Article

Qualitative assessment on the chances and limitations of food fraud prevention through distributed ledger technologies in the organic food supply chain

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Highlights

- The technological capacity of distributed ledger technologies for food fraud prevention was assessed and found suitable. Targeted orchestration and insights into consumer perception are needed to provide solutions to the organic industry.
- The policy is best suited to foster technology advancement due to intrinsic interests for better policy implementation and control and the range of possible actions for support.
- Further research in law, business models, finance and transformation, consumer perception and behavior, and digital infrastructure design is required.

Abstract

The prevention of food fraud is becoming more difficult in globalized supply chains that are increasing in their complexity. Information asymmetry is the major root cause of food fraud and especially problematic in products with value adding credence attributes, such as organic foods. Therefore, vulnerability mitigation is an important task for participants of the supply chain. As statistics show a rise in food fraud cases, certification schemes such as organic farming, fairtrade, or animal welfare are adapting their standards accordingly and can cause barriers to participation in such schemes. Distributed ledger technologies (DLT), such as Blockchains, hold the potential to supervise and manage supply chains and hold promising potential for reducing risk of food fraud from different angles. However, targeted orchestration of the different functionalities is to date missing in the organic food supply chain. This gap is addressed by this study, focusing on the extent to which DLTs can help prevent food fraud in organic-certified supply chains. The findings show that the technological capacity is further advanced than the readiness of industry stakeholders regarding technology adoption. Yet stakeholders approve of the potential benefits of introducing DLTs in their supply chains, which are scarcely used today. Policy schemes hold the potential to overcome current obstacles such as legal prerequisites and financials by fostering technology dissemination through different measures.

Key Words

Organic farming; distributed ledger technology; food fraud; supply chain security

1. Introduction

Food fraud, especially in high-value markets like organic products, is a persistent issue fueled by complex global supply chains (Skorbiansky & Ferreira, 2018; Revoredo-Giha & Gschwandtner, 2021). Complex and multi-tiered supply chains are associated with higher risk for fraudulent activities, especially in the later stages of the supply chain (van Ruth & Nillesen, 2021). The global cost of food fraud and foodborne illnesses is staggering. At a global scale, the damage related to food fraud and diseases caused by spoilt food amounts to USD 40 billion and USD 55 billion, respectively, whereas a single cyber-attack can cost a food company three million EUR on average, demonstrating the need for more resilient solutions (Tripoli & Schmidhuber, 2018; Etemadi et al., 2021).

The EU's Rapid Alert System for Food and Feed (RASFF) plays a crucial role in monitoring and responding to potential threats. It monitors *"incidents that could also fall under the other incident types but are given this type [food fraud] to emphasize the (potential) fraud element of the investigation that spans several notifications"* (RASFF, 2020). Food fraud encompasses various deceptive practices, including dilution, substitution, concealment, and mislabeling (Global Food Safety Initiative, 2018). More generally, food fraud is understood as *"intentional deception for economic gain using food"* (Spink, 2019a). Consumer perceptions of food risks often differ from expert assessments (Frewer et al., 2008; Sammut et al., 2021). Organic products, also including non-food organic produce, are particularly susceptible due to attractive profit margins, freshness, and the credence attribute linked to their production process (Bitzios et al., 2017; van Hilten et al., 2020; Food and Drug Administration, 2023). To enhance traceability and protect consumers, the European Commission explores innovative solutions, including blockchain technology: *"Action 7: The Commission will, as of 2021: in synergy with the work on digital product passports, assess to what extent the traceability of organic products could benefit from blockchain or other digital technologies and envisage, in a second step, a pilot project with stakeholders. These steps will be supplemented by actions under Horizon Europe on the use of blockchain technologies in the agri-food sector as well as other targeted research & innovation actions aimed at developing innovative solutions to trace organic food."* (European Commission, 2021).

Theory on occurrence of food fraud

Criminological theories like the Routine Activity Theory (RAT) shed light on the factors contributing to food fraud. RAT, which focuses on the interplay of Offender, Target, and Guardian, has relevance in understanding food fraud (Cohen & Felson, 1979). Routines, i.e. *"any recurrent and prevalent activities"* in the food sector, as part of supply and demand management, create multiple opportunities for criminal Offenders, especially in complex supply chains (Lord et al., 2017). Guardians do not need to be human and can include technological surveillance (Cohen & Felson, 1979). Looking at food fraud, these could be plausibility checks, analytical measures, devices, and other technologies, such as Distributed Ledger Technologies (DLT), surveilling the intersection of the three theory elements. Figure 2 illustrates the elements of RAT and their intersections, illustrating the aspects that must mutually occur to allow a criminal act according to RAT. This is the presence of a potential Target, a motivated Offender and the absence of Guardian i.e., control mechanism. RAT was employed as the theoretical backbone to guide the literature as well as expert interviews to reflect on the potential roles experts might have or take.

Figure 1 Elements of Routine Activity Theory by Cohen and Felson (1979).

Food fraud prevention in the food supply chain
The prevention of food fraud is an essential issue in the food industry. To improve the understanding of the topic, it is helpful to view it in the context of other dimensions of food risks concerning food quality, food safety, and food defense. Companies in the food industry employ numerous systems and mechanisms to prevent food fraud. Besides industry association standards like the global food safety initiative (GFSI), the requirement to install food safety mechanisms is also grounded in legal frameworks for food hygiene. In the European context, for instance, EC regulation 852/2004 obliges food companies to install a Hazard Analysis Critical Control Point (HACCP) system (European Commission, 2004). The prevention of food fraud requires a continuous management system. A general approach to food fraud prevention includes vulnerability assessments, appropriately designed mitigation strategies, and their validation and verification after implementation. All steps require a detailed analysis and understanding of the supply chain, stakeholders, and market mechanisms. Clear parameters for determining the fraud risk of a supply chain must be set and can be translated into risk mitigation measures. A study by Ruth et al. (2017) identified a set of 31 factors for the assessment of food fraud vulnerability, which can be clustered into technical, time related and spatial opportunities, economic factors, plus cultural and behavioral, and technical as well as managerial control measures. The authors recommend the comparisons of individual fraud risks in different supply chains and the identification of respective countermeasures. The categories *Opportunities*, *Motivations* and *Control measures,* based on RAT, address supply chain characteristics e.g., complexity of committing fraud, detectability (technology), economic factors and corruption, price asymmetries and political factors. All categories reflect a certain degree of information asymmetry, which at the core allows for fraud to occur. Findings suggest that products with value adding attributes like a defined provenance, organic production or specific processing have higher vulnerability scores (Silvis et al., 2017; van Ruth et al., 2017). Digitizing the supply chain and the connection of data points obtained from vulnerability assessments, allow for risk mitigation real time, which this study investigates through the lense of DLTs.

Mitigation measures include raw material specifications, analytical surveillance, supplier management and auditing, and supply chain issue monitoring (Nestec ltd., 2016). From a scientific perspective, the approach has been described as the *Food Fraud Prevention Cycle*. The approach presents a holistic view of food safety, starting with the acknowledgment of food fraud as an individual type of food risk, assessment of vulnerability and prevention strategies and decision-making tools, as well as the inclusion of social and criminological perspectives, which lifts the problematic to a company-wide topic to be included in enterprise risk management (Spink, 2019b).

While dedicated software is state of the art in the industry to support food fraud prevention, the scientific literature shows an increasing interest in research on DLT applications in food authentication. Still, the prevalence is higher in other fields, such as finance, data management, and supply chain management (Karaarslan & Konacaklı, 2020). Research studies focusing on food investigate aspects such as the digital representation of products (Lo et al., 2019), the solution to challenges in the supply of specific food products like meat or dairy (Antonucci et al., 2019), or third-party certification (Dos Santos et al., 2021). Such elements can contribute to the design of a DLT-based food fraud prevention system.

DLTs are a superordinate category of decentralized database technologies. Due to the rise of cryptocurrencies, blockchain technology become the most prominent approach for DLT. Its decentralized characteristic allows data sharing across multiple ledgers in a synchronized manner, which can be orchestrated by so-called smart contracts, which can control access to data (Natarajan et al., 2017; Anwar, 2019). Further design features of DLTs include access management, degree of openness and trust, openness, chain architecture, identity management, security mechanisms, consensus mechanisms, representation of assets, and legal ownership status (Natarajan et al., 2017; Lo et al., 2019). These characteristics of DLT are fit to support food fraud prevention systems in the food chain.

Adding to the latest research in the field of DLT applications in the food supply chain by focusing on a holistic and practice-relevant approach, this study pursues an analysis of the readiness of the food supply stakeholder for DLT. More specifically, this study aims to assess the following questions:

- R1: To what extent can DLTs help to prevent food fraud against the background of routine activity theory, by controlling target or offender or functioning as guardian, respectively?
- R2: How are stakeholders in the organic food industry familiar with DLTs today?
- R3: What is the role of the human factor i.e., what are potential hurdles for the practical implementation of technical feasible measures?

These goals are approached via a complementary two-step research process, combining a structured review of current scientific literature and, in a second step adding the human factor through expert interviews. The second part aiming to challenge, confirm and expand the findings from the literature review. This approach is precious, as there is a lack of empirical studies noticeable in the current body of research.

The remainder of the paper is structured as follows: the following section outlines the methodological approach. The third section presents the results of the structured literature review and expert interviews. In section four, the results are discussed jointly against the background of the research questions. Section five concludes the paper and points toward further research needs.

2. Materials and Methods

Its theoretical capacities and practicability must be assessed to evaluate whether a technology fits a particular purpose. The scientific community has encouraged the exploration of perceptions and experiences concerning DLTs in the context of the organic food supply chain through interviews or surveys over the last few years (Rogerson & Parry, 2020; Westerlund et al., 2021). This study combines a structured literature review and expert interviews with individuals engaged in the supply chain of organic foods in Germany. The Routine Activity Theory (RAT) (Cohen & Felson, 1979) is central to the study and was applied to both the literature review focus and the structure of the expert interviews. Studies selected through the literature review were screened with regards to insights on Targets of food fraud in the organic supply chain, fraud mechanisms and occasions (Offender) as well as technological means for vulnerability reduction by DLTs (Guardian). Expert interviews were conducted afterwards to expand on and contrast the findings with stakeholders in the German organic market, addressing their experiences, concerns, digital literacy, and perception of limitations with regards to DLTs. Figure 1 provides an overview of the research steps and methods completed during the study.

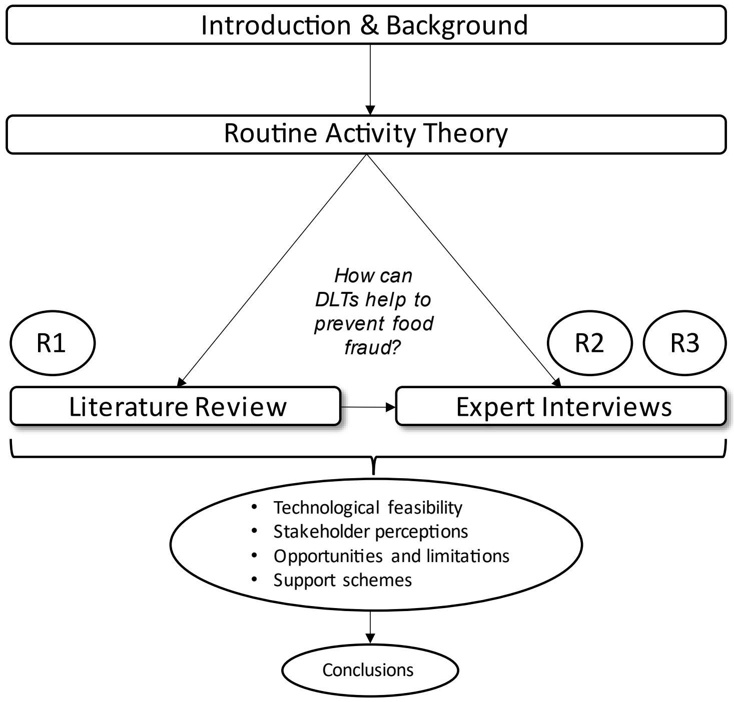

Figure 2 Illustration of the research procedure and methods related to research questions.

The literature review was performed using the *Preferred Reporting Items for Systematic reviews and Meta-Analyses* (PRISMA) methodology, which provides clear criteria for the inclusion or exclusion of research papers in a review and has served researchers in the field of sustainability research well, e.g., in the context of sustainable supply chain management (Moher et al., 2009; Paliwal et al., 2020). Criteria for the consideration of studies in the review are "peer-reviewed", "full-text" journal articles, "review or research" articles, and no book contributions.

The search was based on the following search string that combines the relevant terms for our study:

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Distributed ledger technology AND Blockchain AND Organic farming AND Food Fraud AND ((Control AND Prevention) OR (Detection AND Analysis))
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The selection of search terms aimed to identify potentially insightful papers from different angles, as the alternative terms work complementarily, e.g., (better) control mechanisms support prevention and detection, require suitable analytics. For both resulting search strings, we considered the first ten result pages in Google Scholar after filtering all publications before 2017 to ensure the recency of results.

Table 1 Search Terms used in the literature review.

1)	Distributed Ledger Technology	Blockchain	Organic Farming	Food Fraud	Control	Prevention
2)	Distributed Ledger Technology	Blockchain	Organic Farming	Food Fraud	Detection	Analysis

Afterwards, we screened eligible studies for relevant findings regarding the research goal and theory by reading the title and abstract and, in case of doubt, the entire text body.

Building on the literature review findings, we conducted expert interviews with individuals from the German market. Expert interviews are particularly suited to research processes where the field of interest is still largely unexplored, as it offers an unrivaled density of information and data compared to other methods like observation or quantitative approaches (Bogner et al., 2009). The status of an expert is attributed to persons with specific implicit or explicit knowledge about a defined area (Bogner et al., 2009; Kaiser, 2014). We derived an interview guideline based on knowledge gaps identified in the literature review. The interview guideline was pretested with individuals related and unrelated to the subject matter to ensure comprehensibility, continuity of questions, structure, and duration of the interviews (Kaiser, 2014; Baur & Blasius, 2019). It can be accessed in Annex I. Experts from different supply chain stages were approached by e-mail with a follow-up 14 days after the first contact. The selection of experts rested upon their verifiable status within their role in the organic food chain, potential relevance, the precision of information to be shared, and availability for sharing this information (Kaiser, 2014). With regards to the inclusions of farmers as experts, it has to be acknowledged that despite the fact that farmers might not be IT-experts with regards to DLTs, many of them use various digital applications and tools, voluntarily, but also per request of the authorities, to manage their daily work on farm.

Thus, valuable insights with regards to user experience, data collection and risk management could be expected. Interviews were held in the between June and September 2022 via video call or in-person, depending on the availability and preference of the interview partners, recorded after consent had been given, and fully transcribed*[1].

Content analysis after *Mayring* was chosen for the interview evaluation (Mayring, 2015). This methodology has been refined over several decades since its conceptualization in the 1980s and is commonly used in evaluating expert interviews (Flick, 2009; Mayring, 2015). Of the three alternative techniques for content analysis (summary, explication, and structuring) suggested by *Mayring*, the structuring approach was applied to highlight relevant aspects of the material and evaluate it according to the theoretical background (Flick, 2009; Mayring, 2015). Categories of analysis were derived deductively as provided by the theoretical background and completed by inductively derived categories from the interview contents (Ruhr Universität Bochum, 2022).

3. Results

The following chapter presents the results of the research in two parts, firstly presenting

3.1 Overview of reviewed studies

In addition to the results relating to the organic food chain, the screening process also included studies on other credence goods with similar characteristics like organic foods, e.g., halal or foods with a protected designation of origin. Studies identified as eligible for the review were recorded according to study title, authors, country, study target, and analysis method. The systematic literature review yielded 27 peer-reviewed, accessible reviews or research studies, which were analyzed and synthesized. The main reasons for excluding studies after removing duplicates were off-topic studies, i.e., dealing with food fraud in general or non-peer-reviewed contributions. The search procedure results are summarized in the following flowchart (Figure 3).

It should be noted that 15 of the 27 studies identified as eligible for further processing were review studies, sometimes combined with case study evaluation. Six studies contributed to the field of technology architecture design, and three dealt with technology adoption and implementation issues in qualitative or quantitative research designs. An overview of the studies considered can be found in annex II. The following paragraphs summarize the findings of the literature review regarding the control effectiveness of DLTs in the three areas proposed by RAT.

*[1] To ensure privacy of interviewees the transcripts are not accessible to the public.

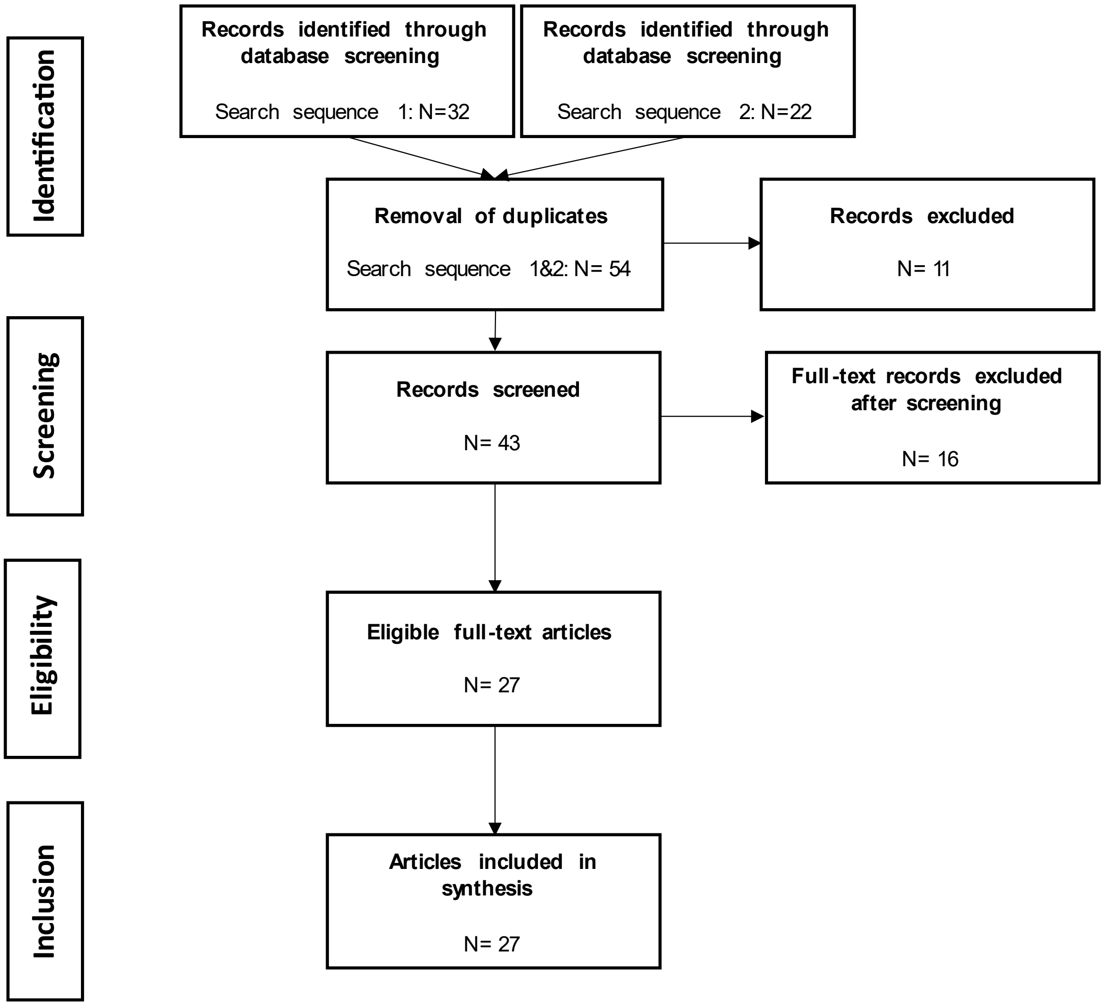

Figure 3 The results of the systematic literature review according to the PRISMA scheme.

Control the effectiveness of DTLs

The literature review revealed multiple solutions to support food supply chains in general and certified supply chains, particularly using DLTs. The identified studies were analyzed against the three main aspects of RAT to lay out the current state of research on DLTs regarding their control effectiveness, protection of Targets, and guarding functions in food fraud.

The basic concept of DLTs is to replace trust between participants in an international network with technological features like disintermediation of the data storage process, cryptography, and immutability of records (Tripoli & Schmidhuber, 2018). This concept is superior to the current practice of institutions and companies, relying on third-party input and manual data verification. Usually, these checks are also risk-oriented and randomized, leaving a large part of the supply chain physically unchecked each time and relying heavily on humans' capacities for control (Wallace & Manning, 2020).

Although DLTs are not immune to processing false information, commonly known as the *"garbage in – garbage out"* problem, through consent mechanisms applied within the network, incoherent or implausible data can be detected and excluded (Katsikuli et al., 2021). Consent mechanisms require all participants to confirm newly entered data for correctness before permanently storing it in the ledgers. Particularly in the context of food fraud, *Leung et al. (2021)* suggest a three-phase consensus protocol that (1) requires firstly local nodes to vote for the truthfulness of a data entry, then (2) validating nodes that are selected in a randomized manner, and finally (3) an approval phase, where all nodes in the network are required to validate the proposed data block. In a simulation set up, the proposed protocol achieved 94,1% precision in fraud detection (true positives), and 93,3% of all food fraud cases were detected, provided that the network contained a maximum of 1/3 malicious nodes (Leung et al., 2021).

Besides the entry of false information into the network, the problem of double-spending can occur, meaning the usage of certificates for specific products under organic farming for another batch of conventionally produced products (Westerlund et al., 2021). Digital-physical parity of the certified products and the certificate can overcome the problem. However, the link between the physical product and its digital representation remains vulnerable in the system (cf. Lo et al., 2019; Katsikouli et al., 2021). The interlinkage of different supply chain processes and functionalities, such as documentation or financial transactions, is another possibility to supervise rather than trace back supply chain activities (Mao et al., 2018). The connection of DLTs and technologies from the Internet-of-Things (IoT) is a purposeful way to bridge the physical product and the distributed ledger.

The *initial moment of trust,* i.e., the moment when data are entered for the first time into the ledger network, and the digital-physical linkage between DLT and the product are weak points that researchers acknowledge. Still, only a few viable solutions have been suggested. Ideally, an orchestration of smart contracts IoT devices such as sensors, automated laboratory tests, agricultural machinery or drones, and conditional actions such as financial transactions would be used to triangulate and verify data on the ledger (Parra Domínguez & Roseiro, 2020). Additionally, physical and digital links or representations such as radio frequency identification (RFID) tags or non-fungible tokens (NFTs)*[2] can be implemented to report the physical location or proof of uniqueness and genuineness of a record.

Limitations concerning detecting criminal activities via DLTs are addressed in the literature. Triangulation with other data sources to the system must occur in such cases. Data manipulation from within the network can be prevented by consensus mechanisms (Wallace & Manning, 2020; Katsikouli et al., 2021). Although labels and certification schemes are used to signal specific quality-related information backed by third-party certification, trust is still needed from such third parties, which can be considered outsourcing of trust (Tian, 2018). Since DLTs facilitate such processes, they can significantly reduce transaction costs due to the omission of middlemen in the trading process and can help achieve fairer prices. These positive effects are assumed to occur at all supply chain stages, especially for farmers (Aldag, 2019). In turn, DLTs can add value not only through the facilitation of the certification process but also by offering integrated services like insurance, trade finance, and land registry management to access, which would otherwise cause significant hurdles, especially to micro-, small- and medium-sized companies in the organic sector (Tripoli & Schmidhuber, 2020; Wallace & Manning, 2020). A competitive edge can be realized by providing proof of the company's advantageous activities.

A prerequisite of successful food fraud prevention is the technology adoption of all potential Target groups of food fraud in the supply chain. *Rogerson and Parry* (2020) describe the adoption challenges of DLT as two-fold. On the one hand, reservations against the technology itself due to negative media and associations with cryptocurrencies create a trust issue with the technology. On the other hand, amongst those who are convinced of the effectiveness of DLTs, more general obstacles to adoption exist. These include missing support from management, budget restrictions, concerns regarding the potential impact on workers, user-friendliness, interoperability, scalability, and regulatory issues (Paliwal et al., 2020; Rogerson & Parry, 2020; van Hilten et al., 2020).

Technologies and measures that enable the prevention of food fraud occurrence can be considered as Guardians. These can be sensors, analytical measures for the detection of specific markers, and applications in the fields of IoT and Artificial Intelligence (AI). No measure alone can verify the authenticity of a food product, making methodical triangulation a necessity (Wallace & Manning, 2020). The six critical types of traceability withing the food supply chain related to products (process, genetic composition of the product, inputs, undesired components like pathogens or diseases, measurement, which refers to the standards, and procedures related to traceability) can be supported and automated by DLTs, without the requirement of a central authority (Sengupta & Kim, 2021; Westerlund et al., 2021). A primary hurdle in authentication is the (lack of) available representative reference data sets to match sampling results, like comparing fingerprints (Wallace & Manning, 2020; Katsikouli et al., 2021).

Further, existing systematics like HACCP can be used as a base and upgraded with a DLT-based safety system. However, such a setup would require governments, third-party certifiers, and other authorities to cooperate for data verification (Tian, 2018). Besides the technical challenges associated with creating chain interoperability, there is also a requirement for clear standards for data protection in intra-chain data exchanges. Regulators must create a framework that enables the implementation of technologies such as DLTs and foresightedly anticipated potential impacts on stakeholders in case of regulatory changes. In marine shipping, digital document management and trade finance are already further advanced, also using DLT-based solutions, and might thus serve as role models (Tripoli & Schmidhuber, 2020).

Based on the systematic literature review, the preliminary conclusion can be drawn that DLTs can help prevent food fraud in various ways, but not as a standalone measure. Still, the technology has not achieved a large share of dissemination to date. The main reasons are trust issues towards the technology, general management concerns, challenges about the digital infrastructure, and missing regulatory frameworks. Therefore, the expert interviews following the literature analysis had confirmatory character but also aimed to expand the knowledge in the key areas to be

*[2] Non-fungible tokens are special tokens that represent unique, collectible items. They are unique in the sense that they cannot be split or exactly changed for other non-fungible tokens of the same type.

addressed against the background of RAT: a) Experience with food fraud in organic products and currently implemented countermeasures, b) Concerns about the authenticity of organic foods and perceived need for improved solutions, c) State of digitalization within the company, d) Knowledge about and experience with DLTs, and e) Perception of limitations.

3.2 Results of expert interviews

Seven interviews with stakeholders along the organic food chain covered the primary production levels, wholesale, retail, and organic farming associations. The response rate was heterogenous amongst the interviewees, which could be explained by season, i.e., harvest time in summer for farmers, but also the sensitivity of the topic and potential fear of sharing experiences and views. While the openness to speak amongst farmers was high, only one wholesaler and one retailer were available, in addition to two organic farming associations. Overall, the response rate was 31%. The sample characterization is depicted in Table 2.

Table 2 Overview of the interview sample.

Role in the production chain	No. of interviews	Size of Company	Type of company	Description
Farmer	3	F1: 2 staff F2: 3 staff, plus seasonal workers F3: 2 staff, plus family	F1: farm and commercial F2: farm F3: farm	F1: Cattle farm with direct marketing of beef, forage, 18ha, member of an organic farming association F2: Arable farm, biogas plant, 400ha, member of an OFA F3: Chicken and cattle farm, member of an OFA
Organic Farming Association (OFA)	2	OF1: 300+ staff; 6000+ members OF2: 100+ staff; 140.000 members globally	OF1: association OF2: association	OF1: Larger OFA, mainly active in Germany OF2: Smaller OFA, active at the global scale
Wholesaler	1	100+	GmbH	R2: Trader of organic products with a portfolio of >3000 products, focus on fresh produce
Retailer	1	2	GbR	R1: Retailer of organic and non-organic unpacked wholefoods, small business

Status of food fraud prevention

By including representatives from different stages of the supply chain in the interview sample, both the role of the Target and Offender could be considered from the participants' perspective. Participants stated with differing degrees of openness that they have or have had touching points with cases of food fraud in the past. Further, they are aware of possible loopholes and workarounds that would offer entry ways for fraud in their specific field of work.

The *types of food* fraud with which the individuals were familiar depended on the interviewees' role in the supply chain, yet all of them were aware of weak points within their immediate scope of business. Farmers and retailers named improper storage of products or insufficient separation of organic and conventional flow of goods as the main entry gates of fraud. The organic farming associations, however, described a more structural view on their touching points with food fraud issues but reported on rare but regular cases of fraud within their community. It was further stressed that risk profiles are highly dependent on geography and product groups, as are the countermeasures and assessment tools used.

The *self-perception* regarding the risk of food fraud in the immediate business environment of the interviewees varied. While farmers and the retailer do not perceive their businesses as being at risk of becoming a Target of food fraud, the wholesaler and organic farming associations differentiate between the objectively existing possibility of committing fraud in their environment and the perceived one, arguing that the level of trust and social control in the industry of organic farming is sufficiently high to keep these risks from materializing. Amongst the stakeholders, the clear tenor was that there are ways to deceive and be deceived if sufficient criminal energy is present. Although there are theoretical aspects that could be updated to improve the reliability of the system, this is practically not feasible from an economic or resource perspective. The primary production and distribution level is an entry gate for potential fraudsters. The currently used countermeasures include organization of workflows, (paper) audits, plausibility, and cross-checks, both manually and software supported. Also, the downside of not being able to communicate all benefits related to private organic standards over EU organic farming was mentioned. Despite being well connected on a personal level, the extent of cooperation within the networks of the interviewees varies from close to none to more elaborated systematics of data exchange, depending on the business mode and scale. Whereas a farmer with direct marketing has few connecting points, the wholesaler and organic farming associations, dealing with many different standards and products, work in multiple data silos. Apart from organic farming-related software support, farmers are yet familiar with using different digital tools and platforms but wish for more integration i.e., fewer redundancies and interfaces. Especially farmers face a high workload when it comes to documentation for the organic label, and even more if they participate in different certification schemes in addition to organic certification.

Amongst the interviewees, there was no practical experience with DLT applications, although there was some familiarity with the technology and its possibilities. Amongst the farmers, the knowledge was most limited, whereas the other groups saw the concrete applicability and advantages of the technology. One interviewee from the organic farming associations stated that the association is actively following up on projects exploring the certification sector's options. Regarding digitalization as a prerequisite for more advanced solutions within a company, the interviewees are heterogeneously advanced, with company size and the personal ambition of the persons involved being the main determinants. Solutions ranged from none to more sophisticated, web-based reporting tools, e.g., on farms. Various systems, platforms, and software are available but not harmonized and involve multiple interfaces. Yet, simple, web-based solutions were mentioned in appreciation.

Regarding the prospect of implementing DLT-based solutions to prevent food fraud, the interviewees drew a clear view of what a novel solution to the organic farming certification should provide. They came up with examples of how current procedures could be improved. These included a digital veterinary diary on the farm level, eliminating redundancies in audit schemes, and better use of synergies in data points.

An open topic remains the responsibility to take the initiative. Especially in a fragmented sector like organic farming, with many SMEs, no player alone can take the burden of developing an entire network solution. The main barriers perceived are the initial effort needed for implementation, the challenge of orchestrating the different stakeholders, economic feasibility, and legal considerations. Further, the concern was mentioned that for DLT solutions to be used as proof of authenticity, trust in the technology would be required, which depends on understanding the technology. One crucial issue the respondents mentioned is the equalization vs. connection of data and the general flexibility of the system.

Further, potential barriers to adoption should be as low as possible. The interviewees see various chances for implementing DLTs in their business environment, with a preference towards use in a B2B or M2M context. To what extent DLTs can replace trust built by personal interaction between actors, especially towards consumers, remains yet to be explored.

Farmers argued that the industry is characterized by personal relationships and interaction, both between business partners and in direct marketing. They see other use cases than food fraud, for instance, when integrating precision farming technologies. Still, increased transparency would allow consumers to make a better-informed choice when buying food. Organic farming associations see a case in their internal work by protecting themselves from being deprived of license fees, e.g., by underreporting volumes.

Overall, the interviewees see potential where DLT solutions could add value in the organic sector to prevent food fraud, but also from a holistic perspective, taking other labeling schemes and the wider business environment and processes into account. The interviews did not show a clear tendency towards which stakeholder or stakeholder group - such as certifying bodies, input providers, or authorities - should initiate such developments.

4. Discussion

In the following section, the findings from (i) the structured literature review and (ii) the expert interviews are jointly discussed regarding industry vs. technology readiness for the technology and the specific situation in the organic farming industry. Support mechanisms from the policy side are outlined as a promising way forward. The section concludes with a reflection on the research approach.

4.1 Industry readiness vs. technological capacity

Researchers and experts equally mentioned the lack of empirical research in the field from academia and at the same time low maturity level of DLT applications within the industry applications creating a *hen-and-egg* problem (Westerlund et al., 2021). Lack of scholarly insight on the topics limits the industry community. At the same time, very few demonstration cases hinder the investigation of practical examples, creating a chasm between theory and practice. This was shown in the interviews with experts who had heard of the technology but had never considered it in the context of their own business. In contrast, others could envision a precise use scenario within their own business but had no idea where to start implementing it. Also, organic farming associations, acting as license givers, welcomed the use of the technology, contrasting the conclusions drawn by some researchers who predicted certifiers' business models to become superfluous with the implementation of DLTs (van Hilten et al., 2020). The interviewees' perceived potential of DLTs within their business networks went beyond facilitating certification to include integration with smart farming technologies and application in supply chain processes. Examples given were the integration of machinery data and field registry information into the certification process, data from subsidy applications, license fee management, and enterprise resource management. Such observations are reflected in the literature, also accompanied by the conclusion that implementation in a traditional sector like agriculture is a challgenge (Demestichas et al., 2020).

Further findings suggest the combinations of analytical data, IoT for data collection and input to the DLT, financial transactions, credit evaluation, or insurance, combined with intelligent algorithms such as deep learning networks in a DLT environment to maximize the benefit for stakeholders and design viable solutions (Mao et al., 2018). A prerequisite to adopting a new solution according to the interviewees is that it should be easier than anything else to use. . From a technological perspective, isolated or product group-specific solutions for verifying organic products are available. These could be analytical tools such as biomarkers and spectroscopic fingerprints, IoT-supported tracking of products, remote and nearby sensing, as well as statistical tools and AI of which results can be embedded into a DLT solution (Rogerson & Parry, 2020; Tripoli & Schmidhuber, 2020; Katsikouli et al., 2021). Yet controlling the initial moment of trust, which describes the challenge of uniquely linking physical artifacts with their digital representations in an immutable way throughout the entire supply chain, remains a challenge (Katsikouli et al., 2021). This issue was raised both in literature and interviews. This problem cannot be solved by DLTs alone and requires orchestration with smart technologies such as RFID tags, sensors, and IoT applications, in general, to exclude or limit human intervention as far as possible and improve network reliability and allow for independent entry of data by third parties, such as governments or laboratories (Tian, 2018; Aldag, 2019). Given the challenge of integrating DLT solutions into existing infrastructure without requiring standardization, Iftekhar et al. (2020) developed a flexible Hyperledger-based solution. It can be linked to various systems stakeholders use while extracting only information relevant to the network, referring to a mindful use of data (Iftekhar et al., 2020). Such an inclusive approach also supports the global representation of different regulatory and cultural environments (Chandra et al., 2019).

Another challenge lies in the complexity of the food supply chain itself. Mainly, the currently implemented solutions for integration DLT technology for traceability of food items (currently not focused on organic food) from Walmart*[3] or Albert Heijn*[4] target simple products that are not intensely processed, e.g., raw fruits/vegetables or plain chicken. However, implementing DLT approaches becomes more complex for highly processed products, e.g., apple cake or fruit yogurt. For such products, the supply chain becomes a supply network/matrix, and in the DLT, many different information chains are merged. This will highly increase the complexity of the implementation, stating further research need.

Overall, it can be summarized that the technological elements are available. Still, currently, a lack of targeted orchestration of such elements leads to a purposefully designed technological infrastructure to offer to target groups that are interested but need guidance to start relating activities.

4.2 Openness to DLT adoption in the organic farming industry

Regarding technology dissemination, the literature review and the interviews with industry stakeholders conveyed the coherent picture that DLTs are not at the forefront of technological infrastructure development in the organic sector. Although some interviewees had heard about it, a consolidated and coordinated approach is lacking.

From the body of literature reviewed in this study, there was little indication as to why the adoption of DLTs in (organic) food supply chains is low. Besides general barriers to technology adoption, such as lack of familiarity, indecision due to missing support from top management, budget concerns, inability to judge consequences for operations, complexity, technological challenges, and means to judge cost against benefits (cf. Davis 1985), DLT-specific barriers apply, too. The first specific barrier mentioned in the interviews was a negative association with the technology as such due to lousy publicity creating a *"trust issue with the trust-machine"* and at the same time lack of appropriate accompanying communication towards consumers on blockchain trials. The second reported barrier was understanding and managing the true requirements DLT solutions set towards data architecture and defining the appropriate optimum setup for such solutions (Rogerson & Parry, 2020). This perception was reflected in the interviews, as questions were raised to which extent trust generated by DLTs could replace, e.g., the on-farm shopping experience. Alternatively, prior knowledge could be required to make DLTs a trusted and practical solution on the consumer level, taking different levels of digital literacy amongst consumers, especially against the background of associations with cryptocurrencies (Roy et al., 2018; Sengupta & Kim, 2021).

*[3] Walmart requires Lettuce, Spinach suppliers to join Blockchain | E-Agriculture (fao.org) ;

*[4] Juicy details: Albert Heijn uses blockchain to make orange juice production transparent | Ahold Delhaize

This means that before incentivizing the adoption of DLT solutions in the organic sector, implications on the different stakeholder levels need to be assessed to a greater level of granularity, which was also proposed on the farm level by the literature (van Hilten et al., 2020). Neither internal development capacities nor a deeper understanding of the technology should be required, as the functionality is relevant for users, not the functioning itself. This resonates with the findings of *Demestichas et al.,* who identified cost reduction, risk reduction, timesaving, and increase of trust and transparency as the key drivers for technology adoption. At the same time, user-friendliness and productivity gains were identified as crucial elements to convince users (Demestichas et al., 2020).

4.3 Opportunities and limitations

There are different opportunities to pursue but also limitations to be considered for the use of DLTs in food fraud prevention in the organic farming sector. Multiple approaches and niche solutions are available to problems, but the attempt to scale up such solutions in real business environments is missing to date and operating examples are missing. Open questions regarding the degree of standardization required, regulatory implications, and the question of ownership are limiting the progress (Paliwal et al., 2020). Researchers have suggested different entities to take the moderating role, e.g., industry associations or policy makers (van Hilten, 2020; Sengupta & Kim, 2021). At the same time, the value added to a business could not be sufficiently demonstrated to date and is doubted by some experts (Malešević et al., 2020). Another area where DLT solutions can provide benefits is circumstances when a product has features or credence attributes that fall out of line with regular certification schemes or are subject to regulatory restrictions. If these attributes offer customers added value, DLTs can bridge this gap. This case was illustrated by *Scuderi et al.* on juice made from PGI-protected *Arancia Rossa di Sicilia* (Red orange of Sicily). While the orange fruit itself falls under PGI protection and can be labeled accordingly, juice from the oranges cannot be labeled using the EU PGI label (Scuderi et al., 2019). A DLT solution would allow for the provision of information on the oranges' origin. This application case can be transferred to organic farming, e.g., in cases where farmers engage in activities that go beyond legally or private standard requirements. The biggest obstacle to date is a missing driving force to progress the developments. From a global perspective, governments are the stakeholder group with the regulatory power, interest, and resources available to foster such developments. In the European context, the groundwork for this as already been laid in the organic farming action plan and initiatives on other more general use cases such as notarization and diploma management (Parra Domínguez & Roseiro, 2020; European Commission, 2021).

4.4 Policy Support

Interview participants express a positive attitude toward using Distributed Ledger Technologies (DLTs) for preventing food fraud but highlight existing uncertainties. Policy makers should link food fraud related policy making with the promotion of adopting advanced technologies. Since food fraud policy development is in initial phases of development, too, there is an exceptional chance to expand upon the existing and generate synergies through cooperation and coordination (Spink et al. 2019). As traceability data are stored with different stakeholders within the supply chain, regulations can path the way to provide standardized data to trace back product origin (van Hilten et al. 2020). Policymakers aiming to promote innovation adoption should focus on areas like research and development, technology infrastructure, and education. These measures should align with the goal of facilitating and supporting technology dissemination, whether through market interventions like taxation or subsidies or through regulatory actions. In an EU context, private sector accelerator programs significantly outnumber initiatives by public authorities (Parra Domínguez & Roseiro, 2020). While several private sector accelerator programs cover topics relevant to the food, agriculture, and retail sectors, limited policy-related information is available. The European Union's tendering website lists a few DLT-related tenders, but none currently relate to organic farming or food fraud. The European Union's website that calls for tenders in various research fields (https://etendering.ted.europa.eu/) yields 14 search results related to DLTs. However, only five are still active as of October 2023, and one opened in August 2022. Issuing tenders specific to DLT applications in organic farming could align with the Action Plan for the Development of Organic Farming (European Commission, 2021). Addressing the knowledge gap on DLT applications could involve creating educational infrastructure through research funding, grants, and regulatory frameworks. A DLT-based approach may enhance regulatory control, making it a government priority. Therefore, governments are expected to play a pivotal role in fostering DLT adoption, benefiting various industry use cases and regulatory functions.

4.5 Threats to validity

The study aims to assess the practical applicability of Distributed Ledger Technologies (DLTs) for preventing food fraud in organic farming. To achieve this, the researchers conducted a systematic literature review and qualitative interviews. The literature review focused on freely accessible studies via Google Scholar, potentially missing some behind paywalls, as the results should be reproducible without any financial effort. Subjective bias in the analysis was minimized through a structured approach using the PRISMA method and discussion among authors, as the papers were mainly analyzed by one of the co-authors.

The expert interview response rates varied due to factors like timing and vacation seasons. Still the results provide a multi-faceted yet exact picture of the current state of the industry and the partial convergence of content, i.e., information saturation. Still, the perspectives and opinions on distributed ledger technology in the organic food supply chain may be influenced by the personal characteristics of the interviewees and the size of the interviewed companies. Alternatively, analyses on one value chain stage, e.g., farmers, could have been focused on to generate even more in-depth responses. Despite this, the interviews offered a comprehensive view of the industry, reaching information saturation. While the study generated valuable insights, further research could involve multiple coders to enhance interview evaluation and ensure intersubjectivity.

5. Conclusions

DLTs, despite their potential in curbing food fraud Guardian within the organic farming sector, haven not seen widespread adoption. These findings could apply across the EU, as Germany is a crucial organic food market. Key issues addressed in the literature and confirmed in expert interviews include data protection, costs, business models, consumer perceptions, and digital infrastructure. Industry players should familiarize themselves with DLT benefits and foster collaborations through knowledge networks and consortia. Exploring and orchestrating DLT applications in insurance, finance, license management, and logistics data are essential for viable business cases in organic farming. Policy has been identified as the most important body to foster the adoption of DLTs in the organic farming sector for combating food fraud. Policy actions might involve funding education, calling (research) tenders for EU-level food fraud prevention solutions, and grants for relevant companies. Further, the legal framework needs to be innovation friendly e.g., concerning data protection. Consumer acceptance and its impact on payment willingness and purchasing habits require exploration. Assessing drivers in various supply chain stakeholder groups is necessary to create the right adoption environment. Lastly, integrating technologies like IoT, AI, biochemical analysis, and others must be considered.

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Annex I

Interview Guidance

Welcome and presentation of the interview targets

Welcom, Mr/Ms/Mrs [interviewee Name)

Thank you for taking the time to discuss the potential of distributed ledger technologies in the context of food fraud prevention today. My name is [interviewer name] and I am looking forward to our discussion. As indicated, the interview is estimated to take approximately 30 minutes. The interview will be conducted as part of a master degree research project at the University of applied scienes, Fulda and is going to be recorded for documentation. Thanks for sending back the information sheet in prior to our exchange. The record is going to be transcibed anonymously, so that only the results of our discussions will be considered in the research process. After conclusion of the project, all data will be deleted. Do you agree to the recording?

ask, if information sheet was not sent and ask for signing.
If participant agrees to recording, repeat on record.

Main questions	Topics for further detailed questions	
Introductory questions		
Briefly describe your role at [company name]	Position in the supply chain, name of the position, tasks, years of experience in the company, which certifications	
Have you had exposure to food fraud related issues in your work context so far?	name different types of food fraud	
What is your judgement of the current situation?	is the topic present in your company	
Which types of organic products does your company work in or with?	product categories, unprocessed/processed	
Prevention of food fraud		
Which countermeasures against food fraud are currently applied in your company? Welche Maßnahmen gegen Lebensmittelbetrug werden aktuell in Ihrem Unternehmen unternommen? [Target;Guardian]	Are these countermeasures performed internally or externally? Do they suffice? Which tasks are allocated in quality management?	
Welche weiterführenden Maßnahmen sind in Planung? [Target;Guardian]	strategic positions towards food fraud and authenticitystrategische Ausrichtung zum Thema Lebensmittelsicherheit und Authentizität	
Have you been object of food fraud in the past or were you able to discover or prevent a case of fraud? [Offender]	this could be irregularities detected during audits; what are potential weak points in your area of business?	
How do you collaborate with business partners to prevent food fraud? [Offender;Target]	Does the cooperation work? Is there an understanding of trust between the stakeholders?	
Prerequisites and digitalization		
Have you heard of DLTs before?	If needed, mention the term blockchain and also an explanation: "DLTs, in more general terms sometimes also referred to as lockchain (although if being precise, blockchain is a technology type out of the group of DLTs), is a digital system that records transaction data of digital and phyical items. The technology organizes data in so blocks, which can only be adjusted upon the agreement of the block network. The opposite can be referred to as the typical data silo in a corporation."	
Is your company considering introducing such technologies or are there even experiences?	on stratgic or operational level? Is there a timetable?	
Limitations		
Which prerequisites are necessary from your point of view to promote the implementation of such solutions?	What are current holdbacks? Are there internal obstacles or prejudices? Is there an understanding of the regulatory implications?	
Do you expect to create and added value for your customers, if a DLT-based authentification system was in place?	Willingness to pay more, creation of trust, verification of marketing claims	
Do you expect obstacles on the regulatory side regarding the implementation?	Data protection, competition law, further obstacles	*if not mentioned*

Closure and goodbye

Thank you very much for the interview. Do you have any further questions for me at this point?
Are there any additionals points you would like to add?
In case of questions at a later point, please feel free to contact me under the details provided.
The next steps are going to be the evaluation and processing of the interviews, aiming to finalizes the study in the month of September (2022).
Good bye.

Annex II

Study title	Author(s)	Year	Country	Study Target	Method of analysis	Sample Size
Sequence 1						
An Exploration of Blockchain-based Traceability in Food Supply Chains: On the Benefits of Distributed Digital Records from Farm to Fork	Mika Westerlund, Soham Nene, Seppo Leminen, Mervi Rajahonka	2021	global	Insights on the benefits of applying blockchain technology for traceability in food supply chains	Literature Review and investigation of five case studies	5
Credit Evaluation System Based on Blockchain for Multiple Stakeholders in the Food Supply Chain	Dianhui Mao, Fan Wang *, Zhihao Hao and Haisheng Li	2018	China	provide a blockchain-based credit evaluation system to strengthen the effectiveness of supervision and management in the food supply chain	Experimental software development of the blockchain architecture	N/A
Emerging Opportunities for the Application of Blockchain in the Agri-food Industry	Tripoli, M. & Schmidhuber, J.	2018	global	overview on opportunities of DLT application in the field of food and agriculture	Literature review	N/A
Application of distributed ledger technology Blockchain in agriculture and allied sector: A review	Lalita Garg and Kamal Kumar	2021	India	Overview on application of DLTs in agriculture and similar sectors	Literature review	N/A
The supply chain value of POD and PGI food products through the application of blockchain	Alessandro Scuderi, Vera Foti, Guiseppe Timpanaro	2019	Italy	Suggestion of a blockchain model for PDO and PGI products	Literature review and case study analysis	N/A
Identifying Food Fraud using Blockchain	Hoi Wen Leung, Adriane Chapman, Nawfal F. Fadhel	2021	global	Development of a resilient, voting-based consensus protocol	Review and protocol development	N/A
The Use of Blockchain Technology in Agriculture	Mustafa Cem Aldag	2019	global	Exploring the use of blockchain technology in agriculture	Literature review	N/A
The influence of blockchain-based food traceability on retailer choice: The mediating role of trust	Marion Garaus, Horst Treiblmaier	2021	Austria	Exploring the influence of food traceability on retailer choice and the mediating role of trust	experiments and online survey; multivariate modelling	279
An information System for Food Safety Monitoring in Supply Chains based on HACCP, Blockchain and Internet of Things	Feng Tian	2018	China	Real-time traceability system for food and integrated risk management	Mixed (dissertation)	N/A
Blockchain: case studies in food supply chain visibility	Michael Rogerson, Glenn C. Parry	2020	global	Investigation how blockchain can enhance visibility and trust in supply chains; its limitations, and potential impact.	Qualitative analysis undertaken via case studies drawn from food companies using semi-structured interviews.	4

Blockchain for Organic Food Traceability: Case Studies on Drivers and Challenges	Mireille van Hilten, Guido Ongena, Pascal Ravesteijn	2020	global	Application of blockchain to improve organic or fairtrade food traceability from "Farm to Fork" in light of European regulations.	Case study evaluation	4
Blockchain Technology in the Food Industry: A Review of Potentials, Challenges and Future Research Directions	Abderahman Rejeb, John G. Keogh, Suhaiza Zailani, Horst Treiblmaier, Karim Rejeb	2020	global	Comprehensive overview of the potential benefits and challenges of blockchain in the food supply chain	Systematic review and bibliometric analysis	61
Blockchain Redefining: The Halal Food Sector	Geetanjali Ramesh Chandra, Iman Ali Liaqat, Bhoopesh Sharma	2019	Arab Emirates	Addressing various challenges of the Halal Food Industry and how DLTs can play a role in redefining the current system	Review and hyperledger fabric composer playground (experimental study)	N/A
Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study	Pamela Danese, Riccardo Mocellin, Pietro Romano	2021	Italy	Investigating BC systems for food fraud prevention grounding on the situational crime prevention	Multiple case study	5
Food Provenance: Assuring product integrity and identity	C.A. Wallace 1 and L. Manning	2020	global	Case study to demonstrate the opportunities and limitations to technological approaches of food provenance assurance	Literature review	N/A
Blockchain: a brief review of Agri-Food Supply Chain Solutions and Opportunities	Pedro Roseiroa and Javier Parra-Domínguez	2020	Europe	Presenting blockchain and DLTs from business perspective and bring examples of European Programmes and Projects that are supporting innovative solutions to reach the market.	Literature Review	N/A
Applying Distributed Ledger Concepts to a Swiss Regional Label Ecosystem	Saša Maleševi , Michael Lustenberger and Florian Spychiger	2020	Switzerlan d	Proof of concept, how a DLT would benefit a regional label ecosystem	Interviews and artefact prototyping	14 (interviews)
Meeting Changing Customer Requirements in Food and Agriculture Through the Application of Blockchain Technology	Ushnish Sengupta, Henry Michael Kim*	2021	Canada	Summarizes state of adoption in Canada	Literature review	N/A
Blockchain in Agriculture Traceability Systems: A Review	Konstantinos Demestichas, Nikolaos Peppes, Theodoros Alexakis and Evgenia Adamopoulou	2020	global	Analysis of the research activities performed over the last years e as the basis for conducting further research in order to better address demonstrate a taxonomy of different ideas	Literature review	N/A
Consumers' Intention to Adopt Blockchain Food Traceability Technology towards Organic Food Products	Xin Lin, Shu-Chen Chang, Tung-Hsiang Chou, Shih-Chih Chen, Athapol Ruangkanjanases	2021	China	study consumers' adoption of blockchain food traceability technology for organic food products	Face-to-face interview; PLS modelling	300

Blockchain technology for cybersecurity applications in the food supply chain: A systematic literature review	Niloofar Etemadi, Yari Borbon-Galvez, Fernanda Strozzi	2021	global	Focused on the intersection between cyber-risks, blockchain and food supply chains	Literature review completed by authors' key word research	N/A
On the Benefits and Challenges of Blockchains for Managing Food Supply Chains	Katsikouli, Panagiota; Wilde, Amelie Sina; Dragoni, Nicola; Jensen, Henning Høgh	2021	Denmark	Analysis of potential impacts on SME food businesses that are not using blockchain yet	Literature review and case study analysis	5
Application of Blockchain and Internet of Things to Ensure Tamper-Proof Data Availability for Food Safety	Adnan Iftekhar , Xiaohui Cui , Mir Hassan , and Wasif Afzal	2020	China	Exploring and building an uncomplicated, low-cost solution to link the existing food industry at different geographical locations in a chain to track and trace the food in the market.	Merging Hyperledger Fabric, an enterprise-ready blockchain platform with existing conventional infrastructure	N/A
Sequence 2						
Optimizing the Trust Factor of Organic Agriculture Business	G. B. I. De Silva	2019	global	Formulate a computer science approach to optimize the trust factor in organic agriculture ecosystem.	Mixed (dissertation)	N/A
Optimising traceability in trade for live animals and animal products with digital technologies	M. Tripoli & J. Schmidhuber	2020	global	Assessment of emerging innovations and digital technologies to improve animal traceability systems and control food safety risks	Literature review	N/A
A Content-Analysis Based Literature Review in Blockchain Adoption within Food Supply Chain	Jiang Duan, Chen Zhang, Yu Gong, Steve Brown and Zhi Li	2020	global	his paper applies a content-analysis based literature review in blockchain adoption within food supply chain	Content analysis based literature review	N/A
Third Party Certification of Agri-Food Supply Chain Using Smart Contracts and Blockchain Tokens	Ricardo Borges dos Santos, Nunzio Marco Torrisi and Rodrigo Palucci Pantoni	2021	N/A	Development of a method for efficient, unrestricted publicity to third party certification (TPC) of plant agricultural products, starting at harvest.	Literature review and proof of concept	N/A

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