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Assembling Blockchain and IoT for Smart Food-Supply Chain

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Globalization and extreme competition in the market have made the food supply chain more complex than before. To address the complexities in the food supply chain, blockchain has become more evident than the traditional ways. Use of blockchain technologies can ensure the efficiency, transparency and reliability of the food supply chain starting from the farms to forks. This study focuses on the applicability of blockchain systems to the agriculture field and provides comparative analysis among the existing methodologies that are dedicated to uplift the security, effectiveness and reliability of blockchain based food supply chains. This research has also proposed a novel model that couples blockchain and IoT based sensor modules, which can be applicable in real-life scenarios. The proposed method essentially follows a multi-layer architecture where each layer is presented by means of a blockchain technology. Each layer is fed by the ambient conditions which may impact better quality of crops. The IoT module will ensure better farming as well as the blockchain system will ensure the quality of the end product. If the packaged food degrades in quality, the reason behind the degradation can be located by the model presented in this paper. The presented framework may reach promising efficiency in practical life but the framework implementation cost may create a burden for the investors.

Keywords: Blockchain; food supply chain; ledger IoT; sensors; smart farming.

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1. INTRODUCTION

Since the past decade, there has been rapid growth in the field of crypto-currency. It started with bitcoin, the peer-to-peer version of the first electronic cash that was developed by S. Nakamoto in 2008 [1]. The backend technology that governs the working of such digital crypto-currency systems is blockchain. As it suggests from the word, blockchain is nothing but a chain of blocks or modules that is used to store information with a digital signature in a decentralized and well-scattered network that makes more secured and transparent transactions. It is basically a digital ledger. With time, it has been proven that blockchain technology is more reliable since it is decentralized. It is more secure, hence extensive works are being made using this technology in the domain of healthcare system, food supply chain system, financial sectors, agricultural fields, etc. without the involvement of any intermediary block chain. It enables the peer-to-peer transfer of any digital data which is not possible in the existing traditional technologies.This new concept made a significant impact in society [2]. Since no middle man or trusted third party is involved during any transaction, the technology for money transactions became extremely secure. At the same time the process is fast. This led to a massive impact in the US money market in the year 2016 to make a profit of 10 billion USD. The principal characteristics of blockchain technology are transparency, immutability, auditability and most importantly decentralization [3].

Besides this, blockchain technology is a promising field if it is coupled with artificial intelligence to form a decentralized data storage system. [4]. In brief, blockchain technology is typically a digital ledger that stores all the transactional information into the storage on the process of accessing the product. It is nothing but a peer-to-peer network and the ledger is collectively controlled by all the participating parties or nodes. The blockchain technology in agriculture would be much more efficient as compared to traditional systems since it would not only control the quality but also maintain the cost of items by maintaining the profit of the farmers. This technology permits the traceability of data in the food supply chain and thus ensures the safety and quality of food. It is a smart way of farming at significantly low cost and highly secured without any intervention from any middle man. It also ensures the provision for insurance as well. This paper focused on blockchain technology in the agricultural sector and reviewed several works on blockchain in the field of agriculture coupled with IoT-based sensors. It is a well-known fact that farming and agriculture is the largest source of GDP in India. In fact, farming and agriculture constitute almost 70% of the rural economy in India, and at the same time India is the largest exporter of certain agricultural products like rice, tea, jute, etc. India has a huge scope in the international market if agriculture and farming are carried out more smartly and cheaply. Certain problems faced by the Indian agricultural sectors would be faced much efficiently if the agricultural sector deploys blockchain technology [5].

The Internet of things (IoT) is a network of some physical things or some hardware devices like sensors coupled with any microcontroller having the ability of data transmission over the internet. IoT has got a vast range of applications starting from smart home technology, healthcare, smart farming, education, defence, etc. [6]. Based on the applications, the sensors could be made using nano-science or semiconductor technology or the sensors can be optical or electro-magnetic and many more. The sensors can monitor the presence of any physical entity that is applied over a vast spectrum of applied science.

Section 2 explains the literature review of blockchain technology and IoT, the related works, the impact of blockchain in agriculture and certain pros and cons of the technique; in section 3 we have proposed a framework; section; 4 explains the future scope of blockchain technology; and finally section 5 concludes the research.

2. LITERATURE REVIEW

The concept of blockchain was first stated in 2008 by S. Nakamoto with the emergence of the first cryptocurrency bitcoin [1]. Blockchain technology is a digital ledger system, primarily used in the crypto-economy [7]. The issue of the double-spend problem was eliminated by blockchain technology in the domain of crypto-currency. This was achieved with the help of public-key cryptography [8] where every agent was assigned with a private key and a public key which was shared by all agents. The coins were allowed to transfer from one person to the other and in every transaction, a signature or a hash

code was generated. However, the transactions are made to be traceable but this was made in such a way no third party could interfere at the same time the identity of the coins owner are kept confidential [9]. So the chain of transactional records has a complex mathematical problem that is computed by a miner who generates a hash key after every transaction making it secured. The miners can complete the network and effectively solve the problem by using a certain high-speed CPU or GPU; after solving the problem, the miner can mine new coins and they can spend that by adding corresponding public and private keys. It is needless to say with the increase of the network, the mining problem becomes more and more complex to ensure security and that is being solved by a powerful mining computer. As the algorithms of mining complexity rise the system uses ASIC machines or cloud-based mining tools. The advancement of such hardware to ensure secured mining made a game-changing leap in the field of the crypto-economy of the globe. Blockchain technology relies extremely on the hashes and hash functions [10].

A hash is the result or the output coming from the transaction details generated by a hash function. A hash function is an algorithm that can encrypt certain transactional details into digital information. The property of collision resistance [11] in the hash function makes it extremely difficult to break. This makes the crypto-currency extremely secure as compared to other traditional online transactions.

Based on such a deep impact in the domain of crypto-currencies, extensive research is being made in blockchain technology. Moreover, there are many other fields where this technology could be used and certain countries have already adopted the technology in food supply chain, education and healthcare [12], agriculture [13], [14], and a decentralized voting system in the elections [15].

For the past few years, it is evident that the IoT is transforming the agricultural sector into a much smarter one. The scarcity of freshwater, presence of heavy metals in the soil makes the quality of crops worse. Due to the increase in population, shortage of water makes the life of the farmers much difficult, so an alternate way of farming must be adopted where the soil conditions are tested before harvesting. Some sensors are to be implemented that will detect the presence of metals or moisture in the soil that would send some messages to the farmers so that they can act accordingly [16].

Due to the immense advantage possessed by both the IoT and Blockchain, it is important to assemble these two concepts which in turn can benefit the agriculture field. The aim of the current study is to couple IoT with the blockchain technology so that the food quality can be maintained with the highest profit margin in a decentralized way.

2.1 Related Works

A comprehensive review on research articles are classified into two classes; first, in the field of blockchain in agriculture to ensure our goal; second; the research papers have been focused on the cutting-edge trends in IoT-based systems that monitor several physical parameters in the domain of farming.

Bechtsis, Tsolakis, Bizakis, & Vlachos [17] have observed that the emerging economies have promising growth in the field of agriculture, at the same time there is a huge possibility of misconduct in the food supply chain system for packaged foods, so the researchers have felt that making a system to monitor food quality is very important so they made a framework based on blockchain technology. The authors have investigated a bi-stage containerized food supply chain by designing a hyperledger fabric framework. Bechtsis et al. [17] have observed that the blockchain technology coupled with food SC operations helped in providing much improved traceability. Besides this the blockchain technology enabled the research by allowing optimizations in global food SC systems.

Kamilaris, Fonts, & Prenafeta-Boldú [18] have reviewed the growth of blockchain in the agriculture and the food supply chain and discussed some present works and challenges in this domain. Benefits of blockchain in the food supply chain are food security, safety and integrity have been ensured; besides this waste production could be reduced to maintain ecological balance at the same time farmers would be benefited by using a good management system for proper supervision. The authors have reviewed some companies that succeeded in overcoming certain goals like supervision, animal welfare, traceability, financial

growth, waste reduction, faster production for certain food products.

Xiong, Dalhaus, Wang, & Huang [19] have studied certain pros and cons of blockchain technology in agriculture. The authors have observed that the traditional method of Information and Communications Technology (ICT) in farming is not acceptable since in some cases this technology may not avoid the biases of the individuals controlling the ICT; on the contrary, blockchain is a decentralized technology that is much trustworthy to both the consumers and the farmers. Blockchain enables us to keep track of past stages of the end product. This data-driven technology is much smarter in farming that not only monitors the quality of end products but also facilitates timely payments. Blockchain technology also focuses on agricultural insurance by monitoring the climate by integrating the use of GPS into it. The smart farming system will be beneficial to both farmers and consumers since the system is entirely automated, any change in the model after implementation is nearly impossible, this makes it more trustworthy than ICT or Artificial Intelligence (AI)-based technologies so the risk of manipulating results in the favour of stakeholders will be hard. However, Xiong et al. [19] have also mentioned some of the drawbacks of the technology that might lead us to the scope of research: first, the benefit of the farmers is dependent on the size of the farm so small scale farmers may not join the network. Second, the huge cost of initialization.

Leng, Bi, Jing, Fu, & Van Nieuwenhuyse [20] have studied agricultural supply chain systems and implemented them using double chain architecture based on blockchain technology. The authors have found the decentralized paradigm is highly fruitful in the domain of distributed economy. The authors have addressed some problems like adaptive rent-seeking and resource matching; security and intervention of government or any third party that may disrupt the quality or cost of products. The research proposes a public blockchain-based framework in the agricultural domain to ensure security and more privacy by focusing on the dual chain structure and its storage mode, resource rent-seeking, and matching mechanism, and consensus algorithm.

Lin, Huang, Fang, Wang, Hua et al.[21] have made a comprehensive study in the technical details of blockchain-based technology in agriculture highlighting the pros and cons of the technology and stating some of its challenges in the post COVID-19 era.

It has been evident from the work of Kodali and Sahu [22] that almost 40% of earths land is used in farming, consuming a huge percentage of freshwater. Due to the rapid increase of the population, the requirement for freshwater is increasing every year. For better irrigation, it is very essential to monitor soil moisture to encourage smart farming. So IoT based models are needed that monitor soil moisture. The research was carried out using nodemcu board that has a moisture sensor IC (LM393) the data from the sensor is fed to the public IoT based cloud called losant using MQTT protocol that sends a signal to the farmers phone based on the sensor data the farmer will irrigate the soil.

Weather monitoring is highly important for smart farming. Hence; Kodali and Mandal [23] have implemented 4 sensors to monitor temperature, humidity, light, and pressure with NodeMCU. Whenever there is any abnormality the admin gets an SMS and necessary action will be taken.

Kumar, Chandra, Kumar, & Manikandan [24] proposed a system that can monitor the soil moisture using a homemade soil moisture sensor and Arduino Uno microcontroller at a very low cost to manage freshwater usage in irrigation. Kumar et al. have made the sensor by using a simple thermocol sheet with a couple of copper wires. The range the significantly good as the number of such modules is increased. By varying the potentiometer, the sensitivity could be controlled.

Soil Moisture can also be monitored using different types of moisture sensors with different soils and by that data, moisture amount could be predicted [25].

Apart from that, soil moisture could be monitored using Arduino (microcontroller) coupled with artificial neural networks, as done in India by Athani, Tejeshwar, Patil, Patil, & Kulkarni [26] or any modern microcontrollers the soil moisture monitoring could also be done using relatively cheaper devices like atmeg323 or teensy 2.0 microcontrollers coupled with moisture sensors.

It is evident from various researches that nano wires made by zinc oxide or graphene or tin

oxide provide a very low cost with high efficiency in measuring the relative humidity of a particular region. If we couple the sensor with microcontrollers like Atmeg or Arduino using the analog PAM mode, the humidity can be monitored, which would encourage much smart farming. Kuang, Lao, Wang, Xie, & Zheng [27] have designed a high sensitivity humidity sensor using tin oxide nanowire providing almost linear variation of data around 30 degree centigrade. So, this kind of sensor is highly useful in tropical regions.

The presence of heavy metals in the agricultural soil makes the soil infertile and contamination of metals in the crops may cause degradation of the quality of harvested crops. So monitoring the concentration of different heavy metals is highly essential before plantation. Such a model was formulated by Jia, OConnor, Shi, & Hou [28]. On the other hand, the ultra-portable Near-infrared (NIR) sensor detects the level of plastic pollution in soil [28].

Visible and infrared reflectance spectroscopy coupled with machine learning technique was reviewed by Jia et al. [29] the soil contamination was predicted, and this technique acts as a promising as well as a low-cost technology that could be coupled with the blockchain technology in the agricultural sector. The technology is capable of monitoring the presence of soil components like Ferric oxides, and other organic salts. The inclusion of neural networks and random forest made it possible to detect the presence of soil components at very high accuracy.

It was stated by Hong-Yan, Zhuang, Singh, Jian-Jun, Dong-Sheng, & Run-He [30] in their work that iron, copper concentrations in the soil near the Baoshan Mine in Hunan Province, China, were so high that it affected the nearby agricultural lands. So the contents of iron, copper and some other metals were analyzed and soil spectral reflectance was measured with an ASD FieldSpec FR spectroradiometer by using partial least square regression (PLSR) models.

The consumption of Arsenic contaminated food is known that it may cause several life-threatening diseases, so, Shi, Liu, Wang, Chen, Fei, & Wu [31] has made a framework based on reflectance spectroscopy in the soil to monitor Arsenic pollution in rice fields by using partial least square regression models obtaining around 68% accuracy.

Cadmium, Chromium, Lead, Copper, Mercury and Arsenic are known to be highly toxic elements that affect soil fertility. Presence of these heavy metals would not permit mass production of good quality crops. Song, YLi, Yang, Ayoko, Frost, & Ji [32] have studied the reflectance spectra of these metals within the visible and near-infrared and the mid-infrared regions and predicted their concentrations depending on some correlation patterns in reflectance spectra. On the other hand, the presence of Zinc in soil may also lead to soil infertility. Sun & Zhang [33] have researched a framework to monitor the concentration of Zinc in agricultural lands by soil reflectance technology coupled with Visible and near-infrared reflectance spectroscopy. Moreover, monitoring presence of any heavy metals in the agricultural soils of Bulgaria is predominantly done by near IR spectroscopy [34].

Real time air pollution monitoring is highly necessary to achieve smart farming. So some IoT based devices are to be used that can monitor the presence of smog or any other pollutants that might affect the crops. A mobile GPRS based sensor array was developed by Al-Ali, Zualkernan, & Aloul [35]to monitor the presence of CO, NO2, SO2 from the air. The system includes a microcontroller module, GPS module and the GPRS system along with the sensor array. The data from the sensor array is fed to the GPRS system, then coupled with the GPS, the microcontroller can monitor the presence of air pollutants.

2.2 Impact of Blockchain in Agriculture

It has been observed in many cases that dual chain-based blockchain technology improves both quality and quantity of agricultural products ensuring manufacture at low cost with maximum profit [36]. However, it is obvious that the initial cost of installation and the cost of computational resources are significantly large, as well as the acceptance of this technology to the farmers are not that popular as of right now, but still looking at the benefits of the consumers as well as farmers this technology will be fruitful in the near future. From the works of several researchers [17-36], it can be summarised as follows:

i. Low cost of farming

ii. Climate and other physical factors could be monitored without manpower.

iii. Decentralized system will lead to a significant reduction of the middle man or government or private companies so that the farmers wont get deprived.

iv. Even if the food product gets damaged, we can track the flaw with significant ease with the help of a hash key. So good quality products will be ensured to the customers at a minimum price without compromising the profit.

Hence blockchain technology ensures good quality food products by monitoring the entire chain of farm-to-fork. In the near future, during the post-pandemic economy [37], it will be a better alternative to traditional farming.

2.3 Advantages and Disadvantages of Blockchain Technology

Based on our understanding in the field of Blockchain, following immense benefits are summarized for supporting the food supply chain.

Firstly, any nodes in the chain can view the resources on the public service platform without knowing the private information of the enterprise, which not only guarantees the authenticity, integrity and non-tampering of transaction data but also ensures the privacy of user information.

Secondly, diverting enterprise information and transaction data can reduce the redundant amount of information recorded by nodes and improve the throughput rate and consensus speed of the system to a certain extent.

Thirdly, business expansion can be easily implemented between platforms and platforms, platforms and financial institutions.

3. PROPOSED FRAMEWORK

There are certain things that a farmer needs to keep in mind before harvesting the crops. The quality of soil, presence of moisture in it, air pollen, air pollution, and many more are highly significant. So, several IoT-based devices are coupled to monitor all the physical conditions to grow crops. It has been observed that the presence of any metals in the soil makes it infertile and the quality, as well as the quantity of crops, degrades, hence monitoring the presence of soil pollutants is highly advised. It is needless to mention that soil pollution also leads to soil erosion. Besides this, the humidity or other weather conditions are also significant. If there is any possibility of bad weather the farmers should not invest much in farming, so weather needs to be monitored and the forecast has to be much more accurate since based on the forecast data the investment has to be done on the field. Traditionally, if the farmer feels ambient conditions are suitable only then they start to grow crops or invest in farming. The prior aim of this study is to develop a farming system with no middle man or the intervention of any company. So for the sake of producing good quality products at a low cost and significant profit margin, an IoT-based system is proposed that will provide the necessary information to the investors so that they act accordingly. A similar study [37] has coupled IoT with machine learning algorithms in order to implement a smart farming system without human interference. The idea of a smart farming system is approached by the current study with the objective of identifying the location of food degradation by means of a blockchain.

This study presents a framework that will address the underlying problems that may appear in the agriculture field. A multi-layer model is approached in this study where each layer is dedicated to a specific task. The framework is constructed in such a way that the best quality service can be offered at a minimized cost. A decentralized mechanism is favored in this framework that will monitor and control the production cost and quality service.

To ensure good quality food product at minimal costing coupled with maximum possible profit, the food supply chain is depicted by the following blocks as shown in Fig. 1.

a. Sensor module

The sensor module or the sensor block is essentially developed by some sensors along with microcontrollers and data transmission devices to send the data to the cloud. A sample prototype of the sensor module is depicted in Fig. 2.

The prototype of the sensor module is subdivided into three segments.

- **Data collecting hardware system**

  In the prototype, we wish to implement four sensors to collect some of the significant data in farming as depicted in Figure 2. These are:

- **Soil moisture detector**

  IC LM 313 is a semiconductor chip that is basically a low voltage regulator that could be used to monitor the presence of moisture or not.

- **Humidity sensor**

  Low-cost zinc oxide nanowires could be used to monitor humidity in air.

- **Soil pollution detector**

  The presence of heavy metals could be measured using IR spectroscopy technique.

- **Air pollution detector**

  GPS coupled air pollution monitoring system could be implemented.

- **Microcontroller**

  The microcontroller, Arduino Uno is the most widely used device for IoT applications could be used that has a provision to process multiple data coming from the sensors and provide the necessary information to the cloud-based system

- **Output module**

  This module should have some cloud-based protocols so that the data from the microcontroller could be accessed remotely.

Based on the sensors information, the farmers or the investors would act accordingly to ensure maximum profit. Every sensor would produce a certain hash code based on some data. Now certain sensor modules are significant that basically monitor the physical conditions like soil moisture, fertility, presence of heavy metals, weather conditions, etc.

b. Farming and irrigation

If the farming conditions are favorable, the sensor modules would provide the necessary hash code and hence the farming would initiate, depending on soil moisture data, the required irrigation would be done. The quality of the planted crops would be tested, based on that some hash code would be generated by solving some hash algorithms.

c. Transportation to cold storage

The planted crops would be sent to the cold storage, over there the quality would be re-tested, and a hash code would be generated for every single product.

d. Preparation of end products
e. Packaging and transportation to retailer store
f. Ready to sell in grocery stores

After every block, the quality of food is checked and based on that certain hash key is generated by the system before transferring it to the successive block. This would monitor the food quality at minimum cost (that is if there is any degradation in the end product, it would be easily identified) and this ensures maximum production at a significantly low cost. Since the system is decentralized, no middle man is involved in this entire chain making the system more trustworthy.

4. RESULTS AND DISCUSSION

This study has identified possible ways for uplifting the security of the agriculture field. Use of multi-layer architecture coupled with blockchain and IoT sensor modules can ensure maximized profitability. The framework presented by this study suggests that without a favourable weather and other relevant conditions, farming and irrigation cannot proceed. Constant monitoring of the weather reports and soils nature by the IoT sensor module can assist in decision making process. The major emphasis of this research is to assess as well as locate the degradation of food quality. If the location of the impairment can be specified, it will immensely benefit the manufacturers to identify their mistakes. The trustworthiness of the system is also confirmed because of the involvement of blockchain based methodology which essentially follows decentralized system.

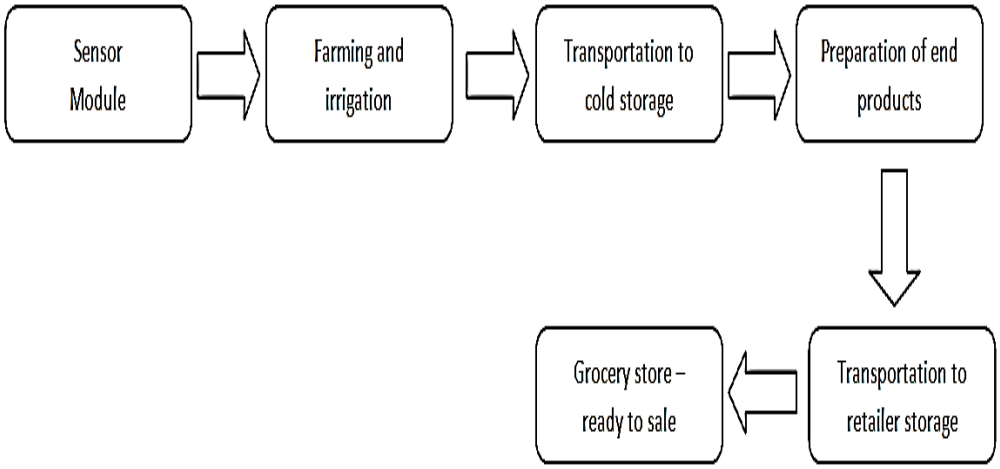

Fig. 1. Proposed blockchain model for food supply chain system

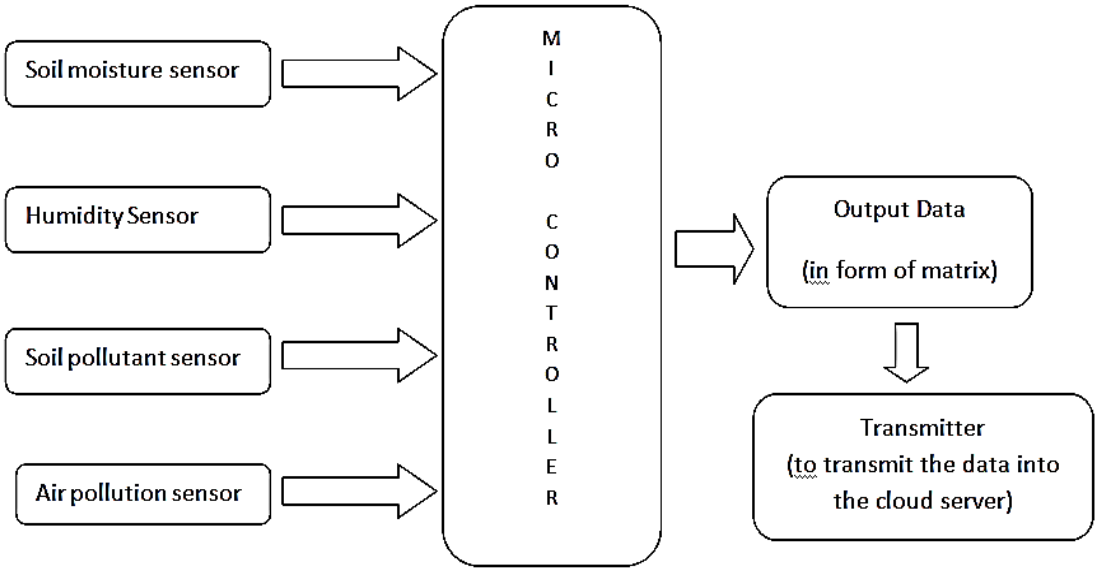

Fig. 2. Prototype of the sensor section

5. CONCLUSION

An exhaustive discourse on the existing blockchain-oriented agriculture field is addressed in this study. This study has also addressed the areas which can create a baseline to conduct further research. In the near future, blockchain-based smart farming would be an alternate method in the agricultural sector. This would not only improve the quality of food at a low cost, but also it will drive the agro-economy of the country. However, the greatest challenge is the initial cost of computation and sensor installation is high, but in the long haul, it will be a better way of farming both in terms of quality and profit. This would accelerate the economy of a nation in the post-pandemic era.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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