 4.0

CAQ: Critical appraisal questions

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# 1. Introduction

## 1.1 Description of problem situation

### 1.1.1 Navigating the complexity of current food safety management system

The food industry is facing an extensive transformation driven by growing customer demand for safer, higher-quality food products. As global supply chains become more interdependent and complex, food safety has become of prime concern, having serious consequences for public health and consumer confidence. In the last few decades, multiple public and private food safety management standards (such as HACCP, and ISO 22000, BRCGS and FSSC 22000) have been developed and updated in order to assist organisations in designing, implementing and maintaining their food safety management system (FSMS) and manage food safety risks throughout production, processing and distribution (Luning & Marcelis, 2020). Audits of FSMS is crucial for ensuring compliance with these standards, providing a safeguard that enhances public trust in the safety of food products.

However, the complexity of modern supply chains poses inherent risks. Traditional FSMS audits, which are often manual and conducted periodically, provide only a limited snapshot of compliance, focusing on isolated points in time rather than a continuous view of food safety practices (Kotsanopoulos & Arvanitoyannis, 2017; Awuchi, 2023). Without the ability to monitor food safety conditions in real-time, potential hazards may go undetected, posing risks of foodborne disease outbreaks, contamination incidents, and other public health emergencies (Panghal et al., 2018). Such incidents can result in significant economic losses for food producers, costly recalls, as well as damage to brand reputation, impacting communities and entire industries.

The food industry must quickly transition to a digital transformation process due to the dynamic nature of food production and distribution today (Bezerra et al., 2024). Public health organizations and regulatory authorities rely on accurate, up-to-date audit information to make timely decisions that protect consumers. On the other hand, traditional audit methods, which depend on paperwork, manual checks, and periodic site visits, struggle to capture real-time changes in food safety conditions. This absent of ongoing can oversight generates gaps that can allow safety risks to amplify between audits, especially in large-scale, globally distributed supply chains (Chandan et al., 2023; Kotsanopoulos & Arvanitoyannis, 2017).

The growing complexity of food supply chains, combined with limitations in traditional auditing, highlights a critical need for more responsive and precise approaches to food safety management. Digital technologies offer a potential solution, with capabilities for real-time monitoring, automation, and advanced data analysis. However, despite the potential of digital tools to transform FSMS auditing, their integration has been slow and inconsistent, resulting in considerable barriers in effectively addressing food safety risks in an increasingly globalized food industry (Donaghy et al., 2021; Oriekhoe et al., 2024).

### 1.1.2 Complexity of the audit system and its stakeholders

The audit system for FSMS operates as a complex framework, covering not only the actual auditing process but also the broader network of organizations and stakeholders that ensure its reliability and effectiveness. These include accreditation bodies, scheme owners, certification bodies (CBs), as well as auditors and auditees directly involved in the audit process. All of them contributes distinct roles and responsibilities, which maintain food safety standards and ensure compliance with national and international regulations (Kleboth et al., 2016; Luning & Marcelis, 2020).

At the foundational level, accreditation bodies play a pivotal role by overseeing the performance and credibility of certification bodies. Their primary responsibility is to ensure that CBs are competent and consistent in conducting audits aligned with specific food safety schemes. Scheme owners manage the design and maintenance of certification schemes, assign accredited CBs to perform third-party audits, and ensure that audits adhere to the scheme's requirements, promoting trust in the certification process (Evans & Taylor, 2019; "Swainson's Handbook of Technical and Quality Management for the Food Manufacturing Sector," 2018). Certification bodies act as intermediaries, planning and managing audits in line with the schemes they are authorized to implement. They are responsible for assigning qualified auditors, defining the scope and objectives of audits, and ensuring that audits cover all necessary compliance requirements. During the planning stage, CBs collaborate with auditors to determine audit schedules, allocation of resources, and preparation documents. Auditors then refine these plans, adapting them to the specific needs of the auditee and regulatory expectations (Kleboth et al., 2016; Evans & Taylor, 2019; "Swainson's Handbook of Technical and Quality Management for the Food Manufacturing Sector," 2018).

The execution stage involves auditors conducting on-site or remote inspections, collecting data, and verifying compliance with FSMS standards. This stage relies on the cooperation of

auditees, who provide access to facilities, records, and personnel to facilitate the evaluation. Effective communication and transparency between auditors and auditees are critical at this stage to ensure the accuracy and reliability of findings (Kleboth et al., 2016; Kuzmina et al., 2023).

The evaluation stage involves analysing collected data, identifying non-conformities, and assessing overall compliance. This step may include feedback loops between auditors, auditees, and scheme owners to ensure interpretations align with scheme requirements and evolving regulatory requirements. Certification bodies review the auditor's findings to verify consistency and accuracy before the audit progresses to the final phase (Jacxsens et al., 2011; "Swainson's Handbook of Technical and Quality Management for the Food Manufacturing Sector," 2018).

The reporting stage concludes the audit process, where auditors organize their findings into a comprehensive report. This report is shared with certification bodies, scheme owners, and auditees to ensure accountability, transparency, and corrective action where necessary. This reporting phase is essential for ongoing improvement and for demonstrating compliance to external actors, including customers and regulators (Kleboth et al., 2016; "Swainson's Handbook of Technical and Quality Management for the Food Manufacturing Sector," 2018).

While roles and responsibilities are clearly defined, the complexity of this system introduces coordination challenges, particularly as globalized supply chains and dynamic food systems demand timely and effective compliance verification (Singh et al., 2022). Understanding this complexity is essential for assessing how digital innovations can be integrated meaningfully into FSMS auditing systems.

### 1.1.3 Digital tools and technologies in FSMS auditing

Digital tools and technologies are essential to contemporary FSMS audits, offering improvements in accuracy, traceability, and operational efficiency. The most popularly technologies include Internet of Things (IoT) sensors, blockchain, artificial intelligence (AI), and cloud-based audit platforms. These digital technologies support a variety of audit functions, from real-time environmental monitoring and automated documentation to predictive risk detection and remote inspections (Traversa et al., 2022; Qian et al., 2022). Several studies have demonstrated the potential of these technologies. For example, Sartoni et al. examined digitalization in food safety management system, showing that AI and other digital technologies can reduce manual workload and detect risks beforhand (Sartoni et al.

2024). Castka et al. evaluated remote audit tools used during COVID-19 and emphasized the benefits of reduced travel and increased accessibility (Castka et al. 2021). Blockchain has also been studied for its potential to enhance transparency and traceability in audit trails (Tian, 2017; Silva et al., 2022). Despite these growing studies, few studies have investigated how specific digital tools align with the practical activities and responsibilities of different audit stakeholders. For example, Kleboth et al. focused on the relationship between CBs and auditees, emphasizing the role of trust but not the application of digital tools (Kleboth et al. 2016). Bezerra et al. explored drivers and constraints in the digitalization of food quality and safety control but did not link these tools to distinct audit phases or stakeholder roles (Bezerra et al. 2024). Similarly, Radovet et al. analysed diverse perspectives on technological and managerial barriers but offered limited insights into tool applicability in quality control system (Radovet et al. 2025).

Consequently, there is a clear research gap regarding how digital tools are functionally integrated across the FSMS audit systems, from planning to reporting, and how these tools interact with the specific roles of certification bodies, auditors, and auditees. The benefits of digital technologies are widely acknowledged, yet the literature lacks a structured, phase-specific, and stakeholder-focused assessment. Addressing this gap is critical to advancing digitalization in FSMS auditing and to ensuring that technological solutions are appropriately designed and adopted by all parties involved.

This study aims to contribute to that gap by identifying which digital tools are currently used or recommended for FSMS auditing, examining how they support different phases of auditing, and analysing the technological and managerial barriers that influence adoption from multiple stakeholder perspectives.

### 1.1.4 Technological and managerial barriers in the adoption of digital tools

The implementation of digital tools in FSMS auditing is influenced by a variety of technological and managerial barriers, many of which have been studied in the broader context of I4.0 technologies in food production and quality control systems. These barriers arise from a combination of technical limitations, organizational readiness, stakeholder roles, and varying levels of digital literacies (Bezerra et al., 2024; Donaghy et al., 2021). Studies on the integration of I4.0 have shown that digital adoption is not a matter of technical issue, but also one that involves structural, managerial, and cultural factors within food businesses (Singh & Malhotra, 2022; Sartoni et al., 2024). Understanding the conclusions from this existing research is

essential for clarifying which barriers have been well researched, and where critical gaps remain in more specialized applications, such as FSMS auditing.

***Technological barriers:*** Various hurdles have been noted in the implementation of Industry 4.0 technologies. Boz et al. describe these barriers as stemming from technical infrastructure such as hardware, software, data formats as well as production environment characteristics (Boz & Martin-Ryals, 2023). Bezerra et al. reported that one of the most critical barriers to digitalization in food quality control is the incompatibility between legacy systems and advanced technologies like IoT and blockchain (Bezerra et al., 2024). Their study, which focused on broader quality and safety management in food businesses, emphasized that integrating such tools often requires complete system overhauls, that many companies are hesitant to invest in. Similarly, Singh and Malhotra, in a cross-industry study on I4.0 in agri-food sectors, observed that the absence of standardized interoperability protocols and fragmented digital infrastructure continue to hinder tool deployment (Singh & Malhotra, 2022). Data security also emerges as a consistent concern. Singh and Malhotra noted that reluctance to adopt cloud-based or remote systems often stems from fears of data breaches, particularly in organizations without robust encryption protocols. These findings suggest that while technological barriers are well-studied in broader food systems, current research does not yet specify how these issues play out across the different phases and stakeholders of FSMS audits.

***Managerial barriers:*** These categories of barriers have likewise received considerable attention in the context of I4.0 integration in food production and safety management. From a techno-managerial perspective, managerial barriers involve organizational structures, procedures, competencies, and literacy (Sartoni et al., 2020; Luning & Marcelis, 2020). Bezerra et al. reported that low digital awareness and insufficient staff training consistently hinder digital adoption (Bezerra et al. 2024). Donaghy et al. highlighted that resistance to change remains a dominant challenge, particularly in organizations where traditional methods are deeply embedded (Donaghy et al. 2021). Sartoni et al., in their study on digital transformation enablers, emphasized that lack of leadership commitment and inadequate communication between departments contributed to poor implementation outcomes (Sartoni et al. 2024). However, these studies are largely concerned with food processing environments, logistics systems, or organization-wide digital transitions. Few, if any, have focused specifically on FSMS auditing and the roles of auditors, certification bodies, auditees, or scheme owners within this context. There is little empirical evidence addressing how managerial barriers manifest

differently across stakeholders involved in the audit process, or how tools like remote auditing platforms, AI-based risk assessments, or cloud systems are perceived and adopted by these actors.

In conclusion, while several studies have mapped technological and managerial barriers in the broader context of food safety digitalization and I4.0 implementation, there is a clear gap in understanding how these barriers apply within the specific setting of FSMS auditing. In particular, no study has yet comprehensively examined the alignment between digital tools and the practical tasks of FSMS audit stakeholders, nor have they analysed how these actors experience or overcome technological and managerial challenges. This study addresses this gap by exploring how digital tools are used or proposed in FSMS audits and by investigating the key adoption barriers faced by multiple stakeholders.

## 1.2 Research demarcation, aim and questions

### 1.2.1 Demarcation of research

This research is focused on understanding the barriers to digitalizing FSMS auditing processes, specifically from the perspectives of multiple stakeholders, including auditors, certification bodies, scheme owners, and auditees.

***Focus on FSMS auditing in the food industry based on FSSC22000:*** The study will limit its scope to companies that have implemented the FSSC 22000 standard and use private standards. This focus excludes companies or auditors that work solely with other standards like BRCGS. This demarcation allows the research to concentrate specifically on users of the FSSC 22000 standard, gaining insights into the types of digital tools they use and understanding the challenges or motivations behind their adoption of these tools.

***Food Safety Management System (FSMS) auditing process:*** This study focuses on specific stages of the FSMS auditing process, namely planning, execution, evaluation, and reporting. While the broader audit system includes activities such as the assignment of auditors and the scheduling of audits by certification bodies, this research is demarcated to the core auditing actions undertaken by the auditor. This targeted scope allows for a detailed exploration of how digital tools are applied during these specific stages and their direct impact on the auditing process.

By concentrating on the main stages of the audit process, not pre- and post-processes of audit, the study aims to focus on the stages where digital tools are implemented and where technological and managerial barriers are most relevant. This approach ensures that the findings remain precise and actionable, providing insights into the integration of digital tools in the audit process of FSMS.

***Geographical scope:*** The study is limited to examining the impact of Industry 4.0 on the adoption of digital tools and technologies in Food Safety Management Systems auditing processes within the European Union (EU). The geographical demarcation is guided by the Digital Economy and Society Index (DESI) 2022, which evaluates EU countries based on dimensions such as connectivity, human capital, digital technology integration, and digital public services (EU Digital Economy and Society Index 2022). According to DESI 2022 shown in Figure 1, the Netherlands ranked among the top five, demonstrates a similarly high level of digitalization and readiness to implement digital technologies. These rankings indicate strong digital infrastructures and progressive adoption of digital tools across various industries, including the food sector. While the food industry often lags behind others in digital transformation (Virmani & Singh, 2024), focusing on these digitally advanced countries provides a relevant context for exploring both the potential and challenges of adopting digital tools in FSMS auditing. By narrowing the geographical scope to countries with high digital uptake, such as the Netherlands, the study aims to analyse regions where digital tools are already in use. This focus enhances the relevance of findings by identifying barriers in contexts where digital readiness is less of an issue, providing better insights about digital adoption across the EU food sector.

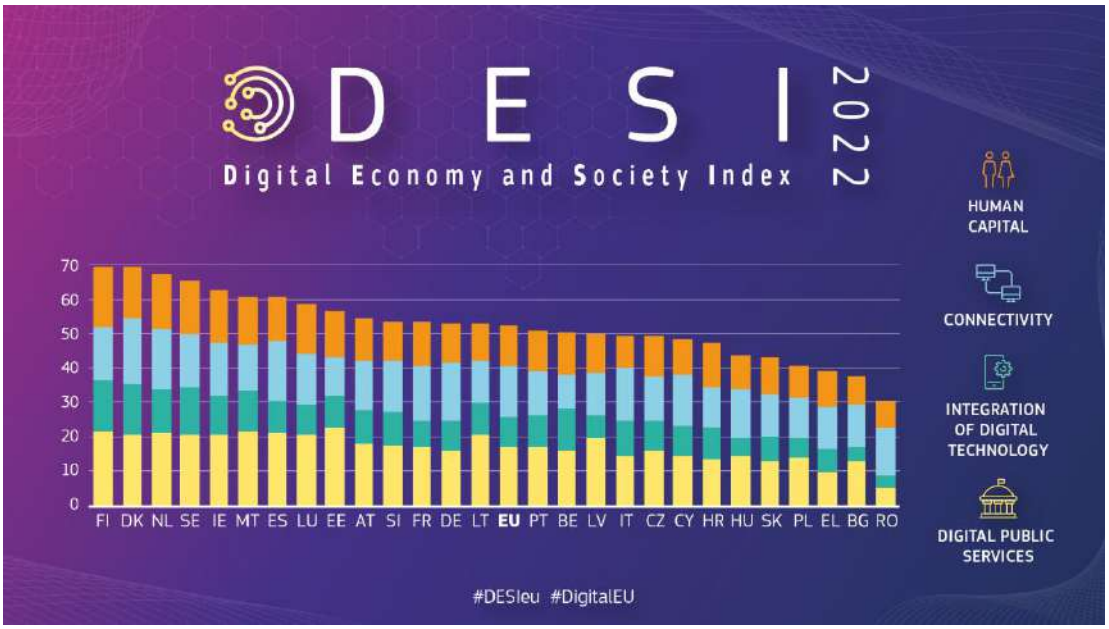


*Figure 1: Digital Economy and Society Index 2022*

## 1.2.2 Research aims and questions

The study aims to gain insight into investigating the technological and managerial barriers to the adoption of digital tools and technologies that can support FSMS auditing processes from multiple stakeholder perspectives.

RQ 1. Which digital tools and technologies are identified in the literature for use in FSMS auditing, and what are their specific functionalities in the auditing process?

RQ 2. What are the technological (RQ2a) and managerial (RQ2b) barriers in FSMS auditing according to the literature?

RQ 3. Which digital tools and technologies are currently used in the different stages of FSMS audits, and how are they applied in practice, based on expert insights?

RQ 4. What are the technological barriers that could hamper the adoption of digital tools and technologies in FSMS audits from a practice-based perspective?

RQ 5. What are the managerial barriers that could hamper the adoption of digital tools and technologies in FSMS audits from a practice-based perspective?

# 2 Research Methodology

## 2.1 Research design

This study applied a qualitative research design to explore technological and managerial barriers that affect the adoption of digital tools in Food Safety Management System (FSMS) auditing. Two complementary qualitative methods were used in a semi-systematic literature review and semi-structured expert interviews. This design was selected to enable an in-depth investigation of both literature and practice surrounding the adoption of digital tools in FSMS audits.

The literature review aimed to address RQ1, RQ2a, and RQ2b by identifying digital tools and technologies discussed in the scientific literature and by categorizing the technological and managerial barriers associated with their adoption. A semi-systematic approach was chosen to allow for flexibility in reviewing both peer-reviewed research and relevant grey literature, with a focus on capturing emerging trends in FSMS digitalization. To complement the literature findings, semi-structured interviews were conducted with professionals involved in FSMS auditing, including auditors, certification body representatives, scheme owners, and auditees. These interviews provided practical insights for answering RQ3, RQ4, and RQ5. They focused on the real-world use of digital tools in audits and on identifying perceived barriers to adoption from various stakeholder perspectives.

The interview data were analysed using thematic analysis, allowing for the identification of recurring patterns and context-specific challenges. These findings were compared with those from the literature to explore consistencies and gaps. The combined use of literature review and interviews ensured that the study captured both theoretical understanding and applied experiences, enhancing the robustness of the conclusions.

## 2.2 Semi-systematic literature review

A semi-systematic literature review was conducted to explore barriers influencing the adoption of digital tools in FSMS auditing. This approach was chosen to allow for a structured yet flexible analysis of both academic studies and relevant industry sources. It enabled the integration of theoretical frameworks with practical developments in digitalization, providing a broad understanding of the current state of FSMS auditing. The review focused on identifying key digital tools and technologies, their functions within the audit process, and the challenges associated with their adoption. In particular, it examined how these tools are applied across different audit phases and what technological and managerial barriers are reported in the

literature. To ensure methodological transparency and rigor, the review process was guided by predefined research criteria and a clear search strategy. Core concepts and relevant synonyms were established to structure the screening and selection of sources. These steps enabled the identification of common themes and patterns, laying the groundwork for subsequent comparison with expert insights collected through interviews.

### 2.2.1 Search criteria

To ensure relevance and quality, the review applied predefined inclusion and exclusion criteria. It focused on publications written in English and published within a defined timeframe. The search targeted peer-reviewed studies and industry reports indexed in reputable databases such as Web of Science and Scopus, as recommended by (Snyder, 2019).

Table 1 outlines the specific criteria used to select literature relevant to the research questions.

*Table 1-Search criteria*

| Subject | Inclusion | Exclusion | Explanation |
|---|---|---|---|
| Language | English | Any other language except English | Only English written articles and reviews are included in this project since it is the main language of scientific literature |
| Publication date | Publications from 2010-2024 | Publications before 2010 | To ensure the relevance of the data but also include important literature. |
| Location | EU | - | The research focus is only on European countries for greater specificity and relation to the EU food law implementation. |
| Type of Publication | Scientific articles and published books | Non confirmed websites | To ensure the information provided is valid and accurate |
| Database | Scopus<br>Web of Science<br>Google Scholar | Other databases | Research from most disciplines can be found in these databases since they offer options for specific filtering of sources. |
| Subject mater | FSMS, digital audit, digital tools, digitalization, barriers, Stakeholder`s perspective | Not relevant content | Priority to the documents mostly related to the research |

### 2.2.2 Definition of core concepts and synonyms

To conduct a semi-structured literature review, core concepts, and synonyms and related terms were used to create search strings in databases, helping to expand the range of relevant scientific literature. Table 2 presents key core concepts and their synonyms relevant to conducting the literature review.

*Table 2- Definition of core concepts and synonyms*

| Core concepts | Associative concepts | Synonyms and connecting terms |
|---|---|---|
| **Digital tools** | Digital technologies | Digitalisation, Internet of Things (IoT), Blockchain, AI, Remote auditing platforms, Automation tools, Smart sensors, Audit software |
| **Audit** | Digital audit, Remote Audit | audit process, digital records audit, third party audit, auditing, real-time monitoring |
| **FSMS** | Food Safety Management Systems | Food Safety, Food industry, ISO 22000, HACCP |
| **Barriers** | Constraints, Obstacles | Impediments, Limitations, Challenges |
| **Technological** | technical | Technical Adoption Process |
| **Managerial** | Organizational | Leadership, food business |

### 2.2.3 Definition of search strategies

To create a precise research strategy, a search string diary is developed that includes specific keywords. To minimize bias and ensure accuracy, multiple articles and sources were referenced for each research topic. For greater efficiency, a qualitative systematic research approach was implemented, using the search string diary table as the foundation for the literature review. Boolean search strings were developed and applied in Web of Science, Scopus or Google Scholar databases. Table 3 shows an example of keywords combinations applied and relevant findings.

*Table 3- Search string diary*

| RQ | Search string diary | Database | Hits | Relevant | Snowball findings | Total |
|---|---|---|---|---|---|---|
| RQ 1. Which digital tools and technologies are identified in the literature for use in FSMS auditing, and what are their specific functionalities in the auditing process? | | | | | | |
| RQ1 | ( ALL ( "digital tools" OR "Advanced digital technologies" OR "smart technologies" OR "IoT" OR "artificial intelligence" ) AND TITLE ( audit* OR "auditing *" OR "remote audit" OR "digital Audit" OR "digital records | Scopus | 37 | 7 | 1 | 8 |

| RQ | Search string diary | Database | Hits | Relevant | Snowball findings | Total |
|---|---|---|---|---|---|---|
| | audit" ) AND ALL ( "Food Safety Management Systems" OR "FSMS" OR "food industr*" OR "food safety management" OR "food safety" OR "ISO 22000" OR "HACCP" ) ) AND PUBYEAR > 2011 AND PUBYEAR < 2025 AND ( LIMIT-TO ( LANGUAGE , "English" ) ) | | | | | |
| RQ1 | "digital tools" OR "Advanced digital technology" or digital* OR REMOTE OR virtual or "smart technolog*" (All Fields) AND food OR "Food Safety" OR "Food industr*" (Topic) AND audit* OR "auditing" OR "audit process" OR "remote audit" OR "digital Audit" Or "digital records audit" (Title) | Web of Science | 21 | 7 | 2 | 9 |
| RQ 2. What are the technological (RQ2a) and managerial (RQ2b) barriers in FSMS auditing according to the literature? | | | | | | |
| RQ2 | ("digital tools" OR "digital technologies" OR "digitalization") AND ("adoption" OR "implementation") AND ("FSMS" OR "food safety management system") AND ("audit*" OR "auditing") AND barrier OR hurdle OR obstacle OR constraint OR limitation OR issue OR Impediment -accounting –medicine year 2020-2025 | Google Scholar | 32 | 5 (3 overlaps) | 0 | 2 |
| RQ2 | ( TITLE ( "Digital Tools" OR "Digital technolog*" OR "digital solution" OR "automated tools" OR "big data" OR digitalization OR digitization OR iot OR blockchain OR tool* ) AND TITLE-ABS-KEY ( "food safety" OR "food management system" OR fsms OR "fssc 22000" OR haccp OR food OR "food safety" OR "food industry" OR qms ) AND TITLE-ABS-KEY ( audit OR "digital audit " OR " remote audit " OR "virtual audit" OR auditing OR "QMS audit" ) AND ALL ( technological OR barrier OR "technical hurdle" OR obstacle OR constraint OR limitation OR managerial ) AND NOT TITLE-ABS-KEY ( financial OR trade ) ) | Scopus | 24 | 7 (4 overlaps) | 2 | 5 |
| RQ2 | "digital tools" OR "digital technologies" OR "digitalization" and "adoption" OR "digital*" OR technologic* (All Fields) and food OR "Food Safety" OR "Food industr*" (All Fields) and "audit*" OR "auditing" OR remote OR virtual (Topic) not accounting and medicine (All Fields) and barrier OR hurdle OR obstacle (All Fields) and 2024 or 2023 or 2022 or 2021 or 2020 (Publication Years) | Web of science | 61 | 2 | 1 | 3 |
| | Total | | | | | 27 |

### 2.2.4 Selection of relevant articles and data collection

Relevant publications were selected based on an initial screening of titles and abstracts, followed by full-text analysis. Critical appraisal questions (CAQ) were developed to ensure only high-quality, relevant studies are included. These questions extract essential information on technological and managerial barriers and current trends in FSMS digitalization.

### 2.2.5 Critical appraisal questions

A set of critical appraisal questions for evaluating the study and resources addressing each research question. These questions focus on the relevance, validity, and quality of information related to technological and managerial barriers in adopting digital tools for FSMS auditing are shown in Table 4.

*Table 4-critical appraisal questions*

| No. | RQ | critical appraisal questions |
|---|---|---|
| 1 | general | What was the aim of the study? |
| 2 | | What was the methodology used (review, interviews, empirical / grey literature/data…etc) |
| 3 | | At which industry the study was applied? what was the scope of the study? |
| 4 | | what type of auditing is considered? (internal auditing second party audit, 3rd party audit) |
| 5 | RQ1 | Which digital tools or technologies have been mentioned for auditing? |
| 6 | RQ1 | What **functionalities** do these tools provide in the context of FSMS auditing? |
| 7 | RQ1 | How do the identified tools **support** the audit process (e.g., data collection, real-time monitoring, reporting)? |
| 8 | RQ2a | Which **technological barriers** to digital tool adoption are mentioned in the study? |
| 9 | RQ2a | How can these technological barriers hamper the adoption of the mentioned digital tools or technologies? |
| 10 | RQ2a | how do the technological barriers vary among stakeholders (e.g., auditors, certification bodies, scheme owners)? |
| 11 | RQ2b | What kind of **managerial barriers** to digital tool adoption are identified in the study? |
| 12 | RQ2b | How are these managerial barriers hamper the adoption of the mentioned digital tools or technologies? |
| 13 | RQ2b | How do the managerial barriers vary among stakeholders (e.g., auditors, certification bodies, scheme owners)? |

### 2.2.6 Analysis of literature findings

A semi-structured literature analysis was conducted to address the research questions by systematically reviewing and synthesizing findings from relevant studies. The analysis process was designed to ensure that the extracted data directly contributed to answering the research questions and identifying common themes across studies.

Relevant text segments were first extracted for each CAQ and grouped according to the corresponding research question. For example, for research question 1, the literature was examined to identify digital tools and technologies applied in FSMS auditing, including their functionalities and the audit phases in which they were used. The extracted data were recorded in a structured Excel spreadsheet to enable systematic comparison across sources. The collected material was then reviewed in depth to identify patterns and similarities. Recurring topics were coded under thematic labels that reflected the key insights emerging from the literature. In the

case of digital tools, examples of identified themes included traceability enhancement, real-time monitoring, remote accessibility, and automation of compliance processes. Where explanatory responses were extracted, such as those related to how a technology supports a particular audit phase, or how barriers affect implementation, the text was paraphrased to improve clarity and consistency while maintaining the core meaning of the original source. Descriptive or factual elements, such as tool names or directly reported barriers, were retained in near-original form for traceability and accuracy. For research questions 2a and 2b, which focused on technological and managerial barriers, the identified findings were grouped into specific subcategories such as lack of standardization, data security concerns, limited digital infrastructure, resistance to change, and insufficient training. These were further organized into broader categories to facilitate thematic interpretation and discussion in later chapters.

The results of the literature analysis were summarized into tables to support the development of chapter 3. These tables reflect the relationship between tools and audit phases, the nature of identified barriers, and the alignment between literature findings and the overarching research questions. This structured process ensured a transparent and consistent approach to synthesizing literature-based evidence on the digitalization of FSMS auditing.

## 2.3 Semi-structured Expert interviews

The second phase of the study involved conducting semi-structured interviews with professionals involved in FSMS auditing. These interviews aimed to gain practical insights into the technological and managerial barriers that affect the adoption of digital tools and technologies in audit processes. Participants were selected from multiple stakeholder groups, including auditors, auditees, certification body representatives, and scheme owners, in order to gather a broad range of experiences and perspectives.

### 2.3.1 Design of the expert interview

The interviews were guided by three research questions focused on identifying current digital tools used in FSMS audits (RQ3), as well as technological (RQ4) and managerial (RQ5) barriers affecting their adoption. The interview structure included open-ended questions designed to encourage participants to share detailed experiences and perspectives. These questions were developed in advance but were flexible enough to allow for follow-up inquiries where needed.

Each interview began with a short introduction to the study objectives, followed by clarifications of relevant terms and concepts. A visual slide presentation was used to introduce key terms such as “digital tools” (e.g., IoT, blockchain, AI), “FSMS auditing,” and the distinction between technological and managerial barriers. The interviews then proceeded through three structured sections: Part A explored the digital tools currently in use or proposed in FSMS auditing, Part B focused on technological barriers, and Part C addressed managerial barriers. Examples of questions included, “What are typical technological barriers that may constrain the adoption of digital tools in FSMS audits?” and “According to you, what are the managerial barriers that could hamper adoption?” All questions were open-ended, which allowed participants to elaborate on their responses. Interviews were conducted either in person or via Microsoft Teams, depending on participant availability. Before the interview, each participant received an information letter and consent form outlining the study’s purpose, their rights as a participant, and the use of audio recording. Interviews lasted approximately 45 to 60 minutes. A complete version of the interview guide, including categorized questions, is available in Appendix A.

### 2.3.2 Selection and recruitment of experts

Experts were selected through purposeful selection, based on three key criteria. The first factor was involvement in FSMS auditing, either through direct implementation or oversight. The second factor was experience with or exposure to digital tools and technologies used in food safety contexts. The third factor was affiliation with one of the main stakeholder groups in the FSMS auditing process, including auditors, auditees, certification bodies, or scheme owners. These criteria ensured that participants had relevant knowledge and practical insights to contribute to the study. All interviews were conducted in English with professionals based in EU countries. Prior to participation, each expert received an information letter and consent form outlining the purpose of the study and the interview guide. Although scheme owners were listed as one of the stakeholder groups being targeted, they did not have any available experts who could be part of the study, or who volunteered to be a part of the study. Consequently, the expertise provided is limited to those of auditors, auditees, and certification bodies. The expert profiles are summarized in Table 5.

*Table 5-Selection and recruitment of experts*

| Expert No. | Experts` perspective | Year of experience |
|---|---|---|
| Expert NO.1 | Auditee | 12 |
| Expert NO.2 | Auditee | 20 |
| Expert NO.3 | Auditor | 12 |
| Expert NO.4 | Auditor | 7 |
| Expert NO.5 | Representative of certification body | 27 |
| Expert NO.6 | Representative of certification body | 24 |
| Expert NO.7 | Auditor | 10 |

### 2.3.3 Analysis of expert interview findings

After conducting the expert interviews, the recordings were transcribed, reviewed, and corrected for any inaccuracies. The transcripts were then read multiple times to ensure understanding the data and remove the errors. Subsequently, the responses were organized in an Excel sheet and subjected to qualitative content analysis. This approach was used to systematically analyse the data collected from the expert interviews. As outlined by Vaismoradi et al. (2013), thematic content analysis is a qualitative research method used to identify recurring patterns in textual data by coding and clustering meanings into themes (Vaismoradi et al. 2013). This method was chosen for its ability to explore patterns of experience across diverse participants while maintaining transparency in interpretation. This process involves carefully reading and re-reading the transcriptions, coding the data, and interpreting its meaning. From the transcribed text, key terms or concepts, referred to as units of analysis, were identified, such as “cost”, “resistance”, and “real-time monitoring”. Next, sentences containing these units of analysis were extracted and grouped based on their similarity or relevance, forming core of meanings. Each core of meaning was labelled according to its conveyed message, for example, “integration”, “resistance to change”, “cost”, and “security concerns”. Ultimately, when multiple cores of meanings reflected different aspects of the same issue, they were clustered into broader categories such as “usability and complexity”, “resistance to

change", and "financial constraints". This entire process was manually conducted in Microsoft Excel and is documented in Appendix E. The findings derived from this analysis are presented in Chapter 3 and 4.

# 3 Results and Discussions

## 3.1 Digital tools and technologies used in FSMS auditing

The semi-structured literature review identified digital technologies that *are used* for FSMS auditing, with a focus on their functionalities in audit processes. Table 6 summarizes the digital tools and technologies identified from the literature review. Through the literature review, 10 digital tools and technologies were identified, each contributing to various aspects of FSMS auditing. It is explicitly categorizing each technology according to the number of publications, their underlying functionality, and their specific contributions to FSMS auditing. The analysis covered 27 publications, and the subsequent sections outline findings from the semi-structured literature review, detailing the technologies that have been explored for FSMS auditing.

*Table 6- Digital tools and technologies in FSMS auditing in literature*

| **Tools and Technology** | **Number of Publications** | **Functionality** (Specific to food safety management system auditing) | **How it supports FSMS auditing** |
|---|---|---|---|
| Blockchain | 14 | A decentralized digital ledger that ensures audit **data integrity** and enhances **traceability**, **minimizing fraud** and tampering risks in food safety audits (Hakami et al., 2023; Conter, 2024). | • Blockchain enables rapid verification of traceability records, secures audit logs, and prevents data falsification in FSMS audits (Chandan et al., 2023; Oriekhoe et al., 2024).<br>• Blockchain enhances audit transparency by allowing immutable records of transactions, reducing the risk of fraudulent activities in the supply chain (Lei et al., 2022). It enables automated verification of certifications and compliance documents, facilitating seamless integration with FSMS requirements (Jang et al., 2024).<br>• Blockchain-based smart contracts provide auditors with real-time validation of compliance standards, reducing manual verification efforts (Noh et al., 2023). |
| AI & machine learning | 9 | AI-based algorithms **process large datasets** to **detect anomalies, predict non-compliance risks**, and optimize FSMS audit decision-making (Sartoni et al., 2024). | • AI supports predictive compliance monitoring and risk-based audit prioritization (Maiberger & Sunmola, 2022; Sartoni et al., 2020).<br>• Machine learning improves fraud detection accuracy and enables automated reporting, reducing auditor workload (Jang et al., 2024).<br>• AI-powered chatbots and virtual assistants assist in audit preparation and compliance checks (Ismail et al., 2024).<br>• AI-driven image recognition enhances hazard detection in food processing facilities (Lei et al., 2022). |
| IoT (Internet of Things) | 8 | A network of interconnected devices that continuously collect r**eal-time audit-related data**, improving **monitoring** efficiency in food supply chains (Lei et al., 2022). | • IoT sensors provide continuous monitoring of critical control points (CCPs), such as temperature and humidity (Lei et al., 2022).<br>• IoT devices enhance real-time compliance tracking, reducing reliance on manual checks (Hassoun et al., 2023).<br>• Integration with AI allows for automated pattern detection and early warning alerts in food safety (Mahmud et al., 2023).<br>• |

| Tools and Technology | Number of Publications | Functionality (Specific to food safety management system auditing) | How it supports FSMS auditing |
|---|---|---|---|
| Video conferencing | 8 | Digital platforms that facilitate remote food safety audits and stakeholder consultations, allowing auditors to **conduct inspections efficiently without physical presence** (Mahmud et al., 2023). | • Video conferencing enables remote auditing, reducing travel costs and logistical challenges while allowing efficient oversight of FSMS compliance through virtual site inspections (Castka et al., 2021).<br>• Video conferencing improves accessibility of expert auditors and facilitates hybrid auditing models, ensuring continuity in audit processes even during disruptions (Deuss & Honey, 2023). |
| Digital audit platforms | 7 | Integrated software solutions that automate audit workflows, standardize compliance **reporting**, and ensure **secure audit documentation storage** (Alma'aitah et al., 2024). | • Audit software streamlines document management, improves traceability of audit evidence, and facilitates multi-stakeholder collaboration in FSMS audits (Ismail et al., 2024).<br>• Digital platforms enable real-time tracking of non-conformities and corrective actions, ensuring accountability in food safety management (Dong et al., 2022).<br>• Cloud-based audit systems enhance accessibility and reduce the risk of data loss, improving compliance verification efficiency (Moghadasi et al., 2018).<br>• Automated FSMS dashboards provide audit insights through visual analytics, assisting decision-makers in compliance evaluations (King, 2020). |
| Cloud computing | 5 | Cloud-based platforms that **store** and **process FSMS audit data**, enabling remote **accessibility** and **secure data management** (Moghadasi et al., 2018). | • Cloud computing improves data accessibility and remote collaboration (Moghadasi et al., 2018).<br>• Cloud-based platforms enable real-time tracking of audit findings and corrective actions (Dong et al., 2022).<br>• It Enhances document security and traceability while reducing data loss risks (Ghazali et al., 2023). |
| Digital document & record-sharing platforms | 4 | Digital tools that allow **secure** and **efficient sharing** of audit **reports**, **compliance documents**, and FSMS **records** (Ismail et al., 2024). | • Record-Sharing Platforms enables real-time sharing of audit documentation between auditors and food businesses, reducing delays in compliance verification and improving transparency (Bezerra et al., 2024).<br>• It enhances document traceability by integrating with blockchain-based audit logs (Jang et al., 2024). |

| Tools and Technology | Number of Publications | Functionality (Specific to food safety management system auditing) | How it supports FSMS auditing |
|---|---|---|---|
| Digital signatures | 4 | Encrypted signatures used to **verify the authenticity** and **integrity** of digital audit **reports** and **compliance documents** (Kleboth et al., 2016). | • Digital Signatures ensure document security, prevent tampering of FSMS audit records, and enhance legal validity of digital audit reports (Mahmud et al., 2023).<br>• It enables paperless auditing processes by streamlining approval workflows for compliance documentation (Deuss & Honey, 2023). |
| Trusted Computing (TC) Technologies | **4** | **Security technologies** that ensure FSMS audit data **integrity** and **prevent unauthorized access** to sensitive audit information (Silva et al., 2022). | • TC enhances cybersecurity in digital audits by providing hardware-based encryption and tamper-proof logging mechanisms (Lei et al., 2022; Mahmud et al. 2023).<br>• It enables secure authentication of auditors and auditees during remote audits, ensuring audit credibility (Ghazali et al., 2023). |
| Robotic Process Automation (RPA) | **2** | The use of software robots to **automate repetitive audit-related tasks**, **reducing human error** and **improving efficiency** (Almayyahi et al., 2024). | • RPA automates routine audit tasks, such as data validation and report generation (Almayyahi et al., 2024).<br>• It reduces human error and improves efficiency in compliance documentation (Jang et al., 2024). |

As outlined in Table 6, The analysis reveals that the most frequently mentioned technologies include blockchain, AI & machine learning, IoT (Internet of Things), video conferencing, and digital audit platforms. These tools have been extensively researched for their potential to improve audit traceability, enhance compliance monitoring, automate audit tasks, and facilitate remote auditing. Blockchain was a most mentioned digital technology in FSMS auditing, as it is a decentralized digital ledger that ensures data integrity and records traceability (Hakami et al., 2023; Conter, 2024). It supports rapid verification of traceability, ensuring the credibility of audit logs and compliance documentation (Chandan et al., 2023; Oriekhoe et al., 2024). The second most mentioned technologies was AI & machine learning is a key technology for predictive compliance monitoring, risk-based audit prioritization, and automated reporting. It processes large datasets to identify anomalies in FSMS compliance (Sartoni et al., 2024). These functions allow auditors to detect potential risks in real time practices (Maiberger & Sunmola, 2022; Sartoni et al., 2020). The next was IoT devices facilitate real-time compliance tracking and environmental monitoring, providing immediate alerts for non-compliance (Lei et al., 2022). Following that, video conferencing is used for virtual site inspections and remote auditing, facilitating cost-effective and efficient remote audits (Mahmud et al. 2023; Castka et al. 2021). Digital audit platforms contribute to audit workflow automation, standardized compliance reporting, and streamlined document management. They enable centralized audit data storage, improve audit traceability, and ensure multi-stakeholder collaboration (Alma'aitah et al., 2024). Other notable technologies include cloud computing, digital document & record-sharing platforms, digital signatures, trusted computing technologies, and robotic process automation. Cloud computing ensures secure, remote access to FSMS audit data, while digital document-sharing platforms and digital signatures enhance audit transparency and record authenticity (Moghadasi et al., 2018; Ismail et al., 2024). These findings indicate that FSMS auditing is increasingly integrating digital technologies to improve audit performance and enhance compliance oversight. However, despite the extensive research on these technologies, the review also highlights barriers in their implementation, as discussed in subsequent sections on technological and managerial barriers.

## 3.2 Technological barriers to implementing digital technologies in FSMS auditing

The literature review systematically analysed technological that hinder the adoption of digital FSMS auditing tools, identifying frequent obstacles discussed in recent studies. Table 7 outlines technological barriers identified through literature analysis, categorizing these barriers clearly according to their frequency, and their impact on FSMS auditing.

*Table 7-Technological barriers in adoption of digital tools and technologies in literature*

| Technological barriers | Number of publications | Description (How they hamper adoption of digital tools and technologies) | Relevant tools & technologies |
|---|---|---|---|
| Integration and interoperability barriers | 18 | • Many FSMS audit tools are not compatible with legacy enterprise systems, requiring significant customization efforts and leading to inefficiencies and delays in audit processes (X & Rogala, 2022).<br>• The lack of standardized digital and technical frameworks prevents smooth interoperability between audit management systems and regulatory databases, making seamless integration difficult and causing inefficiencies in data exchange and compliance reporting (Sartoni et al., 2024; Mahmud et al., 2023).<br>• High dependency on outdated legacy systems and limited investment in digital transformation strategies create integration challenges, reducing the efficiency of digital tools in compliance verification and resulting in inconsistent adoption of advanced auditing solutions (Moghadasi et al., 2018; Oriekhoe et al., 2024). | Digital Audit Platforms, AI, Blockchain, IoT |
| Data security & transparency concerns | 15 | • Fear of cybersecurity threats, unauthorized data access, and lack of trust in digital recordkeeping discourage food companies from fully adopting digital audit systems (Ghazali et al., 2023; King, 2020).<br>• Blockchain solutions reduce security risks by encrypting transaction records, but concerns remain over potential hacking vulnerabilities (Lei et al., 2022).<br>• Inconsistent data-sharing policies across food supply chains further hinder transparency in digital audits (Jang et al., 2024). | Blockchain, AI, Cloud Platforms |
| Infrastructure & connectivity limitations | 12 | • Poor internet connectivity in remote locations inhibits real-time data collection and remote audits (Mahmud et al., 2023).<br>• Limited bandwidth and outdated network infrastructure affect the performance of cloud-based and IoT-driven audit solutions, leading to delays in FSMS audits (Alma'aitah et al., 2024). | IoT, Cloud Computing, Digital Audit Platforms |

| Technological barriers | Number of publications | Description (How they hamper adoption of digital tools and technologies) | Relevant tools & technologies |
|---|---|---|---|
| | | • Lack of necessary infrastructure and digital skills slows the adoption of advanced digital auditing tools, limiting their effectiveness in FSMS audits (Sartoni et al., 2024). | |
| Scalability issues | 10 | • Many digital FSMS auditing tools struggle with handling large-scale audits across multiple supply chain entities, limiting their effectiveness in global food safety compliance (Dong et al., 2022; Jang et al., 2024).<br>• The scalability of digital technologies is challenging due to the complex nature of food production. Large datasets require robust system upgrades, but many existing infrastructures cannot support them. This limitation restricts widespread adoption (Silva et al., 2022; Chandan et al., 2023). | Blockchain, IoT, AI |
| Inadequate IT support | 8 | • Lack of reliable IT support services for maintaining and troubleshooting digital audit tools creates inefficiencies in audit execution and reporting (Alma'aitah et al., 2024).<br>• Food safety companies with limited IT expertise struggle to implement and sustain digital auditing systems, leading to frequent disruptions (Silva et al., 2022). | All digital tools |
| High energy consumption | 8 | • Some digital auditing tools, particularly blockchain and AI-driven compliance solutions, require substantial computational power, increasing operational costs (Ghazali et al., 2023).<br>• High energy consumption poses sustainability concerns for food safety enterprises that aim to minimize their carbon footprint while adopting digital solutions (Lei et al., 2022). | Blockchain, AI, Cloud Computing |
| Technical standardization issues | 7 | • The absence of universal standards for digital audit tools results in inconsistencies in data reporting and validation (Mahmud et al., 2023). Differing compliance frameworks across regions hinder seamless adoption and cross-border audit harmonization (Oriekhoe et al., 2024).<br>• Absence of unified guidelines and regulatory frameworks for digital audits makes compliance challenging for companies adopting FSMS digital tools (ISO & IAF, 2020). | Digital Audit Platforms, Blockchain, AI |
| High data entry workload | 6 | • Excessive manual data entry due to incompatibility of digital audit tools with existing FSMS documentation increases auditor workload and the likelihood of errors (Bezerra et al., 2024).<br>• The lack of AI-driven automation in certain digital platforms prolongs data processing times, making audits more resource-intensive (Ismail et al., 2024). | Digital Audit Platforms, AI |

A review of the literature identified multiple technological barriers that hinder digitalization in FSMS audits. Several technological barriers were consistently highlighted, including integration and interoperability issues, cybersecurity risks, high implementation costs, insufficient technical expertise, and limited digital infrastructure and connectivity. These barriers vary based on factors such as organizational size, industry readiness, infrastructure, and regulatory landscape (Sartoni et al., 2024; Bezerra et al., 2024). Many barriers stem from limited technological maturity, data security concerns, integration challenges, and high operational costs, making digital adoption inconsistent across the industry. The most frequently mentioned barriers in the reviewed studies include integration and interoperability barriers, and data security and transparency concerns, with more than 15 publications discussing their impact. The most prominent ones identified was integration and interoperability challenges, frequently emphasized by Sartoni et al. and Mahmud et al. These authors stressed that integrating digital tools, particularly blockchain and IoT, with existing legacy systems significantly impeded practical implementation (Sartoni et al., 2024; Mahmud et al., 2023). Cybersecurity and data privacy risks were extensively discussed by Ghazali et al. (2023) and King (2020). These authors emphasized concerns related to sensitive audit data breaches, underscoring that stakeholders are cautious about adopting cloud-based and blockchain platforms due to potential vulnerabilities (Ghazali et al., 2023; Lei et al., 2022; King 2020). Another significant technological barrier is the absence of unified technical standards and interoperability protocols, referred to as technical standardization issues. The wide variety of digital FSMS auditing technologies, including blockchain systems, IoT devices, and AI-driven audit platforms, results in incompatibilities concerning data formats, software interfaces, and integration capabilities. Such standardization challenges obstruct the seamless integration of emerging digital tools into existing FSMS infrastructures, consequently restricting their operational efficiency and scalability (Sartoni et al., 2024; Hassoun et al., 2023). For instance, several studies highlight how the lack of standardized protocols notably complicates the integration of IoT sensor data into central compliance management systems, causing substantial operational disruptions and inefficiencies during audits (Mahmud et al., 2023; ISO & IAF, 2020; Oriekhoe et al., 2024O). Other barriers, such as high energy consumption and scalability issues, were mentioned in fewer studies but are still relevant in specific industry contexts. Overall, the literature clearly indicates integration hurdles, data security and transparency concerns as critical barriers to adopting digital FSMS auditing tools, emphasizing the need for targeted strategies to overcome these barriers.

## 3.3 Managerial barriers to implementing digital technologies in FSMS auditing

Beyond technological constraints, managerial and organizational barriers also significantly affect the adoption of digital tools in FSMS auditing (Bezerra et al., 2024; Sartoni et al., 2024). The literature review systematically identified and analysed these managerial barriers, which are summarized in Table 8. The table categorizes these barriers based on frequency, detailed descriptions, and implications for FSMS auditing, providing insights into organizational and strategic issues that must be addressed to facilitate digital implementation.

*Table 8- Managerial barriers in adoption of digital tools and technologies in literature*

| Managerial barriers | Number of Publications | Description (How they hamper adoption of digital tools and technologies) | Relevant tools & technologies |
|---|---|---|---|
| Resistance to Change | 20 | • Employees reluctant to adopt new technologies due to lack of familiarity and perceived complexity hinder FSMS audit digitalization (King, 2020).<br>• Cultural resistance to automation creates inefficiencies in adapting to AI-powered audit tools, slowing the transition process (Kuzmina et al., 2023). | All digital tools |
| Financial constraints | 15 | • High initial costs associated with implementing digital audit tools discourage small and medium-sized food enterprises from transitioning to digital FSMS auditing (Dong et al., 2022).<br>• Additional costs for continuous software updates and cybersecurity enhancements further burden companies with limited budgets (Silva et al., 2022). | Blockchain, AI |
| Lack of digital knowledge & training | 15 | • Many food safety managers and auditors lack sufficient training on digital auditing technologies, reducing the effectiveness of implementation (Sartoni et al., 2024).<br>• The absence of structured digital literacy programs results in inefficient use of digital FSMS audit tools (Bezerra et al., 2024).<br>• Lack of formal training and limited expertise in digital auditing methods prevent auditors from effectively utilizing digital FSMS tools (Mahmud et al., 2023; Kleboth et al., 2016).<br>• The need for retraining auditors on new digital tools slows the overall audit workflow and reduces short-term efficiency (Ismail et al., 2024). | AI, IoT, Digital Audit Platforms |

| | | | |
|---|---|---|---|
| Uncertainty regarding return on investment | 12 | • Organizations are hesitant to invest in digital auditing tools due to concerns over uncertain cost-benefit ratios and perceived risks of implementation (Bezerra et al., 2024).<br>• A lack of measurable short-term benefits discourages businesses from transitioning to digital FSMS auditing (Silva et al., 2022). | Blockchain, Digital Audit Platforms |
| Lack of clear regulations & compliance guidelines | 10 | • The absence of well-defined regulatory frameworks for digital auditing creates uncertainty, making it difficult for companies to ensure compliance (Mahmud et al., 2023).<br>• Varying audit regulations across countries result in inconsistent digital adoption practices, creating compliance challenges for global food businesses (Oriekhoe et al., 2024). | Digital Audit Platforms, AI, Blockchain |
| Lack of leadership commitment | 7 | • Limited support from management for digital transformation in auditing leads to slow adoption and underutilization of available technologies (Sartoni et al., 2024; Conter, 2024).<br>• Resistance from top-level executives to invest in digital auditing due to uncertainty about ROI further delays implementation (Bezerra et al., 2024). | All digital technologies such as AI, IoT, Digital Platforms |
| Lack of IT outsourcing strategies | 5 | • Many organizations lack the expertise to manage digital audit technologies internally and do not outsource IT management, leading to inefficiencies and system failures (X & Rogala, 2022).<br>• The absence of IT service providers with expertise in FSMS audit technology further complicates adoption (Mahmud et al., 2023). | Cloud Computing, AI, Digital Platforms |

The analysis highlighted that resistance to change is the most frequently cited managerial barrier, discussed in over 20 publications. Additionally, financial constraints, limited digital knowledge, and inadequate training were prominently discussed, each appearing in at least 15 studies. The significant financial burden of implementing and maintaining advanced digital technologies, such as blockchain and AI, was particularly emphasized by Silva et al., noting that such costs disproportionately restrict adoption among small and medium-sized enterprises (SMEs) (Silva et al., 2022). Another crucial managerial barrier identified is the lack of clear regulations and compliance guidelines, reflecting regulatory ambiguity and insufficient standardized guidelines for digital FSMS auditing practices. Stakeholders are often uncertain about the acceptance and validity of digital or remote auditing procedures due to unclear regulatory frameworks, which in turn reduces their willingness to adopt these technologies (Oriekhoe et al., 2024; Silva et al., 2022). Silva et al. specifically highlighted that without explicit regulatory endorsement from authoritative global bodies such as the Global Food Safety Initiative (GFSI), stakeholders remain uncertain about the legal and compliance acceptability of digital audits (Silva et al., 2022). Consequently,

some stakeholders remain cautious in fully embracing digital auditing methods, significantly delaying their broader adoption across the industry (King, 2020; Alma'aitah et al., 2024). Addressing these managerial barriers requires targeted strategies, including proactive leadership support, effective change management practices, dedicated workforce training programs, financial incentives, and the establishment of clear regulatory guidance, to facilitate smoother and more widespread adoption of digital FSMS auditing tools.

## 3.4 Digital tools and technologies and barriers identified through the expert interview

Semi-structured interviews were conducted with experts representing auditors, auditees, and certification bodies, to gain practical insights into digital tools used in FSMS auditing and barriers encountered. The thematic analysis of the interviews highlights the role of digital tools in FSMS auditing and the barriers that hinder their adoption. These findings offer valuable practical insights and supplement results derived from the literature review. In the following discussion, results are presented by explicitly linking expert statements with related findings from the literature, highlighting areas of consistency, harmonization, and contradictions.

### 3.4.1 Digital tools used in FSMS auditing in practice

The interviews reveal that various digital tools are being used at different audit stages to improve efficiency, compliance monitoring, and data collection. Experts identified multiple digital tools, notably IoT sensors, cloud-based documentation systems, AI-driven auditing platforms, and remote auditing software. Table 9 presents the digital tools and technologies explicitly identified from expert interviews, summarizing insights according to their functionality.

*Table 9- summary of digital tools or technologies could be or are used in FSMS auditing that mentioned by experts*

| **Digital tools and technologies** | **Technology category** (functionality) | **Expert(s) mentioning** |
|---|---|---|
| IoT sensors (Testo Saveris 2, Emerson GO),<br><br>Digital checklists (QMS audits) | Compliance monitoring and data collection | More than half |
| Cloud-based platforms (Safefood 360°, Intelex),<br><br>AI-powered compliance assistants (HACCPBuilder AI, FoodDocs AI) | Audit documentation and management | More than half |
| Remote Auditing Tools (Microsoft Teams, AuditComply, Live streaming cameras),<br><br>Audit Management Software (iAuditor, QMS Audits) | Audit execution and remote inspections, Live virtual site inspections and document sharing | More than half |
| AI-driven data analysis tools (IBM Food Trust, Power BI) | Reporting and evaluation, Risk analysis, compliance trend identification | Almost half of experts |
| Blockchain (IBM Food Trust) | Secure, transparent audit records for traceability | Less than half |

From the qualitative analysis of expert interviews, several digital tools clearly emerged as significant in practical FSMS auditing, including IoT sensors, cloud-based audit management systems, remote auditing platforms, and AI-driven compliance tools.

***IoT sensors*** were frequently highlighted by most experts for their essential role in improving compliance monitoring. Experts noted that IoT sensors significantly enhanced real-time data collection and accuracy, thus allowing proactive intervention when deviations occur. As illustrated by an expert's statement: *" Many food businesses now use smart sensors like Testo Saveris 2 to track temperature and humidity in storage areas. Instead of relying on manual checks, we can access real-time data and ensure compliance remotely."* This practical insight aligns closely with literature findings, notably by Hassoun et al. (2023) and Lei et al. (2022), who similarly emphasized IoT's effectiveness in enhancing audit accuracy and real-time compliance management. However, experts also pointed out connectivity and sensor reliability issues as practical challenges, adding a nuanced perspective not extensively highlighted in the reviewed literature.

The second frequently discussed tool by the experts was ***cloud-based audit management systems***, such as Safefood 360° and Intelex. Experts consistently acknowledged these platforms' effectiveness in improving documentation efficiency, transparency, and real-time access to compliance data. According to one expert: *"Cloud-based systems transformed our audit processes, greatly improving documentation accuracy and reducing administrative workload by allowing immediate access and sharing of data."* These experiences closely reflect literature findings, particularly Alma'aitah et al. (2024), who emphasized similar operational efficiencies. Nevertheless, experts uniquely underscored practical challenges associated with user interface complexity, indicating a need for greater attention to user-friendliness and platform training.

***Remote auditing platforms*** like Microsoft Teams and AuditComply also received substantial attention from experts. Most experts agreed these tools were essential during operational disruptions, particularly in recent global situations like the COVID-19 pandemic. As stated by one expert: *"Remote auditing platforms allowed us to maintain audit schedules seamlessly, significantly cutting down travel costs and logistical challenges. However, some sensory aspects remain difficult to assess remotely."* This aligns well with literature that acknowledges remote auditing's cost efficiency and operational flexibility (Castka et al., 2021; Mahmud et al., 2023). However, the limitation regarding sensory inspection was strongly emphasized by experts, providing a new practical insight into remote auditing's limitations.

**AI-driven compliance tools** were also prominently mentioned, particularly for their predictive analytics and automated risk assessments. Experts found these AI-based solutions beneficial for enhancing risk identification capabilities and audit prioritization. An expert clearly illustrated: *"AI algorithms have greatly streamlined our audit processes, identifying risks proactively. However, auditor trust in these systems is still developing due to occasional transparency issues."* This perception mirrors the literature, where Sartoni et al. (2024) acknowledged AI's potential in

automating and enhancing auditing precision. Still, the experts introduced a practical concern regarding trust and algorithm transparency that is less prominently addressed in academic studies.

Overall, expert insights clearly highlighted IoT sensors, cloud-based audit management systems, remote auditing platforms, and AI-driven compliance tools as the most relevant and impactful digital technologies currently used in FSMS auditing. These tools were seen to substantially support auditing through improved accuracy, efficiency, and operational flexibility. However, practical considerations highlighted by experts, such as sensor reliability, user-interface usability, and auditor trust, indicate important areas for future research and practical improvements, beyond existing literature discussions.

### 3.4.2 Technological barriers identified through expert interviews

This section presents technological barriers identified from the thematic analysis of expert interviews. The qualitative approach enabled detailed insights into the practical barriers encountered by stakeholders when adopting digital FSMS auditing technologies. Table 10 summarizes the key technological barriers identified by experts, categorizing them clearly, describing each barrier briefly, and illustrating stakeholders' perspectives through representative quotes.

*Table 10- summary of technological barriers that could constrain the adoption of digital tools in FSMS audits that mentioned by experts*

| Technological barrier | Description (How they hamper adoption of digital tools and technologies) | Expert(s) Mentioning |
|---|---|---|
| **Connectivity and infrastructure problems** | Poor Wi-Fi coverage, bandwidth limitations, and infrastructure issues disrupt remote audits, leading to delays and inefficiencies | More than half |
| **Data security & trust issues** | Companies hesitate to store audit data on cloud platforms due to cybersecurity risks and concerns about unauthorized access | More than half |
| **System compatibility & integration issues** | Many legacy ERP systems do not integrate well with digital compliance platforms, requiring costly adjustments | Almost half of experts |
| **Usability challenges** | Some digital tools have complex interfaces that slow adoption, with employees preferring manual methods instead | Almost half of experts |
| **Reliability issues (IoT sensors) and complexity** | Sensor malfunctions or inaccurate readings result in unnecessary manual verifications and operational disruptions. | Less than half |
| **Lack of sensory input (remote auditing)** | Remote audits limit auditors' sensory inspection capabilities (visual, smell), significantly affecting audit completeness and reliability. | Less than half |

several key technological barriers emerged prominently from the qualitative analysis: connectivity and infrastructure problems, data security & trust issues, integration and interoperability issues, usability challenges, and reliability issues (IoT sensors) and complexity.

Connectivity and infrastructure problems and data security & trust issues were consistently mentioned by most experts. Most experts noted that poor internet connectivity significantly compromised audit quality and reliability. An illustrative expert statement clarified this point: "*Poor internet connectivity during remote audits frequently disrupts live inspections, causing auditors and auditees frustration and often necessitating additional on-site visits.*" This aligns with literature insights from Mahmud et al. (2023), who noted similar connectivity limitations. Nevertheless, the explicit emphasis on operational disruptions due to poor infrastructure adds new practical dimensions, highlighting the urgent need for improved technological infrastructure. Experts also highlighted substantial cybersecurity concerns, emphasizing stakeholder fears about potential breaches, unauthorized access, and vulnerabilities in cloud-based platforms. Many experts expressed reluctance to fully adopt cloud solutions due to these security concerns. As

illustrated by one expert: " *Many companies are hesitant to store sensitive audit data in cloud-based platforms because they worry about data breaches*." This strongly supports literature findings by Lei and Ghazali, who emphasized similar security challenges, reinforcing the critical need for robust cybersecurity measures to facilitate adoption (Ghazali et al., 2023; Lei et al., 2022; King 2020).

System compatibility & integration issues are mentioned by almost half of the experts. Stakeholders frequently reported substantial difficulties in integrating new digital tools with legacy ERP systems and existing infrastructure, highlighting severe compatibility issues. Experts emphasized the significant operational disruptions caused by these integration challenges, clearly illustrated in the quote below: *"Integrating digital audit platforms with our older ERP systems, such as SAP, has been exceedingly challenging, resulting in frequent delays and higher than expected costs.*" This expert insight aligns closely with the findings of Hassoun et al. (2023) and Sartoni et al. (2024), who similarly underscored integration difficulties. However, expert opinions provided additional practical details specifically related to widely used ERP systems, highlighting practical complexities beyond general literature discussions.

In summary, expert insights confirm major literature-identified barriers, notably the most critical technological barriers identified by experts were connectivity limitations, cybersecurity risks, integration and interoperability challenges. However, they uniquely highlight practical usability challenges and reliability concerns with digital tools, emphasizing the need for tailored infrastructure improvements and user-centred design.

### 3.4.3 Managerial barriers identified through expert interviews

This section discusses managerial barriers to adopting digital FSMS auditing technologies, based on thematic analysis of expert interviews. The qualitative analysis provided practical insights into organizational and managerial obstacles faced by different stakeholders. Table 11 clearly summarizes the managerial barriers identified by experts, briefly describing each barrier and providing illustrative expert quotes highlighting their practical impact.

*Table 11- summary of managerial barriers that could constrain the adoption of digital tools in FSMS audits that mentioned by experts*

| Managerial barrier | Description (How they hamper adoption of digital tools and technologies) | Expert(s) Mentioning |
|---|---|---|
| **Resistance to change** | Employees prefer traditional methods over digital tools due to familiarity and lack of trust in automation | all experts |
| **Financial constraints** | High costs of digital platforms limit adoption among SMEs and small certification bodies | More than half |
| **Lack of digital knowledge & training** | Insufficient training and lack of digital awareness hinder effective tool usage, causing frustration and mistrust. | More than half |
| **Inconsistent auditor expectations** | Some auditors demand fully digital audits, while others insist on paper-based documentation, causing confusion for food companies | Less than half |
| **Lack of regulatory recognition** | Lack of regulatory recognition (e.g., GFSI not approving fully remote audits) discourages adoption. | Less than half |
| **Loos of social contact and sensory evaluation** | The loss of social interaction and in-person engagement discourages auditors from using remote tools, as they limit auditors' sensory inspection capabilities, affecting audit completeness and reliability. | Less than half |

From the qualitative analysis, several managerial barriers prominently emerged that resistance to change, financial constraints, lack of digital knowledge & training, lack of clear regulations, inconsistent auditor expectations, and concerns regarding loss of social interaction in remote audits.

Most experts prominently highlighted resistance to change as a primary barrier. Stakeholders noted a significant organizational reluctance to shift from traditional audit methods to digital solutions, often due to scepticism and discomfort with new technologies. As illustrated by an expert: "*Digital tools can make audits faster and more efficient, but they can't replace the experience and judgment of an auditor. We still need in-person verification for high-risk areas."* This aligns directly with literature findings by King (2020) and Sartoni et al. (2024), who also emphasized the challenge of managing change and stakeholder resistance. Yet, expert interviews uniquely revealed deeper practical insights, specifically linking resistance to auditor demographics and individual preferences.

Financial constraints emerged as another critical barrier, particularly for SMEs and smaller certification bodies. Experts emphasized the significant costs involved in implementing and maintaining advanced digital systems, such as blockchain and AI. One expert clarified the practical implications explicitly: "*For smaller enterprises, the high initial investments required for digital technologies. They simply cannot justify the costs without clear financial returns."* These insights directly support literature evidence from Silva et al. (2022), highlighting similar financial barriers. However, experts added further context, specifically noting the impact of ongoing maintenance expenses, thus expanding upon literature discussions.

Lack of clear regulations and compliance guidelines was frequently emphasized by experts, who expressed frustration with regulatory ambiguity regarding digital audit acceptability. As illustrated by one expert: "*There is considerable regulatory uncertainty about digital auditing methods, especially remote audits. Clearer guidelines from regulatory bodies like GFSI are needed."* This clearly mirrors literature findings by Oriekhoe et al. (2024) and Silva et al. (2022), underscoring the critical need for clear, standardized regulatory guidelines to reduce stakeholder hesitation and improve adoption rates.

A barrier explicitly emerging from the expert interviews was inconsistent auditor expectations. Experts noted significant practical challenges due to varying digital auditing expectations among different auditors. According to one expert: "*Different auditors have completely different expectations regarding digital documentation, causing confusion and inefficiencies. A standardized approach would be extremely helpful."*

This novel practical insight emerged directly from the interviews, highlighting an important practical gap not significantly discussed in literature. Finally, experts uniquely highlighted the concern regarding loss of social interaction and sensory evaluation in remote audits. Some stakeholders felt remote audits failed to capture essential sensory and interpersonal dimensions of on-site inspections. One expert explained explicitly:" *Remote auditing eliminates direct personal interaction, which is crucial for thoroughly evaluating compliance culture and identifying subtle sensory issues*." This provides new practical perspectives beyond general literature discussions, emphasizing the necessity for hybrid auditing models to maintain audit effectiveness and auditor-auditee engagement.

Overall, expert interviews highlighted managerial barriers including resistance to change, financial constraints, regulatory uncertainties, inconsistent auditor expectations, and diminished sensory evaluation. These findings largely confirm literature insights but add significant practical dimensions, underscoring the need for targeted change management strategies, clear regulatory guidelines, financial incentives, and balanced auditing methods that maintain effective stakeholder interactions

## 3.5 Methodological limitations

This study applied a qualitative research design, combining a semi-systematic literature review with semi-structured expert interviews to explore the barriers to the adoption of digital tools in FSMS auditing. While this mixed approach allowed for in-depth insights, several methodological limitations should be acknowledged. First, the qualitative nature of the research, particularly the use of semi-structured interviews, introduces an element of subjectivity. Although efforts were made to include a diverse range of stakeholders, such as auditors, certification bodies, scheme owners, and auditees, the findings primarily reflect their individual experiences and perspectives rather than objective, quantifiable data. Second, the study is limited in scope to FSMS audits conducted within the EU, with a particular focus on organizations operating under the FSSC 22000 certification standard. Given that digital adoption rates and regulatory frameworks differ across regions, the findings may not be fully generalizable to other food safety schemes, such as BRCGS, or to countries outside the EU. Another limitation arises from the reliance on secondary data obtained through a semi-systematic literature review. While a wide range of sources was analysed, the study may not have fully captured emerging digital solutions or industry-specific challenges that have not yet been extensively explored in academic literature. Furthermore, key technological barriers, including data security risks and interoperability issues, were frequently highlighted by participants but were not quantitatively assessed. Future research could address this gap by incorporating case studies or experimental evaluations of digital auditing tools to determine their effectiveness in real-world FSMS audits. Additionally, while the study included a diverse group of expert interviewees, the relatively small sample size may not comprehensively reflect the full range of digital adoption challenges encountered across different sectors of the food industry. One of the most notable limitations of the study is the lack of inclusion of input from scheme owners. Despite being listed as a stakeholder group, representatives of scheme owners were not available or willing

to be interviewed. The qualitative findings are therefore based on the perspective of the auditors, certification body officials, and the auditees. This constrains the ability of the study to capture potential scheme-related insights on digital tool requirements or adoption processes. Despite these limitations, this study provides a comprehensive exploration of digital tools and their associated barriers in FSMS auditing. The findings contribute to the increasing of knowledge in this area and serve as a foundation for future research and industry advancements.

# 4 Conclusion and recommendations

## 4.1 Research conclusions

This study investigated the barriers to the adoption of digital tools for supporting Food Safety Management System (FSMS) audits, drawing insights from both a semi-systematic literature review and semi-structured expert interviews. The findings provide a comprehensive response to the research questions by identifying digital tools in use, assessing how they support auditing, and analysing the technological and managerial barriers that hinder their adoption.

Regarding the first research question, which focused on identifying digital tools and technologies used in FSMS auditing and how they support the audit process, the literature review revealed a total of 10 tools. Among these, blockchain, artificial intelligence (AI), Internet of Things (IoT), remote auditing platforms, and cloud-based compliance management systems were most prominently discussed. These tools enhance FSMS auditing by offering real-time compliance tracking, automated risk assessments, secure data management, traceability, and improved accessibility for remote audits. For example, blockchain is widely praised for strengthening audit traceability and data integrity, while AI contributes to predictive risk analysis and automated documentation review.

The expert interviews supported these findings and also provided practical insights into how digital tools are actually used. Most experts mentioned the use of IoT sensors for continuous monitoring, cloud-based systems for organizing and retrieving audit documents, and remote auditing technologies that allowed inspections to continue despite travel restrictions or logistical constraints. AI-based tools were also discussed, particularly in the context of trend analysis and pre-audit screening. The tools identified in practice largely overlapped with those mentioned in the literature, suggesting that theoretical developments and practical applications are closely aligned, although experts placed more emphasis on usability and operational limitations than was evident in published research

In addressing the second research question, which explored technological barriers that hamper the adoption of digital tools, the literature review identified eight distinct barriers. Among the most frequently cited were integration and interoperability challenges, cybersecurity concerns, high implementation costs, and limitations in digital infrastructure. These barriers slow down or complicate the adoption process, especially in small and medium-sized enterprises that often lack the resources or technical capacity to implement sophisticated digital systems.

The expert interviews reinforced these findings while also highlighting additional challenges. Several interviewees described difficulties integrating new technologies with existing enterprise resource planning (ERP) systems, particularly SAP. Others noted frequent issues with Wi-Fi connectivity and sensor reliability, especially in older facilities or rural areas. Usability concerns were also mentioned, including frustration with overly complex digital platforms that require significant training. While these concerns are sometimes mentioned in the literature, the interviews provided more detailed and practical descriptions of their impact on day-to-day auditing operations.

The third research question focused on identifying managerial barriers to digital tool adoption and exploring how these barriers vary among stakeholders. The literature review identified seven main barriers in this category. Resistance to change was most frequently reported, followed by financial constraints, lack of digital training, and regulatory uncertainty. These barriers hamper adoption by discouraging investment, lowering confidence in digital tools, and creating confusion about audit compliance expectations. For example, the lack of clear regulatory guidelines for remote or AI-assisted audits leaves certification bodies uncertain about whether these technologies meet scheme requirements.

Expert perspectives confirmed these challenges but also introduced new issues not widely discussed in the literature. Several experts emphasized inconsistent auditor expectations regarding digital documentation, which they felt undermined audit preparation and reduced efficiency. Others noted that the social and sensory elements of in-person audits, such as observing staff behaviour or smelling food environments, were largely lost in remote audits, leading to doubts about the completeness of digital inspections. These points suggest that while managerial barriers reported in literature remain relevant, practitioners face a more complex and nuanced set of challenges when implementing digital audits in real settings.

Overall, the findings demonstrate that digital tools are increasingly integrated into FSMS auditing but that widespread adoption remains hindered by both technological and managerial factors. The overlap between literature and expert perspectives supports the reliability of these findings, while the differences offer valuable insights into the operational realities of digital transformation in the food safety sector.

## 4.2 Recommendations for further research

Based on the findings from both the literature and the expert interviews, the following recommendations can be made to enable the effective adoption of digital tools and technologies in FSMS auditing. These recommendations are oriented towards researchers, industry practitioners, certification bodies, and technology developers.

From a research perspective, further studies are needed to examine how digital tools function across different food sectors and regulatory contexts. Future research could use longitudinal or mixed method approaches to explore the long-term effects of digital tools on audit performance and could examine how auditors build trust in digital systems over time. There is also a need for studies focused on developing standard frameworks for integrating digital auditing tools across various platforms, in such a manner that can overcome interoperability challenges.

For industry practitioners, it is essential to invest in digital tools that are both technically robust and user-friendly. Training programs should be prioritized to build digital literacy among staff and reduce resistance to change. Organizations should also consider hybrid audit models that preserve some of the sensory and interpersonal elements of traditional audits while still benefiting from the efficiency and accessibility of digital tools.

Certification bodies and scheme owners are encouraged to develop clear, standardized guidelines for digital audit practices. These should include protocols for remote audits, acceptance criteria for AI-based assessments, and harmonization of auditor expectations across schemes and countries. Reducing regulatory ambiguity would help increase confidence in digital auditing systems and support more consistent adoption across the sector.

Technology developers should respond to the operational needs identified by auditors and food companies. Tools should be designed with attention to usability, system compatibility, and security. Developers should also provide customization options that allow organizations to tailor systems to their specific audit processes and data structures.

Future research should aim to include the perspective of scheme owners, whose role is critical in establishing digital audit standards, approving technologies, and guiding certification requirements. Their contribution would complement the stakeholder analysis and give a clearer picture of adoption dynamics across the FSMS audit process.

In conclusion, the digitalization of FSMS auditing presents both significant opportunities and complex challenges. A coordinated effort involving all relevant stakeholders is necessary to overcome existing barriers and realize the full potential of digital auditing in ensuring food safety and compliance.

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# Appendices

## Appendix A

### Interview Guide

Rahineh Nomani

Supervised by:

Dr. Pieternel Luning and Dr. Selcen Semercioz-Oduncuoglu, Food quality and design Group at Wageningen University

**Research Title**

**Investigating Barriers to the Adoption of Digital Tools for Supporting Food Safety Management System (FSMS) Audits from Multiple Stakeholders' Perspectives**

### 1. Introduction

This interview is expected to last approximately 30 to 45 minutes, as previously stated in my email. Before we begin, I would like to confirm whether you have any questions regarding the terms, concepts, or the Letter of Consent.

As outlined in the consent form, may I reconfirm your permission to record this interview? Please rest assured that all responses will remain strictly anonymous, and no information will be traceable to you or your organization.

### 2. General questions

First, I would like to ask you a few general questions before diving into more specific topics.

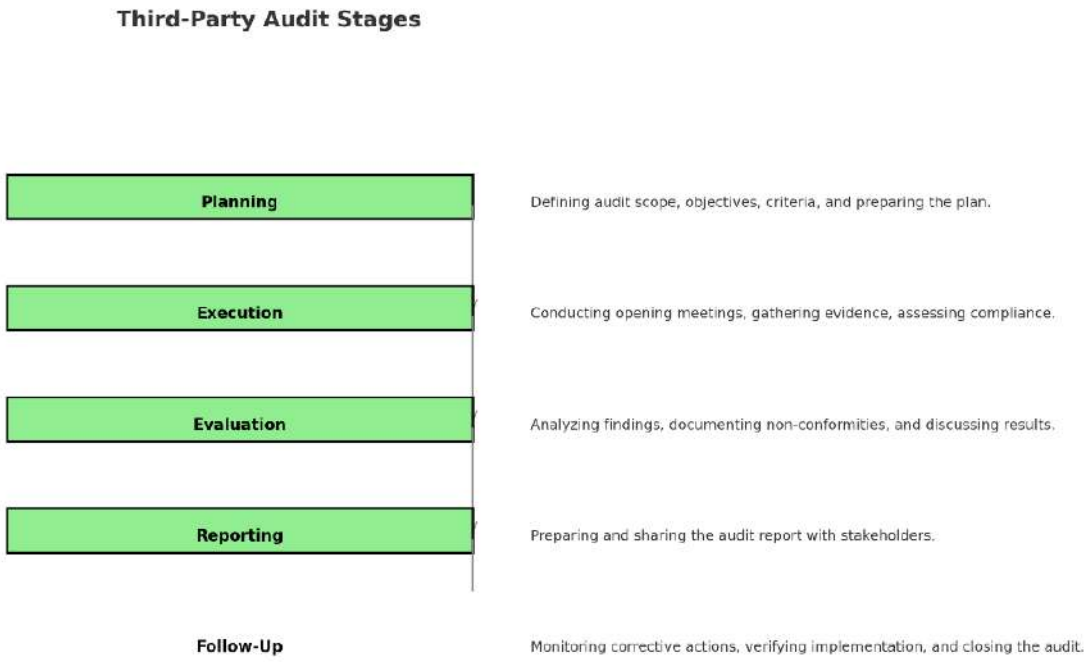
1. Could you briefly describe your main tasks and responsibilities in your current role?
2. How many years of experience do you have in your current role?
3. Can you share some of your experiences with digitalization in auditing?

### 3. Questions related to digital tools in FSMS audit stages

In this part of the interview, I will ask you about digital tools and technologies that are/could be used at various stages of the FSMS auditing process. The research focus is on understanding their

application in the following audit stages: planning, execution, evaluation, and reporting of the audit.

1. Could you tell me what kinds of **digital tools** or **technologies** could be or are used in FSMS auditing?
2. Could you indicate for each tool at **which audit stages** it could be applied and **how** it supports the audit process?




## 4. Questions related to technological barriers

In this next part of the interview, I will ask questions about technological barriers that may affect the adoption of digital tools in FSMS auditing. Technological barriers relate to, among others, characteristics of the food production process (such as the ingredients, process, equipment, and production environment characteristics), and/or technical infrastructure (such as the features of the hardware and software) and/or data (format) characteristics, etc.

3. What are according to you typical **technological barriers** that could constrain the adoption of digital tools in FSMS audits?
4. **How** do these barriers **impact** the adoption process?

## 5. Questions related to managerial barriers

In this final part of the interview, I will ask questions about managerial barriers related to the adoption of digital tools in FSMS auditing. Managerial barriers relate to the characteristics of the organisational structure of a food business (such as the arrangement of tasks and responsibilities), the level of formalisation and use of procedures, the characteristics of their information system, and people-related aspects such as competencies and commitment (motivation commitment) of employees, etc.

4. According to you, what are the **managerial barriers** that could constrain the adoption of digital tools in FSMS audits?
5. **How** do these barriers **impact** the adoption process?

# Appendix B

**Invitation email**

**Contact E-mail:**

**Subject:** Interview request – barriers to digital tool adoption in FSMS audits

Dear [Recipient's Name],

I hope this email finds you well. My name is Rahineh Nomani, and I am a master's student in Food Quality Management at Wageningen University & Research. As part of my research, I am investigating the barriers to adopting digital tools for supporting Food Safety Management System (FSMS) audits from multiple stakeholders' perspectives.

I am writing you this email to express my respect because of the work you are conducting at [Recipient's company Name] to maintain this remarkable level of safety and help consumer protection. Given your expertise in the field, I would be honoured to interview you to gain insights that will enrich my research.

The interview will take approximately 30–45 minutes and can be conducted at your convenience, either virtually (via Microsoft Teams) or in person. I am flexible with scheduling and happy to accommodate a time that works best for you.

Moreover, please rest assured that your participation will remain confidential—your name and company affiliation will not be disclosed. The interview is solely for academic purposes, and you are free to skip any questions you find uncomfortable.

I understand that your time is valuable, and I sincerely appreciate your consideration. Your input will be a valuable contribution to my study, particularly in investigating the barriers related to digital tool adoption in FSMS audits.

I have attached the Interview Guide and Letter of Consent for your review. Please let me know if you would be open to participating, and feel free to reach out with any questions.

I am looking forward to your response.

Best regards

Rahineh Nomani

Wageningen university and research

# Appendix C

Letter of consent

WAGENINGEN
UNIVERSITY & RESEARCH

**Informed Consent based on the format of the**

**WUR Research Ethics Committee for Non-Medical Research**

**Investigating barriers to the adoption of digital tools for supporting Food Safety Management System (FSMS) audits from multiple stakeholders' perspectives**

rahineh.nomanilafmejani@wur.nl

**Study Background**

Thank you for your participation in this study. This study is conducted as part of MSc thesis of the MSC program Food Quality Management at Wageningen University (WU). The study aims to explore the technological and managerial barriers encountered in Food Safety Management System (FSMS) auditing, particularly concerning the adoption of digital tools. This research aspires to obtain meaningful findings to understand which barriers may hamper using digital tools and technologies in FSMS auditing.

**What is being asked of you as a participant?**

As a participant, you are invited to share your insights, experiences and/or knowledge regarding digital tools and technologies in Food Safety Management System (FSMS) auditing through a semi-structured interview. The interview will focus on the types of digital tools currently used or with potential for use in FSMS audits, the stages of the audit process where these tools are applied, and how they function. Additionally, we seek to understand the technological and managerial barriers to adopting these tools and how they play a role across different audit stages. The interview will be online or in-person as you prefer and will last approximately 30–45 minutes. The interview will be audio-recorded to ensure accurate transcription and qualitative data analysis with your consent. You could review the transcribed interview before further data analysis. Participation in this study is entirely voluntary and you have the right to decline involvement at any stage, without providing any reasons, without negative consequences. Additionally, if you consider any question(s) as a confidential topic(s) you are free to refrain from answering them or we can turn off the record.

**What are the benefits of participating in this study?**

By participating, you will help researchers gain insight into the barriers to digital tool adoption in FSMS auditing. The findings and insights from this study may serve as a basis for future researchers to improve audit practices and foster the successful integration of digital tools in the food safety sector. On a broader level, this research aspires to address societal challenges by enhancing food safety management through better use of technology, ultimately benefiting public health, reducing risks of foodborne illnesses, and strengthening trust in global food supply chains. If you are interested, the results of this (thesis) research can be shared with you.

**How will your information be handled?**

All information you provide will be pseudonymised, ensuring your identity remains confidential. Your responses will be processed through qualitative data analysis, your input will not be identifiable, and your name will be removed from the information you share. During the data analysis, you will be identified only by a subject number to ensure that no personal data will be included in any report or publication that may result from this research. The records will be deleted after transcription and verification. The interview transcripts will be archived in a confidential environment, kept for 5 years as part of the data management policy, and not published. You may obtain the transcript of the interview to review and gain access to the final report. The information provided in the interview might be used in publications, including quotes. However, we will ensure that the information cannot be traced to individual participants.

**What if I have questions about the study or change my mind?**

If you have any questions about this study, please do not hesitate to contact Rahineh Nomani (the main researcher) at this email (rahineh.nomanilafmejani@wur.nl) and/or the supervisor Dr. Pieternel A. Luning and Dr. Selcen Oduncuoglu from the Food Quality & Design Group at Wageningen University.
You have the right to withdraw from the study at any time during your participation, without facing any issue or loss of benefits. Furthermore, should you decide to withdraw you may request the removal of any data or information you have provided from the study records.

**I consent to participate in this research and to use my data as described.**

| Name of the participant | Signature | Date |
|---|---|---|
| _____ | _____ | _____ |

# Appendix D

Use of generative artificial intelligent

In this report, artificial intelligence (AI) is used to improve grammar and reduce grammatical and punctuation mistakes. The AI programs utilized for this purpose are Chat GPT and Grammarly (nonpremium) and Google Translate to assist with the drafting and refinement process. It should be noted that AI is used for grammar checks, and after a second review by the author, the correction is added to the report. Additionally, AI-assisted in the literature review by providing explanations for complex concepts found in the article.

# Appendix E

| Expert Number | Raw text- related | Unit of analysis | Context unit | Core of meanings (themes) | Categories | How it affects audits |
|---|---|---|---|---|---|---|
| E 1 | In my previous role, we were experimenting with **digital audit tools**, but adoption was slow. At my current facility, we still do a lot of things manually, but we use some digital systems for specific tasks.<br>For example, we use **IoT sensors** like T**esto Saveris 2** for **temperature monitoring**. These sensors automatically **record pasteurization temperatures and store them** in a **tracking** system, so we can review | IoT Sensors | Companies are experimenting with digital audit tools, but adoption is slow. At the facility, IoT sensors like Testo Saveris 2 monitor temperatures, but manual audits rely on Word documents and Excel sheets, resulting in inefficient entry of findings and reports. | Digital audit tools have been experimenting in recent years, but adoption has been slow. At a facility, IoT sensors like Testo Saveris 2 are used for temperature monitoring, storing pasteurization temperatures for review. However, manual audits still rely on Word documents and Excel sheets. Digital tools are transforming audits, such as real-time monitoring sensors like Testo Saveris 2 for temperature and humidity tracking in food storage areas. These sensors collect data and alert the facility if anything goes out of range, ensuring compliance remotely. | IoT Sensors and Digital Checklists | Improves accuracy but does not integrate with audit documentation |
| E 3 | absolutely. Digital tools are transforming audits, and I've seen it firsthand. For example, we now use **real-time monitoring sensors**, like Testo Saveris 2, to **track temperature and humidity** in food storage areas. Instead of relying on manual logbooks, these sensors automatically collect data and alert us if anything goes out of range. | real-time monitoring sensors | Digital tools like Testo Saveris 2 are revolutionizing audits by automatically collecting temperature and humidity data in food storage areas, eliminating the need for manual logbooks. | | | real-time monitoring |
| E 4 | **IoT-based monitoring** is another game-changer. Many food businesses now use smart sensors like Testo Saveris 2 to track temperature and humidity in storage areas. Instead of relying on manual checks, we can access real-time data and ensure compliance remotely. | IoT-based monitoring | IoT-based monitoring is changing food businesses by enabling real-time data access and remote compliance checks, such as Testo Saveris 2, to track temperature and humidity in storage areas. | | | real-time data access and remote compliance checks |
| E 6 | I mean certainly the Internet of Things was a sort of a consideration in terms of can we leverage more data in a more constructive way. | Internet of Things | The Internet of Things was a consideration for leveraging more data in a more constructive manner. | | | |
| E 7 | Then there are **IoT sensors**, that use in production line, like Emerson GO real-time temperature trackers and Testo Saveris 2, which automatically monitor critical control points such as temperature, humidity, , and pressure in storage and processing | IoT sensors | There are IoT sensors, like Emerson GO real-time temperature trackers and Testo Saveris 2, which automatically monitor critical control points such as temperature, humidity. | | | |
| E1 | in my previous role, we tested **Safefood 360°** for **supplier audits**. It was a centralized platform where suppliers could upload their compliance documents, and we could conduct risk assessments to determine whether a physical visit was needed. The idea was great, but suppliers were not happy about logging into an external system. Many found it burdensome, and only a few key suppliers actually used it properly.<br><br>At our current facility, we use **Microsoft PowerApps** for corrective action and preventive action (CAPA) management. We also have a document management system called TenForce, but honestly, it's not very user-friendly. It requires a lot of manual clicking, and many employees prefer to write documents in Word and then ask someone to upload them. | Safefood 360°<br><br>Microsoft PowerApps | The expert highlights overreliance on outdated reporting methods, requiring excessive manual effort by using different siftware. | The expert discusses the use of AI in document analysis, highlighting its potential to improve document integrity but also adding complexity for users unfamiliar with automated processes. AI-powered tools like FoodDocs AI help identify compliance trends and potential risks in audit data, focusing on critical areas before on-site audits. The company is testing these tools, which analyze historical audit data, despite ongoing development. | AI-powered tools | Increases workload, delays reporting |
| E 2 | For data analysis, we use **Power BI**. It allows us to extract audit data, filter insights, and visualize compliance trends across different locations. However, this requires some IT expertise to build dashboards tailored to audit needs. | Power BI | The expert explains how AI improves document integrity but adds complexity for users unfamiliar with automated processes. | | | data analysis |
| E 3 | We also use **AI-powered tools** like HACCPBuilder AI, it **analyzes audit data** and identifies **trends** in compliance or potential risk | AI-powered tools | AI-powered tools are utilized to analyze audit data, identifying compliance trends and potential risks. | | | analyze audit data, identifying compliance trends and potential risks. |
| E 4 | And then there's **AI-powered risk analysis**. We've recently been experimenting with tools like FoodDocs AI, which analyze past audit data and flag potential risk areas before we even step foot on-site. While AI isn't perfect, it helps us focus on the most critical areas during an audit. | AI-powered risk analysis | AI-powered risk analysis tools like FoodDocs AI help identify potential risk areas in audit data, focusing on critical areas before on-site audits. | | | identify potential risk areas in audit data |
| E 7 | We've also started testing **AI based risk assessment tools**, like FoodDocs AI, which analyze historical audit data and flag potential risks before an inspection. It's still evolving, but it's promising. | AI based risk assessment tools | The company is testing AI-powered risk assessment tools like FoodDocs AI, which analyze historical audit data to identify potential risks before inspections, despite its ongoing development. | | | |