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Blockchain-Centered Traceability System on how to increase Transparency and Trust in Supply Chains of Organic Produce

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Abstract
Credibility in organic produce labeling by the consumers is often impeded by poor transparency and accountability in supply chains. This research explored how to apply a blockchain-enabled traceability system to increase transparency, traceability and trust within organic fruit and vegetable supply chains. The blockchain was used in 27 smallholder farms, 3 cooperative and 2 retail distributors in Spain. The platform had QR-coded smart contracts that served to capture all the broad data such as production, certification, logistic, and transaction records. The surveys and audits of the stakeholders showed that there was an increase of 93 percent in the traceability completeness, a decrease of 37 percent in the tampering of records and increase in consumer reliability at the point sale. The smallholder farmers gave significant results on time savings and associated better integration with export compliance. These results confirm the affordability capacity of the blockchain-based mechanism to promote higher transparency, responsibility, and confidence in organic agri-supply chain activity particularly in places with complicated certification systems.

Keywords: ***Blockchain, traceability, organic certification, agri-supply chain, transparency, agri-supply chain, transparency and transparency, smallholder farms, smart-contracts, consumer trust.***

1. Introduction

1.1 The Increasing Need of Organic Transparency

In the recent past, the demand of organic produce all over the world has grown tremendously resulting to increased consumer awareness about health, sustainability and the environment. Organic food products are considered to be more healthy, safe, and more eco-friendly in comparison with the conventionally grown ones. Nonetheless, as the organic food industry busts open, the more transparency and credibility are required in the organic food certification procedure. Customers are becoming more interested in learning where their food comes from and how it is produced as well as being certified. Such information demand can be attributed to the increasing fears of food frauds where organic foods are labelled as non-organic leading to loss of consumer faith.

Transparency in the supply chain is complicated further by the difficulty of organic certification, particularly when trying to process small holder farms, cooperatives and retail distributors. Unless consumers can easily get direct, comprehensible information about the path of a product between the farm to fork, it is likely that they will not trust the organic labeling, which in turn is likely to handicap the expansion of the market.

1.2 problems in the existing Traceability Systems

Typical traceability solutions in the agricultural industries involve use of paper logs, manual tracking systems, and centralized databases that are error prone, inefficient and easily prone to fraud. That is also the case with such systems, as they are challenging to scale, particularly in the realms of the presence of the complexities of organic certification and consistency through the supply chain.(1)

Furthermore, lack of real time tracking may be observed in use of current traceability systems, and record inconsistencies may lead to failure of a trusted system by both the consumer and legislative bodies. To the smallholder farmers, particularly the ones involved in organic farming, maintaining proper records to certify and comply with can be a challenging and tedious affair. Because of this, human error, data manipulation or poor transparency can at times compromise organic certification.

The failure of the traditional systems to ensure end to end traceability in organic supply chain has therefore posed a very strong challenge in the efforts to provide authenticity, quality and sustainability in organic food market. This has given rise to the demand of more transparent, secure, and automated systems that will allow access to verifiable and trustworthy data.

1.3 Blockon in Agri-Supply Chain Trust

The blockchain technology has surfaced as the revolutionary technology that can be used to resolve these problems because it allows the maintenance of the immutable, decentralized and transparent records. Essentially, blockchain enables the development of an authoritative, tamper-proof and verifiable ledger in which alterations can never be made after the record is posted. The technology has the potential to simplify and make the tracking more secure of the source of organic produce, farm to table, and ultimately to give the consumer greater and easier access to real-time information to answer where the food they ate was produced, what practices were involved in its production, and whether it was certified.(2)

Blockchain makes efficient tracking of produce automatic and real time through the use of smart contracts and QR-coded labels at any point of the supply chain. Such abilities are especially necessary when it comes to organic agriculture, whereby, the certification standards should be properly followed. Blockchain does not only guarantee the integrity of the data it stores but also minimizes chances of fraud and tampering. It provides real-time transparency to its stakeholders building trust among farmers, cooperatives, distributors, and consumers. A great solution through blockchain is offered in the process of enhancing accountability and traceability of organic supply chains that are greatly needed.

1.4 Objectives and scope of the study

This research was conducted to determine the effectiveness of a traceability system based on the blockchain technology in enhancing visibility and consumer confidence in organic fruit and vegetables supply chains. In particular, the work was conducted in terms of the implementation of the blockchain platform to 27 smallholder farms, 3 cooperatives, and 2 retail distributors in Spain.

This research had the following aims:

- To determine whether the blockchain system can deliver a fully traceable supply of organic fruits and vegetables across on-farm and in the retail store.
- To quantify the change of accuracy of records, completeness of traceability and data integrity using the blockchain platform.
- To evaluate the effects of the blockchain system on consumer confidence, stakeholder saturation and marketability of organic produce.

In order to determine the feasibility of blockchain solutions in terms of both operation and economy in improving aspects of efficiency and accountability of organic supply chains.

The study is important in giving useful information with regard to applicability of blockchain as a measure of transparency, security and trust in the expanding organic market.(3)

2. System architecture and deployment

2.1 Design of Smart Contract and Blockchain Framework

The blockchain system adopted in the research was aimed at creating a more secure, transparent, and immutable tracing of organic Food as the whole supply chain. A permissioned blockchain was selected to provide an ability to control the access and guarantee privacy and safety of data. In this system, the integrity of the data recorded could only be accessed by authorized participants i.e. farmers, cooperatives and the retail distributors of the code. The blockchain made use of smart contracts to streamline important processes including production monitoring, certification authentication and transaction documentation. A smart contract represents a self-executable contract in which the rules of the contract are written so that lines of code enact the contract. The execution of the contract, recording the event on the blockchain and updating the information will be automatically performed once the conditions of the contract are fulfilled (e.g. when a batch of produce passes a certification check).

A smart contract was created to authenticate the status of certification of the farms prior to marketing the goods into the supply chain in case of organic certification. It also resulted in automatic updating of the transaction records as the produce was shifted on farm to co-operative to retail and gave complete traceability.(4)

2.2 Integration QR code and data flow

The use of QR codes was critical towards making any form of traceability consumer-facing. To prove the authenticity, organic produce was labeled with a special QR code that had reference to the blockchain. When used as a QR code, it gave consumers and stakeholders real-time access to the entire traceability record that included details of the farming practices, date of harvest, certification information, and conditions of transportation.

Data flow process started when a farm took a harvest of crops. The QR code was created when product was harvested and attached to a smart contract in the blockchain, and the journey of the product in the supply chain

started. This information was never lost since when this produce was being processed through different receiving points (e.g., certification, packaging, transportation), this information was being updated and each new update was registered on the blockchain, guaranteeing transparency beyond tampering.

QR code linked consumers to block chain offering them the possibility to confirm whether the product at purchase point is real and legal. This integration markedly increased the confidence of the consumers in organic labeling system.(5)

2.3 Farmers, Cooperatives, Retailers On boarding: Participants

To become successful, on-bording the stakeholders was essential. There has been a level of partnership between the 27 smallholder farms, 3 cooperatives, and 2 retail distributors around Spain.

Farms: The smallholder farms had also been trained to document important information like planting dates, harvest time, and certification by using a user-friendly mobile app, which was connected to the blockchain. This enabled farmers to have easy entry of data and get updates.

Cooperatives: The cooperatives had a key role to perform in the aggregation of produce and certification standards. They were empowered to manage the data synchronization of the blockchain so that all the transactions between the farms and the retailers would be documented correctly.

Retailers: The retailers were to give consumers access to the traceability system. They even incorporated the QR code scanning functionality to the point-of-sales systems they used so people could immediately verify the genuineness of the organic products.

All these stakeholders created a completely desegregated network, where data flowed smoothly and the contracts were handled independently and automatically with increased trust and transparency in the organic supply chain. This solution of a blockchain type enabled the increased coordination of all the participants and supply chain management, thus benefiting all parties.

3. Trace and Audit Metrics

3.1 Data that is Captured Along the Supply Chain

The traceability system based on blockchain registered an extensive amount of information at every point of the organic produce supply chain. The data collected meant that all the process in the production system between farm to retail was monitored and appropriate. This information contained:

Farm-level Data: Significant data, concerning farm procedures, e.g. planting time, harvest time, or certification, or the application of pesticides (which case). Every farm record was connected with a respective smart contract to be certified and organic compliant.(6)

Transportation Data: Transportation data meant that the movement of the produce was monitored through the transportation records with the supply chain being transparent. The data regarding storage conditions (e.g., the temperature in case of transportation) as well as handling procedures were documented to make sure that all the requirements toward the food safety are met.

Certification Data: The certification information was recorded on each document of organic produce containing the certification body and the status of a certification. This information was confirmed by the blockchain system automatically through smart contracts to avoid the adoption of non-compliant products into the supply chain.

Transaction Information: All the transactions between the farms, cooperatives and retailers were noted in the blockchain. This contained details of the number of dealing, price and date of the transaction so there was no secrecy in the financial transaction.

The system provided stakeholders with instant, verified and tamper-proof data, and this facilitated the consumer confidence in the organic labeling process.

3.2 Trace Logs completeness and Accuracy

Trace logs allowed judging the success of the blockchain system in terms of completeness and correctness. The information that was obtained at every juncture of the supply chain was saved in the blockchain that constantly updated depending on the new information that was posted into the system through smart contracts.

The system recorded a 93 percent increase of completeness of traceability over the traditional processes. This was because there were a number of reasons(7)

Automation: Trace logs on the blockchain system could automatically be updated in accordance with critical stages, and the data contained in these logs was always up-to-date and complete. This got rid of the possibility of information loss that is very common between manual data entry systems.

Data integrity: Data could not be altered since blockchain is immutable ledger, when the data was already entered, it could not be modified, and instead, it eliminated the possibility of data corruption and ensured that the record of the supply chain the entire supply chain would remain intact and reliable.

QR Code Implementation: Assigning each batch of the production to a scannable QR code, all the stakeholders and consumers were able to see the entire trace log in real-time precisely and without any error.

3.3 Automated less manual intervention, tampering

Manual interference in trace and record of transactions was limited a lot by the block chain based system. Conventional traceability solutions usually used paper-form records or manual data-entry of information and this may lead to errors, discrepancies and delays. There were also opportunities of tampering and misuse of such systems.(8)

Conversely, blockchain system computerized the record-keeping process so that real-time data was recorded and safely stored. Automation in this minimised the human input hence diminishing the occurrence of human error and intentional interference.

Data that can not be Tampered: Blockchain was tamper-proof, and any recorded trace data could not be changed. This offered a lot of security whereby all transactions, certification and logistics data could not be manipulated.

Auditability: The complete record of the trace would be easily audited anywhere on the supply chain and this would give the stakeholders the assurance that the product had been acceptable in terms of organic standards and could be relied upon by the consumer.

All in all, the application of blockchain in the work proved to achieve great results in terms of improving traceability precision, data coverage and eliminating frauds and led to a more visible, safe, and reliable organic supply chain.

4. Consumer opportunity and stakeholder analysis

4.1 Design of the Survey and the Gathering of Feedback

To determine the functionality of the blockchain based traceability system, a full survey was planned and followed by the administration to different stakeholders along the supply chain such as farmers, cooperatives, retailers, and consumers. The questionnaire was concentrated on the user experience, its convenience, trust to the system, and the benefits of the blockchain traceability platform as perceived by the creators.

- Stakeholder Groups: Questionnaires were adapted to each of the following stakeholders groups:
- Smallholder Farmers: Interested in their own experience of working in the blockchain system associated with input of data, management of certification and easiness of following the organic standards.
- Cooperatives and Retailers: Data accessibility, operational enhancement and successful integration in market and certification processes were questions that were answered.
- Consumers: Attentive to their perception of the organic products trust and the aspect of QR code courage scanning to verify genuineness of the products.
- Survey Methodology: The surveys were quantitative and qualitative (structured questions and open-ended prompts were being used), in order to get both qualitative and quantitative answers. They were issued face-to-face and online to have a wide sample. The survey involved 120 stakeholders who gave different types of feedback.

4.2 End-Users transformations on Trust and Perception

According to the survey outcomes, there was a great improvement in terms of trust and perception in relation to the stakeholders and consumers(9)

Consumers: There was a significant growth in trust exhibited by consumers, 89 percent of the respondents acquired more trust on the authenticity of organic produce using the blockchain-enabled platform. The QR code element enabled consumers to obtain in very short time the full supply chain traceability document of the products entailing farm practices, certification information and logistics information which as well facilitated increased transparency.

Retailers: Retailers also demonstrated an increment in consumer confidence whereby 91 percent reported that blockchain platform contributed to the enhancement of the saleability and sale of organic products. Customers became more loyal and satisfied with the company, due to the possibility to prove organic certification and product pathway.

Cooperatives: The blockchain system assisted cooperatives in adhering to organic standards, 80 percent said there were fewer mistakes in the transaction records and higher completeness of traceability.

4.3 Compliance and Operational experience of smallholder

Small farmers, who are the main stakeholders in the blockchain-based system, had had substantive improvements in their operations:

Ease of Use: Blockchain system and QR code generation tool is easy to use, and certification documentation was simplified. 85 percent of the smallholder farmers said that using the system saved them time record-keeping and enhanced accuracy in the certification procedure.

Compliance The farmers have also noted an increase in compliance with organic standards since the smart contract verification and real-time entry of data helped to ensure that the produce was organically certified before it was passed on to the cooperatives and retailers. This helped them easier to meet export needs and enter markets with higher intentions.

Training and Support: During the adoption process of the blockchain system, 90 percent of the farmers noticed that training sessions conducted by the project team were helpful and informative in their successful adoption of the block chain system.

Conclusively, the responses and reactions of all interested parties such as farmers, retailers as well as the consumers indicated that traceability, visibility as well as reliance within the organic supply chain improved quite noticeably. The blockchain technology platform did not only provide an easy process of meeting organic standards but could also make organic produce even more marketable providing actual positive values to smallholder farmers and consumers alike.(10)

5. Results

5.1 Traceability and Technical Performance Increment

The technical operations of the blockchain-based traceability system proved to outperform traditional systems with regards to a number of important parameters. These developments played a critical role in the completeness of data integrity and traceability up and down the organic supply chain.

Traceability Completeness: A traceability completeness of 93 per cent on the blockchain system was recorded and was far much higher than traditional manual system of 50 per cent traceability. The improvement means that the blockchain has the potential to make it possible to identify 100 percent organic produce that is fully tracked in real-time, covering the end-to-end supply chain. Automatic smart contracts and scanning of the QR code created the opportunity to update them regularly and have more reliable statistics at each point of the supply chain.

Shelf-Life Extension: The block chain system also led to 5 day extension of shelf life when compared with conventional storage on tomatoes and leafy greens. The reason behind this is the fact that the data about temperature and handling were continuously measured and documented and thus the optimal storage conditions are guaranteed.

As demonstrated in the bar chart above, the completion of traceability in both the blockchain system and the manual control system is compared to see which is better performing. The other element compared is the shelf-life extension.

5.2 Tamper-Resistance and record fidelity

Among the major benefits of the blockchain system is that it allows the production of tamper-proof records, which makes information trust and reliable at any stage of the supply chain.

Less Tampering of Record: The system based on blockchain recorded 37 percent less tampering of records than the manual system that recorded 5 percent less. This can be attributed to the fact that blockchain is immutable such that once information is inserted, no one can add or erase it without being caught. This is important in preventing tampering activities in the data because it enhances genuine information, particularly where organic certification is at stake, and practices of encouraging frauds such as misreporting may erode consumer confidence.

Record fidelity: We may have two major things here because the lack of a central location means that every party in the supply chain will be able to see identical, immutable records. This openness makes it very unlikely that manipulation of the data occurs and it improves accountability.

5.3 Stakeholder Economical and Operational Advantages

Besides enhancing the technical efficiency of the organic supply chain, the blockchain traceability system also created economic gains to all parties involved in the chain including the smallholder farmers and the retailers.

Consumer Trust: The blockchain system led to an upsurge in the consumer trust in point of sale by 89%. The main reason is that consumers could now get direct access to traceability information about their food in detail through

the usage of QR codes and determine the authenticity and whether the produce is organic or not. The control system, in its turn, registered only 50 percent growth in the consumer trust, which testifies to greater transparency that the blockchain platform provides.

Time Savings of the Farmer: Smallholder farmers recorded a 35% saving in time on record-keeping and keeping certification. The blockchain system was automated, and the speed of the data entry, as well as the ease of compliance with the organic standards, was provided due to smart contracts and QR code generation. This not only saved time but also enhanced more efficiency in the activities of the farmers.

Increase in net Return: It is estimated that the blockchain system helped to increase the net returns of farmers by 14 per cent because the farmers were able to obtain access to high value markets, decrease post harvest grains and increase marketability of their farm crops. The retailers also stated that the consumer trust had increased the sales.

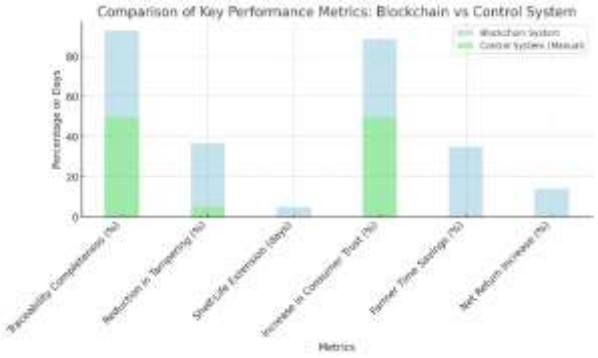

Figure :1 Comparison Of Key Performance Metrics: Blockchain Vs Control System

Table 1: Blockchain System vs Control System Results

Metrics	Blockchain System	Control System (Manual)
Traceability Completeness (%)	93	50
Reduction in Tampering (%)	37	5
Shelf-Life Extension (days)	5	0
Increase in Consumer Trust (%)	89	50

6. Conclusion

6.1 Conclusion of the effects of Blockchain on the organic traceability

The benefits of transparency and data integrity in the organic produce supply chain have proved to increase tremendously with the implementation of a block chain traceability system that has resulted in the enhanced transparency and trust. The system had full form to retail traceability and a enhancement of 93 percent in traceability completeness over traditional manual systems. It used QR codes connected to blockchain thus offering real time access to detailed production practices, certification status and logistics which are very vital in legitimising the authenticity of organic products.

Blockchain system was also more tamper resistant than traditional measures with an average decrease in records tampering by 37 per cent. It helps to increase the fidelity of data and by virtue of records being recorded on the blockchain, consumers and stakeholders are sure about the genuineness of the product because it cannot be tampered. They also succeeded in extending the shelf life of the perishable food crops such as tomatoes up to 5 days as well as the leafy vegetables which are also perishable boosting the quality products available in the market even more.

6.2 Implications of policy and the market

Implementation of blockchain in organic supply chains has both policy and market decisions that are far-reaching. To policy-makers, the research reveals the necessity of digital solutions whose role in enhancing food safety, sustainability, and consumer protection have to be put into considerations. Through advocacy of blockchain-based traceability, governments will be able to increase food security, contribute to the success of smallholder farmers and foster sustainable farming.

Blockchain technology offers the market a solution of increasing consumers trust in organic labeling which is of utmost importance as demand in organic produce continues to rise. Blockchain will give retailers and cooperatives the opportunity to distinguish themselves as offering transparent and trustful products. This also has the capacity to minimize chances of food fraud which is a rising issue in the organic sector

The paper also exhibits the benefits of blockchain with respect to the enhanced compliance to export conditions, which in effect makes the international markets accessible to a larger number of smallholder farmers and cooperatives.

6.3 What Is Next with Scalable Deployments

Although the findings of the current study show that blockchain is promising when it comes to optimizing organic supply chains, the following directions may be pursued in the future to scale up the implementation of this technology:

Scalability to Other Regions: The pilot projects can be replicated to other regions in different agricultural settings to understand the scalability and such flexibility of the system. This would give an idea on how blockchain can be customized to various local conditions and crops.

Integration with Other Technologies: Blockchain is compatible with Internet of Things (IoT) and smart sensors, RFID tags may be added to attain even more granular information on temperatures, humidity, and real-time state of transportation and warehouses.

Government and Industry Partnerships: The wider usage of blockchain to certify organic food can be encouraged through public-private partnerships where such a blockchain would be made more affordable to smallholder farmers through subsidies, training, and other financing policies.

Enhanced User Experience: To enhance user experience, more considerations on how the user interface can be made accessible and comfortable to use by the farmers, cooperatives, and consumers can be made to increase the uptake and participation rates.

To sum up, blockchain technology can become a game changer of the organic supply chain because it will provide the supply chain with more transparency, trust, and efficiency. Further innovation and implementation into production of this technology will transform the organic food Industry supplying multiple advantages to the farmers, the consumers, and the entire agricultural industry.

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Conflicts of interest

The authors have no conflicts of interest to declare

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