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# Food traceability model using blockchain technology

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**ABSTRACT**

The complexity and globalisation of food supply chains raises concerns over food safety, authenticity and provenance. Data fragmentation, fraud and lack of transparency mean traditional traceability solutions are often ineffective and diminish consumer confidence. Blockchain technology can solve these limitations as it is decentralized, transparent and immutable. This study shows that blockchain technology has the potential to change the food traceability landscape by allowing food products to be securely and verifiably traced from raw ingredients to consumers. We discuss how such a system can improve openness, immutability, and information integrity. We will discuss the issues of scalability, interoperability, data security and stakeholder collaboration in the food sector in the implementation and adoption of blockchain. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) and design science research (DSR) methods were used to develop a blockchain-based food traceability model, ChickenTrax, from 33 papers from 2020 to 2025. Its goal is to enable real-world deployment within the poultry sector and to improve the knowledge of the advantages and limitations of the use of the blockchain technology for a more robust and reliable food traceability system (FSTS).



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## 1. INTRODUCTION

There is an emerging awareness among customers regarding the significance of the origin and quality of the food that they purchase. Because of this concern for specifics regarding the manufacturing process of items that are eaten, there has been a significant increase in the demand for traceability technologies. A collection of methods referred to as "traceability" allows for the tracing of the origins of products, as well as their treatments and the processes by which they are submitted [1]. In recent year, food traceability has become increasingly critical for all stages of the supply chain since food traceability are able to track products through all the production process until it reaches the consumer. This phenomenon is driven by rising consumer concerns about food safety, quality, and ethical production, as well as the complexity of global food supply networks. Therefore, effective food traceability systems (FSTS) are essential for quickly identifying the source of contamination, preventing food fraud, and improving supply chain efficiency [2].

Globally, food supply chains have transformed into a more sophisticated network, which also makes supply chain challenging to maintain especially their transparency, immutability, security, and data integrity [3]. Although, various technologies have been employed to enhance food traceability, for instance radio frequency identification (RFID), near field communication (NFC), and sensor networks. These systems still often suffer from limitations in data security, interoperability, and the ability to handle vast amounts of data in real-time Lu *et al.* [4]. It is in reaction to these challenges that a number of countries have designed and implemented their food safety legislation and traceability systems. One of the instances is India, which founded the Food Safety and Standards Authority in 2006 in order to keep an eye on their food business. The introduction of these regulations highlights the rising acknowledgment of the significance of effective and efficient traceability systems for the purpose of protecting customers and ensuring the safety of food [5].

Blockchain revolutionizes value chain digitization and performance. It ensures data validity by securely communicating asset histories and transaction records amongst stakeholders. Distributed ledger designs can improve process automation, system security, transparency, and trust via decentralized consensus, smart contracts, and cryptographic safeguards [6]. For unique and secure product traceability, the ECP-96 traceability coding system has been used to use blockchain technology in food safety traceability, utilizing milk as a case study to construct a framework. Hyperledger Fabric provides blockchain infrastructure, whereas Go is used to provide traceability [7]. Blockchain technology improves halal food supply chain traceability and security. It strengthens halal products by recording supply chain transactions and stages in real time [8].

This study aims to perform a comprehensive analysis of recent developments and challenges in the adoption of blockchain technology for food traceability. The presentation will delineate the architecture, clarify its core principles, and examine the prospective advantages of implementing this technology, it will provide a comprehensive analysis of the scientific context, with specific focus on recent developments and challenges in the implementation of blockchain technology for food traceability. Furthermore, we like to revolutionize food traceability and building more sustainable and resilient food systems by developing the food traceability model with blockchain technology.

## 2. METHOD

### 2.1. Review method

In order to minimize the potential for bias and increase the level of confidence in our results, we have decided to make use of preferred reporting items for systematic reviews and meta-analyses (PRISMA) as our method of approach for our literature review. This is because PRISMA has a proven track record of ensuring that reviews are systematic and reproducible This methodology facilitates the development of a well-organized pathway for conducting a literature review, which includes identifying and screening sources in order to guarantee that the review is comprehensive and transparent. We intend to see the completion of nine specific procedures through the utilization of this methodology that can be seen on Figure 1, which will get us closer to achieving results that are more relevant. In addition, PRISMA provides a clear and step-by-step pathway that assists researchers in navigating the often complex stages of a literature review. This structured roadmap involves the careful identification, selection, and critical appraisal of relevant studies, as well as the transparent reporting of inclusion and exclusion criteria. Such an approach reduces the risk of overlooking significant sources, enhances the comprehensiveness of the review, and ensures that the process can be replicated or audited by future researchers. The systematic nature of PRISMA also contributes to reducing subjectivity, as each decision point in the review is guided by explicit criteria rather than personal judgment alone [9].

### 2.2. Research questions

The following are the research questions for this paper:
RQ1: what key components that important for developing model food traceability with blockchain technology?
RQ2: what are the challenges that need to be faced for implementation?
RQ3: what is the proposed model that can be implemented for food traceability with blockchain technology?

### 2.3. Review protocol

We established a detailed review protocol, presented in Table 1, to enhance the systematic nature and thoroughness of our research. This protocol directs our search organization and dictates the criteria for study inclusion.

### 2.4. Searching process and study selection

Following the first-round search based on our protocol, we identified 895 studies across various databases, including PubMed, IEEE Xplore, Science Direct, and Scopus. These results were managed and organized using mendeley reference management software. Our study selection involved two phases; an initial screening of titles and abstracts, followed by a full-text assessment. To ensure only relevant studies were included, we first evaluated the title and abstract and identified studies against our research question. We found only those that appeared relevant proceeded to the second phase, where their full texts were thoroughly examined to confirm their suitability.

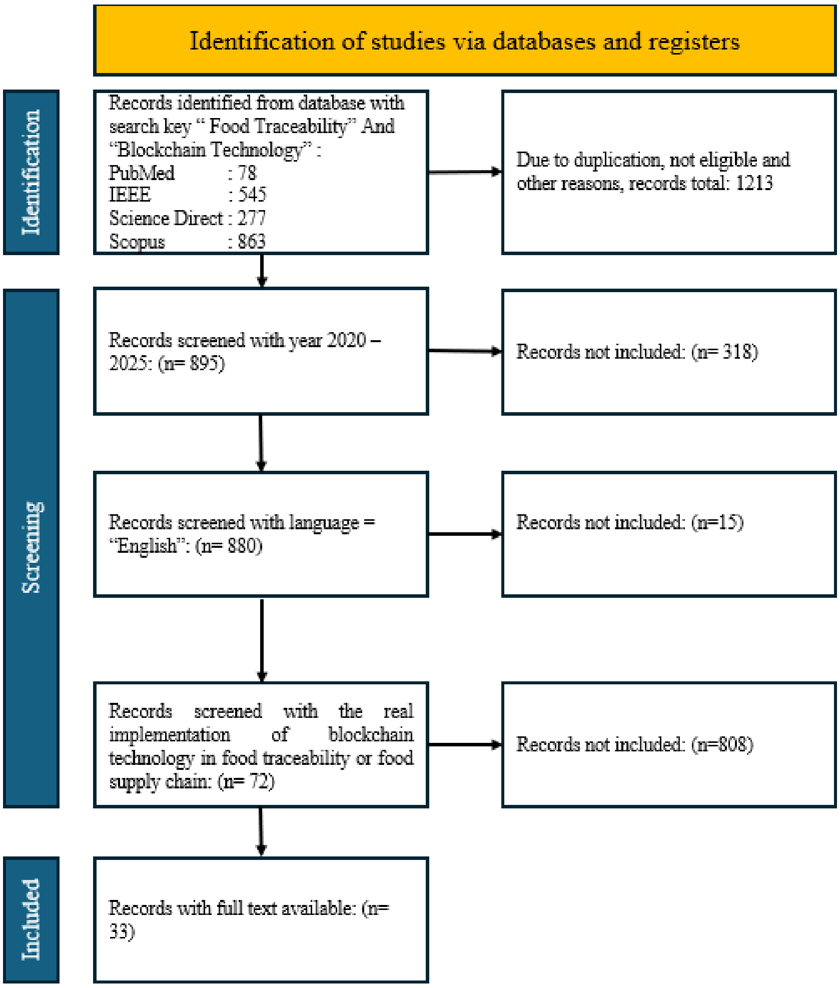


Figure 1. PRISMA flow diagram

Table 1. Review protocol

| Review protocol | |
|---|---|
| Search protocol | Description |
| Type of publication | Articles published as international journal and conference |
| Year | 2020-2025 |
| Language | English |
| Search field | Titles, abstracts, and keywords |
| Search keywords | "food traceability" and "blockchain technology" |
| Inclusion criteria | - An empirical investigation that concentrated on essential components and challenges of creating a food traceability model with blockchain technology.<br>- Publication that explain the real implementation model of blockchain technology in food traceability or food supply chain. |
| Exclusion criteria | - Blockchain papers that aren't available in full text.<br>- Blockchain research without an implementation strategy and results analysis based on empirical data.<br>- Articles in which the primary language was not english.<br>- Publication that are not related to blockchain technology and food traceability. |

## 2.5. Data extraction

Our selection process yielded 33 papers that will be included in this study. These papers will be carefully read, studied, and comprehensively analyzed. We will record crucial details such as the study's basic information (author, year, and journal), the research methods employed, the problem statement and objectives, the variables investigated, the primary results, identified research gaps, recommendations for future research, and the overall conclusions.

### 2.6. Risk of bias evaluation

In addition to network mapping of the primary evidence base, we applied the ROBIS tool to reflect on potential risk of bias within our review process. Additionally, we find that for all domains on the scientific paper's conclusions are supported by trustworthy and solid data as being showed on Table 2 and Figure 2.

Table 2. Risk evaluation

| Risk of bias | |
|---|---|
| Domain | Concern |
| Eligibility | Low |
| Identification and selection | Low |
| Data collection and study appraisal | Low |
| Synthesis | Low |

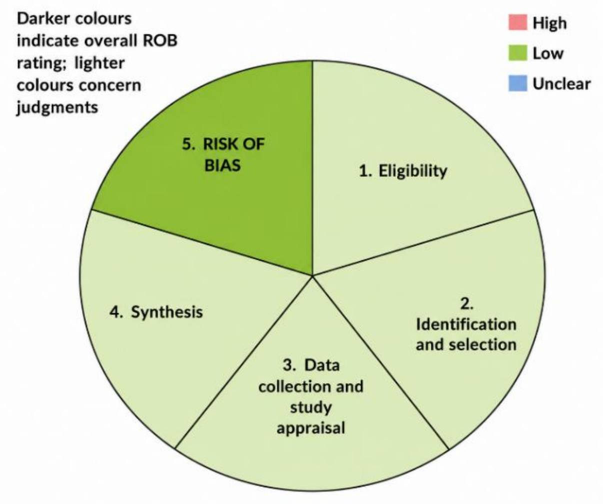


Figure 2. Ratings

### 2.7. Data synthesis

Narrative data synthesis integrates findings from multiple studies with varied techniques and contexts to create a comprehensive knowledge of the research subject. Comparing chosen literature results shows patterns, similarities, and inconsistencies in research objectives, methods, and outcomes. Critically reviewing and organizing each study's main findings into topic categories or fundamental research problems helps interpret the existing data. The synthesis summarizes the data and highlights research patterns, inconsistencies, and gaps, helping to understand the topic better and make educated decisions and study objectives.

### 2.8. Reporting review

Write a thorough evaluation report utilizing PRISMA 2020. The following subjects will be covered in this report: background, goals, methodology, main conclusions, implications, research gaps, future research, and conclusions. We intend to create an open, thorough, and trustworthy systematic review that will improve knowledge of the food traceability with blockchain technology paradigm with the aid of these PRISMA stages.

### 2.9. Model creation

Design science research (DSR) develops tangible products to address issues and disseminate the information acquired via these endeavors. Accumulating design knowledge guarantees the transference of successful design examples, allowing them to extend "far beyond a singular success narrative." Researchers standardize design information to enable specialists in the relevant discipline to utilize it for creating solutions. Design principles serve as a means to codify design knowledge by delineating precise actions required to create an artifact that fulfills a particular objective. Design principles necessitate a robust kernel theory to elucidate the rationale and mechanics of a design, which we implement to derive and substantiate meta-requirements. We modified the design science research methodology (DSRM) for the creation of an IT artifact (model) and the extraction of design information as on Figure 3. Based Peffers *et al.* [10], we like to create a model/artifact that having the essential components ready for the implementation with the challenges consideration.

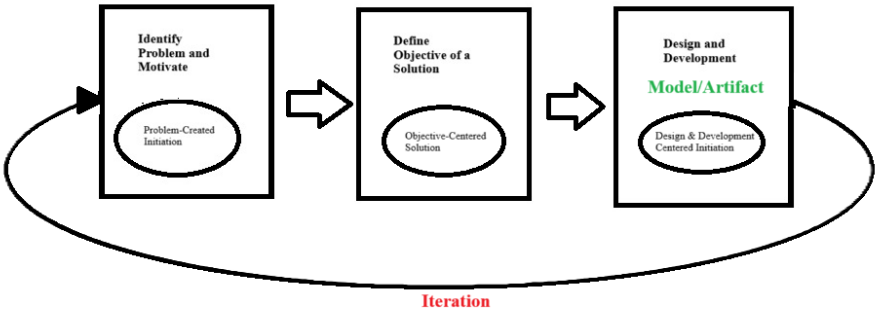


Figure 3. DSRM–model creation

## 3. RESULTS AND DISCUSSION

Using a list more than 1,846 keywords related to "food traceability," and "blockchain technology" documents taken from a few chosen studies were subjected to a keyword co-occurrence analysis using the VOSviewer software. The 1,846 keyword is reduced to 39 keywords that are pertinent to the study by producing an entry for at least 12 occurrences. Several unique word clusters can be seen in the co-occurrence network data as on Figure 4, each of which represents a different field of study with a related topic. Dominant and established study themes are suggested by central keywords in the network, which often coincide with many other terms. Similar experimental techniques were used to build the other network diagrams in this study.

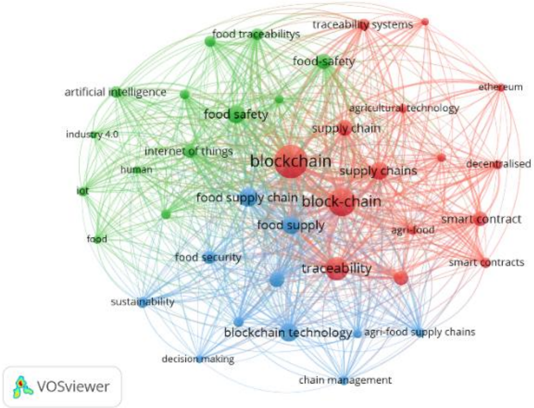


Figure 4. Co-occurance mapping

The distribution of the research results was then classified into three cluster groups as described on Table 3. Each cluster has a different number according to its classification. Cluster one consists of fifteen points, cluster two consists of thirteen points, and cluster three consists of eleven points.

Table 3. Cluster group

| Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|
| Agri-food | Artificial intelligence | Agri-food supply chains |
| Agricultural technology | Food | Agricultural supply chains |
| Block-chain | Food industries | Agriculture |
| Blockchain | Food industry | Blockchain technology |
| Decentralized | Food quality | Chain management |
| Distributed ledger | Food safety | Decision making |
| Ethereum | Food traceability | Food security |
| Sales | Food traceabilitys | Food supply |
| Smart contract | Food-safety | Food supply chain |
| Smart contracts | Human | Supply chain management |
| Supply chain | Industry 4.0 | sustainability |
| Supply chains | Internet of thing (IoT) | |
| Traceability | IoT | |
| Traceability systems | | |
| transparency | | |

### 3.1. Food traceability definitions and concepts

The term "food traceability mechanism" refers to a system that records and monitors the movement of food items from the point of production all the way to the consumer's hands. The collection, documentation, and storage of crucial information includes details about the product's origin, ingredients, production methods, transit routes, and distribution networks. Everyone from producers to regulators to merchants to consumers may easily access and verify this data [11]. An FSTS bolsters customer trust, accountability, and transparency in the food industry by enabling swift product recalls and pinpointing the sources of infectious diseases and contamination; consequently, it strengthens the security and safety of food supply chains. Food security and safety are crucial for consumers, particularly with fresh food products [12]. One of current traditional fresh food supply chain can be looked in Figure 5.

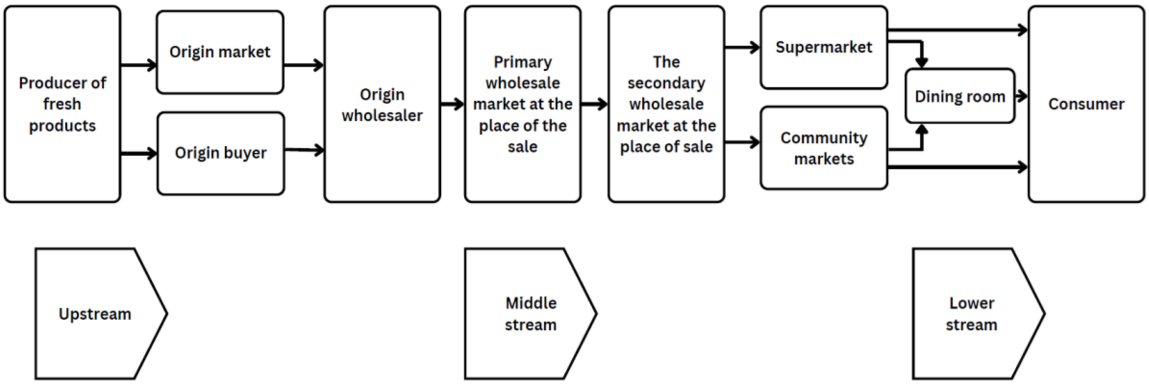


Figure 5. Traditional fresh food supply chain

### 3.2. Food traceability with blockchain technology

Since the inception of Bitcoin in 2008, blockchain technology has swiftly advanced, extending well beyond its original application in cryptocurrencies. Currently, numerous blockchain architectures are available, each tailored to address distinct requirements regarding transparency, security, scalability, and governance. Blockchains can be classified into public, private, consortium, and hybrid forms like in Table 4. Comprehending the differences among these categories is crucial for determining the most appropriate technique for a specific industry, be it financial, healthcare, supply chain, or governmental applications [13].

Table 4. Blockchain architecture

| Blockchain type | Examples | Consensus mechanism(s) |
|---|---|---|
| Public blockchain | Bitcoin and Ethereum | Proof of work (PoW) and proof of stake (PoS) |
| Private blockchain | Hyperledger Fabric and Corda | Practical Byzantine fault tolerance (PBFT) and raft |
| Consortium blockchain | Quorum and Energy Web Chain | Proof of authority (PoA) and Istanbul BFT |
| Hybrid blockchain | Dragonchain and XinFin | Delegated proof of stake (DPoS) and PBFT |

Food traceability uses blockchain technology to track product data from animal agriculture to the store shelf in real time [14]. It also covers animal reproductive, nutritional, welfare, agricultural methods, product processing and preservation, packaging and logistics, and customer purchasing habits. Data monitoring in real time enhances supply chain efficiency and reduces food fraud throughout the product life cycle. Online or offline traceability systems may allow food supply chain supervisors or middlemen to breach data.

The blockchain-based food supply chain keeps track of every transaction as it happens. Records that are open, real-time, and can't be changed. This lets everyone in the supply chain see everything. Figure 6 illustrates three tiers for the examination of the blockchain-based food supply chain model [15]:

– Application layer:

The application layer provides supplementary functionalities absent in the platform layer. Smart contracts and the IoT represent the most pragmatic applications inside the food supply chain.

– Platform layer:

The blockchain platform serves as the technological foundation of the platform layer. The platform layer commences the transaction transformation by embodying the blockchain transaction mechanism, characterized as a shared, distributed, and immutable record of transactions.

– Business model layer:

The principal components of the food supply chain ecosystem. This refers to participants, items, time from the supply side to order, inventory management, and stock-out.

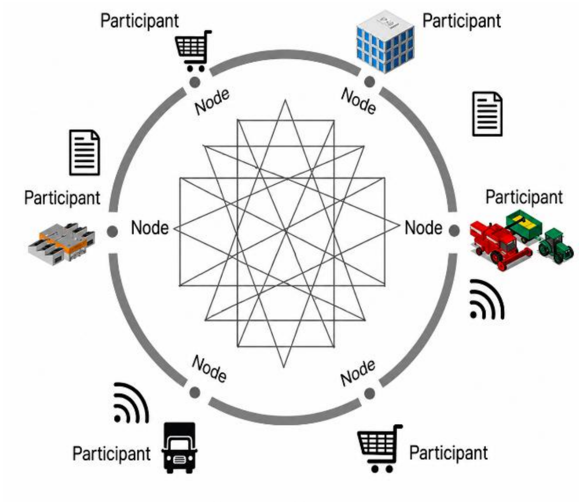


Figure 6. Three-layer model of blockchain-based food supply chain

### 3.3. Customer process product resources model

Manufacturing organizations' strategic and operational levels are linked, thus they must be considered. Effective operational management and strategic decision-making affect strategic efficiency. This efficiency comes from better resource use during transformation. Strategic issues are crucial for market adaptation, but they are not enough without operational response. According to Figure 7, the customer, process, and product resource-based framework (CPPR) addresses these difficulties by creating alignment conditions that link strategic and operational levels. Configuration attributes enable the generation of documents that facilitate correct manufacturing execution and efficient performance. Strategic-operational alignment aspects are critical to sustainability, as they affect manufacturing enterprises' performance. Inefficient managerial processes and transitions are avoided [16].

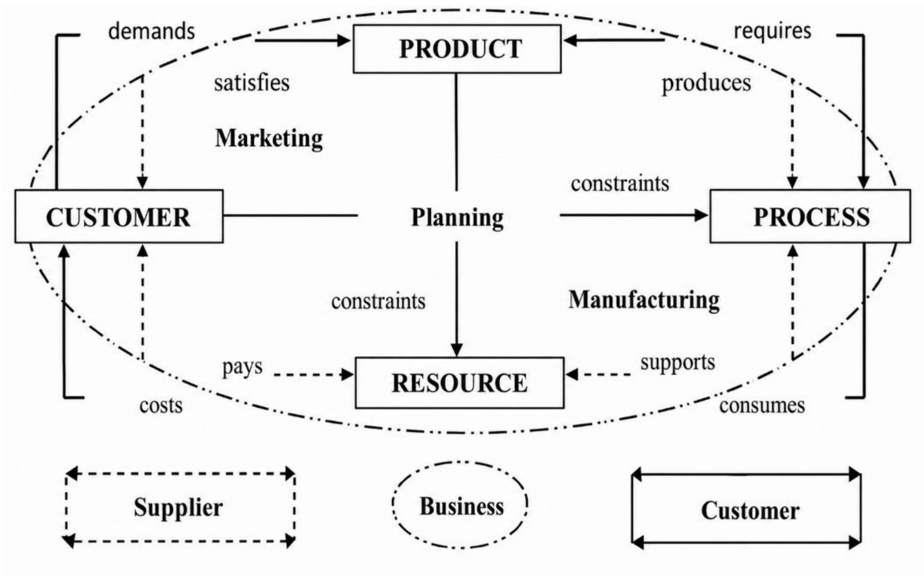


Figure 7. Customer process product resources

### 3.4. RQ1: what key components that important for developing model food traceability with blockchain technology?

Blockchain technology can substantially improve food traceability by providing transparency, accountability, and efficiency. It aims to emphasize the disruptive influence of blockchain while persuading stakeholders in the food business of its essential worth. With the world population increasing and the demand for food transparency rising, adopting blockchain technology in FSTS is not only creative but also crucial for safeguarding the integrity and sustainability of our food supply.

Blockchain technology is essential in modern agriculture and food supply systems for transparent, irreversible, and efficient food tracking. This innovation is supported by many crucial components that provide food traceability integrity and reliability. Blockchain's openness, accountability, and efficiency allow food industry stakeholders to create a traceability system that exceeds global customer standards. We assessed publications that implemented solutions using the Three-layer model of blockchain-based food supply chains to analyse the fundamental components of each food traceability solution, as shown in Table 5 (in Appendix) [2], [4], [5], [17]–[46].

### 3.5. RQ2: what are the challenges that need to be faced for implementation?

Although using blockchain technology to construct a model FSTS has many advantages, there are several challenges that must be resolved for adoption to be effective. Scalability, interoperability, data security, and the stakeholders are some of the challenges that needed to be addressed. Because complex agricultural supply chains create a lot of data, blockchain networks may experience constraints in transaction throughput and data storage capacity. It's critical to confirm that the system can manage growing data loads and transaction rates.

Connecting the blockchain-based system to older IT systems and other popular platforms may be difficult and expensive. A single traceability solution must smoothly transfer data between many systems. Even if blockchain technology is secure, data entry points, blockchain applications, and cryptographic key management may be vulnerable. To prevent unauthorized access and data breaches, rigorous security measures are needed. Some stakeholders may not want to adopt new processes and technologies. This is especially true if they have several installation issues or don't see many benefits immediately away. Table 6 highlights the most discussed issues.

Table 6. Challenges that need to be faced for implementation

| Authors | Scalability | Interoperability | Data security | Stakeholders |
|---|---|---|---|---|
| Lu *et al.* [4], Meera *et al.* [21], Lin *et al.* [26], Ahamed and Karthikeyan [31], Ahmed and MacCarthy [38], Duong *et al.* [39], Agi and Jha [40], and Tharatipyakul *et al.* [42] | V | V | V | |
| Arvana *et al.* [5], Friedman and Ormiston [20], Cerný *et al.* [24], and Behnke and Janssen [25] | | V | V | V |
| Silvestri *et al.* [44], Malik *et al.* [45] | V | | V | |
| Wang *et al.* [43], Lei *et al.* [46] | | V | V | |
| Lahane *et al.* [29], Cao *et al.* [30], and Compagnucci *et al.* [36] | | V | V | V |
| Meafa *et al.* [28], Duan *et al.* [33] | | | V | V |

### 3.6. RQ3: what is the proposed model that can be implemented for food traceability with blockchain technology?

The creation of the proposed model in this study was conducted based on the sequence of activities developed using the DSRM. The DSR for design development consists of three steps, each of which can be stated as follows:

a. Identification problem

This research begins by identifying food tracking difficulties, vital to food supply chain management (SCM). This process involves two methods: a systematic literature review (SLR) using diverse sources of articles and journals to explain blockchain technology's applications to food tracking challenges in current industries by identifying essential components (RQ1) and challenges (RQ2) in developing blockchain-based food tracking SCM and also stakeholders feedbacks as on Table 7. We chose chicken meat, one of the most eaten foods worldwide, based on Food and Agriculture Organization (FAO) of the United Nations data, to provide a real implementation of food traceability with blockchain technology.

b. Define objective of solution

This phase involves identifying several models that constructed to develop our proposed model: the SCM model for the food sector is identified through a literature review centered on the CPPR model, which aligns the strategy and operation with customer expectations for trust, quality, and responsiveness in FSTS using blockchain technology. Farmers, process managers, distributors (traditional and modern), and customers are identified as food SCM stakeholders from SCM components. It also maps blockchain technology to the three-layer food tracking approach for food safety and consumer satisfaction. The identification results are used to build a mapping model:

– Platform layer

The open blockchain systems like multichain are chosen for scalability and stakeholder concerns like cost and complexity. The consensus process, round-robin voting (sometimes termed "mining diversity"), validates and creates blocks using a set of allowed nodes.

Table 7. Stakeholders feedback

| Farmer | Processor | Retailer |
|---|---|---|
| Digitalisation is already present in chicken farming to ensure harvest yields, but it is not yet comprehensive for all processes. | The use of technology should be useful in providing competitiveness to its products. | With "Smart Farm," farmers can easily obtain useful information to ensure their harvest yields and also getting customer trust. |
| The calculation of technology implementation costs must also be ensured to be good for both the short and long term because chicken farm still prefer the traditional methods they are familiar with. | Fear of using technology will make the selling price of meat products uncompetitive. | With digital currencies booming worldwide, this blockchain technology will create a new channel for the product. |
| Data automation is needed to perform reliable analysis of chicken growth and development, allowing for better control of harvest yields. | Requires additional capital to build supporting technology, so the cost calculation need to be correctly estimated. | The food security information need to be clear and correct also easily to be accessed. |

– Application layer

We are using the integrated IoT devices like smart devices, QR/barcodes, and database system to get the data automatically for supporting tracking needs.

– Business model layer

The participants are farmer, processor, courier, distributor, and customer as the food chain business process.

c. Design and development

The findings of the mapping that was done in the step before are utilized in this stage in order to construct a food tracking model for chicken meat which makes use of blockchain technology. As a consequence of the findings of the analysis of the components that are required to construct the initial model for tracking chicken meat using blockchain technology, and after some literation based on the need of the solution. Subsequently, depending on the problems that need to be overcome, the development of a blockchain-based chicken meat tracking model created and we called it ChickenTrax which later can be implemented as a prototype that ready to be used by the poultry farming business. The ChickenTrax model is displayed in Figure 8.

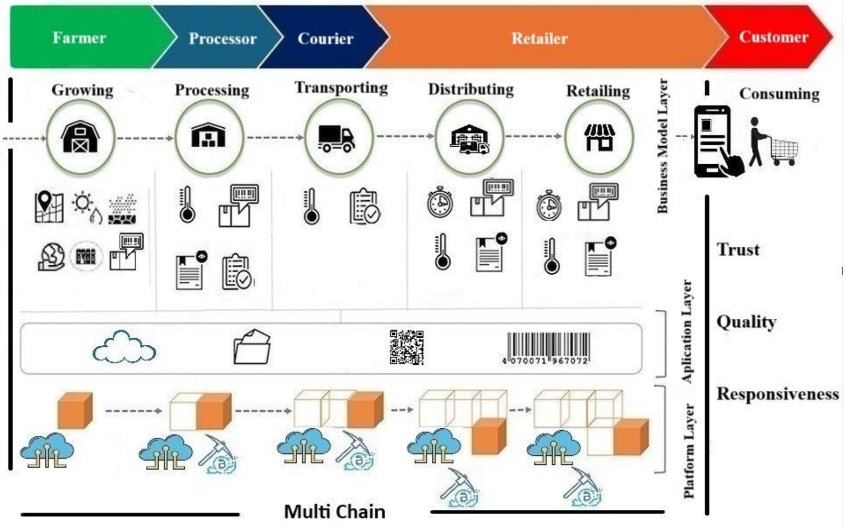


Figure 8. ChickenTrax model

Here are the example of the data flow that can be considered in the proposed model:
Contracts:
StructCage: this structure stores information about each chicken coop, including cageid, cycleNo, temperature, water, foodConsumption, chickenWeight, chickenVaccines, and chickenMedicines.
StructFoodProduct: this structure stores information about each chicken meat product, including productId, productName, origin, currentLocation, status, timestamp, certification, and updatedBy.
Food product mapping: a mapping that connects product IDs (unique identifiers) with Cage and Food Product details, to facilitate easy retrieval of product-related information.
Product updated event: an event to record every update to product traceability data. The event allows external applications to track changes.
Function addProduct: adds a new productId to the traceability system. Only unique product IDs are accepted.
Function updateProduct: updates the current location and status of the product. Each update includes a timestamp and the address of the updater.
Function getProductInfo: retrieves the latest information about the product based on the productId.
Usage farmer: the farmer runs addProduct by adding information about the chicken's growth and development.
Processor: the processor calls addProduct with product details when processing chickens from the farm.
Courier: UpdateProduct to update the product's location and status, such as "In Transit" or "Stored."
Retailer: the retailer will finalize the status as "Delivered" or "In Store."

## 4. CONCLUSION

This paper examines the requirements and challenges of building a blockchain-based FSTS and proposes a model. The findings include the need to use IoT devices for data collection at specific locations and methods; it’s important to choose the right blockchain platform—public, private, or consortium—so that privacy and scalability are established. Establish onboarding and verification protocols for blockchain network participants to verify their identity, credentials, and food safety standards. Furthermore, choose the suitable consensus mechanism for developing the suitable model. Thus, issues with implementing a food traceability framework, such as IoT scalability, would arise. We found the blockchain can be improved for system efficiency and user reliability, but security weaknesses as the most challenging to be overcome could lead to inaccurate agricultural decision-making. Effective blockchain implementation necessitates assessing its compatibility with other systems. Due to infrastructure and change management costs, rapid data storage growth, and untrained users, blockchain technology is expensive. ChickenTrax, a blockchain-based food traceability model, is proposed as a potential solution for a poultry supply chain based on blockchain technology. The model recommends an IoT edge analytics and blockchain platform to improve reliability and responsiveness for offering food security traceability with blockchain technology for getting customer trust for the chicken meat product.

The framework encourages cross-sector adaptation beyond chicken to include seafood, dairy, and other perishable food industries, expanding the use of blockchain-enabled traceability systems in the agri-food business that need to be analyzed further.

We like to continue our research with prototype development based on the ChickenTrax model, prototype deployment and testing cooperating with the related industry to give critical appraisal on prototyping result with performance metrix and quantitative approach.

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## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

The authors declare that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## DATA AVAILABILITY

The dataset used in the study of food traceability model using blockchain technology is available for further research at https://zenodo.org/records/15117697.

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## APPENDIX

Table 5. Key components for developing food traceability with blockchain technology

| No | Authors | Application layer | Platform layer | Business model layer |
|---|---|---|---|---|
| 1 | Lu *et al.* [4] | Temperature sensors, humidity sensors, pressure sensors, global positioning system (GPS) sensors, RFID, and quick response (QR) | Hyperledger Fabric | Food manufacturers, transporters, and consumers |

Table 5. Key components for developing food traceability with blockchain technology (*continued*)

| No | Authors | Application layer | Platform layer | Business model layer |
|---|---|---|---|---|
| 2 | Tan and Ngan [17] | Temperature sensors, humidity sensors, tilt sensors, and shelf-life trackers | General DLT blockchain | Dairy farmers, milk collectors, transporters, processing plants, distributors, consumers, and vendor system development |
| 3 | Chen *et al.* [18] | IoT sensors and smart devices | Ethereum private chain | Producer, processor, carrier, and retailer |
| 4 | Arvana *et al.* [5] | Barcode, RFID, NFC, and wireless sensor networks (WSN) | Hyperledger Fabric | Admin, producer, slaughterhouse, processor, dry aging, and consumer |
| 5 | Mokgomola *et al.* [19] | Manual and automated registrations from IoT devices | Ethereum | Farmers, processors, packers, inspectors, customers, agents |
| 6 | Friedman and Ormiston [20] | IoT devices, AI, and sensors | General DLT blockchain | Farmers, logistics providers, distributors, consumers, civil society organizations, regulatory authorities, blockchain developers, and decision makers |
| 7 | Meera *et al.* [21] | IoT, Omics and DNA barcoding, and digital documentation | General DLT blockchain | Seafood export company, executives, blockchain operators, government, and customers |
| 8 | Rahman *et al.* [22] | Inter planetary file system (IPFS), sensors, servers, and networking devices | EOS blockchain | Farmers, processors, inspectors, customers, and agents |
| 9 | Onu *et al.* [23] | RFID tags, QR codes, and unique digital identifiers | General DLT blockchain | Producers, processors, carriers, retailers, government and regulatory authorities, consumers, and system administrators |
| 10 | Cerný *et al.* [24] | RFID tags, QR codes, and unique digital identifiers | General DLT blockchain | Supplier, carrier, and customer |
| 11 | Behnke and Janssen [25] | QR codes, RFID/NFC, sensors (environmental, quality control), and smart devices | Hyperledger/etherium/corda | Producers, processors, carriers, retailers, government and regulatory authorities, consumers, and auditors |
| 12 | Lin *et al.* [26] | QR codes (2D barcodes), IoT number, and sensors | General DLT blockchain | Producers, processors, distributors, retailers, government and regulatory authorities, and customers |
| 13 | Sunmola *et al.* [27] | Mobile phones, mobile internet, and biometric tools like fingerprint scanners | General DLT blockchain | Farmers, processors, inspectors, customers, and agents |
| 14 | Meafa *et al.* [28] | Sensors and digital communication tools | General DLT blockchain | OEMs, SC managers, procurement and sourcing roles, IT, and digital leaders |
| 15 | Lahane *et al.* [29] | Sensors (temp and humidity), cloud storage, and mobile/web platforms | General DLT blockchain | Farmers, processors, distributors, retailers, SMEs, government, and experts |
| 16 | Cao *et al.* [30] | IoT sensors (suggested), QR codes, and digital terminals/mobile devices | General DLT blockchain | Producers, processors, distributors, retailers, and consumers |
| 17 | Ahamed and Karthikeyan [31] | Edge devices, AES-encrypted storage, IPFS, APIs, and local model training devices | Hyperledger Fabric (permissioned), PBFT consensus, and smart contracts | Suppliers, producers, distributors, wholesalers, retailers, consumers, and central server |
| 18 | Lei *et al.* [32] | RFID, WSN, MEMS sensors, temperature/light sensors, NFC, LoRa, and ZigBee | Ethereum, Hyperledger Fabric, Sawtooth; SHA-256, Merkle Tree, and IPFS | Farmers, processors, distributors, retailers, consumers, and auditors |
| 19 | Duan *et al.* [33] | RFID, WSN, smartphones, colorimetric sensors, and environmental monitoring devices | Consortium blockchain (e.g., Hyperledger Fabric 2.0), smart contracts, IPFS | Farmers, processors, distributors, retailers, consumers, and regulators |
| 20 | Okorie *et al.* [34] | RFID, WSN, edge devices, smartphones, and environmental sensors | General DLT blockchain | Producers, processors, distributors, retailers, consumers, and regulator |
| 21 | Bosona and Gebresenbet [35] | RFID, WSNs, QR/NFC, mobile devices, environmental sensors (pH, temp, and humidity) | Etherium | Farmers, processors, distributors, retailers, consumers, input suppliers, auditors, and caterers |
| 22 | Compagnucci *et al.* [36] | QR codes, MES, ERP systems, I4.0 sensors (implied), and mobile/web apps | Blockchain technology | ICT firms, agri-food SMEs, suppliers, consumers, and universities |
| 23 | Zhang *et al.* [37] | RFID, temperature/humidity sensors, GPS/GIS, cameras, QR codes, and pesticide detectors | Hyperledger Fabric 1.2.0 | Farmers, processors, logistics, warehouse, retailers, regulators, and consumers |

Table 5. Key components for developing food traceability with blockchain technology (*continued*)

| No | Authors | Application layer | Platform layer | Business model layer |
|---|---|---|---|---|
| 24 | Ahmed and MacCarthy [38] | Barcodes, QR codes, RFID, and (implied) sensors for temperature/logistics | IBM food trust and hyperledger | Producers, processors, logistics, retailers, consumers, auditors, and NGOs |
| 25 | Duong *et al.* [39] | QR codes, smartphones; back-end systems | General DLT blockchain | Producers, processors, retailers, consumers, certifiers, and system operators |
| 26 | Agi and Jha [40] | RFID, temperature/humidity sensors, cameras, QR codes, and smart devices | IBM blockchain/EZ Lab/Everledger/Provenance/Bext360 | Producers, processors, carriers, retailers, government and regulatory authorities, consumers, and system administrators |
| 27 | Yele and Litoriya [41] | QR code readers, smartphones, Raspberry Pi, and sensors | Hyperledger Fabric | Farmers, distributors, retailers, restaurants, customers, food inspectors, and network admins |
| 28 | Tharatipyakul *et al.* [42] | QR codes and smart devices | Hyperledger Fabric | Farmers, millers, roasters, consumers, system designers and admins, and potential third-party verifiers |
| 29 | Singh *et al.* [2] | RFID tags, barcodes, NFC, IoT sensors, and QR codes | Ethereum, hyperledger sawtooth, and hyperledger Fabric | Producers, processors, carriers, retailers, government and regulatory authorities, and customers |
| 30 | Wang *et al.* [43] | RFID tags and sensors | Hyperledger Fabric 2.0 | Manufacturers, warehouses, logistics providers, retailers, and consumers |
| 31 | Silvestri *et al.* [44] | RFID, IoT sensors, QR codes, and ERP blockchain integrated | Etherium | Producers, processors, carriers, retailers, government and regulatory authorities, and customers |
| 32 | Malik *et al.* [45] | RFID tags, QR codes, barcodes, IoT sensors, GPS tracking, and NFC | Etherium/hyperledger | Farmers/producers, milk collection agents and transporters, processors/manufacturer, distributors/retailers, consumers, and regulators |
| 33 | Lei *et al.* [46] | RFID tags, barcodes, infrared spectrum detectors, humidity sensors, scanning imagers, and various transducers | Hyperledger Fabric | Suppliers, auditors, consumers, and smart contract agents |

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