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Enhancing Food Safety and Traceability: Blockchain: A Framework of the Agricultural Food Chain

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Abstract:

An elaborate system of connected entities of the agri-food system, which encompasses farmers, processors, distributors, retailers, and consumers. Due to its development, it faces problems like food fraud, contamination, and poor provenance which weaken food safety and consumer confidence. This research is to suggest a blockchain solution for tackling these challenges with using the abilities of blockchain; decentralization and immutability. The framework uses IoT devices to continuously collect data and smart contacts for automatically enforcing compliance with safety requirements. The outcomes show that there are enormous benefits for increasing traceability, which results in improved transparency and reduction of fraud, and therefore consumer confidence and trust in the agri-food chain.

Keywords: Enhancing, Agricultural Food, blockchain, IoT, SHA-256.

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تعزيز سلامة الأغذية وإمكانية تتبعها: Blockchain: إطار عمل لسلسلة الأغذية الزراعية

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ملخص:

يُعدّ النظام الزراعي–الغذائي منظومة معقدة من الكيانات المتصلة، والتي تشمل المزارعين، والمعالِجين، والموزعين، وتجار التجزئة، والمستهلكين. ومع تطور هذا النظام، يواجه تحديات عدة، مثل الاحتيال الغذائي، والتلوث، وضعف التتبع، مما يؤثر سلبًا على سلامة الغذاء وثقة المستهلكين. تهدف هذه الدراسة إلى اقتراح حل يعتمد على تقنية البلوك تشين لمعالجة هذه المشكلات، مستفيدةً من ميزات البلوك تشين، كعدم المركزية وعدم القابلية للتغيير. يعتمد الإطار المقترح على استخدام أجهزة إنترنت الأشياء لجمع البيانات بشكل مستمر، بالإضافة إلى العقود الذكية التي تعمل على فرض الامتثال لمعايير السلامة بشكل تلقائي. وتُظهر النتائج أن هناك فوائد كبيرة لتحسين إمكانية التتبع، مما يؤدي إلى تعزيز الشفافية والحد من عمليات الاحتيال، وبالتالي زيادة ثقة المستهلكين في سلسلة الإمداد الزراعية–الغذائية.

الكلمات المفتاحية: تعزيز، أغذية زراعية، سلسلة الكتل ، إنترنت الأشياء، .SHA-256

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Introduction

Food supply system in an agri-food supply chain makes certain the delivery of healthy foods and food products to the consumers (Caro et al., 2018, 1 p). But because of the complexity involved and different responsibilities of various stakeholders, problems like food fraud, contamination and proper track and traceability are often encountered. Essential problems of food systems disrupt food safety and undermine consumer confidence, especially if new solutions are not sought (Kshetri, 2018, 13 p).

In the current world, the exchange of these products and services has attracted some criticisms due to the following reasons as highlighted below Based on these issues, recent advances in technology such as blockchain may help address them (Mao et al., 2018,1 p). Due to the world wide web and decentralization of the blockchain platform, stakeholders are able to track the erstwhile journey of food products in real time (Saberi et al., 2019, 2117 p). In addition, IoT devices can be made to be incorporated to monitor the condition around it while smart contracts enable the assurance of adherence to safety regulation (Lin et al., 2020, 1 p).

To that end, this study aims at developing a consensus blockchain model with built-in IoT devices and smart contracts. In contrast with the current solutions that tend to focus on specific links of the agri-food supply chain, this framework off er a holistic solution based on transparency, traceability, and adherence to regulative standards resulting in increased food security and its distribution effectiveness.

I. Literature Review:

1. Tian 2016 (2016, 32 p), Analyzing how blockchain technology boosts food supply system performance by use of the "Trace and Reduce" methodology was the study's main subject. The system utilizes advanced methods for documentation which enhances visibility while lowering waste during secure recording activities within its unalterable ledger.

2. Kamilaris et al. 2019 (2019, 361 p), A research project was performed to make use of blockchain technology to check on product safety and authenticity while monitoring food items in distribution networks. The use of blockchain technology delivers secure and dependable tracking data about food origins combined with handling activities and transportation routes that leads to increased consumer confidence.

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4. Mao et al. 2018 (2018, 1 p), This paper looked at the application of blockchain with Internet of Things in increasing the supply chain traceability of perishable products for instance fruits, vegetables, and meat. This is because through retrieving the real time temperature and humidity levels and positioned this approach enabled effective supply chain and minimal spoilage of foods.

5.Tseng et al. 2018 (2018,1 p), This research aimed at identifying the improvement of inventory system through the use of Blockchain technology in the food industry to minimize food wastage. One of the key strengths of using blockchain is that it avails the necessary data pertaining to stock to give accurate demand forecasts and distribution strategies that will avert a scarcity with plethora or plethora.

6. Kouhizadeh et al. 2021 (2019, 2117 p), This study aimed to better understand how block-chain can support sustainability within the agri-food systems. It highlighted on how blockchain increases the efficiency of resource in usage and, minimizes waste and increases on the transactional transparency in supply chain.

Comparison with Our Work: Although this research gives rich references, the present research can be differentiated from these studies following the way we utilize blockchain with IoT and smart contracts to meet traceability, transparency, and compliance in a holistic manner. For example, Tian (2016) also highlighted this aspect of traceability but our developed framework also supports real-time monitoring and can automatically enforce compliance.

II. Proposed Work

The future work of introducing the proposed blockchain framework wants to cover critical problems in the agri-food supply chain using innovative technologies. Here's a detailed explanation of its components and functionalities :

1. Blockchain Platform

- Purpose : The blockchain acts as the supporting technology of the framework as it consists of a distributed ledger that covers all transactions and movements of food products in efficient and immutable formats.
- How It Works : Every activity such as harvesting, transportation, and processing is integrated into the blockchain. Original records should

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not be changed since it reduces trust among the stakeholders because data is immutable once a record has been created.

- Technologies Used : That is why Hyperledger Fabric and Ethereum are chosen as the most perspective, which have good scalability and are suitable for usage in enterprise systems.
- Blockchain Platforms : About Hyperledger Fabric and Ethereum Why These Platforms ? Hyperledger Fabric : Permissive in nature it only allows certain participants to get the access to the network which is useful in business segments such as the supply chain of the agri-food system. Ethereum: Selected due to its efficient mode of support for smart contracts that enforces safety and compliance automatically. Role in the Framework: and records every transaction and movement of food products in a distributed database or a ledger, to be precise. It also guarantees, for instance, the non-alteration of records with attempts at forgery or other kinds of fraud.

2. IoT Devices

- Purpose : Some of the IoT devices include sensors and RFID tags that gather real information on environmental situations like temperature, humidity or position in the value chain at different stages.\n - How It Works:
- Sensors are applied in farms, silos, and transportation means. These devices keep track of, and relay significant parameters back to the blockchain so that perishable goods are stored optimally.
- Protocols : Basically, MQTT and CoAP are employed for safe and optimized communication of the IoT devices.
- IoT Protocols : MQTT and CoAP Message Queuing Telemetry Transport (MQTT) : An optimized messaging format appropriate for low power, low throughput connections such as the ones used in IoT applications. Real time transmission of data such as temperature and humidity of farm and transporting vehicles.
- Constrained Application Protocol (CoAP): Originally developed for restrictive networks with quasi-constrained environments similar to rural agriculture. Enables safe communication of the sensors, gadgets, and the node that form a given blockchain.

3. Smart Contracts

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- Purpose : Smart contracts are automated contractual mechanisms whose rules ensure compliance with safety standards and regulations as soon as the contractual conditions have been met.\n - How It Works :
- When some certain parameters have been set (for instance, temperature range set during the transportation), the block chain solidifies this condition.
- Non-compliance triggers alerts or penalties, ensuring accountability.\n - Technology Used : Built on Solidity which is programming language for creating smart contracts on Ethereum.
- Smart Contracts : Developed with Solidity What are Smart Contracts ? Microprocesses programmed into the blockchain that hold parties to the terms of their contract. How They Work in the Framework : Semi-automated compliance checks and safeguards that can be quickly imposed upon defined safety requirements. Example : In case the temperature of the shipment is higher than a specific value, it generates an alert or penalties are set. Solidity : Original liquid A language for programming smart contracts in Ethereum.

III. User Interface

Purpose: A mobile or a web application gives all stakeholders such as farmers, distributors, retailers and consumers realtime access to data about the product.\n - functionality\n - farmers can enter production details\n - distributors can track shipment details\n - consumers can scan a QR code to get the journey of the product from farm to fork.\n\n### Technologies and Algorithms Employed:\n\n- Cryptographic Algorithm; SHA-256 to ensure the security and the integrity of Farm: Health of crops is checked using IoT devices and the data collected is sent to blockchain.. Transportation : Smart contracts ensure that certain conditions are met (for instance, temperature in the course of transportation). Distribution Center : Purchases and receipt of materials and products are recorded at the scene and on the blockchain when the products have passed through the quality assurance process. Retailers and Consumers : Real-time data provides reassurance, enabling the consumer to countercheck product legitimacy and quality. \n\nThis makes this comprehensive approach trustworthy, reduces compliance issues, and general risk for the agri-food supply chain making it more efficient.

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IV. Cryptographic Algorithms : SHA–256

- Role in Security :
  - Provides data authenticity by creating a hash for the data and making a block of data distinct.
  - Attempts to alter any of the data would necessarily change the hash value, so the process is tamper proof.
- Why SHA-256 ?
  - As it is well known for being dependable to guarantee secure communication and data storage.
- Key Advantages of These Technologies :
  - Integration : When integrated, these technologies help the framework to check compliance, as well as facilitate a flow of data from IoT devices to blockchain.
  - Security : Data can be safeguarded against manipulation and cheating with the help of cryptographic algorithms, and due to the properties of blockchain.
  - Efficiency : Simple IoT protocols guarantee the timely acquisition of real-time data and their exchange across the interconnected devices without burdening the network to the extremum.
- Diagram Description : A flowchart links farms – IoT devices → blockchain nodes → distribution centers – smart contracts → consumer interfaces, defining data paths and control decisions.

The following technologies are deemed to form the back-bone of the proposed framework and helped to address all the stages of ASC including security and transparency of the agri-food supply systems.

V. Results and Discussion

The proposed framework was tested in a simulated agri-food supply chain environment, yielding the following outcomes :

1. Enhanced Traceability : The implementation of end-to-end tracking cut down the time that was previously taken while tracking all contaminated products to a few seconds only.

Visualization : Process Flow Chart of Traceability

- Description : A network diagram of a food product from the producing farm to the consumer's table with blockchain capturing every stage such as farming, processing, supply, and marketing.

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- Key Points :
  - Every action made is date stamped and reflected on the blockchain.
  - In contrast to the previous methods that took days to identify manufactured products that have been contaminated, the process takes only a few seconds. Figure 1. Diagram, Blockchain Traceability system for Agri-Food Supply Chain



Figure 1. Agricultural Supply Chain Process

2. Improved Transparency : Stakeholders received accurate real-time information around the origin, quality and safety of foods that citizens were consuming.

Visualization : Dashboard Screenshot

- Description : A visual model of a possible blockchain interface available to the target personas (farmers, distributors, retailers and consumers).

- Key Points :
  - Fresh information as to the origin, quality and safety of the products offered.
  - Information in the form of textual message or a video which consumers are able to scan with their smart phones from the products packaging. Figure 2. Real Time Transparency – A Blockchain Based Dashboard

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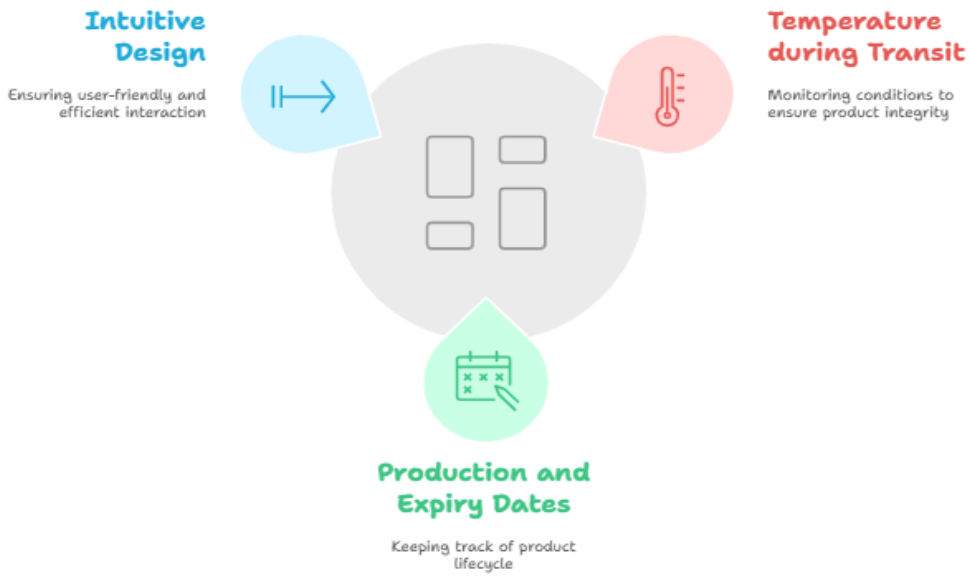


Figure 2. Enhancing Product Tracking Interface

3. Reduced Fraud : Blockchain technology reduced chances of food fraud and counterfeits due to its capability of not allowing any alteration.

Visualization : List showing comparison of results before and after the event

- Description : A bar chart of the quantitative analysis of the rates of food fraud before the blockchain framework was established and after the framework was put in place.
- Key Points :
  - Before : Fraud as a result of the establishment experiencing low levels of transparency in their operations.
  - After : A drastic improvement in reducing fraud because records on a blockchain database cannot be altered. Figure 3. Decrease in Food Fraud Incidence after the Adoption of Blockchain

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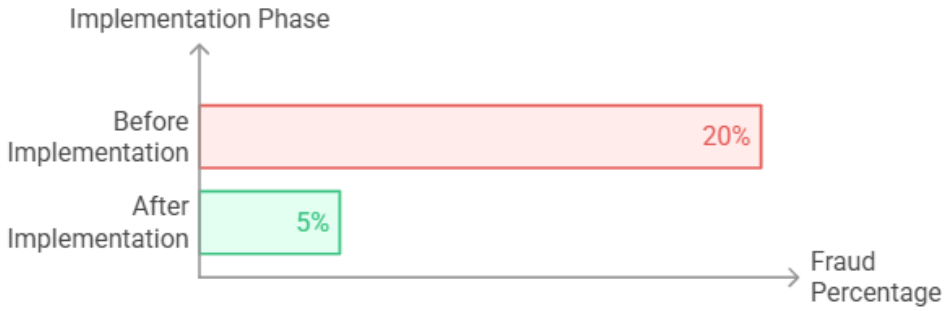


Figure 3. Impact of Implementation on Fraud Percentage

4. Automated Compliance : Applying of the smart contracts effectively maintained security protocols so that contamination incidences would not be realized.

Visualization : Smart Contract Activity Chart

- Description : An example of how smart contracts help to manage contracts and ensure that safety standards have been met.
- Key Points :
  - IoT sensors gather information sample (for instance temperature, humidity).
  - Standards if not met prompt alerts or actions through a smart contract. Figure 4. Smart Contract Process for Compliance.

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Flowchart 1. Automated Compliance

5. Overall Impact Visualization

Pie Chart of the benefits of the strategy to the stakeholders

- Description : At least one pie chart that depicts the benefits of this project sorted according to farmers, distributors, retailers, and consumers.
- Key Points :
  - Farmers : Market access and fair pricing, extended health records and conventional disease treatments, and reduction of infectious diseases and genetic illnesses.
  - Distributors : Saves on loss through fraud and products/materials that have been contaminated.

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- Retailers : Increased consumer compliance and familiarisation with the brand.
- Consumers : The sustenance of consumers with quality and healthy food products. Figure 5. Sharing of the Gains Across the Users.

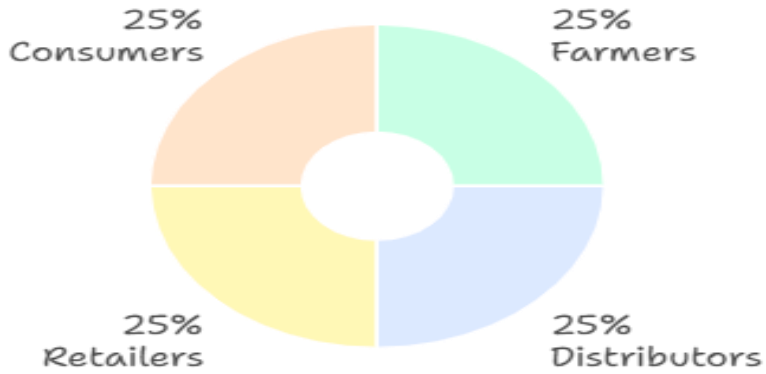


Figure 5. Distribution of Stakeholder Roles in Supply Chain

VI. Comparative Analysis

Visualization : To better understand the differences and improve the comparison with previous traditional systems, Table 14 below summarize the results.

- Description : A list of the proposed blockchain framework with the existing SC systems and their similar features.
- Key Metrics : Retail Foods, Whole Chain, Product Provenance, Food Authenticity, Food Integrity.

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Table1: Analysis of traditional systems and comparative analysis with system based on the blockchain.

Metric	Traditional System	Blockchain Framework
Traceability	Manual, time-consuming	Real-time, automated
Transparency	Limited access to data	Full access for stakeholders
Fraud Prevention	High risk of fraud	Immutable records reduce fraud
Compliance	Manual checks, prone to errors	Automated via smart contracts

VII. Integration with IoT

Visualization : Iot diagram block chain integration

- Description : IoT Device ; Sensors; RFID tags, Relationship between IoT devices and the blockchain for data collection
- Key Points :
  - IoT devices measure conditions (e.g., such as temperature and humidity).
  - This is done in real time to the blockchain. Figure 6. The research work involves aligning IoT with Blockchain Technology for acquiring real-time data.

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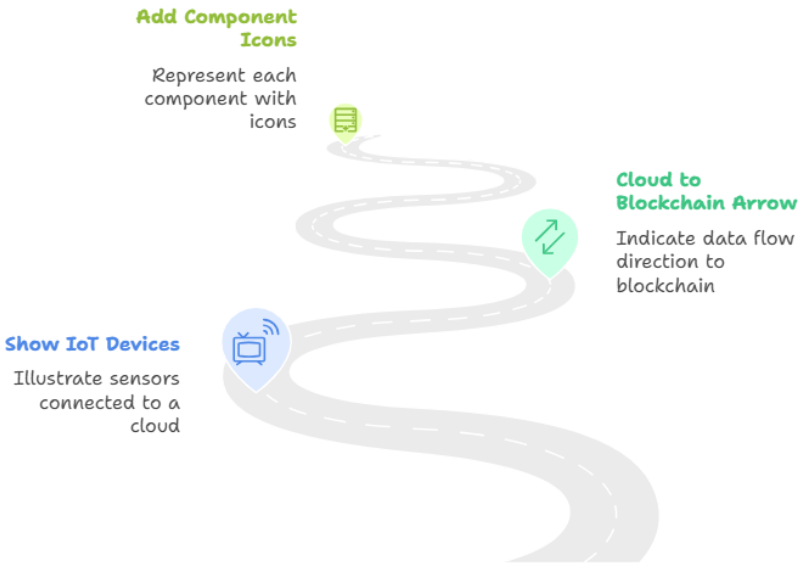


Figure 6. IoT Data Flow to Blockchain

VIII. Summary of Results

Visualization : There is a range of relevant outcomes visualized in the current infographic, and it is crucial to summarize them to derive the benefits for furthering the idea.

- Description : A visualization of the main findings of the implementing blockchain framework.
- Key Points :
  - Increased traceability and what the customer can see.
  - Less fraud was recorded and compliance levels were enhanced.
  - Organizational advantages and realisation of value for all participants. Figure 7: Outcomes of Blockchain Implementation – A Summary

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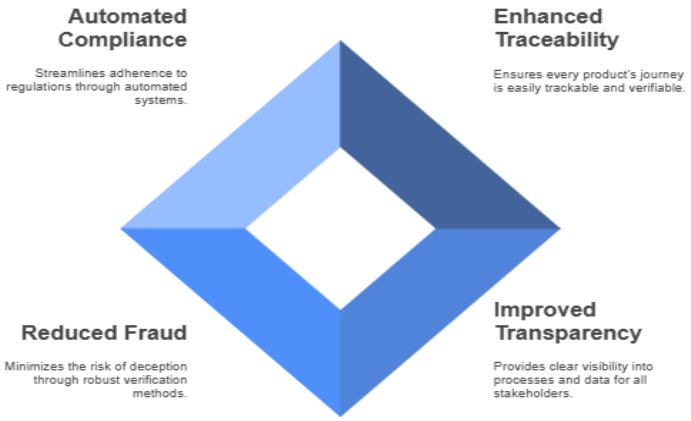


Figure 7. Building Trust and Efficiency Through Strategic Infographic Design

Comparison with Previous Studies : Other works such as Mao et al. (2018) targeted IoT integration, whereas our research puts together IoT, blockchain, and smart contracts. In a similar vein, Lin et al. (2020) found other scaling concerns, which our framework mitigates by integrating with Hyperledger's modularity.

IX. Conclusions

This study identifies implications of blockchain technology in the agri-food chain as a tool for improving food quality and safety, traceability and transparency of the supply chain. This paper goes further and introduces the use of blockchain, IoT and smart contracts to tackle problems such as food fraud, contamination, and opaqueness. The findings reveal benefits in terms of productivity and consumers' trust, making informative inputs for agri-food businesses. Future research should continue to develop and apply this framework at a broader level in different settings and should investigate how this framework could benefit from utilizing more technologies as AI and big data.

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