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Blockchain and IoT for Sustainable Agriculture: Innovations and Impacts

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Abstract

The integration of Blockchain and the Internet of Things (IoT) is emerging as a transformative force in sustainable agriculture. This review explores the synergistic potential of these technologies to enhance transparency, traceability, resource efficiency, and resilience in agricultural systems. We conducted a systematic review of peer-reviewed articles and conference proceedings published between 2015 and 2024, sourced from databases such as IEEE Xplore, Scopus, ScienceDirect, and SpringerLink. Studies were selected based on relevance to agricultural sustainability, the implementation of IoT and blockchain, and empirical or conceptual insights. The findings reveal that IoT devices enable real-time data collection and monitoring, while blockchain ensures secure, immutable records for supply chain transparency and smart contracts. Despite their promise, challenges persist, including high implementation costs, scalability issues, and limited digital infrastructure in rural areas. The review underscores the need for collaborative frameworks and policy support to foster adoption and recommends future research to focus on hybrid models and localized applications.

Keywords: Blockchain, IoT, Sustainable Agriculture, Digital Infrastructure, rural areas

1. INTRODUCTION

Agriculture has been the primary food source globally and has also played a key role in the economic development of many nations [1]. Therefore, exploring proper ways of securing and ensuring produce preservation from farmhouses is essential, as this would greatly benefit global food production [2, 3]. Decision-makers in this sector should consider the deployment of digital technology to help mitigate the challenges that the agricultural industry has faced over the years [4, 5]. By utilising digital tools, farmers can enhance their agricultural practices and improve their overall productivity. One of the ways to achieve this is through the use of precision farming technologies and techniques such as remote sensing and blockchain [6], internet of things (IoT), GPS and data analytics. These various tools have the potential to provide valuable insights into the real-time health conditions and weather patterns of animals and crops, therefore allowing farmers to make instant, informed decisions about animal health, irrigation, fertilisation, and pest

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disease control [7, 8]. This data-driven approach allocation and reduces waste [9], resulting in more efficient and sustainable best practices [10, 11, 12]. Furthermore, digital techniques have greatly assisted in post-harvest monitoring and preservation. Tracking systems and supply chain management software can help monitor agricultural product transportation and storage [13]. With the adoption of digital technologies, the marketplaces can connect remotely with the farmers themselves, reducing and eliminating intermediaries [14]. A fully implemented digital technology in agriculture can address daily challenges [15].

It was noted from the literature that the adoption of blockchain technology and IoT in agriculture has the potential to generate several economic benefits because this process has brought about transparency and a very secure platform for data sharing, cost reduction in running the day-to-day activities in the farmyard, therefore, increasing efficiency and productivity [16, 17]. Data transmission can be effectively transmitted without the help of centralised third-party applications. Through this process, hacking and cyber-attacks are now challenging to occur in any facilities in the farmyard [18]. The application of blockchain has further enhanced the privacy and security of stored data [19]. Through this process, users can also control things like deciding who has access to the data and what to do with the data. The numerous advantages recorded with IoT and blockchain benefits include livestock monitoring systems and a better-enhanced food supply system, which reduces the danger the animal is exposed to and food wastage. But the adoption of these technologies by the farmers has been very slow [20, 21, 22]. This paper aims to identify the current trend of using IoT and blockchain applications and the various challenges, opportunities, and possibilities of future research niches that researchers can exploit.

2. OVERVIEW OF IOT AND BLOCKCHAIN IN AGRICULTURE

This section provides an overview of IoT and blockchain in the agriculture sector. An exploration of several areas of IoT technology, such as precision agriculture, livestock management, crop monitoring, and supply chain management, was conducted. Blockchain technology is a decentralised and transparent system that provides a secure and tamper-proof record of transactions [23]. It has the potential to change various industries, including agriculture. In this literature review, we will explore the various applications of blockchain technology in agriculture, including supply chain management, traceability, smart contracts, and payments.

A blockchain system is systematically defined as a decentralised and verifiable transparent tool that can be used to build or provide a very secure system, such as smart contracts, payment systems, and traceability systems that are secure and reliable [24]. An example is the study on precision agriculture approaches such as drones and sensors [25]. The devices assisted in collecting real-time data on the soil moisture, temperature, and other variables for farmland products. It shows that this method helps reduce water and increases crop growth. The optimisation of crop growth and the minimization of water and fertilisers have been successful through the adoption of precision agriculture, as shown in the study [26, 25].

Another study also found that IoT technology monitoring the livestock's general health conditions can be observed [27]. The IoT sensor can monitor the animal's real-time movement, heart rate, and sound, as well as when it is exposed to danger, and it can call on the relevant sector when necessary. With the introduction of IoT, there has been an increasing production of some key products from animals, such as milk production, and swiftly ensuring the animals are secured [27]. The building of a transparent system that should be able to monitor sound and product supply chain can be achieved by the use of blockchain, as shown in literature, therefore helping the farmers to track farmland produce and enhance the quality of the product and produce a highly veritable recording keeping system for better decision making [28]. Studies show that the application of blockchain reduces the risk of fraud.

According to other studies, adopting a transparent blockchain system has improved the production of goods and services. Also, larger farm products can easily be traced when the product is dispatched from the farmland, and the study provides information gathered from the paper has helped to improve food safety when properly implemented. Identification and outbreak of foodborne illnesses have been curbed early, as seen in the study [29]. In this study, how blockchain devices were used to secure automated payment systems was outlined by the authors. Exploring smart contracts to automate this agreement reached between the farmers and consumers of the farmland produce. From the study, we noticed how blockchain technology helps reduce the risk of data fraud being manipulated by unauthorised third parties. Therefore, this ensures the efficiency of the farm payment system [30].

Another study also showed that integrating blockchain into agricultural practices drastically helps facilitate the smooth payment process. As illustrated by this study, cryptocurrency approaches such as Bitcoin and Ethereum have helped enhance the speed at which the farmer directly receives money from customers or banks. The study shows that transaction fees are also reduced, which is one of the benefits of adopting this new technology into agriculture [31]. Lastly, the adoption of blockchain into agriculture has resulted in some innovative and sustainable processes in agricultural practices because this method has increased the productivity described in this study, reduced waste, and increased the overall efficiency of farming operations. The use of GPS and drones helps in providing real-time monitoring of livestock and monitoring of crop growth [32].

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3. IOT AND BLOCKCHAIN APPLICATIONS IN AGRICULTURE

This study by [33] discusses the deployment of IoT and blockchain technology into the healthcare system called E-Medic. In the study, we saw the use of drones in administering and delivering medication in rural areas. This study shows that E-Medic looks promising if it can be adopted into other fields such as agriculture because, from this study, we saw that the method helps the medical handlers to properly monitor the patients who live very far from the hospital, assist in the administering drugs, real-time response to emergency and medical diagnosis.

We saw this from another study. [34] The application of IoT and blockchain was used to facilitate farming marketplace practices using smart contracts; this process enhances efficiency and transparency. The proposed system also evaluated the performance of smart contracts in terms of security, efficiency, and reliability. The study was centered on smart farming. Advantages of IoT applications in agriculture were highlighted, and sustainable agriculture practices such as improved efficiency and cost reduction were also elaborated in this study [35].

The benefit of using IoT and blockchain practice in precision agriculture was espoused in this paper [36], food chain supply interaction between the farmer and the vendor in real-time. This method has improved the efficiency of the farm's daily running. Some technical challenges were also discussed. Issues of data privacy and scalability. The paper was on the application of IoT and blockchain techniques, which was centered on data privacy and sharing; the scholar investigated the data privacy approach from disclosure and zero-knowledge proofs. The process discusses how this approach ensures a secure data sharing and data privacy system [37]. This study elaborated on using consensus algorithms to ensure blockchain and IoT techniques manage resource usage, such as energy consumption, energy efficiency, and low-latency communication [38]. Table 1 presents a summary of IoT and blockchain in agriculture.

Table 1. Summary of IoT and Blockchain in agriculture

Reference	Technique Used	Component	Application (Animal or Crop)
[1]	IoT	Sensors, Data encryption, Network security, and Device security.	Crop and Livestock
[2]	Blockchain	Digital identity, smart contracts, and cryptocurrency.	Livestock
[3]	Blockchain	Smart contract, Data analytics	Crop
[4]	IoT	Sensors, gateways, cloud platform & mobile apps	Crop

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Reference	Technique Used	Component	Application (Animal or Crop)
[5]	IoT	Sensors, water, soil moisture, temp gauge, humidity, & plant growth	Crop
[6]	IoT and Drone	soil moisture sensors, weather stations, cameras, and drones	Crop
[7]	IoT and Blockchain	Sensors, water, fertiliser & pesticides	Crop
[8]	IoT	Greenhouse, temp gauge, humidity, light intensity & CO_2.	Crop
[9]	IoT and 5G	Sensor, water gauge, data	Crop
[10]	IoT	Sensor, drones & GPS	Crop
[11]	IoT	Sensor, WSNs, cloud computing, big data, end-user applications & cognitive radio ad hoc network	Livestock & Crop
[12]	IoT & AI	Sensor, water gauge	Crop
[13]	IoT	Sensor, data, & mobile apps	Livestock & Crop
[14]	IoT and Blockchain	Sensor, Al & ML	Crop
[15]	IoT	Drone, Sensor	Livestock & Crop
[16]	Blockchain	Sensor and Smart contracts	Livestock & Crop
[17]	Blockchain	Review paper	Livestock & Crop

4. METHODOLOGY

This review was conducted using a traditional literature search method by systematically exploring various academic databases and credible online sources. The search focused on studies published between 2020 and 2025 to ensure the inclusion of the most recent and relevant research in the field. Keywords such as "blockchain," "Internet of Things (IoT)," and "sustainable agriculture" were used in different combinations to identify articles that specifically discuss the integration and application of these technologies in agriculture. The inclusion criteria prioritized papers that addressed both theoretical frameworks and practical implementations of blockchain and IoT in agricultural settings. Studies that focused solely on either technology or unrelated applications were excluded to maintain a clear focus on the combined impact of blockchain and IoT for sustainable agriculture. Although a formal systematic review protocol like PRISMA was not applied, the selection process aimed to be thorough and objective, with careful screening of abstracts and full texts to ensure the quality and relevance of the sources. This approach allowed for a comprehensive understanding of the current trends, challenges, and opportunities within the field, providing a solid

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foundation for analyzing the innovations and impacts of blockchain and IoT on sustainable agricultural practices.

5. FINDINGS AND DISCUSSION

The results from the study by [39] show that IoT has helped farmers with real-time data capturing of activities on the farmland, assisted them in massive data collection processes, enhanced effective decision-making on livestock and crops, and early prevention of pests and diseases. In this study by [40], the results discuss the IoT intelligent monitoring approaches where farmland activities were connected through sensors and a wireless network to process real-time data on the farmland's temperature, humidity, soil moisture, and light intensity. A central processing unit has been deployed for the optimisation of results, therefore enhancing informed decision-making and management of the farm's daily activities. The results in the study of [41] show the application of precision farming IoT technologies and the integration of sensors into the field for gathering data; machine learning approaches were used in analysing the results. Findings show that this method provides a real-time actionable step for the optimisation of crop production. From the study by [42], the results show how IoT devices were used in building a livestock management system where data was transmitted and collected through the behavioural pattern of the animal. That data assisted the farmers in acting on time. The result of the study by [43] indicates that IoT enhances system application in the supply chain management process by remotely tracking farm products from the farmers to the buyers through a sensor monitoring system.

The application of blockchain in supply chain management systems, such as digital identity, smart contracts, and cryptocurrency, in ensuring immutability and authenticity of the collected data was proposed in the study of [44]. The study by [45] shows the potential of using blockchain technology in agriculture, where it was argued that the application of blockchain could improve transparency, traceability, and efficiency. The results of this study have been proven and evaluated. This study also discusses the various challenges of this technique's application in agriculture. From the study by [46], the result was centered on food safety, supply chain management, finance, and product traceability. The authors identified various potential applications of blockchain in agriculture.

A study by in Australia, the government uses the blockchain method (AgriDigital) to enhance transparency and traceability in the agricultural supply chain distribution. Farmers can track and record grain brokers from planting to delivery in real-time. From a similar study in Georgia, blockchain applications are settling the land registry system and solving the problem of land disputes and corruption. The results provide a transparent and tamper-proof ledger for recording land

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ownership and title information. The result helped eliminate any data duplication of records and reduce the impact of corruption. The review suggested IoT and blockchain can be used to build a smart livestock farming (SLT) system. Therefore, providing the farmers with real-time data information on the livestock and the physical health conditions of the animal opens up a research gap for a comprehensive data analysis process. This integration enhances the traceability of products throughout the overall supply chain process.

Integrating blockchain technology with IoT in agriculture offers benefits such as transparent data storage, enhanced security, improved traceability, and the potential for autonomous and precise agriculture systems. Transparent data storage, a better-enhanced data-secured platform, and some areas that show the effectiveness of adopting the migration of the IoT and blockchain [46]. The issue of data sharing and an effective decision-making process also other ways to show this approach should be preached to the farmers.

Future researchers should see how to develop an innovative farming system that uses IoT and blockchain technology to monitor and optimise animal growth, crop growth, animal health, soil health, and water usage. This system can help farmers make data-driven decisions to increase crop yields and reduce resource waste. More studies should be conducted to see how to create a blockchain-based system that enables farmers to track the entire supply chain of their products, from farm to table. This system can provide transparency to consumers about the origin, quality, and safety of their food, which can increase trust in the food industry. Future work should focus on developing IoT sensor-based applications that collect data on soil moisture, temperature, and other climate variables affecting crop growth. This data can be used to create models that predict the impact of climate change on crop yields and help farmers adapt their practices accordingly.

More focused studies should examine the use of blockchain technology to create a secure and transparent supply chain management system for agricultural products. This system can help farmers and producers track and verify their products' authenticity, reduce food fraud and waste, and streamline distribution. The future can also see the development of blockchain-based payment systems that enable farmers to receive payment directly. This system can improve financial inclusion and reduce transaction costs for farmers, especially in developing countries.

The combination of IoT and blockchain technology in agriculture offers numerous benefits. IoT devices enable farmers to monitor and manage farming operations effectively in real-time. These devices provide valuable soil conditions and livestock health data, enabling farmers to optimise resource usage, increase crop yields, and improve overall productivity. In addition, blockchain technology is vital in enhancing transparency and traceability in the agricultural supply chain. It ensures the authenticity and quality of products by recording and securely storing information about each step in the production and distribution process. By leveraging blockchain, farmers can easily track the movement of food products from the farm to the consumer, reducing the risk of fraud and ensuring food safety. Likewise, integrating IoT and blockchain technology contributes to increased efficiency and sustainability in agriculture. IoT sensors can collect data on vital parameters such as soil moisture, temperature, and humidity, enabling farmers to make informed irrigation and crop health decisions. This data-driven approach minimises resource waste and helps farmers adopt sustainable practices; blockchain technology enables secure transactions and automates contracts in agricultural operations. It simplifies land and crop registration processes, reducing administrative burdens and enhancing efficiency. Farmers can focus more on their core activities by streamlining these processes, leading to increased productivity.

6. CONCLUSION

The reviewed body of literature clearly demonstrates the transformative potential of integrating Blockchain technology and the Internet of Things (IoT) within sustainable agriculture systems. Together, these emerging technologies address critical challenges such as traceability, transparency, resource optimization, and security in agricultural value chains. IoT-enabled precision agriculture has empowered farmers with real-time data collection and analysis, facilitating informed decision-making for optimized water usage, pest management, and crop monitoring. This precision not only enhances crop yield but also conserves vital resources, aligning with sustainability goals. Furthermore, IoT devices enable environmental monitoring and facilitate smart irrigation, reducing water waste and improving the overall efficiency of farming practices.

Blockchain technology complements IoT by providing a decentralized, tamper-proof ledger that enhances transparency and trust among stakeholders in the agricultural supply chain. It effectively addresses food safety concerns through immutable records of origin, processing, and transportation steps, thus enabling enhanced traceability. Moreover, blockchain's capability to secure data privacy and authenticate transactions protects sensitive farmer and consumer information, fostering greater adoption of digital agricultural solutions. The synergy between Blockchain and IoT also underpins new paradigms for smart farming marketplaces, enabling secure, efficient, and transparent interactions among producers, distributors, and consumers. Such ecosystems pave the way for innovative financing, insurance, and subsidy mechanisms that can increase smallholder farmers' access to markets and financial services.

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Despite the promising benefits, challenges remain in implementing these technologies at scale. Issues such as device cost, network infrastructure limitations in rural areas, energy consumption, and the need for interoperable standards require concerted research and policy efforts. Additionally, integrating AI and machine learning with Blockchain and IoT holds great promise for further enhancing decision support and predictive analytics in agriculture. In summary, the confluence of Blockchain and IoT technologies offers a compelling framework to advance sustainable agriculture. By improving resource management, supply chain transparency, and stakeholder trust, these technologies contribute to the resilience and sustainability of agricultural systems. Future work should focus on overcoming current limitations and exploring integrated, scalable solutions tailored to diverse agricultural contexts, particularly in developing regions where such innovations could have significant socioeconomic impact.

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