ALGORITHMIC GOVERNANCE FOR FOOD SUPPLY CHAIN TRANSPARENCY: AN UMBRELLA REVIEW

Research full-length paper

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Abstract

Fraud in food supply chains is a severe threat to food safety and sustainability. Mitigating it requires effective mechanisms to ensure transparency and traceability along food supply chains with several autonomous and distributed actors. Recent research shows that algorithm governance can be a promising approach in food supply chains to achieve this goal. This study reports findings from an umbrella literature review of empirical research on digital technology for transparency in food supply chains. The findings show challenges in food supply chains, food supply chain management, the need for digital technologies, digital technology and traceability, and the use of blockchain in food supply chains. Based on these findings, we draw implications for research on algorithmic governance: (i) the specific features and configurations of the digital technologies used and how they differ, (ii) the involved actors and how they interact, (iii) the reasons of the benefits and drawbacks of algorithmic governance, (iv) the temporal aspects of data collection and verification, (v) the spatial aspects of data sources and nodes, and (vi) the need for sociotechnical data management.

Keywords: Food supply chains, Traceability, Transparency, Algorithmic Governance, Literature review, Umbrella-review, Empirical

1 Introduction

According to the World Health Organization, almost one out of 10 people globally suffer sickness due to foodborne disease each year. Food hazards can cause over 200 diseases caused by bacteria, chemicals, and other contaminations, and foodborne and waterborne diarrhoeal diseases can kill about two million people annually (Duan et al., 2020). A crucial challenge in the food supply chain is food fraud, i.e., any deliberate action of businesses or individuals to deceive others regarding food integrity to gain undue advantage (European Commission, 2020). Types of food fraud include adulteration, substitution, dilution, tampering, simulation, counterfeiting, and misrepresentation of production method or its origin, for instance, intentional mislabeling or masking a defect or contamination. Combating this threat is an urgent concern because of the steep increase in food fraud attempts across increasingly complex global supply chains with negative consequences for consumer trust, financial interests, and, crucially, sustainability, especially in terms of public health and harm to the environment (Spink and Moyer, 2011).

Food systems worldwide are organized in *supply chains* that span food products' production, processing, and consumption. Food (sometimes agri-food) supply chains can be structured in different ways but are generally heterogeneous and highly distributed, involving "a set of interdependent companies that work closely together to manage the flow of goods and services along the value-added chain of agricultural and food products" (Folkerts and Koehorst, 1997).

Increasing *transparency* in food supply chains is necessary for companies and governments to prevent food fraud and ensure food safety. Food supply chains include multiple stakeholders, such as food producers, retailers, governments, and customers. Global food supply chains are complex and must abide by different regional policies and responsibilities (Duan et al., 2020). Thus, responsibility of a food supply chain is distributed across all actors in the supply chain (Nurgazina et al., 2021). Traceability of food relies on achieving a sufficient degree of coordination and cooperation among all stakeholders in the food supply chain based on shared rules that are either enforced manually or automatically through the use of digital technology. Such mechanisms depend on developing reliable approaches to ensure the transparency of each operation along the supply chain and, thus, its traceability. We define supply chain transparency as "the practice of disclosing detailed and accurate information about operations and products, such as their origin and sourcing, manufacturing processes, costs, and logistics" (Montecchi, Plangger and West, 2021). Traceability is then "the ability to follow the movement of a food through specified stage(s) of production, processing, and distribution" (FAO, 2017, p. 4). Evidence from the literature on food traceability shows that it emerges as a problem of data management, that is, collecting, storing, cleaning, accessing, and analyzing data of sufficient quality and quantity to be able to document and trace the path of a food item along the supply chain. Food chain transparency relies on "[t]he ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, using recorded identifications." (Olsen and Borit, 2013, p. 148). However, enabling data sharing is challenging. Food supply chains are often not designed to be transparent or traceable (Bateman and Bonanni, 2019). Their distributed nature causes many frauds to happen at the local level and often remain invisible (Duan et al., 2020).

Because of such challenges, recent literature points to the emergence of combinations of digital technologies and innovative governance mechanisms to improve traceability and transparency in supply chains (Mikalef, Pateli and van de Wetering, 2021). Food supply chains are organized as networks of autonomous organizations that are spanning geographical locations and operational phases, with the purpose of delivering food-related products such as meat, fish, wine, vegetables, and organic oil. Such networks of globally distributed autonomous organizations can be considered meta-organizations (Leong et al., 2023), that is, organizations whose agents are legally autonomous and not linked through traditional legal or employment relationships. With the emergence of new digital technologies such as blockchain, *algorithmic governance* of meta-organizations is being considered. That is; governance is performed through the adoption of digital technology to govern the behavior of the involved stakeholders and ensure their alignment with the meta-organization's purpose (Mini et al., 2021; Möhlmann et al., 2021).. A promising digital technology for algorithmic governance is blockchain, which is an append-only ledger of data distributed and synchronized across the nodes of a network, using a distributed consensus mechanism (Rossi et al., 2019; Dubey et al., 2023). Blockchain implementations thus ensure data storage that is immutable, distributed, decentralized, secure, consensus-based, and unanimous. In the context of food supply chains and transparency, data about a food item added to a blockchain would, for example, be immutable and protected from potential fraudulent acts.

In sum, food supply chains are prone to fraud because of their highly distributed, meta-organizational characteristics. Digital technology, such as blockchain, is considered to enable algorithmic governance to improve transparency. Despite enthusiastic calls for algorithmic governance across several domains, there is a need for a more in-depth understanding of the unfolding of this phenomenon in specific contexts to inform theorizing (Lumineau, Wang and Schilke, 2021). This is particularly urgent in the case of food supply chains, a complex context in which traceability is a prerequisite to implementing transparency with broad social, economic, and environmental implications.

The paper therefore investigates the following research questions:

1. *What is known about digital technologies for food supply chain transparency?*

2. *What are the implications for research on algorithmic governance of food chain transparency?*

To answer our research questions, we conducted an umbrella literature review. An umbrella review is a tertiary type of study used to provide an overview and examination of a body of literature (Paré et al., 2015). Our findings sections summarize our analysis of what is known in the literature in five themes: (i) challenges in food supply chains, (ii) food supply chain management, (iii) the need for digital technologies, (iv) digital technology and traceability, and (v) specifically considering blockchain in food supply chains (the most prominent digital technology in our review). In sum, algorithmic governance of food chain traceability has considerable potential but faces significant challenges and gaps in the current literature. Using the 5W and 1H approach, we discuss six themes for IS research on algorithmic governance, inviting researchers to investigate further: (i) the specific features and configurations of the digital technologies used and how they differ, (ii) the involved actors and how they interact, (iii) the reasons of the benefits and drawbacks of algorithmic governance, (iv) the temporal aspects of data collection and verification, (v) the spatial aspects of data sources and nodes, and (vi) the need for sociotechnical data management.

2 Algorithmic governance and food supply chain traceability

The European Union (EU) stresses the importance of traceability in the food supply chain to achieve transparency through the ability to follow the movement of any food-related product or substance that will be used for consumption and through all stages of production, processing, and distribution (European Commission, 2007). A traceability system generally encompasses “the principles, practices, and standards needed to achieve traceability of food products, regardless of how these are implemented” (Olsen and Borit, 2018, p. 143). The main components of a traceability system are a mechanism for identifying a traceable unit of a product, a mechanism for documenting any transformation that has occurred, and a mechanism for recording the attributes of the unit (ibid.). The way these traceability mechanisms identify, document, and record a unit are implemented and used in food supply chains in practice is a highly relevant theme in IS due to the combination of social practices and technological solutions required to get an overview across boundaries that separate logistical phases, geographical and legislative areas, and legal accountabilities.

While traceability systems could, in principle, be entirely based on paper, digital technology is increasingly used in the food industry today to exchange information among supply chain partners in such meta-organizations in a flexible way (Gosain, Malhotra and El Sawy, 2004). Identification and localization technologies have proved very important in this respect and span approaches based on alphanumerical codes, bar codes, radio frequency identification (RFID), geographical information systems (GIS), and Global Positioning System (GPS) (Olsen and Borit, 2018). Combined, this has enabled traceability both forward, through tracking, i.e., the ability to follow an item downstream along the supply chain, and backward, through tracing, i.e., the ability to identify the origin of an item upstream (Schwägele, 2005). More recently, distributed ledger approaches such as blockchains have been proposed as a real-time, trust-based approach to forward traceability. Blockchains enable a decentralized approach to demonstrate product governance and chain of custody of product units, preventing tampering risks (Azevedo, Gomes and Romão, 2023). Blockchains exist in various incarnations with different applications, for instance, depending on the acceptable nodes in the network and which consensus mechanism is chosen (Dasaklis et al., 2022).

While promising, the practical governance of the mechanisms involved in traceability systems poses significant challenges from an IS perspective. First, supply chains (not only in the food industry) suffer from limited transparency into and across the activities of suppliers and sub-suppliers, which is particularly problematic as these are often located in different countries or macro-regions with different regulations, such as the USA or the EU (Katsaliaki, Galetsi and Kumar, 2022). Second, the previous point leads to a chronic difficulty in collecting, integrating, and analyzing standardized data from different actors and points along the supply chains. More than an issue of large volumes, there is a lack of cross-organization mechanisms to handle the veracity and variety of the available data (Dasaklis et al., 2022). Finally, there are significant hidden costs in implementing and integrating new technologies (even if apparently simple) for supply chain traceability, including training staff to use and maintain it over time (Yadlapalli, Rahman and Gopal, 2022). In sum, these practical challenges point to a need to shed further light on the process of governing food supply chains as intrinsically distributed organizations.

On the theoretical level, a food supply chain can be conceptualized as having the characteristics of a meta-organization, that is, "an organization whose agents are themselves legally autonomous and not linked through employment relationships" (Gulati et al., 2012, p. 573).

This observation brings forth two interrelated aspects (Leong et al., 2023) of interest to the IS literature on food supply chains. First, it is the division of labor. In a traditional organization, tasks are divided based on the organization's goals, and people are hired to work on these tasks. In meta-organizations, however, actors move in and out of tasks more freely, and hence, the division of labor must be rather broad to accommodate diverse actors' strategies (Gulati, Puranam and Tushman, 2012). Second, and perhaps more relevant to food supply chains, is the problem with integrating efforts. This is the issue of persuading members to cooperate to maximize the system's value as a whole for a given division of labor (Leong et al., 2023). An example from food chains would be to adhere to food safety standards and share data to be able to trace accordingly. In food supply chains, every step and every supplier counts towards the final product, which means that every actor needs to cooperate to reduce the risk of product failure (with the risk of disease and poisoning) (Astill et al., 2019). Further, the centralized organizing of food supply chains makes them vulnerable to bribery, and a single failure can disrupt the entire network (Duan et al., 2020). We conceptualize the shift from manual governance to governance via digital technologies in food supply chains as *algorithmic governance* (Lumineau, Wang and Schilke, 2021; Mini et al., 2021).

Blockchain has intensified the focus on algorithmic governance in meta-organizations in the last years (Mini et al., 2021). Two features of blockchain are particularly relevant (Lumineau, Wang and Schilke, 2021). First, there is decentralized consensus, which addresses the information-sharing problem described above. When information is shared in a network, such as a meta-organization, consensus is required on the actual state of the information. To achieve consensus, a decentralized network requires consideration of the consensus algorithms. Blockchain provides one solution to this problem, as consensus is reached where no keystone actor owns the sole decision right. Second, blockchains enable the use of smart contracts, which are scripts that perform specific actions if prescribed conditions based on transactions on the blockchain are met. This can potentially reduce the need for intermediaries in supply chains and, hence, is relevant to the division of labor problem described above.

3 Research method

An umbrella review is a tertiary type of study that summarizes findings from multiple systematic reviews (quantitative or qualitative) and hence is suitable in domains of study where such exist (Paré et al., 2015). Starting from existing systematic reviews, umbrella reviews typically seek to impose an overall coherence and provide higher-level overview by grouping these reviews together (Grant and Booth, 2009). Following this rationale, our objective was to get an overview of the state of the art regarding the use of technology for food supply chain transparency that we use as a basis to discuss algorithmic governance in the domain and theoretical implications for IS.

Umbrella review protocol design. We followed the guidelines from (Aromataris et al., 2015) combined with more generic advice for analyzing the past to prepare for the future (Webster and Watson, 2002). Starting from the practical problems within the domain of food supply chains as described in the introduction, we wrote a study protocol to get an overview of the status of food supply chain operations in terms of core concepts, processes, responsibilities, procedures, and supporting technologies for increased transparency between stakeholders. We defined the phenomenon we sought to understand as: "The current state of the art of practices and technologies used in food chains for transparency."

Identifying the literature: constructing the search string and search. The final search string we used in this study is (see also Table 1):

“((agr AND *food) OR "*food systems" OR "*food chain" OR "*food supply chain*") AND technolog* AND transparen*”*

We searched the Scopus database (https://www.scopus.com/) in February 2023. We chose Scopus because it is one of the most comprehensive scientific literature databases and has advanced search and rigorous quality-control measures (Gusenbauer and Haddaway, 2020). The search gave 493 results. To check for existing reviews, we filtered “Only reviews,” giving 66 results. Since this is a significant number of papers, we decided to do an umbrella review of these reviews.

Inclusion and exclusion. The inclusion and exclusion criteria used are:

1) (Inclusion) The title, keyword list, and abstract make it explicit that the paper is related to food supply chains.
2) (Inclusion) The paper is a review paper.
3) (Inclusion) The study must contain a clearly defined research question/aim.
4) (Inclusion) The problem statement must address traceability and/or transparency.
5) (Inclusion) The study must include a technology.
6) (Inclusion) The study must be based on a clear research design (research method).
7) (Inclusion) The study must be written in English.
8) (Inclusion) The study must be of sufficient technical quality (e.g., language is readable).
9) (Exclusion) The main research question(s) focus(es) on chemical/physical food analysis (e.g., DNA, chemical elements).

The papers were split within the research group. We documented the reason for exclusion when a paper was excluded according to the above criteria. Uncertain cases were discussed and assessed jointly by all authors.

Studies included. After assessing the papers based on inclusion and exclusion criteria, 15 papers were left and were analyzed. The papers included in the review were: 1) (Pakseresht et al., 2023); 2) (Tzachor et al., 2022); 3) (Probst, 2020); 5) (Srivastava and Dashora, 2022); 6) (Masudin et al., 2022); 7) (Rocha, de Oliveira and Talamini, 2021); 8) (Samoggia and Beyhan, 2022); 10) (Astill et al., 2019); 11) (Duan et al., 2020) 12) (Nurgazina et al., 2021); 13) (Galvez, Mejuto and Simal-Gandara, 2018); 14) (Antonucci et al., 2019); 15) (Feng et al., 2020).

The use of blockchain for algorithmic governance emerged as a main theme as many papers were specifically about blockchain. The papers that contained claims about blockchain were IDs 1, 3, 5, 7, 8, 10, 11, 12, 13, 14, 15. That is 11 out of 15 papers. All papers were analyzed in the umbrella review, while only the papers making claims about blockchain were included in the blockchain-specific analysis.

Concept matrix. To extract material from the papers, we constructed concept matrixes in line with the advice by Webster and Watson (2002). A concept matrix is a tool (often a table) to synthesize the main concepts identified across the relevant articles in a literature review. The first concept matrix is used to get an overview of the studies (Table 1).

The second concept matrix we used was concerned with blockchain application, as this is a crucial technology for meta-organizing. We created a separate concept matrix for blockchain applications because this technology was highlighted in most studies. There were several claims (concepts) that emerged from the literature inductively.

A central claim about blockchain was that it enhances trust between actors in the food chain. This trust is a result of several characteristics of blockchain technology. Two main characteristics of blockchain claimed to be significant were traceability and transparency, enabling food supply chain actors to know the content and whereabouts of products and their ingredients. To allow for the sharing of the information necessary for traceability and transparency, blockchain is used for data storage and data sharing. Blockchain is also said to contribute to data security. As a result, blockchain is used to manage contracts and secure payments between actors. In total, blockchain is said to contribute to the digitalization of food supply chains.

Concept	Description
Keywords	Keywords listed in the paper meta-data
Purpose/Research question	The purpose of the study or the research questions posed.
Method	The method used for the review
Empirical	Is the review focusing on empirical studies or not
Key findings	Key findings the study claims
Main technologies used	The technologies the study finds are used
Technology contribution to transparency	The claims made about how technology contributes to transparency
Identified challenges with technology	The challenges the study identifies regarding using technology for transparency
Description of the food chain	How is the food chain described or defined in the study
Description of food supply chain management	How is food supply chain management described or defined in the study
Definition of traceability/transparency	How traceability and transparency are defined in the study
Responsibilities and accountabilities (who is responsible for what)	The descriptions of responsibilities and accountabilities as described in the study

Table 1. Concept matrix for overview of studies with a description of concepts.

Claims about the impact of blockchain were analyzed to see how they linked to the properties of blockchain claimed to be utilized. The properties of blockchain are described in e.g. (Lumineau, Wang and Schilke, 2021; Schueffel, Groeneweg and Baldegger, no date). The properties of blockchain were linked to six different concepts, which were: 1) *immutability*, that data added to a ledger cannot be modified; 2) *distributed*, that all network nodes have their own copy of the ledger; 3) *decentralized*, that all network nodes work together to verify and validate ledger transactions; 4) *secure*, that blocks are cryptographically linked, and data may be encrypted; 5) *consensus* among the nodes in the network governs what data is accepted for inclusion into the blockchain; and 6) unanimous, once data is added to the ledger, all nodes unanimously accept the data as part of the record from that point on.

Finally, the claims were analyzed to see if blockchain was used with other technologies. Three main technologies were highlighted: smart contracts, AI and IoT.

Data extraction and analysis. Papers were divided between the authors, who extracted data from the papers according to the concept matrices. To test the concept matrices, each author read three papers and filled in the matrices. This was followed by a meeting to discuss interpretations and adjust concepts. Practically, the concept matrices were in a shared MS Excel sheet. If an author was unsure about a categorization, the research team was consulted, and an agreement was reached.

The concept matrix was filled in as follows. For 'Keywords,' we extracted the keywords listed in the papers. In terms of 'Purpose/Research question,' we extracted the purpose or research question as specified in the paper. If none was specified, the field was left blank. In terms of 'Method,' we extracted the method as specified in the papers. For 'Key findings,' we extracted the key findings as specified in the papers. For the food supply chain, we extracted any descriptions or definitions of the food supply chain. If no description was found, we left the field blank. For 'Description of the food supply chain management,' we extracted any descriptions or definitions of the food supply chain management. We included food supply chain management in addition to descriptions of the food supply chain to identify if there were any particular descriptions of management aspects. For 'Definitions of traceability/transparency,' we extracted any descriptions or definitions. For each field, if no description was found, we left the field blank.

Finally, we mapped the technologies proposed in the reviewed articles and the emerging technological challenges. We realized that most articles discussed the use of blockchain. As a result, we became interested in mapping the claims made about this emerging technology. We classified each claim into two disjoint non-exclusive categories: the area or domain where blockchain is claimed to have an impact and the specific blockchain property that makes the impact possible. We classified areas of impact by inductively clustering articles. This process resulted in the following areas: Financial, Contractual, Traceability, Transparency, Storage, Shared, and Digitalization. The results of the analysis are presented in the following findings.

4 Findings

4.1 Challenges in food supply chains

A food supply chain is defined as "a set of interdependent companies that work closely together to manage the flow of goods and services along the value-added chain of agricultural and food products, in order to realize superior customer value at the lowest possible costs" (Folkerts and Koehorst, 1997:11). Thus, a food supply chain involves numerous stakeholders, such as producers (farmers, fishers), processors, suppliers, distributors, wholesalers, retailers, and consumers, all collaboratively managing the flow of goods and services along the value chain (Galvez, Mejuto and Simal-Gandara, 2018; Srivastava and Dashora, 2022).

Our study highlights the importance of upholding product quality along the supply chain. For instance, a halal supply chain ensures that halal product quality is retained through the supply chain (Masudin et al., 2022). This includes paying attention to handling processes, ensuring food safety, and addressing the risks associated with food production, such as varying quality, environmental factors, and complex production procedures (Galvez, Mejuto and Simal-Gandara, 2018; Astill et al., 2019; Nurgazina et al., 2021; Masudin et al., 2022).

Ensuring food quality, preventing food fraud, and safeguarding consumer health rely on traceability and comprehensive information. This involves addressing challenges and risks inherent in the value chain, such as vulnerability, transparency issues, reluctance to share traceability information, information asymmetry, and the threat of food fraud. Accomplishing these goals requires a commitment to transparency, digitalization, supportive systems, and adherence to labeling regulations (Duan et al., 2020; Nurgazina et al., 2021). This, in turn, calls for enhanced collaboration, increased efficiency, and the implementation of systems to ensure compliance, authentication, and consumer protection (Galvez, Mejuto and Simal-Gandara, 2018; Astill et al., 2019; Duan et al., 2020; Nurgazina et al., 2021).

In summary, a food supply chain involves diverse stakeholders collaboratively managing goods and services along the value chain. The studies emphasize the importance of upholding product quality while addressing challenges like varying quality and environmental factors. Ensuring food quality, preventing fraud, and safeguarding consumer health rely on traceability, comprehensive information, and a commitment to transparency, digitalization, and collaborative systems in the value chain.

4.2 Food supply chain management

Food supply chain management involves planning and executing activities related to sourcing, procurement, manufacturing, and logistics. Various traceability implementation practices have been introduced in food supply chain management, such as tracking food through forward and backward linkages, enabling efficient recall processes, and contributing to public health by identifying and isolating problematic products or ingredients (Astill et al., 2019; Srivastava and Dashora, 2022). Traditional paper-based systems are time-consuming and error-prone, while technology-driven solutions offer improved accuracy and speed in recording and exchanging information (Astill et al., 2019). As a result, there is an ongoing shift from traditional paper-based or local computer systems to address these inefficiencies towards adopting technological innovations to enhance traceability. Technologies encompass Radio Frequency Identification (RFID), barcodes, smart tags, Wireless Sensor Network (WSN), and DNA-based techniques. Technological advancements provide more efficient means of recording, exchanging, and managing information in the supply chain (Astill et al., 2019).

Moreover, food supply chain management involves significant coordination and collaboration across various stakeholders, including suppliers, intermediaries, third-party service providers, and customers (Pakseresht et al., 2023). Effective collaboration and integration among these parties are essential for the successful management of the food supply chain (Galvez, Mejuto and Simal-Gandara, 2018; Pakseresht et al., 2023)

4.3 Need for digital technologies

Food supply chains are more vulnerable than supply chains in other industries. External factors, such as temperature and transport, may affect the quality of the product. Processed foods have more complex production with multiple ingredients, increasing the risks of product failure, e.g., food-borne disease, food poisoning, low-quality food, counterfeit products, or mislabeling and undeclared ingredients. As every step and every supplier in the supply chain counts toward the final product, food supply chains need close collaboration to reduce the risk of product failure (Astill et al., 2019).

Because modern food supply chains are complex, they involve many intermediaries who are not always willing to share the information necessary for traceability. In addition, modern supply chains are often centralized, with a single entity controlling information flow. This challenges transparency and potentially causes information asymmetry and distrust (Duan et al., 2020). This may affect food authentication and our trust in a product’s label descriptions, such as origin, processing method and technology, and composition (Antonucci et al., 2019).

However, traceability and transparency in the supply chain allow stakeholders and consumers access to non-distorted, factual, relevant, and timely information about a product (Astill et al., 2019). For example, a functioning traceability system may identify problem ingredients and contribute to efficient food recall and public health. Opening supply chain information may benefit both industry and consumer health and prevent food fraud. Emerging technologies can provide efficiency in recording and exchanging information needed for traceability in food chains, e.g., Radio Frequency Identification (RFID), barcodes, smart tags, Wireless Sensor Networks (WSN), and DNA-based techniques (Duan et al., 2020). This highlights the importance of transparency and traceability in food chains by shifting towards technology-driven traceability, handling risks associated with centralized supply chains, and securing food.

To summarize, food supply chains are vulnerable to product failure, including food-borne disease and mislabeling. To address these challenges, our analysis highlights the importance of transparency and traceability in food chains. This requires a shift towards technology-driven traceability.

4.4 Digital technology and traceability

How technology contributes to traceability: The analysis shows that in terms of technological contribution to traceability and transparency, Blockchain is the predominant technology mentioned in the reviewed papers, with 11 out of 13 papers discussing it. The Internet of Things (IoT) is mentioned in four papers: AI, RFID, and QR in two, and smart packaging, GPS, Bluetooth, smart contracts, data mining, and digital sandboxes in one. In general, blockchain technology is seen as a critical contributor to traceability and transparency in food supply chains, as it enables end-to-end traceability by providing a common technological framework and allowing consumers easy access to the story of foods. Blockchain records digital product information at each step of the supply chain, including origination details, batch numbers, processing data, expiry dates, and shipping details. On the one hand, the decentralized nature of blockchain eliminates the need for intermediaries to verify and authenticate transactions, thus improving the efficiency of traceability systems and reducing costs in the supply chain (Srivastava and Dashora, 2022). On the other hand, the immutability of blockchain records is found to ensure data integrity and help reveal food safety issues. It strengthens safeguards related to food authenticity and allows retailers to manage product shelf life. Some authors discuss how blockchain technology brings trust, transparency, and value exchange to business networks and can facilitate transactions and collaborations across organizational silos (Galvez, Mejuto and Simal-Gandara, 2018; Antonucci et al., 2019; Srivastava and Dashora, 2022). As a result, some authors propose blockchain as a means to address food safety concerns and contamination risks. It helps verify the origin of input materials, ensures compliance with labeling claims (e.g., kosher, organic, allergen-free), and provides end-to-end traceability to manage and prevent outbreaks. The use of blockchain facilitates transparency, allowing consumers to access reliable information about food products and make informed choices (Galvez, Mejuto and Simal-Gandara, 2018; Antonucci et al., 2019; Duan et al., 2020; Srivastava and Dashora, 2022; Pakseresht et al., 2023). In addition, the analysis identified several benefits of using blockchain technology. Blockchain may improve food traceability, information transparency, and recall efficiency. It helps prevent food waste, enables ecological footprint assessment, and guides food surplus distribution. Using unique digital identifiers assigned to food products in blockchain enables source identification of foodborne illnesses and helps avoid fraud. The digital nature of blockchain technology allows for on-farm data sharing and promotes collaboration (Antonucci et al., 2019; Duan et al., 2020; Rocha, de Oliveira and Talamini, 2021; Pakseresht et al., 2023). Building on this observation, several authors find that the interaction of blockchain-based technology with other technologies may prove fruitful. The integration of blockchain with IoT technologies may be a means to achieve better efficiency and traceability in food chains (Rocha, de Oliveira and Talamini, 2021; Srivastava and Dashora, 2022; Pakseresht et al., 2023). RFID and wireless sensor networks are mentioned explicitly as IoT technologies that can be combined with blockchain for various purposes, such as knowing the geographical origin of produce and monitoring farmlands. IoT devices contribute to real-time data collection, enabling better control, monitoring, and traceability throughout the supply chain (Duan et al., 2020; Srivastava and Dashora, 2022; Tzachor et al., 2022; Pakseresht et al., 2023).

The above indicates that blockchain technology, possibly integrated with other technological paradigms such as the IoT, can enhance traceability, transparency, and food safety in supply chains by providing reliable and immutable records, eliminating intermediaries, and facilitating real-time data collection and sharing.

Technological challenges: Despite these possible advantages of using blockchain, there are challenges to designing, implementing, and operating a blockchain system. Specific to supply chain traceability is the fact that while data on the blockchain is immutable, the system in itself provides no validation of the data put on it in the first place (Galvez, Mejuto and Simal-Gandara, 2018; Duan et al., 2020; Probst, 2020; Nurgazina et al., 2021), except a consensus among the nodes in the blockchain network. In addition to the physicality of sensors providing data, this is referred to as the cyber-physical barrier and is a key distinction between financial and supply chain usages. Even though the data stay immutable, the blockchain does not have a verification mechanism to prove whether the raw data were correct. In case of sensor tampering, the blockchain will have nothing to do with detection (Astill et al., 2019).

So far, demonstrations of blockchain traceability systems in food supply chains have been small-scale (Rocha, de Oliveira and Talamini, 2021; Srivastava and Dashora, 2022), but still at significant cost and effort. Scalability and availability of necessary technological infrastructure, such as internet connectivity, are also challenges listed in the papers, e.g. (Feng et al., 2020; Probst, 2020; Nurgazina et al., 2021). This issue might be even more significant in a food supply chain, which is set apart by the presence of many small actors with limited technological competency interacting with large and sophisticated actors (Nurgazina et al., 2021).

The issue of societal and consumer acceptance (Astill et al., 2019; Nurgazina et al., 2021) is related to the above points, as they all point toward the question of trust and equitable distribution effort and value between the supply chain actors, as well as the lack of and need for regulatory actions in this space (Antonucci et al., 2019; Duan et al., 2020; Srivastava and Dashora, 2022).

Other, more general, but still applicable, challenges are also present for food supply chains. Due to the immutability of the data on a blockchain, privacy, for instance, in terms of right of deletion, presents enormous design challenges to ensure that correct data is put on the blockchain from the outset (Galvez, Mejuto and Simal-Gandara, 2018; Duan et al., 2020; Srivastava and Dashora, 2022). Furthermore, the security and complexity of the systems involved require additional skills, knowledge, and capital from both developers and users in all stages of development and planning (Galvez, Mejuto and Simal-

Gandara, 2018; Feng et al., 2020). Lastly, the environmental aspects of blockchain implementation have long been critiqued (Antonucci et al., 2019; Nurgazina et al., 2021).

4.5 Blockchain in the food supply chain

Several studies highlight the potential of blockchain technology in enabling traceability and transparency in the food supply chain. It can enhance the visibility of information from the production stage to the end consumer, increasing trust and reducing information asymmetry (Astill et al., 2019; Feng et al., 2020; Probst, 2020; Nurgazina et al., 2021; Masudin et al., 2022; Samoggia and Beyhan, 2022; Srivastava and Dashora, 2022; Pakseresht et al., 2023). Some studies focus on specific contexts or sectors, such as halal supply chain and halal logistics (Masudin et al., 2022), food supply chain (Probst, 2020; Nurgazina et al., 2021; Masudin et al., 2022; Samoggia and Beyhan, 2022), and valorization processes (Feng et al., 2020; Pakseresht et al., 2023). They explore the potential applications of blockchain in these areas and highlight its benefits in terms of traceability, integration, and eliminating intermediaries.

Despite the promises of blockchain technology, the studies acknowledge various challenges and limitations associated with the implementation of blockchain technology. These include scalability, privacy, security, lack of regulations, technical difficulties, and the need for deeper understanding and skills among stakeholders (Astill et al., 2019; Duan et al., 2020; Samoggia and Beyhan, 2022; Srivastava and Dashora, 2022). According to Antonucci et al. (2019), although these "technologies appear very promising and rich of great potential showing a good flexibility for applications in several sectors but are still immature and hard to apply due to their complexity." Despite promises, there are challenges related to scalability, security, cost, privacy, storage, energy consumption, latency, and interoperability (Duan et al., 2020).

Several studies discuss the necessity of integrating blockchain with other technologies, such as the Internet of Things (IoT) (Astill et al., 2019; Srivastava and Dashora, 2022), Artificial Intelligence, Machine Learning (Probst, 2020; Tzachor et al., 2022), and smart contracts (Probst, 2020), to improve efficiency and information transparency in the food supply chain. In addition, collaboration and efforts to take social and contextual aspects into account are essential for successful blockchain adoption. Studies emphasize the importance of involving various stakeholders, including rural anthropologists, ecologists, and data cooperatives, in the design and implementation process (Astill et al., 2019; Samoggia and Beyhan, 2022; Tzachor et al., 2022).

Claims/categories. We identified 119 claims about blockchain technology relating to the following impact areas: Financial, Contractual, Traceability, Transparency, Storage, Shared, and Digitalization (Table 2). The first four areas are relatively self-explanatory. Storage refers to claims that the benefit of a blockchain is only pure storage capability. Shared refers to claims that, in addition to storage, the blockchain provides a way for at least two actors to exchange data. Lastly, Digitalization maps claims stating that the benefit of using blockchain is not due to specific properties of the blockchain itself but only the motivation for actors to digitalize their operations in order to be able to make use of a blockchain.

Financial	Contractual	Traceability	Transparency	Storage	Shared	Digitalization
16	14	61	32	11	22	23

Table 2. Number of claims regarding each of the effect categories.

The first two categories, Financial and Contractual, are there for completeness and to map the uses not concretely connected to supply chains. As expected, traceability and transparency are most frequent, present in over half of the 119 claims analyzed. Perhaps more surprisingly, the Storage, Shared, and Digitalization categories account for 64 claims, meaning that whereas the claim purports to be about blockchain, a simpler system would have sufficed to achieve the same effect.

Properties of blockchain. The count of properties mentioned in the papers is presented in Table 3.

Immutable	Distributed	Decentralized	Secure	Consensus
13	8	12	4	4

Table 3. Number of claims referencing each of the concrete blockchain properties.

The most prominent properties are immutability and decentralization/distribution. In the context of supply chain traceability, the former ensures that reported data cannot be retroactively changed unilaterally, contributing to increased trust in the on-chain data, whereas the latter ensures that all actors in the supply chain have read and write and storage privileges, contributing to increased ability to add and verify data, and hence improved data quality and completeness. However, it does not show that a blockchain is necessary to achieve these advantages.

Map claims/categories to properties of the blockchain. Further, we analyzed the co-occurrence of effects and properties to map how blockchain contributes to these areas. The results are shown in Table 4.

	Financial	Contractual	Traceability	Transparency	Storage	Shared	Digitalization
Immutable	2	1	7	3	0	1	1
Distributed	2	0	3	4	0	2	0
Decentralized	3	1	4	4	0	0	1
Secure	0	0	3	1	0	2	0
Consensus	0	0	3	0	0	2	0

Table 4. Number of co-occurrences of effects and blockchain properties in claims.

The most obvious observation is that relatively few (23%) of the claims are grounded in concrete descriptions of how blockchain contributes to the stated effect. This might be because the reviewed articles are literature reviews; thus, they are not necessarily focused on concrete empirical cases. However, the claims are even less justified by concrete properties for the Storage, Shared, and Digitalization categories. This supports our claims regarding these categories, namely that blockchain technology, in these cases, acts as a motivating force for digitalization rather than a necessary enabling technology.

5 Discussion

Food fraud is a significant societal challenge. Increased transparency is needed. Digital technology and algorithmic governance are considered promising means to this end. By conducting an umbrella literature review and documenting what is known about digital technology in food chains to date, it is possible to identify themes relevant to algorithmic governance. We do so by discussing six themes based on the "5W and 1H" approach (Dubin, 1978; Whetten, 1989). The themes are discussed in relation to the potential for algorithmic governance (Mini et al., 2021) and meta-organizational characteristics (Leong et al., 2023).

Theme 1: What. A crucial step for the IS field to develop knowledge about algorithmic governance of food chain traceability would be to provide more detail into the technologies (e.g., IoT and blockchain) suggested to improve traceability. Moving beyond the rudimentary mappings, this article uncovered in the literature (see section 4.4) and generic claims of the potential of technologies, different technologies vary significantly, making it necessary to identify what specific features matter. For instance, what are the specific features or even implementations of blockchain used with which combination of systems and sensors. We would expect blockchains not to help if the data going into the blockchain is not provided by verified and traceable sensors (Astill et al., 2019). To provide more detail, one could map specific configurations of meta-organizational collaboration, that is, division of labor and integration of efforts (Leong et al., 2023), used in specific food supply chains, and investigate the specific features of digital technology that supports this collaboration.

Theme 2: Who. The use of algorithmic governance (Mini et al., 2021) has the potential to impact who is collaborating in food supply chains and how the collaboration is managed. The reviewed literature suggests how food chains involve multiple stakeholders (Srivastava and Dashora, 2022), the challenges and risks, including lack of transparency (Masudin et al., 2022), and issues of information asymmetry (Galvez, Mejuto and Simal-Gandara, 2018) – indicating meta-organizational challenges (Leong et al., 2023). Blockchain is pointed to as improving traceability and transparency, which could support the integration of efforts from a meta-organizational perspective (Leong et al., 2023). If blockchain can standardize coordination in the food supply chains, it would broaden the possibility of cooperation and inclusion, opening to a wider variety of actors (Leong et al., 2023). It would be relevant to investigate how blockchain transforms food supply chain traceability collaboration and potentially challenges current keystone actors relying on what the literature says is a problematic form of centralized governance (Duan et al., 2020). Another important question would be which actors can use technology to govern their collaboration concerning traceability. Finally, researchers could consider the broader implications of algorithmic governance of food traceability. Are new actors allowed on the stage? How is trust impacted, and does it impact broader concerns such as sustainability goals?

Theme 3: Why. The reviewed literature identifies several benefits of using blockchain for food traceability, including immutability that may increase trust (Galvez, Mejuto and Simal-Gandara, 2018), integrate blockchain with IoT (Duan et al., 2020), and potential for decentralization to eliminate intermediaries (Srivastava and Dashora, 2022). However, there are also drawbacks, such as blockchain not being fraud-proof (Tzachor et al., 2022), user privacy (Srivastava and Dashora, 2022), and practical issues such as cost and consumer acceptance (Astill et al., 2019). Such findings open avenues for further investigation into why actors become involved in algorithmic food traceability – particularly beyond the motivations of current keystone (i.e., big and established) actors. For citizens, could algorithmic governance increase trust in food safety, provenance, and sustainability? For governmental agencies, would algorithmic governance improve their capacity to enforce regulations? Moreover, in line with digital transformation literature, would algorithmic governance open for startups in the field to provide safe and traceable food with a competitive advantage outside current food supply chains?

Theme 4: When. A crucial question is whether it is suitable for food supply chains to adopt algorithmic governance to improve traceability. The reviewed literature discusses several sociotechnical challenges and limitations of blockchain, such as scalability, privacy, security, lack of regulations, technical difficulties, and the need for skills among stakeholders (Samoggia and Beyhan, 2022; Srivastava and Dashora, 2022). Technologies can be immature for application in certain food supply chains and hard to apply due to their complexity (Antonucci et al., 2019). More studies are needed to detail when food chain domains are suitable for algorithmic governance. Other conceivable approaches, e.g., digitalizing food supply chains using traditional databases rather than blockchain. More studies are needed to understand the costs of algorithmic governance of meta-organizations, including consideration of the sociotechnical challenges of implementation.

Theme 5: Where. In the review, several papers pointed to early examples of using algorithmic governance for traceability, such as by IBM and Walmart (Yiannas, 2018). The lack of more variety among places currently using it suggests that the technological maturity of places and actors will vary. Several factors affect this, including underlying technical infrastructure, human factors such as proper training and expertise, contextual factors such as which sensors are available, and environmental factors such as energy consumption (Nurgazina et al., 2021). Despite some initial findings in particular sectors, such as Halal production (Masudin et al., 2022), this presents relevant questions for scholars, such as how algorithmic governance would work in countries with disparate legal institutions and how different cultural contexts will affect the effectiveness of these solutions.

Theme 6: How. This theme addresses underlying processes that may support improved food traceability by algorithmic governance of food chains as meta-organizations (Leong et al., 2023). The literature review has shown that the field currently rests on a limited number of empirical studies that can provide nuanced insights into how algorithmic governance may work in specific contexts. Studies can investigate implementations in new contexts, considering costs, effects on traceability, how collaborations are influenced, and how solutions are implemented and used. Further, the dynamic interdependence between social and technical dimensions should be considered in more detail (Orlikowski and Scott, 2008). A sociotechnical and particular focus on data and data management is also warranted to understand food chains as meta-organizations (Astill et al., 2019).

6 Conclusion

Algorithmic governance of food supply chains provides a framework for understanding and studying the potential role of blockchain and other digital technologies in food supply chains as meta-organizations working towards the common goal of ensuring a transparent and safe food supply. The reviewed literature highlights many potential benefits of adopting blockchain as part of a traceability system. However, they also acknowledge important socio-technical challenges and limitations demonstrating the need for additional research in this area. Future research will need to consider aspects relating to technology, as the level of detail in specifying the contribution from blockchain to claimed impacts is low, society, as the societal perception of the trustworthiness of the system greatly affects the value to stakeholders, and governance, as the introduction of new technology will alter the mechanisms through which actors cooperate and reduce information asymmetry. Introducing blockchain technologies along well-founded principles of algorithmic governance and thorough research into the 5W+1H themes discussed above can potentially increase food supply chain transparency, safety, and equity.

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