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Transforming agricultural supply chains: Leveraging blockchain-enabled java smart contracts and IoT integration

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Abstract

The proposed idea is to give all the agricultural stakeholders secure storage. We must automate several processes utilizing brilliant codes to reduce risks and errors. The suggested schema applies Blockchain, source codes, and IoT on a farm network to enhance the analysis of agrarian datasets and tracking products to raise the productivity of agro-based supply chains. The application's architecture will fix the faults found in earlier research. In the suggested method, sensors give us information about the environment. The Blockchain ledger stores our data in blocks. We create special agricultural automated codes in the treatment layer to automate task decisions.

Keywords: Blockchain; Java application; Smart contracts; Agriculture; IoT; Supply chain management

Contents

1. Introduction 651
2. Fundamentals 653
   2.1. The blockchain 653
   2.2. Agro-supply chain 653
   2.3. The contribution of IoT 654
   2.4. Blockchain 3.0 655
   2.5. Consensus algorithms 656
   2.6. Ethereum 2.0 656
3. Expanding the horizon 656
4. Related work 657
5. The research 659
   5.1. Validation of the model by blockchain and our personal programming Java source code 659
   5.2. Design and conception of the proposed database architecture 659
   5.3. Benefits of the proposed agricultural database architecture on water and energy management 661
   5.4. Benefits of the proposed agricultural database architecture on plant nutrients 662
   5.5. Analyzing the optimum conditions for tomato growth on a farm and in a warehouse 662
6. The project's application experiments 664
   6.1. The application code's description 664
   6.2. The interfaces of the application 665
7. Results, performance, latency, and data security analysis 667
   7.1. Results 667

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7.2. Performance and latency ... 667
7.3. Data security and analysis ... 668
8. Discussion and conclusions ... 668
Declaration of competing interest ... 671
Acknowledgments ... 671
References ... 671

1. Introduction

In the agriculture industry, centralized databases have several drawbacks that may impair efficacy, efficiency, and transparency. The following list of disadvantages of centralized databases in agriculture is followed by an investigation of how Blockchain technology might resolve these problems:
- Data Silos: Information kept in separate systems that are unable to communicate with one another efficiently is known as a data silo, which is frequently the result of centralized databases. Collaboration may be hampered as a result, and limited insights may arise.
Security Issues: Centralized databases may be compromised. A compromised single point of failure may result in data tampering, illegal access, or the loss of important information.
Lack of Transparency: Because of centralized control, stakeholders in the agricultural supply chain may not have full visibility throughout the process. This lack of openness may lead to participants mistrusting one another, which impedes traceability.
Inefficient Procedures: Centralized databases may make Data administration, retrieval, and updating inefficient. This database could hamper the decision-making speed and agility needed in the fast-paced agriculture industry.
- Dependency on mediators: To handle and validate data, farmers, distributors, and other players could rely on intermediaries. This technique increases expenses and puts the system at risk of bottlenecks.

The purpose of the study is to list the effects of Blockchain technology on the advancement of the agricultural industry and to illustrate the potential applications of Blockchain in this profitable sector. The architecture can never eliminate vulnerability at the security level; it can only reduce it. Blockchain solved these situations by promoting decentralized apps while guaranteeing certain norms of saving data and dispatching it to all stakeholders. A crucial cause for strengthening the security of the agricultural system model is to implement Blockchain and IoT simultaneously and benefit from their advantages.

IoT collects environmental data while Blockchain stores and verifies them. The source codes will operate as the data analyzer, handling the transactions to provide conclusions as results. The Smart contract algorithms control interactions with different data segments. All network participants (providers, farmers, customers, distributors) will be able to visualize data and follow the updates of products. The structure chooses a unique consensus algorithm to verify data correctness and save it on blocks making it almost impossible to change. The block's data is verified, organized, and unchangeable.

The suggested project gathers environmental data about the growth process of farm products. The data got sent to all network members and contains all the details about soil pH, light, temperature, and humidity. Every period, the participant will get the most recent information when a client is fully informed about the goods. He will have the possibility to order these goods based on their growth data statistics. The buyer will be pleased with the information provided and excited to participate in this business transaction. Additionally, the farmer shares data with clients and wins their trust when he shares his crop quality transparently. Identification of the product's owner is another benefit the agro-supply chain offers.

Developing machine learning algorithms has greatly improved agricultural production prediction and optimization capacities. But as we correctly point out, the drawbacks of centralized databases create barriers that may prevent the full potential advantages these sophisticated algorithms have to offer from being fully realized.

Agriculture has benefited greatly from machine learning algorithms, especially those that employ data analytics and predictive modeling approaches. Farmers may use this research to make well-informed decisions about how best to manage their crops, allocate their resources, and optimize their overall agricultural operations. Blockchain solves many of the drawbacks of centralized databases. Because of its decentralized design, data is dispersed among a network of nodes, reducing the possibility of a single point of failure and enhancing security [1]. The term "agriculture robots" usually refers to equipment used in agricultural productivity. An essential part of the robot family, they often have sophisticated vision, independent decision-making, control, and accurate execution skills. Furthermore, they can meet production targets accurately and efficiently even in challenging, hazardous, and complicated circumstances. Several parts and services, such as sensors, internet access, bionics, artificial intelligence, autonomous navigation, and imaging systems, go into making up agriculture robots.

As examples of new technologies, consider Field Robots, which are mechatronic, mobile operation devices with decision-making capabilities that can perform a variety of agricultural production tasks either fully or partially automatically; Tillage Robots, which are intelligent machines used to cultivate the land; Seeding Robots, which help farmers save time and money by precisely sowing seeds; and Field Information-Collecting Robots, which gather data and help farmers make invisible decisions. Agricultural biotechnology, monitored environment agriculture (CEA), and agri-drones are more options. These technologies' benefits will decrease if centralized databases are used because of potential issues with centralized data systems [2].

The comparison between Blockchain and Central Database is mentioned in the following lines: [3]

Trust Establishment:
Blockchain: Functions without the need for any trusted party.
Central Database: Depends on a central trusted party for operation.

Data Confidentiality:
Blockchain: All nodes inherently have visibility of the data.
Central Database: Access is restricted to authorized individuals.

Robustness/Fault Tolerance:
Blockchain: Data is decentralized and distributed among nodes.
Central Database: Data is centrally stored in a database.

Performance:
Blockchain: Requires time to reach consensus (e.g., 10 mins for Bitcoin).
Central Database: Allows immediate execution and updates.

Redundancy:
Blockchain: Each participating node maintains the latest copy.
Central Database: Solely, the central party possesses a copy.

Security Measures:
Blockchain: Utilizes cryptographic measures by default.
Central Database: Relies on traditional access control methods.

The necessity for transparency, productivity, and traceability motivates and leads to building a Java application that uses an IoT and Blockchain system to collect data in the agriculture sector. Doing this ensures that the data collected by different sensors is safe, impenetrable, and available to authorized stakeholders. The Java program tracks a product's lifespan, from harvesting to the customer's hands.

The potential advantages it delivers to the agriculture business are motivated to develop such an application. Farmers can improve their crop management techniques by relying on real-time data, resulting in higher yields and less resource waste. Distributors and retailers may guarantee the legitimacy and quality of the goods they sell, fostering client confidence and raising the overall effectiveness of the supply chain. The ability of customers to make educated decisions concerning the agricultural products they buy promotes market openness and sustainability. Ultimately, the Java application fusing Blockchain and IoT technology empowers participants across the farming sector, boosting decision-making based on data and altering how we perceive and engage with our food supply chains.

A lack of thorough investigation on a specific topic leads to a potential research gap. In this instance, the use of Blockchain technology is the primary concern. Unfortunately, many academics only intentionally explore the development of Blockchain applications for the financial industry, omitting the deliberate examination of its other potential benefits. They need to pay further attention to the agriculture industry in particular and grasp the wide range of advantages Blockchain might bring to this industry.

Blockchain can transform agriculture by making storing and retrieving crucial data easier. This technique covers information about businesses, organizations, goods, sales, deals, automation, and tracking. Farmers, suppliers, distributors, and consumers may all gain from increased transparency, tracing, and responsibility throughout the agricultural supply chain by utilizing Blockchain technology. Record-keeping, verification, and authentication procedures may be more effective by storing information about businesses and organizations on the Blockchain.

Additionally, the automation and monitoring capabilities of Blockchain can significantly improve several components of the agricultural system. Blockchain can allow real-time surveillance of farming operations, including crop development, soil health, weather conditions, and equipment performance, by integrating IoT devices, measurements, and data analytics. These findings can enhance precision farming practices and maximize resource allocation while reducing waste.

Nevertheless, regarding Blockchain study and deployment, the agriculture sector needs more attention despite its enormous potential. Researchers can close this gap and reveal significant advantages for the farming sector, ultimately resulting in higher profitability, sustainability, and higher quality of life for those working in agriculture by carrying out more in-depth research and examining the complete ability of Blockchain technology in agriculture.

The suggested model introduces a comprehensive framework for organizing and evaluating stakeholder, product, and transaction data. It entails grouping private data about network users into a "user section", a special place to record details about individuals using the network. Similarly, product information is kept in the "product info section", making it easy to organize and retrieve pertinent product-related information. Each member knows their obligations and rights, encouraging a collaborative trust-based atmosphere. Transaction data got logged in the "transaction section", allowing surveillance and examination of financial activity inside the network.

This model aims to simplify data management using IoT improvements. In particular, it intends to gather agricultural data from IoT devices to make it easier to analyze critical elements controlling plant growth automatically. The system can assess the data collected to decide if the plants' growing circumstances are optimal. Evaluation of variables, including temperature, humidity, light, wind, and seasonal fluctuations, are all part of this evaluation.

Different strategies can serve the gaps in the present circumstances. First, a thorough investigation of the ideal growing conditions for various plant varieties got established. We will receive the execution of surveys, the consultation of experts, and the discovery/visit of farms and agricultural businesses. These activities help to acquire insightful information for this study. The suggested model seeks to compile all of this data to build a complete database of diverse plants' optimal growing environments.

Additionally, the research will concentrate on identifying the best soil pH levels and nutrients needed for each variety of plant. Understanding the unique requirements of various plants is crucial since these elements substantially influence the health and production of plants.

The hesitation of some academics to embrace automation in particular activities is a significant issue that needs to deal with in addition to the current research gaps. The automated identification of the ideal conditions for producing high-quality crops and dataset analysis is one such challenge. Although automation can potentially improve and streamline these procedures, some researchers might be reluctant to adopt it entirely because of various worries.

Researchers may save time and money while assuring the most outstanding results for high-quality crops by automating their recognition of ideal circumstances for the growth of crops.

The research's primary objective is the creation of novel source codes for the building that can automatically ascertain sensory information like the appropriate soil pH, temperature, humidity, and light composition. The project's use of Java code in the Smart contract is one of its innovative features. By utilizing this code, the system can independently assess and interpret the sensory data, delivering insightful information about the ideal conditions for plant development.

The suggested approach provides helpful information and automated evaluations for improving plant development factors by dealing with these research gaps and utilizing a structured data management system. This model can enhance farming methods and increase crop production. Additionally, it shows a thorough comprehension of the state of the field at present and positions the planned study within the context of prior research. Another potential area for the study is the inclusion of additional cutting-edge innovations, such as artificial intelligence (AI). The system may deliver current observations and results based on predictive analysis by merging AI algorithms and techniques.

2. Fundamentals

2.1. The blockchain

The centralized approach is untraceable and needs to be clarified. User transparency, tracking products, and confidence in cooperative systems are some of the main issues facing the conventional supply chain environment. The users should resolve these difficulties by allowing access to data while safeguarding it from being changed by others. We can use Blockchain technology to alleviate these problems by integrating new technologies into the supply chain [4].

Since governments, producers, and consumers must work closely together to maintain contemporary food supply chains, quick and accurate information delivery is critical for reducing food safety incidents and guaranteeing the steady operation of food supply chains. Simultaneously, as digital technology advances, product information transparency is ensured by Blockchain technology's traceability mechanism. It gives consumers access to all essential information, from farm to table, reducing information asymmetry and facilitating a better understanding of product origin and transportation. This technology reduces health risks and expedites the prevention of fraud across the supply chain. Food safety and efficient supply chain management are closely related to global health. Customers now demand more and more from shops in terms of total openness on food-related information and increased levels of safety across the whole supply chain. The tracking system of Blockchain technology can make the environmental information of green products transparent, and its transparency and traceability benefits can be precious in this case.

A blockchain-based food tracking system can boost customers' interest in organic agricultural goods. A food traceability system built on Blockchain technology can improve customer perceptions of product quality, product trust, and environmental information transparency. Additionally, the motivation of customers' purchasing intentions is their views of product quality, product trust, and clarity of environmental information. Perceptions of product quality, product trust, and ecological information transparency significantly mediate the link between customer purchase intention and a blockchain-based food traceability system. The conclusions provide helpful information to retailers and company managers seeking to boost product sales. They also assist relevant policymakers in achieving the ultimate objective of green and sustainable growth in the food sector [5].

The Blockchain creates permanent and tamper-proof records, saves registered transactions, and uploads data chronologically to a digital, decentralized, distributed ledger. Additionally, it may benefit every domain and every logistical procedure, including warehousing, transportation, and payment [6].

The agriculture sector needs creative solutions to boost crop production. Agribusiness that sustainably enhances production and resilience, decreases or eliminates greenhouse gas emissions, and achieves national development with food security or Climate-Smart Agriculture (CSA). The combination that could improve the agricultural system must comprise IoT equipment, machine learning, and Blockchain. The injection of Smart contracts and programming source codes automates many tasks and avoids human intervention [7].

The production, processing, transportation, and distribution of food to final consumers are all affected by the global-interconnected system of many actors linked by complex interactions that make up modern agriculture supply chains. All these layers keep track of all the items' long and intricate operations from production to packing, shipping to storage, and distribution [8].

2.2. Agro-supply chain

The scientific field of agronomy is concerned with crop and soil management. Soil testing is done in the first step to evaluate the properties of the soil and determine which amendments and fertilizers are best. Additionally, this phase offers crucial information about the nature of the soil. The soil gets then prepared using techniques like tilling and aeration to provide the ideal environment for planting. The planting of seeds, also known as seedlings, takes place in the next phase [5].

Some clients are curious about the origin of the food they purchase, the delivery method, and the product's quality. Customers get informed that the information is unchangeable or silently removed since it is available thanks to Blockchain technology. Small farm owners will be able to attract investors and grow their businesses using Blockchain technology thanks to the distributed ledger's transparency, which lets all participants know the product's level of quality even if the firm is still in its early stages [9]. A supply chain is the series of relocations, transformations, and exchanges that items or services make from raw materials or natural resources to a finished product for the final consumer. The administration of a supply chain is a challenging task that involves organizing all the logistics and operations involved and covering several businesses, suppliers, and customers [10].

The following benefits come from the combination of Blockchain, IoT, Artificial intelligence, and big data in agriculture 4.0: [11]

(a) The wise use of environmental assets, such as the quantity of water available for irrigation.

(b) Increase agricultural output while avoiding the risks of rapid climate change.

(c) Manage the significant crop waste.

(d) Improve the market.

(e) Optimize the management of the food supply chain.

The following list of crucial stages describes a typical agro-supply chain: [12]

(a) Production: Information about the gathered data of crops, pesticides, fertilizers, and equipment.

(b) Processing: Details about the plant and its tools, application processing techniques, and batch numbers. Additionally, the financial interactions with the manufacturers and distributors got noted.

(c) Distribution: The product is made available after packaging and labeling; based on the category product, delivery times got restricted to a specific range. The Blockchain registers shipping information, routes, storage conditions (such as temperature and humidity), and transit times for each mode of transportation.

(d) Retailing: The merchants (retailers) carry out the product's deals. The chain lists specific details on each item, including its quality and quantity, expiration dates, and storage requirements.

(e) Consumption: The consumer is the chain's final link; when purchasing a product, he requests specific details on quality requirements, the place of origin, production processes, Etc. The buyer can scan a QR code on a food item to view all the details, from the manufacturer and supplier to the retail outlet, using a mobile phone with Internet access.

First, digital agriculture may offer decision-supporting tools, helping farmers comprehend better scenarios and take advantage of the crop's behaviors according to the time of year, the weather, the growth of a plot, and the presence of illness on the crops. The Moroccan government tries to enhance crop output and deal with the dry seasons that have afflicted the nation by synchronizing initiatives with partners across the planet to automate the farming business [13]. They attempt to rely on unique technologies that automatically transmit their sensor data for algorithmic analysis, processing it into helpful facts and guidance.

They provide efficacious watering by linking various items like wireless sensor networks. They allow for identifying the driest regions so that you may water those first. These Internet-connected devices modify the field watering schedules depending on information from the nearby weather prediction (rain level and temperature). The wireless device design for the irrigation software program is part of the model's solution. A development model, a transmission panel, and a capturing module with sufficient sensors comprise a sensor node (humidity, wind, precipitation, rainfalls, temperatures, and water levels).

2.3. The contribution of IoT

Blockchain technologies may enhance IoT technology. Corporate operations speed up using IoT, sensors, RFID, Wi-Fi, and other intelligent protocols. The marine sector, Smart homes, e-health, Smart grids, and logistics management using Radio-Frequency Identification (RFID) technology are a few examples of IoT applications [6].

The IoT's devices, networks, and applications' top layer includes a highly crucial and challenging responsibility represented at the security level. IoT security needs include: [7]

- Confidentiality: Only authorized people can access the data in this context.
- Integrity: the condition in which the content of data received remains unchanged.
- Data freshness: It is crucial to guarantee that every network transaction is brand-new and fresh.
- Non-repudiation: Nodes prevent the denial of sending a message that had got transmitted prior.
- Authentication: This requires that every communication equipment has a unique identity.

The safety of using IoT and guarding against attacks on the data and systems depends on developers, researchers, and manufacturers that must be aware of threat areas. We may classify IoT security risks into the following types:

- Eavesdropping: The attacker attempts to get valuable data, such as usernames, passwords, and node identification. This approach has the tendency to be used to target RFID devices.
- HELLO flood: The attacker changes every node to act as a parent to another node. The packets got thereby redirected to each other. As a result, several nodes and packages will be out of reach.
- Denial-of-service (DoS) attack: This frequent attack got used when an attacker sends many packets to deplete the battery. The best target for this attack is low-end devices. The attacker employs a data traffic stream to destroy the battery.
- Malicious node: It creates fake nodes throughout the network that are challenging to identify.
- Jamming attack: This kind of DoS attack aims to disrupt the communication channel by generating radio interference that burns out IoT devices.
- Power analysis: By taking control of this node's computing resources, the attack stops the execution of the cryptographic method. This method prevents the nodes from establishing trust among other nodes.
- Wormhole attacks: create a tunnel between two linked nodes. The attacker tries targeting the packets that are in

the matching location. It could subsequently tunnel them to another place.

- Distributed DoS attack: This technique prevents the server from providing services to the network's intelligent nodes.

- Man-in-the-middle attack: This kind of attack modifies direct communication between two parties. The transmission via an unreliable channel is very dangerous. It transfers messages that the attacker has changed.

Lately, it has been evident how useful sensors and the Internet of Things are for increasing food security and agricultural sustainability. The idea or sensing and actuator layer, the network layer, the cloud layer, and the application layer are the additional four tiers of the Internet of Things architecture for smart agriculture that this study supplied. This paper examines state-of-the-art IoT and sensor technologies for agriculture and some potential applications, such as monitoring crop diseases, administering fertilizer, forecasting and harvesting, climate conditions, crop disease detection, and auditing (yield, quality, processing, logistic tracking). This review also provides various agricultural sensors capable of detecting many factors, including water level, livestock, plant disease, smoke, flame, electrical conductivity, CO2, moisture, nitrate, pH, temperature, humidity, light, and weather station. The study emphasizes the benefits of IoT in smart agriculture, such as increased productivity, reach, lower resource requirements, cleaner practices, flexibility, and better product quality.

IoT-based smart irrigation is a cutting-edge technology that uses the Internet of Things to automate and enhance irrigation systems. This system ensures that plants, lawns, and crops get the right amount of water while minimizing waste and conserving water resources. Intelligent irrigation systems combine sensors, controllers, and cloud-based software to collect real-time data on soil moisture, weather, and plant water requirements. With this information, irrigation schedules, water flow rates, and other parameters guarantee that plants get adequate water when needed.

These systems have many settings, including agriculture, golf courses, and landscaping for residences and commercial buildings. Smart irrigation systems include lower costs, more efficiency, improved plant health, and less water waste. Installers of intelligent irrigation systems may save money and time by eliminating the need for manual watering.

Fertilizer administration IoT is a critical application that uses IoT technology to optimize fertilizer consumption; it contains smart agriculture. Farmers may adjust the amount and kind of fertilizer they apply to their crops by using the up-to-date information this program provides on the condition of their soil and its nutrient content. Farmers can determine when and how much fertilizer is needed for their crops by using a variety of sensors, such as temperature, humidity, soil moisture, and NPK sensors. This study leads to more efficient and effective crop growth and development and less environmental impact.

Overuse of chemicals, including pesticides, can harm the ecosystem. IoT technology makes data-driven decision-making for managing agricultural diseases and pests more straightforward. Farmers may assess the success of their pest control plans and modify their activities by evaluating data obtained from sensors and other sources. Farmers may spot patterns and trends in crop health and select effective pest control techniques by analyzing the data generated by sensors and the Internet of Things (IoT) using machine learning (ML) and other data analytics technologies.

Many innovative agricultural practices utilize IoT technology to improve forecasting, harvesting, quality control, processing, logistics, yield monitoring, and forecasting. IoT and sensors may be used in the field to collect data on various factors, such as temperature, humidity, soil moisture, and plant development patterns, that affect agricultural output.

The weather has a significant influence on smart farming. The amount and quality of agricultural products may be affected by climate change. Alternatively, farmers may use the Internet of Things to deploy sensors in the field to monitor temperature, humidity, and water levels to collect real-time environmental data.

A critical IoT used in smart agriculture is fire detection. Farmers may utilize IoT devices to monitor fire hazards in their woods and crops. These sensors can identify variations in flame, smoke, and other fire-related cues. If a fire is displayed, the IoT system may notify the farmer and the local fire department, allowing them to take quick action and contain the fire before it spreads [14].

2.4. Blockchain 3.0

Blockchain 3.0 is intended for enterprise-level application scenarios outside the purview of money and finance and has a secure access mechanism and authority control. This solution includes securities, insurance, financing, and other domains [15]. Practical Byzantine Fault Tolerance (PBFT) and proof of stake (PoS) are the most utilized algorithms by consortium Blockchain. The fundamental principle of PBFT got described in the following: when a node receives data from another node, it does not store it into a block directly but instead sends the data to other nodes for viewpoint exchange, consistency verification, and decision-making.

Ethereum is the world's second-largest Blockchain system. Ethereum's use of smart contracts broadens the notion of Blockchain. The apps that operate on the Ethereum Blockchain are called smart contracts. Ethereum offers the Ethereum Virtual Machine (EVM) to parse the contracts' source code into an opcode sequence that Ethereum defines to carry out the smart contracts. Every Ethereum Blockchain node requires an EVM to carry out contracts and handle transactions correctly.

In real-time, Ethereum virtual machines (EVM) halt potentially harmful transactions as soon as flaws are in place. Since it is impossible to prove programs written in Turing-complete languages, this work's method of identifying vulnerabilities and stopping their executions in runtime complements existing methods. The work has added reinforcement to js-evm and FISCO-BCOS-evm, two popular EVMs. In 100 genuine smart contracts, the strengthened EVMs found and stopped every vulnerability—20 percent that the testing tools could not find [16].

The Interplanetary File System (IPFS) is a P2P version-controlled file system that combines the best items of several successful earlier systems. IPFS combines a self-certifying namespace, an incentive block exchange, and a distributed hash table. IPFS aims to increase web openness. IPFS's features replace HTTP and connect all computing tools to the same file system. HTTP could not utilize the dozens of innovative file distribution methods as much as IPFS [17].

2.5. Consensus algorithms

Proof of work (PoW) involves participants that get connected via a P2P network, which aids in propagating blocks utilizing mathematical complexity but, as we have already seen, consumes a significant amount of energy. PoS is one of the most popular alternatives.

In PoS, the digital currencies are all produced at the beginning, and the quantity never changes because there is no reward in PoS. Members can lock some of their money by sending a unique transaction to join as a stakeholder and join the validator group.

The reward distribution got constantly altered via the Proof of Participation, which mixes PoW and PoS protocols. It is an extension of PoS that provides an additional security measure [18].

When it comes to security, pure PoS-based Blockchains often assume "the majority of stake", whereas hybrid PoW/PoS-based protocols presuppose "the majority of collective resource", where "collective resource" refers to both computing power and "stake" [19]. PoS algorithm results in a self-referential Blockchain discipline where the stakeholders are responsible for maintaining the Blockchain and are given tasks and incentives depending on the stakes they each have as recorded in the ledger [20]. The development of PoS decreases the enormous energy cost of solving CPU puzzles in PoW. PoS is only employed at the finality stage when validators vote about which fork will enter the main chain based on their stake [21].

2.6. Ethereum 2.0

Ethereum Network has experienced an upgrade called Ethereum 2.0, which increases the network's flow rate, effectiveness, and scalability. As a result, the Ethereum network handles more transactions, which reduces latency and expensive gas prices. When the update is complete, Ethereum will achieve its objectives of being an open network for decentralized apps and finance (Defi) [22].

The contribution of Smart contracts and some unique-prepared source codes serve as a bridge to Ethereum 2.0 [23]. Validators power the Ethereum 2.0 Beacon chain. By delivering a transaction to the deposit contract across the Ethereum 1 network, stakeholders that want to be validators must deposit a specified quantity of Ether as a "stake" (32 ETH).

3. Expanding the horizon

The injection of this axe is essential to mention some thoughts that do not directly consider as related work, but at the same time, it gets very expected to find these ideas when you are searching for related work. In other words, they are tangentially related topics to inform research insights and enrich the knowledge balance of the reader. Also, some unconventional connections dive into peripherally relevant areas to illuminate research perspectives.

In agriculture, precise measuring is essential. The climate and type of soil in a field affect the metrics that get tracked. Some of them are "Air temperature and humidity", "Soil temperature and humidity", and "Evapotranspiration" [24].

Security levels and the integration of Blockchain systems with IoT got covered in the study [25]. The Block organizes by the validator, which collects transactions, verifies that they follow the rules, and then adds them to the ledger. The information that got saved in the blocks can no longer be changed. A transaction is proven when it occurs in a Block verified block.

Programs flaws are a common security risk with Smart contracts [26]. For example, the EVM offers a fixed-size data format for integers since an integer variable can only hold a limited range of values. Every Ethereum Smart contract contains an address object that allows it to communicate with other addresses. The query or transaction gets returned from the account whose address created the global variable "tx.origin". This variable goes across the entire call stack. Utilizing this variable to authorize IoT users is prohibited since doing so raises the possibility of phishing attacks.

Greedy contracts are Smart contracts that seize wealth by preventing Ether transfers. This sort of contract needs to be examined and removed by the developer. Attacks that cause a denial of service on Ethereum can result in implementing external functions or influence the gas limit, which causes transactions to fail because of the gas restriction [27].

The issues that occasionally arise when integrating Smart contracts with the Blockchain paradigm may be taken into consideration [28] by Smart contract developers like the ordering transaction, the timestamp dependency, The loop calls problems, the unsafe type of inference, and the unfixed compiler version,

Smart contracts are little pieces of code in decentralized networks like Blockchains. They resemble classes in object-oriented programming languages like Python and Java. Blockchains' intrinsic properties, such as the data's immutability and accessibility, open up a plethora of previously unimaginable possibilities. However, these characteristics make thorough testing crucial, particularly before code launch.

Golang and Java are the primary programming languages used in the Hyperledger chain code, while Docker containers serve as the immediate running environment. Ethereum and Hyperledger are the direct development platforms used in the agri-food sector. And the formation of an alliance chain is the primary form. Blockchain smart contracts have a specific definition and associated purpose for the agri-food business, serving as a significant and potent engine for the sector's digital transformation.

After choosing, developing, and optimizing the technology and the appropriate Blockchain development platform, you may pick the programming language that meets your needs. Programming languages used often to create Blockchain smart contracts include C++, Golang, Java, Solidity, Python, Javascript, and others. Frameworks for developing Blockchain smart contracts include Embark, Brownie, Hardhat, Truffle, Epirus, Etherlime, and others. The primary purpose of selecting the development platform is to offer tool support for the application test procedures.

Java smart contract benefits over Solidity innovative contract advantages:

Widespread Adoption: Java is one of the most popular programming languages with a sizeable developer community. Java may draw on a broader pool of developers if it becomes more popular in the Blockchain industry, boosting adoption and innovation.

Versatility: Developers are already acquainted with the syntax and functionality of Java, a general-purpose programming language. Because of this, developers may find it simpler to go from creating traditional software to creating Blockchain applications using Java.

Current Libraries and Tools: A vast array of libraries, frameworks, and tools are available for Java. For various features, developers may use pre-existing Java libraries, which speed up development and lower the risk of errors.

Enterprise Integration: Business software utilizes Java. Integrating Java smart contracts with current corporate systems may be simpler if they become more common in terms of use.

Robust and Mature Development Tools: Eclipse and IntelliJ IDEA are two examples of integrated development environments (IDEs) that are part of the powerful and mature Java development tools. These tools offer functions that help improve the development process, such as code completion, debugging, and profiling.

Platform Compatibility: Depending on particular frameworks or implementations, compatibility with various Blockchain platforms may vary [29].

Recent initiatives to employ conventional high-level languages for constructing Smart contracts got discussed in the article [30]. Hyper Ledger Fabric supports writing smart contracts in Java and other languages. For example, comparing the non-comment lines of code in Solidity contracts with their translation into Java code consistently shows that the Java code decreases the code lines more effectively.

Even though Smartcheck can examine most real-world vulnerabilities, some invisible flaws could go unnoticed, leading to significant financial losses. To investigate high-risk spots, including timestamp dependency dangers, integer overflow problems, and self-destruct risks, to address these problems, we created a new tool called MSmart. It transforms the Smart contract code into an intermediate form and uses XPath rules and the intermediate representation to search for weaknesses in Smart contracts [31].

This article [32] describes a re-engineering of OpenZeppelin's design of an efficient snapshot process within the JVM for both the ERC-20 and ERC-721 standards in Takamaka. The problem of the types permitted for token holders got addressed soundly, and a novel adoption is described for creating token snapshots based on tree maps, which is feasible in Java but not in Solidity, and is more effective than a literal translation of Solidity code into Java inside the Java virtual machine.

Hyperledger Fabric offers a Smart contract platform with universal languages. It got performed in a distinct Docker container that separated it from the rest and the other peer activities and constructed using various programming languages (at present, Java, Go, and Node.js). Two approaches got operated for building the application using Java: the first uses the SDK Hyperledger Fabric (Java low level), and the second uses the SDK Fabric Gateway (java gateway), an additional SDK that offers APIs at a higher level of abstraction [33].

The Hyperledger Fabric is a structure for running private, permission-based distributed ledger platforms. Although we concentrate on Java-based Fabric Smart contracts, many of the ideas apply to other programming languages and Smart contract platforms—the essential tool to verify the accuracy of smart contracts [34].

4. Related work

The related work section thoroughly examines the collection of knowledge and research accomplished in the area of interest. This section explores the ideas, studies, and approaches used by earlier researchers to deal with topics comparable to the ones that we got examined. This part defines the current state of knowledge, identifies gaps in previous research, and emphasizes the importance of the present study by reviewing and evaluating earlier work.

Product tracking in the current agricultural system needs to be improved, especially in data protection, supplier relationships, and trust and faith in quality. Due to a lack of connection, agriculture is considered one of the last sectors that benefit from technology. The research [35] is one of the projects made in recent years using developed technology to solve traceability and food safety issues and establish confidence among the stakeholders.

Farmers can access real-time information on seed quality, environmental data, and payments thanks to the permanent recording of all sensor data and the recording blocks. The Raspberry Pi connects multiple sensors, like temperature, humidity, moisture, and soil pH sensors. A retailer enters into his account and starts a transaction employing his private key as a signature whenever he wants to purchase available crops.

Since its beginnings, AgriDigital [36] can establish digital trust throughout agriculture supply chains by integrating Blockchain into its technology stack. With AgriDigital, trustworthiness entails that supply chain stakeholders may transfer goods in total security, appropriately assign value to those items, and identify the created values along the supply chain in finance and other modalities. AgriDigital is a service that allows farmers, merchants, and managers to handle contracts, delivery, inventories, invoicing, and payments expertly.

AgriDigital creates a collection of Smart contracts. Trade and data transfers are maintained distinctively in conventional supply chains inside and between companies.

Better agricultural results will come from using technology advancements in the sector to increase productivity while reducing inputs and prolonging harvest lifetimes [37]. Intelligent agriculture may become more accessible and efficient by utilizing cutting-edge technology like Blockchain and explainable artificial intelligence (XAI). The Blockchain is a decentralized, transparent, unchangeable, permanent, and irreversible digital database. It could permanently record member transactions in a certain way. It may be used in "smart agriculture" to track crops from planting to harvest, ensuring and measuring every aspect of food production. Blockchain technology allows for the monitoring and recording of several elements of the growth process, such as the kind of fertilizer, irrigation frequency, and soil condition. Customers are now able to make better-informed purchases because of this.

The agricultural industry may be more transparent and sustainable if integrated with XAI, Blockchain, and smart agriculture. By using this technology, farmers may lessen their negative impact on the environment, increase their production and efficiency, and maintain a safe and traceable food supply. By helping farmers use less water, fertilizer, and pesticides, XAI and smart agriculture contribute to a more sustainable and environmentally friendly agricultural industry.

With these three technologies in mind, the current study focuses on statistical analysis and data retrieval from a research database. The results show that a significant amount of work has gone into "smart agriculture", which uses Blockchain technology to improve decision-making while offering safety. The results of this study suggest that more research is needed to look at how these three technologies might help for the good of humanity.

The absence of cutting-edge technology like fog computing and the Internet of Things (IoT) makes it difficult to track the provenance of agricultural goods in supply chains [38]. Furthermore, the system's conventional centralized design cannot offer a reliable tracing service for farmed items in these supply chains. This study presents a decentralized key management system (DKMS) and peer-to-peer Blockchain-based architecture that integrates self-sovereign identity (SSI) for a dependable and trustworthy agricultural food product traceability service in supply chain networks. Fantom, a public blockchain network, will enable quicker and less expensive transactions. On the other hand, SSI will use DKMS technology on top of Blockchain to guarantee each entity's identification to expedite the supply chain's transaction and verification processes for authenticity, integrity, and secrecy. The concept is composed of many public networks, including Ethereum and Fantom. The Interplanetary File System (IPFS), a decentralized file system, is also the foundation of this endeavor, which aims to provide food traceability and liquidity in the agricultural supply chain.

At the security analysis level, many entities use SSI to authenticate one another. The following characteristics of SSI prevent the participants from succeeding in their identity theft attempts.

- User-Centric Control: SSI centers people's digital identities around them. Users can establish, maintain, and share identification attributes through digital wallets.
- Decentralization: Distributed ledgers, Blockchains, or decentralized technologies are commonly the foundation of SSI systems.
- Verifiable Claims: The foundation of Supplemental Security Income (SSI) is the idea that third parties can provide verifiable digital declarations regarding an individual's characteristics (e.g., age, credentials, or job history).
- Selective Disclosure: People can only divulge the precise identification details needed for a given exchange or conversation under SSI.
- Digital Signatures and Cryptography: SSI uses robust cryptographic methods, such as digital signatures, to guarantee the veracity and integrity of identity assertions.
- Immutable Ledger: The immutability of identification records using distributed ledger technology, such as Blockchain.
- Revocation and Expiration: Verifiable claims may be revoked and expired with the help of SSI systems.
  However, because of its characteristics, any entity will likewise be unable to violate IPFS's data privacy.
- Content Addressing: IPFS locates and retrieves data via content addressing. Files get addressed by the cryptographic hash of their content rather than by their name or location. This technology implies that regardless of where it got kept or who is accessing it, the same material will always have the same address (hash). By lowering the possibility of data leakage or monitoring via file names or URLs, this function contributes to data privacy protection.
- Decentralization: Files get dispersed across several nodes in a decentralized network such as IPFS.
- Encryption: Users can encrypt their data before adding it to the IPFS network, even though IPFS does not offer native encryption for data at rest.
- Access Control: With IPFS, users may limit who has access to read and write data on the network by putting in place access control methods.
- Private Networks: To distribute data among a selected number of reliable peers, users can establish private IPFS networks, sometimes called "darknets".

AgriChain [39] uses a reliable platform to combine a traditional, well-established farm supply chain with a Blockchain-based adaptive and flexible service. The supply chain participants can communicate and share information safely thanks to this approach. The platform unites all parties involved in the agro-food system, enabling them to make and use better-informed choices, do away with pointless paperwork and dockets, and lower supply chain risk. Its management panel gives its stakeholders access to the agricultural operation detail. The stock levels handle every inbound and outbound data point. Farmers, stock feed producers, and other users all gain from this concept.

The supply chain process at Kirana Stores [40] includes obtaining raw materials, processing them into completed merchandise, and then transporting and distributing them for sale to end users. Their supply chains grow and demand vaster warehouses. Consequently, obtaining estimations regarding what to buy and where to find it is a tremendous burden.

The Smart Agrochain [41] architecture contains many components, including current technology and Blockchain. The Agrochain concept relies on Blockchain to control many processes like producing, developing, and supplying food. Blockchain technology guarantees that data storage and computing got distributed among many devices rather than concentrating on a single server. Sensors monitor cultivation-related aspects such as soil, climate, watering, and plant.

This article [4] presents a brand-new monitoring and traceability approach. This strategy to manage food traceability in the agricultural supply chain uses a Blockchain and Smart contract. This model has four layers. The producer agent in the first layer controls all activities that fall within their purview, such as purchasing supplies and selling items. The next layer relates to processor operators that sort, package, and otherwise process the goods. In the transport layer, transfer agents manage all of the duties of the transport function of the supply chain process.

The table below (Table 1) compares between these related work and the proposed work. We can notice that there are some big differences between the platforms that have been studied.

5. The research

5.1. Validation of the model by blockchain and our personal programming Java source code

Concerning our article, we choose quite frankly to deal with Java Smart contracts; we are testing and validating the concept even though we have studied and explored theoretical elements of employing a personal programming source code that represents Smart contracts and it determines the environmental status of the product items and the crops.

The used personal programming source code, as a program, controls how crops and plants behave, checks the values obtained from sensors, and determines the actual environmental state of the production. It counts on functions, methods, and assets that respect the concept of Blockchain distributed system and its services.

Because it is widely used and flexible, Java gives programmers a comfortable and powerful toolkit for creating Smart contracts. Java Smart contracts use the Blockchain architecture as their foundation to provide immutability, security, and participant consensus. People can use this technology in various contexts, including supply chain management, banking and finance, and decentralized apps. Developers may implement challenging logic, manage data structures, and communicate with the Blockchain network using Java's vast libraries and frameworks, facilitating the creation and deployment of Smart contracts.

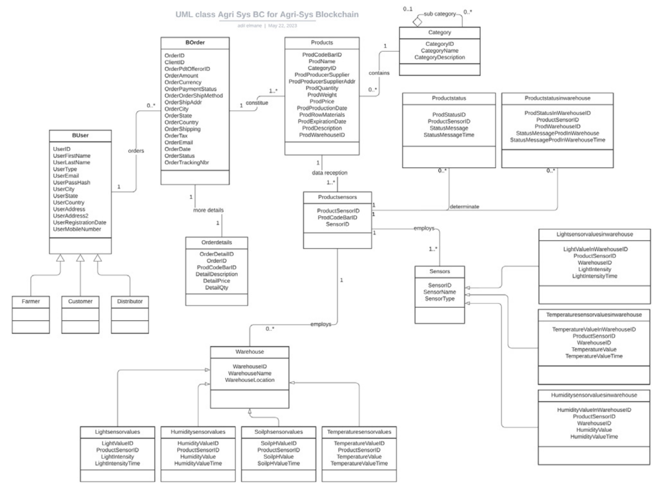

Fig. 1. UML class for the proposed solution AgriSys Blockchain.

5.2. Design and conception of the proposed database architecture

Seventeen tables in this database collect data on customers, items, orders, warehouses, and sensors (Fig. 1). Generally, it indicates that this database got created for a mechanism that keeps tabs on agricultural goods' production, distribution, and sale. The system may also offer real-time surveillance of the items' quality due to using sensors and status messages. The Distributor, Farmer, and Consumer actors imply that the program may handle a variety of roles and permissions. This schema also relates to maintaining and keeping track of a warehouse's inventory.

In our research, Java Smart contracts provide a clear and automated framework for carrying out preset rules and agreements, which are vital in value processing and decision-making procedures. These contracts enable the administration of variables by specifying particular requirements and activities automatically performed when these conditions are fulfilled. Smart contracts may automatically check incoming data, analyze numerous factors, and act following established rules and circumstances. Smart contracts, for instance, can monitor a product's journey through various phases of the supply chain management process, verify its legitimacy and quality, and initiate choices based on predetermined criteria.

As a result, supply chains become more effective and dependable, and inefficiencies will be reduced. Java Smart contracts can perform real-time data analysis on massive datasets, find patterns, and make choices based on data, enabling automatic and well-informed actions.

BUser: The BUser table stores Users' names, email addresses, physical addresses, and mobile numbers.

-Category: Contains data on different product categories.

-Sensors: Contains data on the sensors used to keep track of items.

-Products: Contains data about items, such as their names, categories, producers or suppliers, weights, prices, and warehouses.

Table 1
The comparison between the related work results and the proposed application.

Papers	Blockchain system implementation	Traceability	Smart contracts	Guide for costumers	Getting real-time data	Fraud reduction	Price Transparency	Future techno	Challenges	Security & privacy	IoT assistance	Supply chain management
(32)	DApp of HTML & Angular JS + Ganache testing network	*Not mentioned*	Solidity programming language	Just in the financing field	✔	✔	Rapid & immediate + Reduce transaction costs + The use of Metamask	✔	In analyzing data to make future decisions	✔	Raspberry Pi & sensors	Just a part of the entire logistics/supply chain management
(33)	✔	✔	✔	Handle contracts delivery, inventories & invoicing + simplify connections between actors	*Not mentioned*	✔	Using a decent Smart contract financing treatment	*Not mentioned*	Solving digital identity + improving data integrity	Need some improvement in business privacy	*Not mentioned*	✔
(35)	Web application/ mobile application	All network participants are allowed to track food data + Applying B2B, B2C, & B2A	Ethereum Blockchain with Smart Contracts & TE-ERC20 Token	Learning about the quality & origin of food	✔	Fraud control panel	*Not mentioned*	Label stickers, barcodes, RFID, & security stamps	TPS (transaction per second) is a little bit low + huge rivalry with other enterprises	Necessary protection measures	Equipment for food condition sensors	The financial transactions are not mentioned
(36)	Platform	With the stamping of date & time at each stage through the supply chain	Three types of Smart contracts: Resources, market, and production control	Communication and sharing info safely	*Not mentioned*	✔	Lower supply chain costs	*Not mentioned*	Need more development in other logistic processes	✔	IoT sensors	Agricultural Stock Management (ASC)
(37)	Research prospects	smart agriculture using Blockchain, IoT, and Explainable AI	✔	✔	✔	✔	*Not mentioned*	*Not mentioned*	Adopting automation using Smart contracts can be beneficial	✔	Electronics, robotics, Explainable AI, and IoT	✔
(38)	Platform	✔	✔	✔	✔	Prevent fraudulent transportation	*Not mentioned*	IPFS, SSI, DKMS technology	Complexity	self-sovereign identity (SSI	IoT sensors In future researches	Financial transactions are not mentioned in detail
(1)	Platform	Brand-new monitoring and traceability approach	✔	Check the origin of products + Win costumer's trust	*Not mentioned*	✔	Smart contracts control the buy and sell process	*Not mentioned*	Enhancing transparency for a little bit more	✔	*Not mentioned*	✔
Proposed Work	Java application	✔	Java algorithms (loops, if-else statements, switches)	✔	✔	✔	✔	Product code bar	The financial part of the app	✔	IoT sensors	Visualizing reel time agricultural data + tracking ordered products

-ProductSensors: Products and sensors got connected via the ProductSensors table.

-SoilpHSensorValues: Saves the pH of the soil for each product along with the time it was measured.

-LightSensorValues: Saves each product's light intensity values and time stamps.

-TemperatureSensorValues: Save the temperatures and time captured for each product.

-HumiditySensorValues: Record each product's humidity levels and the time they were taken.

-ProductStatus: Records each product's condition, any messages regarding it, and the time they were captured.

BOrder: This keeps track of the customer, the offeror, the amount, the payment status, the shipment method, the shipping address, and the order date.

-OrderDetails: Record each order's parameters, such as the item, cost, and quantity.

-WarehouseStock: This table contains warehouse data, such as their names and location zones.

-TemperatureSensorValuesInWarehouse: Records the temperatures and the time they were recorded for each warehouse.

-HumiditySensorValuesInWarehouse: Maintains the humidity measurements and the time they got recorded for each warehouse.

-LightSensorValuesInWarehouse: Records the light sensor values and the time they were recorded for each warehouse.

-ProductStatusInWarehouse: Records each product's status in warehouses, any messages or alarms sent, and the time they were received.

(a) Each product may be uniquely identified using the ProdCodeBarID attribute, a primary key in the Product table.

(b) Temperature, humidity, light levels, and soil pH values are characteristics connected to a product's condition that may be stored and tracked using the ProductStatus table.

(c) The Order table contains properties such as OrderAmount, OrderCurrency, OrderShipping, OrderTax, and OrderStatus that offer crucial details about placed orders.

(d) ProdCodeBarID, DetailDescription, DetailPrice, and DetailQty are just a few of the specific details maintained in the OrderDetails table for each product part of an order.

(e) ClientID and OrderPdtOfferorID were linked to an existing user in the User table using UserID references, which can help maintain the database's integrity.

(f) OrderPaymentStatus enables tracking of the payment status in orders, which can help control order processing.

(g) Sensitive data, such as UserPass, is placed in the User table; for this reason, it is hashed and saved cryptographically.

(h) The User database has properties like UserCity, UserState, and UserCountry that may pinpoint the precise location of the actors, including clients.

(i) The sensors that measure the warehouse's temperature, humidity, and light intensity were recorded in the TemperatureSensorValuesInWarehouse, HumiditySensorValuesInWarehouse, and LightSensorValuesInWarehouse

tables, respectively. A sensor ID, product-sensor ID, warehouse ID, value, and time are all included in each table. Foreign keys to the WarehouseStock and ProductSensors tables are among them.

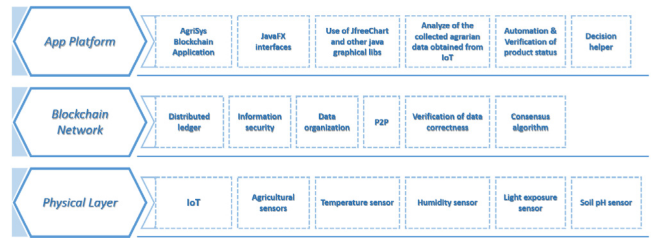

Fig. 2. Technical stack for the proposed solution AgriSys Blockchain.

The technical stack diagram below (Fig. 2) represents the many software elements and technologies constituting a system or software. It demonstrates the many levels and interdependencies, showing how various parts interact and cooperate to provide a particular feature or service.

There are three layers in this technological stack: The Physical Layer, the Blockchain Network, and the App Platform. Numerous IoT devices and sensors, including farm sensors, temperature, humidity, light, and soil pH sensors, are utilized at the physical layer. These sensors gather environmental data and provide real-time data on multiple agricultural aspects.

The Blockchain Network layer has several vital components. While information security procedures protect the integrity and privacy of the stored data. Agricultural data is efficiently stored and retrieved thanks to data organizing techniques, and P2P networking makes it possible for nodes to communicate.

The AgriSys Blockchain application now leads at the App Platform layer, providing users with a JavaFX interface. This application uses the Blockchain network to produce aesthetically beautiful and informative visualizations of agricultural data. It also makes use of technologies like jfreecharts and other graphic display libraries.

5.3. Benefits of the proposed agricultural database architecture on water and energy management

The significant benefits of the e-irrigation include helping to determine the precise amounts of Liter offered for each plant (for instance, 4L), the sorts of plant nutrients provided to the field, and their values. Every little area on a farm got connected to the E-irrigation system, which enables watering to be done automatically without requiring human involvement. Also, it makes the watering calculation much simpler and aids in selecting the watering method (Drip irrigation, subsurface irrigation, and surface irrigation). The most significant benefit is that the E-irrigation systems use less water than classic irrigation methods, which helps preserve the environment because the entire concept is ecologically friendly.

The fundamental principle behind energy management is to use sunshine, a primary light source, mainly because Morocco is sunny. When plants require more light than the sun can provide, LEDs will get exploited as a substitute. Through the method of photosynthesis, sunlight serves as the principal energy source for plants. Yet, there are instances when plants may not get enough sunlight because of circumstances like

Table 2
The ideal conditions for optimal tomato growth in Morocco (After conducting personal research and analysis).

Condition	Optimum values	Acceptable values	Bad values	Explanation
Temperature	20–30 °C	15–35 °C	<15 °C or >35 °C	In Morocco, the ideal temperature range for tomato growth is between 20–30 °C. These values promote photosynthesis and the production of healthy fruit. Temperatures above 35 °C can reduce yields and cause heat stress.
Humidity	65%–75% RH	60%–80% RH	<60% RH or >80% RH	Tomatoes require moderate humidity to prevent excessive water loss through their leaves. The optimum humidity range for tomato growth in Morocco is 65%–75% for healthy growth. However, too low humidity levels can cause stress and reduce plant growth.
Light	8–12 h/day	6–14 h/day	<6 h/day or >14 h/day	Tomatoes are sun-loving plants that require much light to grow and produce fruit. Morocco's ideal sunlight for tomato growth is 8–12 h daily. More light can lead to better fruit quality and yield. Artificial lighting can supplement natural light in areas with low sunlight levels.
Soil pH	6.0–6.8	5.5–7.5	<5.5 or >7.5	Tomatoes prefer acidic soil with a pH between 6.0–6.8. Soil pH can affect nutrient availability and plant growth, so it is [38] essential to maintain the correct pH range for optimal tomato growth. Morocco's ideal soil pH range for tomato growth is 6.0–6.8.

weather or shade from other crops. Under such conditions, the required light for photosynthesis got supplied artificially. LED lighting emits specific light wavelengths that plants need for photosynthesis, so it is a popular option for growing plants inside.

Contrarily, sunlight can occasionally be too much for plants, in which case the controllers need to apply a coating of lime to reduce the amount of light entering the plant development zone. Using lime in white paint to reflect sunlight minimizes the quantity of light that a surface absorbs and reduces the impact of direct sunlight in hot temperatures. Insufficient illumination can cause the plant's development to sluggishly or even stop totally, while excessive brightness can harm the leaves of the crop and reduce the effectiveness of photosynthesis. Using both artificial and natural light to cultivate crops has various benefits such as improved growth rates, increased growth seasons, and reduced energy bills.

5.4. Benefits of the proposed agricultural database architecture on plant nutrients

The following are a few benefits of plant nutrients:
- Macronutrients: The macronutrients nitrogen (N), phosphorus (P), and potassium (K) are crucial for plant development. The growth of leaves and stems depends on nitrogen, flowering and root development depend on phosphorus, and general plant health and disease resistance depend on potassium. These macronutrients must be sufficient for plants to proliferate and produce more blooms and fruit.
- Micronutrients: In addition to macronutrients, plants also need a variety of micronutrients, such as iron, magnesium, zinc, and copper. While being required in small amounts, these minerals are essential for healthy plant development and growth. Micronutrient deficiency can cause limited effects, leaf yellowing, and lower agricultural yields.

There are other advantages like enhancing soil fertility, improving disease resistance, reducing soil erosion, and creating balanced growth with great healthy plant development. Ammonitrate, lime nitrate, potash nitrate, potash chloride, iron, phosphorus 60%, potash sulfate, magnesium sulfate, and sulfuric acid 98% are the main ingredients used by the businesses we visited.

5.5. Analyzing the optimum conditions for tomato growth on a farm and in a warehouse

The table below (Table 2) analyzes Morocco's optimum conditions for tomato plant growth. The values are taken in ranges to determine the perfect environment for Tomatoes growth.

A well-liked and adaptable fruit, tomatoes got eaten widely worldwide. Tomatoes must be stored carefully in warehouses to maintain their freshness and superior quality (Table 3). Tomatoes' ideal storage temperatures and humidity levels are 12–14 °C and 85%–90% relative humidity. Also, it is essential to have good air circulation to avoid moisture collection and the development of mold. Tomatoes should not be exposed to artificial or direct lighting as this might lead them to ripen too soon and lose taste. Tomatoes should get packaged carefully to minimize moisture accumulation. They should get placed in vented containers. Keeping tomatoes away from ethylene-producing fruits is essential because ethylene exposure can hasten their ripening.

These two tables (Tables 2–3) have been written by gathering much information and asking people working in agri-farms. These people are already familiar with how to profit from sensor data and IoT. I can remember that the information in these two tables gets gathered from people who work in a great agri-enterprise named AZURA in the Souss-Massa region in Morocco. These people already studied the best

Table 3
The ideal conditions for optimal tomato storage in warehouses (After conducting personal research and analysis).

Condition	Optimum values	Acceptable values	Bad values	Explanation
Temperature	13–17 °C	8–18 °C	<8 °C or >18 °C	Tomatoes should get stored at a temperature of 13 to 17 °C. Temperatures below ten °C or above 18 °C might expedite ripening or produce chilling damage.
Humidity	85%–90% RH	80%–95% RH	<80% RH or >95% RH	High humidity is necessary for tomatoes to avoid drying out, but too much moisture might encourage fungus growth or germs.
Ventilation	Good air circulation	Adequate air circulation	Poor air circulation	There must be enough air circulation to stop moisture from building up and prevent fungus from developing.
Light	Avoid direct sunlight or artificial light	Low light exposure is acceptable	Direct sunlight or intense artificial light	When exposed to light, tomatoes may ripen too rapidly and get damaged.
Packaging	Ventilated containers	Perforated or mesh containers	Sealed containers	While enclosed containers can result in moisture accumulation and fungus development, ventilated boxes allow for excellent airflow.
EthyleneExposure	Tomatoes get kept away from ethylene-producing fruits	Low levels of exposure are acceptable	High levels of exposure	Tomatoes can ripen and rot earlier due to exposure to ethylene.
Ripeness	Mature green stage	Semi-ripe or ripe tomatoes	Overripe or bruised tomatoes	They guarantee a more extended storage period and the best possible freshness if tomatoes got selected when they are fully grown and green.

environment for the perfect growth of plants and got much real experience while they passed in this enterprise.

The gathered data that filled the two tables above (Tables 2–3) are almost accurate, precise, and very detailed. Concerning the Java source code, we tried to manage all the real-time sensor data and paste them into if-else statements to determine the status of the product based on the rate of the temperature, humidity, light exposure, and soil pH at this moment. After that, the application shows the user the moment's status and checks if the values are optimum, acceptable, or bad for the plant. In this situation, Still, if the value's status shows "Bad", in this case, we need to interfere and add the necessary water, fertilizers, or light according to the situation and the type of alert shown.

The project helps in noticing all the environmental conditions to set the best conditions to grow plants and make the quality production near perfect. Any value got recorded in Blockchain with a detailed description of the real-time environmental situation. The two tables above show the agricultural conditions that we can manage and, at the same time, could impact the productivity of agricultural farms. The project can also help track the product by determining its shipping data from the beginning to the end when it reaches the buyer. The Java code of the research gap ultimately manages these collected sensor data and helps give a clearer picture of the agricultural farm's productivity, fertility, and results. However, some conditions, like wind and the four seasons, also impact productivity.

The four seasons and wind considerably influence tomato crop development and growth. In tomato plants, the wind may have both beneficial and harmful impacts. On the one side, wind can aid in tomato plant flower pollination, increasing the chance of better fruit production. Also, the wind's movement can help strengthen tomato plant stems, which can carry the weight of the tomato as it matures.

Some companies organize their warehouses perfectly and divide them, for example, into three spaces. Each space contains special conditions and specific characteristics, such as precise temperatures, various humidity values, or distinctive lighting that help tomatoes maintain their quality and health. For example, warehouses got divided into three types:
- Reception: characterized by a temperature between 13 to 18 degrees. All the tomatoes produced will get collected for washing and purifying using specialized machines.
- Pre-balancing: characterized by a temperature between 8 to 18 degrees. In this warehouse, washed and purified tomatoes got collected for export cartooning and ticketing.
- Cold Room: Tomatoes destined for export 6 h from the current time got placed in this warehouse, whose temperature ranges between 2 and 9 degrees Celsius.

This study's force is the performance of three different sensors—the Grove Sunlight Sensor, the Raintrip 4-in-1 Soil pH Meter, and the DHT11 Temperature and Humidity Sensor—often used in agricultural monitoring applications. Cost and usefulness are balanced by the distinct benefits each sensor provides in response to certain agricultural requirements.

Possible drawbacks such as ambient impacts and calibration sensitivity need to be acknowledged; the study investigates how well these sensors deliver precise and trustworthy data.
DHT11 Humidity and Temperature Sensor is:
- Cost-Effective: The DHT11 sensor is a great option for projects with limited funds because of its cost-effectiveness.
- Ease of Use: The DHT11 is known for being incredibly user-friendly, making it ideal for novices. Many platform libraries, like Arduino, make programming easier and increase accessibility.

- tiny Size: The DHT11's tiny form factor makes it ideal for applications requiring a reduced footprint due to spatial restrictions.
Raintrip 4-in-1 pH Meter for Soil is:
- Multipurpose: A multipurpose solution that combines readings of pH, moisture, temperature, and sunshine is provided by the Raintrip 4-in-1 Soil pH Meter. This combination provides comprehensive insights into soil conditions.
- Installation Ease: The sensor's simple design for soil insertion makes it easy to install quickly and conveniently, which increases its usefulness in field applications.

Real-Time Monitoring: Thanks to the Raintrip sensor's real-time monitoring capacity, farmers may maximize crop development by making timely adjustments based on dynamic soil pH fluctuations.
Grove Sunlight Sensor is:
- Quantitative Light Measurement: This sensor is excellent at delivering numerical information on light levels, making it easier to determine the amount of sunlight required for photosynthetic activities precisely.
- Broad Measurement Range: The Grove Sunlight Sensor's broad measurement range makes it flexible enough to accommodate a range of common lighting situations in agricultural environments.
- Compatibility: The sensor's ability to integrate with other Grove-compatible devices is enhanced by its compatibility with the Grove interface, which makes it easier to create extensive sensor networks.

Even though these sensors have intrinsic benefits, it is vital to remember that ambient conditions and calibration accuracy can affect how well they work. While higher-quality sensors are available, their greater price may prevent them from being widely used. The strategic integration of these sensors fosters a comprehensive approach to monitoring and controlling crop conditions in agricultural settings, opening the door to data-driven decision-making and increased crop yields.

Integrating Blockchain technology may benefit the agricultural data ecosystem by providing sophisticated security features that meet complex information security requirements. The structured data is kept in blocks, each holding a collection of transactions about the development of agricultural goods. Information like soil pH, light exposure, temperature, and humidity levels are included in these transactions.

A cryptographic hash connects each block in the Blockchain ledger to the one before it, forming a chain of blocks. This relationship guarantees the data's immutability and integrity. Once a block is introduced to the chain, modifying any data (temperature, humidity, soil pH, sunlight values) inside it is nearly impossible without updating the next chain, which necessitates agreement from most network users.

Every block's data is safely decentralized and distributed throughout the network. As a redundancy and resilience measure, every member of the Blockchain network has a copy of the whole ledger. Timestamped data gives a chronological overview of the development process. Smart contracts can be used to automate various tasks, like setting off events when predetermined criteria are satisfied or updating data regularly.

Before being included in a block, transactions are verified via consensus methods such as Proof of Stake (PoS). This structure increases the dependability of the data maintained by guaranteeing that only precise and validated data is added to the ledger. The decentralized and impenetrable characteristics of Blockchain ledger storage enhance the transparency and reliability of agricultural data.

Blockchain's use of cryptographic algorithms improves data security, one of its benefits and security features for agricultural data. Because a cryptographic hash secures each block, it is computationally only possible to change its contents by being discovered. This strong security system is very important in the agriculture industry, where data authenticity and accuracy are critical for making decisions.

Another important benefit is transparency. Since everyone in the network can access the same data, stakeholders are more likely to trust each other. The accuracy and reliability of the growth process details provided to clients are guaranteed by the transparency and the data's consistency. As a result, a safer and more effective supply chain is created, enabling participants to conduct business with assurance and solid data. Overall, the agro-supply chain is made more transparent, trustworthy, and efficient by Blockchain technology's robust and secure framework for handling agricultural data.

A strong foundation of decentralized design, cryptographic security, smart contracts, consensus processes, and open checks supports Blockchain technology in agriculture data. Together, these characteristics help create an information security paradigm that tackles the particular difficulties of the agricultural sector, fostering a trustworthy and resilient data environment.

6. The project's application experiments

6.1. The application code's description

The invention, development, and execution of an application that entirely complies with the rules and principles of Blockchain technology is the primary emphasis when it comes to the Java code or the business application. The Blockchain offers a safe and open platform for logging and validating transactions. The Java code must include certain classes containing the Blockchain's fundamental capabilities to guarantee that the application complies with these distributed concept standards.

The "Block" java class is one of the core classes that got used. This class represents a single block inside the Blockchain and often includes data, a timestamp, and a unique code known as a hash. Blockchain gets created when each block gets connected to the one before it by its hash.

The "Blockchain" java class itself is yet another introductory. This class maintains the chain of blocks, making it possible to perform activities like adding new blocks, confirming the chain's integrity, and fostering consensus among network users. It keeps track of the blocks and offers ways to navigate the Blockchain, check the accuracy of each block, and deal with new blocks.

A "NetworkUser" java class is also essential. Our example represents all the actors involved in the commercial deal of agricultural products. This class symbolizes a participant in the Blockchain system, such as a user or node. It includes user-specific features, including broadcasting transactions to the network, verifying blocks, and generating transactions. When submitting transactions, verifying blocks, and preserving network consensus, the "NetworkUser" class communicates with the Blockchain class.

The class of hashing "Hashingclass" protects the Blockchain's security and integrity. This class offers cryptographic hash algorithms to provide distinct hash values for blocks and transactions. It is challenging to alter the contents in a Block since the hash values got generated using the SHA-256 hashing algorithm.

The "SensorData" java class represents such an example. The data gathered by IoT sensors placed in agricultural areas must be received and stored by this class. It offers ways to evaluate and analyze incoming sensor data to ensure accuracy and reliability. The "SensorData" class keeps a table that arranges sensor readings to simplify accessing and obtaining agricultural data.

The program also includes a Lifecycle class that follows the path taken by agricultural goods from the point of harvest to the consumer. The several phases of the farming cycle are represented by this class, including planting, cultivating, harvesting, interpreting, and distribution. Timestamps, location information, and quality metrics are among the relevant details it keeps for each stage. This class allows the program to overview the entire supply chain comprehensively.

The program uses many graphical representations, including line and bar charts, to improve data visualization and analysis. By utilizing the benefits of visual data representation, these charts make it simpler for users to interpret and analyze the gathered agricultural data. Network users can examine changes in sensor data and make wise judgments using line charts, which can show trends and behaviors over time. Contrarily, bar charts can check many factors or classifications and clearly illustrate the data. The application's visualizations make it easier to understand and comprehend the collected data, whether for tracking production fluctuations, measuring soil moisture levels, or monitoring crop health.

6.2. The interfaces of the application

It quickly becomes clear that the application has the power to significantly impact the agricultural environment as we set out on our research journey into the project's interfaces. This platform provides a comprehensive solution that smoothly integrates data management, graphical representation, and transparency by utilizing the capabilities of the Blockchain, IoT devices, and Java Smart contracts.

The Login interface (Fig. 3) acts as the first entry point into the enormous agricultural data and graphs domain within the network. This interface serves as a gatekeeper by requesting users to enter their specific wallet ID and password, ensuring that only authorized people can access the valuable assets stored within the project. This interface offers a strong layer of safety, securing sensitive data and guaranteeing the privacy of each user's data by applying a secure and encrypted login method.

Fig. 3. The Login interface for the proposed solution (After the insertion of the network participant's wallet ID his password).

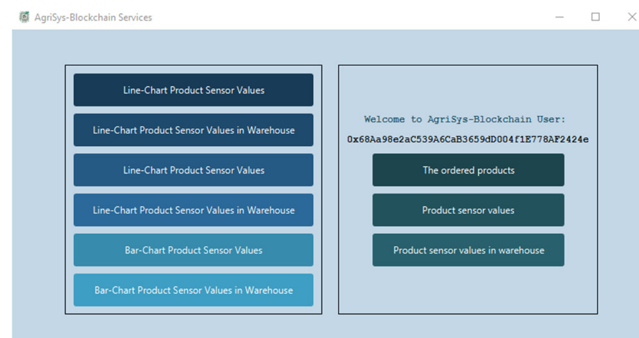

Fig. 4. The menu interface for the proposed solution.

The program allows customers a smooth transition from the Login window to the following interface (Fig. 4), including a welcome notification for the user who enters his correct wallet ID and password. Additionally, it has a variety of buttons that act as access points to other parts of the application. These buttons offer quick access to crucial elements like the table of agricultural statistics and the extensive collection of agrarian graphical representations. The program ensures that users have a complete toolbox to study and comprehend agricultural data by including these numerous interfaces, which are available through the suite of buttons.

As we continue to explore the application's interfaces, we reach the next one (Fig. 5), which is an accurate table that shows the ordered products and all the required information to track them throughout their entire travel, from the harvesting stage to transporting and finally arriving in the buyer's hands. The ordered entity table provides meaningful information, guaranteeing that every part of the product's journey got noticed. The table contains details about the product, including its name and the product code bar ID. The database also contains information on the product offeror, customer, and order IDs to aid in effective tracking. These specifics include information on the buyer, seller, and the particular transaction related to each commodity.

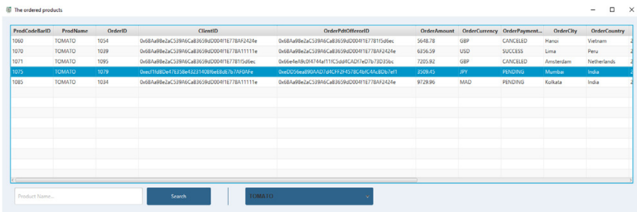

Fig. 5. Accurate table interface that shows the ordered products.

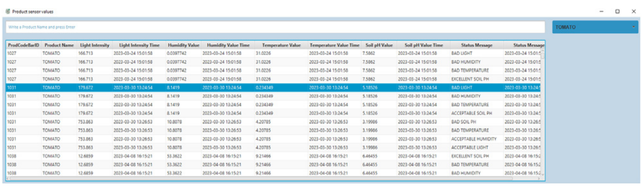

Fig. 6. Accurate table interface that shows the agricultural sensor values and their impact on product status.

Fig. 7. Accurate table interface that shows the agricultural sensor values in a warehouse and their impact on product status.

Let us move on to the following interface (Fig. 6), a helpful table that compiles all the data on numerous agricultural product attributes. This thorough table and associated timestamps show in-depth data, including temperature, humidity, light exposure, and soil pH. The table also contains status messages derived from IoT sensors and transmits pertinent data related to each value. Each table row's unique product code bar ID uniquely identifies each crop. Users get a succinct and convenient summary of the environmental factors and features affecting agricultural goods by grouping the obtained values in a tabular design.

Users may rapidly understand the relevance and consequences of the measurements thanks to these messages, which give context and explanation for the gathered data. Users can preserve ideal soil conditions, modify fertilizer amounts as necessary, and guarantee the optimum growth environment by carefully checking pH levels via the table.

The program expands its capabilities to include tracking product status within warehouses and checking agricultural items in stock (Fig. 7). IoT sensors strategically positioned throughout the storage facilities allow real-time study of essential characteristics, such as humidity, temperature, and light exposure. Users may learn a lot about the agricultural state of the items as they move through the supply chain by integrating these values with the associated timestamps.

IoT sensors used in warehouses improve crop management and surveillance. These sensors continuously record humidity

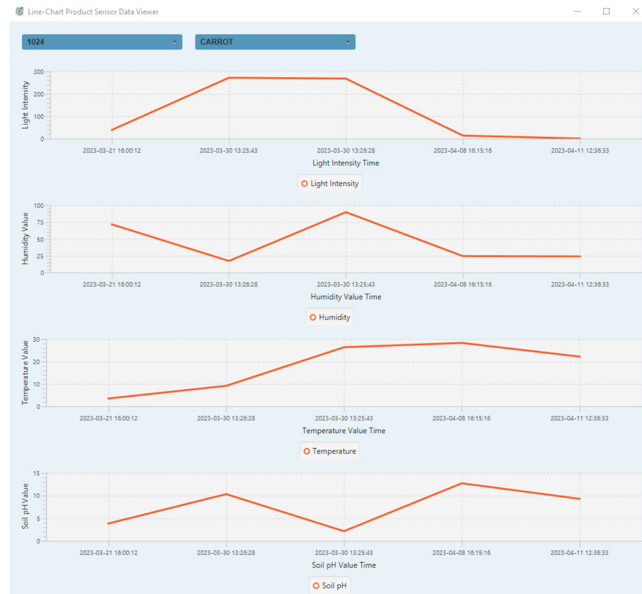

Fig. 8. Line-Chart product sensor data viewer.

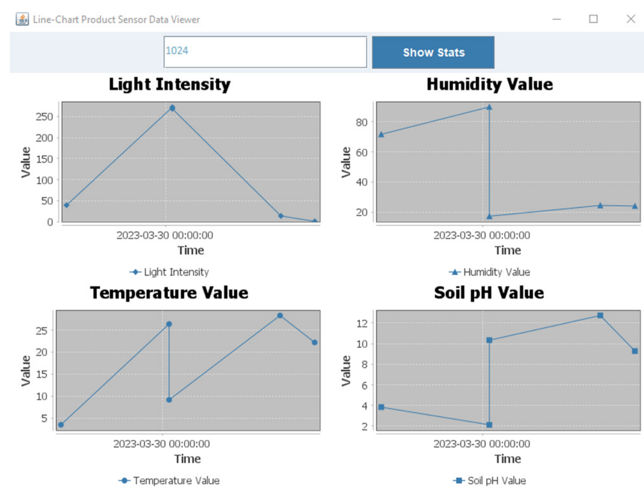

Fig. 9. Another Line-Chart product sensor data viewer.

and temperature data, giving information about the warehouse's moisture. These items make it possible to maintain a consistent temperature and put corrective procedures in place to stop spoiling, increase shelf life, and maintain product freshness. Additionally, the IoT sensors installed in warehouses collect information on light exposure. In the post-harvest phase, light is essential because it may impact agricultural products' nutritional value, color, and quality.

The application's line charts (Figs. 8–9) provide a dynamic view of plant development. Users may see patterns, trends, and oscillations in the development of agricultural goods by graphing the parameter values against their corresponding timestamps. The line charts, for example, can graphically show temperature, humidity, light exposure, and other pertinent parameters, allowing viewers to see how these variables affect the growth of plants.

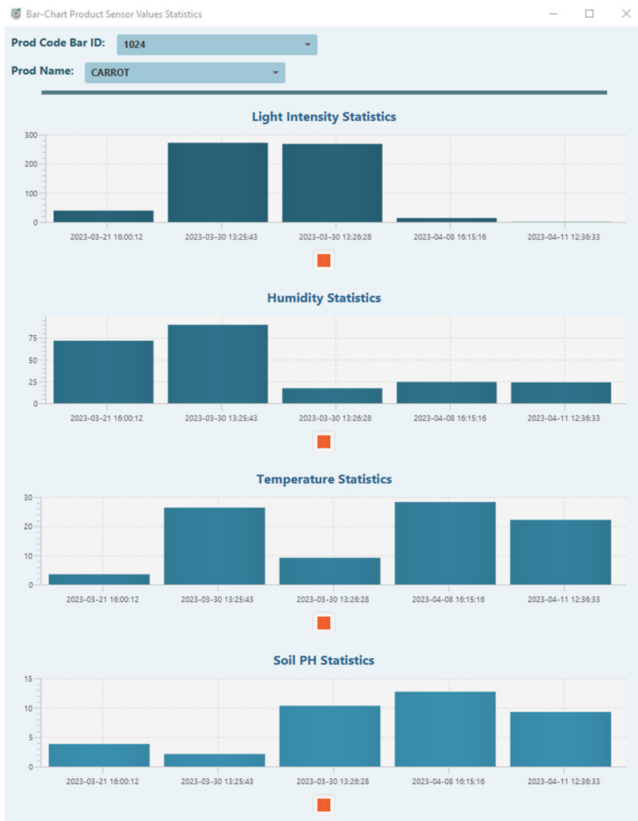

Fig. 10. Bar-Chart product sensor values statistics.

The application includes bar charts (Fig. 10) to give users a comparison picture of the progress of plants. The attribute values for different times got displayed in bar charts. Users may easily see changes and differences by comparing the figures alongside each other, enabling them to make well-informed judgments about crop management. Bar charts, for instance, can show the progress of various plant species or the productivity of crops across multiple storage facilities.

The bar charts give comparative insights, but the line charts offer a dynamic picture of growth through time. In combination, these graph interfaces allow the improvement of agricultural techniques and improve data analysis.

7. Results, performance, latency, and data security analysis

7.1. Results

When working on our project, we discovered a wide range of exciting Blockchain applications when researching several associated publications. These achievements offered distinctive methods and features, improving the ever-expanding universe of decentralized technologies. These applications, ranging from financial services to supply chain management and beyond, showed the enormous potential of Blockchain to revolutionize a variety of sectors. We learned valuable insights about the strengths and weaknesses of previous works and their unique aspects through analyzing them. By merging the most effective components from these pre-existing Blockchain apps into our app model, which we further developed using this in-depth study (table 3), we created a solid and effective solution that explicitly answers the requirements of the thesis.

This detailed comparison depends on several important factors. First, we assessed the various implementation techniques for Blockchain systems, looking at scalability, consensus processes, and interoperability. Second, we looked at each application's strategy for traceability, which ensures data immutability and transparency across the Blockchain network. Another critical investigation zone focused on Smart contracts, looking at their usefulness, programmability, and capacity to automate corporate operations. We also looked at how well the guidelines for users of the apps are, whether they offer simple interfaces and detailed instructions for easy adoption or not. In addition, the effectiveness of real-time data updates inside the Blockchain network was evaluated.

Additionally, we looked at the efficiency of the fraud prevention measures used in each app, including consensus systems and cryptographic methods. The apps' capacity to offer crystal-clear visibility into transaction expenses and cost structures was used to evaluate price transparency. Future technical factors were also considered, such as improvements in Blockchain flexibility, interoperability, and integration with cutting-edge technology like machine learning and the IoT.

7.2. Performance and latency

In Blockchain distributed ledger systems, consumers and researchers choose performance and latency, often at the expense of the application itself. There is a propensity to ignore the overall quality and usefulness of the program in favor of securing quick transactions and remarkable system performance. This strategy may result in the creation of weak, overly-simplistic apps that fall short of satisfying consumers' and farmers' demands and expectations. Additionally, some programs must recognize the importance of including all system stakeholders, like retailers and distributors.

In agriculture, it is crucial to consider the difficulties and complexity of farming techniques, product traceability, and consumer needs. The complex nature of the agriculture business got addressed if transaction speed or platform performance are the only priorities. The resulting project needs to improve in providing a reliable and complete solution since it ignores the significance of the application and only concentrates on performance and latency. It could be insufficient in essential features, usability, and the capacity to catch the demands of all concerned parties. Customers, farmers, or both may become unhappy because their expectations and needs are unsatisfied.

Our program, in contrast, tries to correct these flaws by prioritizing the essential features that it got designed to offer. We are primarily concerned with recording the agricultural data gathered from IoT equipment and ensuring that values attributed to plant development got kept within ideal ranges. Additionally, our application aims to give users of the Blockchain detailed product status information and allow them to track the ordered items on their journey. These objectives take priority over those of performance and latency improvement.

In our work, performance and latency are secondary to the objectives and functions of the application, but it is still crucial to recognize and consider these aspects. Several variables can affect a Blockchain system's performance and latency outcomes for a Java application that receives data from IoT sensors in agricultural fields and stores it in a Blockchain.

First and foremost, the Blockchain network's scalability is essential. The system must effectively manage increased transactions as IoT devices and data nodes grow. The performance might change depending on the Blockchain technology and consensus method selected. However, more recent Blockchain technologies like sharding and sidechains attempt to solve these scaling problems and enhance network performance.

Another crucial factor is latency. In contrast to older PoW mechanisms, newer Blockchain protocols like PoS and delegated proof of stake (DPoS) enable quicker transaction verification and lower latency. The agricultural IoT devices' real-time surveillance features and the Java application's responsiveness got considerably improved by these reductions in latency.

The performance of the Java program itself is also quite important. How well data gets gathered, processed, and communicated with the Blockchain platform can impact the system's quality. The application's responsiveness can be increased by optimizing the code, using practical algorithms, and adopting suitable data structures.

The architecture (Blockchain network—8 nodes) will run with a margin of 100–120 s for latency and a margin of 235–260 transactions per second (TPS) for throughput on a 3.5 GHz Processor device with 32 GB of RAM and a 2 TB drive. When the local network's capacity gets surpassed by traffic, data transfers must wait. Of course, there will be a boost in delay. The latency will rise as the network gets very busy and when we have additional concurrent activity. The performance got improved by adding extra controllers or validators who verify the transactions.

7.3. Data security and analysis

Data security involves these mechanisms:
- Encryption: The Java program uses robust encryption techniques and hashing features like SHA-256 to protect the privacy of agricultural information during transportation and storage.
- The Blockchain system: The data was kept in Blocks, each containing a hash of the one before it, forming a chain of related Blocks. This feature makes it possible to ensure that any change to a Block would necessitate recalculating the hash of all succeeding Blocks, making data manipulation almost impossible.
- Consensus techniques: Because the Blockchain network is decentralized, it uses consensus algorithms like PoS to verify and approve data transfers. These controls minimize harmful conduct by ensuring that only accurate and validated data gets uploaded to the Blockchain.
- Access Control: The Java program includes robust access control techniques to limit the entry and modification of data. This feature stops illegal accessibility or manipulation of confidential agricultural information. For instance, only users who enter the proper Wallet ID and password may access the application's other interfaces.

Data analysis contains these features:
- Machine Learning: The Java program uses machine learning techniques to evaluate the gathered agricultural data. It employs loops and if-else statements to allow users to develop data-driven conclusions on the best growth conditions for specific plant types.
- Predictive Analytics: By taking into account historical agricultural data, weather estimates, and market patterns, it is feasible to provide predictions for crop yields, disease outbreaks, or demands on the market.
- Smart Contracts: The Java program uses Smart contracts to automate and execute agreements connected to agricultural data, such as data sharing, cooperation, or incentive schemes.

The decentralized structure of the Java project combined with a Blockchain promotes trust, lowers reliance, and facilitates effective communication among stakeholders in the farming ecosystem by giving users authority over their data and eliminating the need for mediators.

8. Discussion and conclusions

The world's agricultural landscape has a great diversity in temperatures, soil types, and infrastructure capacities. The project uses Blockchain technology to collect and distribute extensive environmental data connected to agricultural product growing processes, intending to improve transparency in the agro-supply chain. The flexibility of this strategy in various agricultural locations is an important factor to consider. Blockchain technology is scalable and flexible due to its decentralized structure, making it appropriate for use in various agricultural methods and climates. The protocol is adaptable to particular regional needs, guaranteeing its applicability in various geographical areas.

Strategic planning and execution are essential to a project's success in areas with little resources or inadequate infrastructure. The following tactics are suggested as solutions to these problems:

a. Establishing Localized Data Collection Hubs: These hubs should be outfitted with sensors and other equipment that may collect vital environmental data. By acting as nodes in the Blockchain network, these hubs potentially reduce the requirement for substantial infrastructure.

b. Low-Tech Remedies: Implementing low-tech data collection technologies in resource-poor areas. This functionality involves manual data-gathering techniques and recurring Blockchain updates to ensure users can still use the system's transparency in settings with limited resources.

c. Collaborative Partnerships: To make the most of already existing infrastructure and networks, government agencies, farming cooperatives, and local communities can form collaborative partnerships. This strategy makes data collecting easier and increases community ownership and participation.

Transparency is one of the project's main objectives, but the document also examines ways to protect agricultural data from misuse and unwanted access. It highlights the importance of fostering trust between farmers and customers by identifying product owners and transparently sharing crop quality data.

Blockchain technology offers a safe environment for data transit and storage by default since it is decentralized and encrypted. Data integrity is guaranteed since every network member has a copy of the ledger. Data encryption methods can be used to strengthen security by safeguarding the confidentiality of sensitive data.

The Blockchain network must have strong access control systems to stop illegal access and protect agricultural data. Access permissions can be defined and enforced using smart contracts, guaranteeing that only authorized users can see or edit certain data items.

Permissioned Blockchain networks, in which membership is restricted to approved individuals, should be considered. This restricted access helps reduce the risk of data breaches by ensuring that data is only exchanged among trustworthy entities and preventing malevolent actors from accessing the network.

Practicing data anonymization techniques is essential to balancing privacy and transparency. Network members can see aggregated data, which offers insights without disclosing particulars about individual farmers or their plots. This method provides useful information while safeguarding farmers' privacy.

The agro-supply chain must undergo routine audits and compliance checks to remain intact. This solution guarantees that everyone involved follows the set security procedures and that any possible weaknesses are found and fixed immediately.

The open exchange of information about crop quality between farmers and customers promotes trust. Farmers show their dedication to quality by freely sharing information about the growing process, and customers are empowered to make knowledgeable purchase decisions. The agro-supply chain is reliable and strong because of its transparency and security protocols.

Any technology project must comprehend the degree of acceptability among farmers and other stakeholders. Perceived benefits, ease of integration into current processes, and technological familiarity influence acceptance. Surveys, interviews, and focus groups may all be used to gather important information on the expectations and attitudes of stakeholders.

Communicating the advantages of the agro-supply chain project is critical to increase acceptability. Farmers must understand how technology may simplify procedures, facilitate better decision-making, and ultimately increase their businesses' productivity and profitability. Specialized communication techniques that match various stakeholders' unique requirements and worries can be implemented.

Trust-building among stakeholders is based on transparency. Farmers exhibit accountability and a dedication to producing high-quality products by freely sharing data regarding crop quality and details about the growth process. To reassure stakeholders of the technology's dependability, outreach and communication initiatives might emphasize this openness.

Good training programs are essential to achieving successful technology adoption. Training sessions should cover the foundations of Blockchain technology, data interpretation, how to incorporate the technology practically into regular agricultural operations, and the specifics of this study's Java application.

Setting up practical workshops and demonstrations can close the gap between academic understanding and real-world application. During these conferences, stakeholders can ask questions, discuss issues, and engage directly with the technology. The agro-supply chain project's concrete advantages can be demonstrated through real-world simulation.

It takes feedback mechanisms to keep stakeholders involved. Farmers are free to ask for help when needed, and their input helps continuously enhance training programs and technology.

The present paper undertakes a comprehensive analysis of the possible enduring consequences of a suggested agro-supply chain initiative, utilizing Blockchain technology to collect and distribute environmental information on the cultivation process of agricultural commodities.

The Potential Benefits are:

a. Enhanced Agricultural Productivity: Farmers can optimize agricultural operations and achieve higher yields and productivity by using the technology's real-time environmental data.

b. Market Access and Premium Pricing: Farmers may have easier access to markets with greater openness and information about the quality of their products. Moreover, premium pricing may result from quality assurance, increasing farmers' profits.

c. Improved Farmer–Client Relationships: Open communication about crop quality information increases trust between farmers and customers, encouraging enduring bonds and fidelity.

d. Product Traceability and Ownership Identification: This contributes to the overall integrity of the supply chain by improving accountability and ensuring that the proper owner is identified.

The Potential Difficulties and Things to Consider are: Technological Obstacles: Adopting and exploiting the technology may provide difficulties for small-scale farmers and those with low levels of technical knowledge. Programs for customized training are necessary to remove these obstacles.

The Implications for Social Structure are:

a. Empowerment of Small-Scale Farmers: By providing focused training programs and assistance, small-scale farmers can become more adept at utilizing technology, which might help close the gap regarding technology in rural areas.

b. Collaboration Across Communities: The technology promotes cooperative efforts throughout farming communities, cultivating an atmosphere of shared accountability and mutual gain.

c. Raised Consumer Awareness: Open information communication may raise consumer knowledge of agricultural methods, affecting their preferences and decision-making.

d. New Job Opportunities: The creation and upkeep of the technology infrastructure might increase employment in Data analytics, Blockchain development, and related sectors.

A thorough impact assessment that combines quantitative and qualitative analysis is necessary to support strategic choices and guarantee the fair and sustainable adoption of this game-changing technology in the agriculture industry.

Sustainable farming methods might be promoted by integrating Blockchain technology into agro-supply networks. The particular methods by which this technology promotes sustainability are examined in this publication, along with any potential long-term environmental effects.

Encouragement of Sustainable Agricultural Practices:

a. Precision Agriculture: Precision agriculture is made possible by technology that provides real-time environmental data. This data helps farmers maximize resource efficiency, cut waste, and lessen their environmental influence.

b. Resource Efficiency: Farmers with access to comprehensive information regarding soil pH, light, temperature, and humidity may use fewer pesticides, fertilizers, and water resources.

c. Enhanced Biodiversity: Agricultural landscapes may preserve and improve biodiversity using sustainable practices backed by accurate environmental data.

d. Market Incentives for Sustainability: By enabling customers to select items with confirmed environmental credentials, the technology can generate market incentives for sustainable practices, motivating farmers to use eco-friendly methods.

The long-term benefits on the environment are:

i. Soil Health: The technology promoting sustainable practices can enhance soil health and sustain long-term agricultural output.

ii. Water Conservation: Precision agriculture helps to preserve water resources.

iii. Less contamination: Strategically using inputs reduces the chance of soil and water contamination, which benefits nearby ecosystems.

The long-term negative effects on the Environment is the Energy Consumption: If renewable energy sources are not given priority, the energy needed to maintain the Blockchain network and sensor devices might increase carbon emissions.

Mitigation Strategies: a. E-waste Management: Implement efficient e-waste management plans to manage the eventual disposal of electronic devices and hardware parts.

a. Renewable Energy Integration: To reduce possible adverse environmental effects, using renewable energy sources to power technology infrastructure should be given priority.

c. Community Engagement: Promoting awareness campaigns and community involvement to guarantee appropriate technology usage and cultivate a feeling of shared accountability for environmental preservation.

d. Incorporating feedback from stakeholders: To continuously enhance sustainable practices within the agro-supply chain, feedback from farmers, clients, and environmental specialists is included.

The Integration of Emerging Technologies are:

a. Java Application: Thanks to its well-designed architecture, advanced data analysis and decision support technologies are integrated into the system. Due to this integration, the initiative will continue to be at the forefront of data-driven agriculture.

b. IoT Device Compatibility: The agro-supply chain project is built to support the integration of new Internet of Things (IoT) devices to ensure compatibility with the newest sensor technologies that may become available.

c. Blockchain Upgradability: By accommodating protocol updates and innovations, the Blockchain architecture allows the system to take advantage of breakthroughs in Blockchain technology, including better security and scalability.

The Future-Proofing Data Security are:

a. Advanced Encryption: The system uses cutting-edge encryption techniques to protect sensitive environmental data. It is possible to quickly make modifications to reduce potential hazards by continuously monitoring cybersecurity trends.

b. Decentralized Identity Solutions: The system includes decentralized identity solutions to provide safe and private identification of product owners before developing identity management technologies.

A thorough cost–benefit analysis is the foundation for evaluating the high-tech solution's economic feasibility. The study includes both direct and indirect expenses, as well as physical and intangible benefits.

The initial strategy for this project is to use medium-priced sensors that produce the greatest results. Setting up a Blockchain network, purchasing sensing devices, and investing in technological infrastructure are necessary before implementing a high-tech solution. The expenses related to data collecting, integration, and farmer training programs must also be considered. The initial investment amount is essential for figuring out the break-even point and determining whether adoption is feasible.

Operating expenses include periodic upgrades, network administration, and upkeep of hardware and software components. The energy used for data transmission and sensor devices may influence operational costs. Determining the project's long-term viability requires weighing these expenses against the expected benefits.

Limited financial resources and low technology knowledge are two difficulties faced by small-scale farmers. It is important to modify the cost–benefit analysis to consider the unique requirements of small-scale farmers. Cost-sharing, community engagement, and focused assistance initiatives can improve this group's financial sustainability.

Blockchain would quickly be a game-changing technology in the agriculture sector, addressing many issues, including ineffectiveness in the traditional supply chain, problems with food safety, protection, and quality, rising transaction costs, intermediaries manipulating the market, and consumer mistrust of the goods or services. A few of the efforts are visible in many global initiatives, especially in some of the technology's early successful applications in agriculture. However, obstacles like cost, scaling, productivity, privacy protection, and security got treated by Blockchain to realize its potential fully. One drawback of our study is that several of the cases reviewed we looked at were still in progress. Therefore, all analyses depend on the preliminary findings and currently accessible data.

Creating our Blockchain application in Java has been a significant activity that has completely changed how we gather, handle, and use agriculture data from IoT sensors. We have developed a robust tool via our dedication and hard effort that serves farmers and agricultural professionals and improves the whole agricultural supply chain. This decentralized strategy assures the accuracy and trustworthiness of the data and gives all network participants access to current crop conditions and status. Farmers, researchers, and other interested parties may learn crucial information on the growth, development, and environmental aspects impacting crops with just a few clicks.

Our commitment and persistence manifested throughout the development of our Blockchain application. Farmers, academics, and other stakeholders benefit from the application's overall effects. We feel excited about the limitless opportunities it offers for changing agriculture and ecology and assuring food security for the future as we continue to enhance and broaden its usefulness.

Declaration of competing interest

The authors declare that there is no conflict of interest in this paper.

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