Blockchain-Powered Pesticide Tracking in Smart Farming

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***Abstract*—Blockchain-based solution addresses the lack of transparency and accountability in the agricultural supply chain regarding pesticide and preservative usage. Leveraging blockchain technology, our system establishes an immutable ledger to track every stage of the journey from farm to consumer, ensuring data integrity and eliminating the risk of tampering or fraud. Smart contracts automate processes, accurately recording transactions and handling of pesticides or preservatives. Farmers register usage details on the blockchain, providing comprehen- sive information shared securely with retailers and consumers. Decentralization ensures trust among all stakeholders, fostering transparency and traceability. By empowering stakeholders with information about product provenance and safety, our solution aims to improve food safety standards, enhance consumer confi- dence, and promote sustainable agricultural practices.**

I. INTRODUCTION

A. Need

As a result of cutting-edge technology being incorporated into conventional farming methods, the agricultural landscape is deeply changing. Improved crop yields, lower resource use, and more efficiency are the goals of smart farming, which is powered by automation, data analytics, and Internet of Things sensors. However, a major obstacle still stands in the way of this agricultural revolution: the prudent use of pesticides.Inthe era of smart farming, where precision and sustainabilityare paramount, there is an urgent need for a robust and trans- parent pesticide tracking system. Pesticides, while essentialfor safeguarding crop health, can, if mishandled or misused, lead to overuse, environmental harm, crop contamination, and food safety concerns. Current pesticide management practices often lack real-time visibility, accountability, and traceability, making it challenging for stakeholders to ensure safe and sustainable pesticide usage.

1) Enhanced Traceability: Current agricultural supply chains often lack transparency and traceability, making it challenging to identify the sources of pesticide contami- nation or monitor compliance with regulatory standards. By leveraging blockchain technology, stakeholders can access a transparent and auditable record of pesticide usage, facilitating traceability from farm to fork.

2) Improved Accountability: The decentralized nature of blockchain ensures that data records are tamper-proof and verifiable, fostering accountability among all actors involved in pesticide management. By establishinga trustless system of record-keeping, the likelihood of fraudulent or erroneous practices is significantly reduced, promoting integrity and accountability throughout the supply chain.

3) Data-Driven Decision Making: Access to accurate and comprehensive data on pesticide usage enables farmers, producers, regulators, and consumers to make informed decisions regarding agricultural practices, product selection, and policy formulation. By harnessing the power of data analytics and real-time monitoring, stakeholders can optimize pesticide usage, minimize environmental impact, and enhance crop productivity.

4) Consumer Confidence: Heightened consumer awareness and concerns regarding pesticide residues in food products necessitate greater transparency and accountability in agricultural practices. A blockchain-

powered pesticide tracking system empowers consumers to make informed choices by providing access to detailed information about pesticide usage, crop origins, and production methods.

5) Sustainable Agriculture: Sustainable agricultural prac- tices are integral to addressing global challenges such as climate change, biodiversity loss, and resource deple- tion. By promoting responsible pesticide management and fostering transparency in agricultural supply chains,blockchain technology contributes to the advancement of sustainable farming practices and the preservation of natural ecosystems.

B. Purpose

The purpose of this project is to develop and implement a blockchain-powered pesticide tracking system tailored for smart farming practices. This purpose is driven by a multi- faceted objective aimed at addressing critical challenges in agricultural pesticide management and fostering a more trans- parent, accountable, and sustainable agricultural ecosystem. The project seeks to achieve the following purposes:

1) Enhanced Traceability and Transparency: The primary purpose of the project is to establish a robust system for tracking pesticide usage throughout the agricultural supply chain. By leveraging blockchain technology, stakeholders can access a transparent and immutable ledger that records the entire lifecycle of pesticides, fromprocurement and application to disposal. This height- ened traceability fosters transparency and accountability, enabling stakeholders to identify the sources of pesti- cide contamination, monitor compliance with regulatory standards, and mitigate risks to human health and the environment.

2) Optimized Pesticide Management: Another key purposeof the project is to empower farmers, producers, and regulators with accurate and comprehensive data on pesticide usage. By providing real-time insights into pesticide application practices, crop-specific usage patterns, and efficacy metrics, the system enables stakeholders to make informed decisions regarding pesticide selection, application rates, and integrated pest management strategies. This data-driven approach to pesticide management promotes efficiency, minimizes environmental impact, and enhances crop productivity while ensuring the responsible use of chemical inputs.

3) Facilitated Data-Driven Decision Making: The project aims to facilitate data-driven decision-making processes across the agricultural supply chain. By aggregating and analysing data on pesticide usage, crop yields, market demand, and consumer preferences, stakeholders canoptimize resource allocation, streamline supply chainoperations, and mitigate risks associated with pesticide residues in food products. This enables farmers to make informed decisions regarding crop selection, planting schedules, and pest control strategies, while empowering consumers to make informed choices about the products they purchase and consume.

4) Promotion of Consumer Confidence and Food Safety:A fundamental purpose of the project is to enhance consumer confidence in the safety and quality of agricultural products. By providing transparent and verifiable information about pesticide usage, crop origins, and production practices, the system empowers consumers to make informed choices that align withtheir preferences and values. This transparency not only fosters trust between producers and consumers but also promotes food safety, public health, and environmental stewardship.

5) Advancement of Sustainable Agriculture: The project aims to advance the principles of sustainable agricul- ture by promoting responsible pesticide management practices and fostering environmental stewardship. By incentivizing the adoption of integrated pest manage- ment strategies, organic farming practices, and precision agriculture technologies, the system contributes to the preservation of soil health, water quality, and biodiver- sity. This aligns with global sustainability goals andsupports the transition towards a more resilient and regenerative agricultural system.

II. LITERATURE REVIEW

Blockchain technology has garnered considerable attention across various industries for its potential to revolutionize data management, enhance transparency, and mitigate fraud. In the agricultural sector, the application of blockchain has gained traction as a promising solution to address challenges related to supply chain transparency, traceability, and sustainability. This literature review provides an overview of key studies and research findings pertaining to the use of blockchain technology in pesticide tracking within the context of smart farming.

Blockchain and Food Safety Assurance: Blockchain tech-nology has garnered attention for its potential in ensuring food safety and quality assurance in the agricultural sector.Tapscott and Tapscott (2017) and Liu et al. (2020) have demonstrated how blockchain can create an immutable and transparent record of food production, processing, and dis- tribution, enabling stakeholders to trace product origins and verify authenticity. By enhancing transparency and traceability, blockchain-based systems build consumer trust and confidence in the safety and integrity of the food supply chain, particularly regarding pesticide tracking, where accurate documentation can prevent contamination and ensure regulatory compliance.**Pesticide Application and Associated Challenges:** While pesticides are crucial in modern agriculture, their misuse oroveruse poses risks to the environment, human health, and crop quality. Blockchain adoption offers a means to trace pesticide usage from production to field application, promoting better control and accountability.

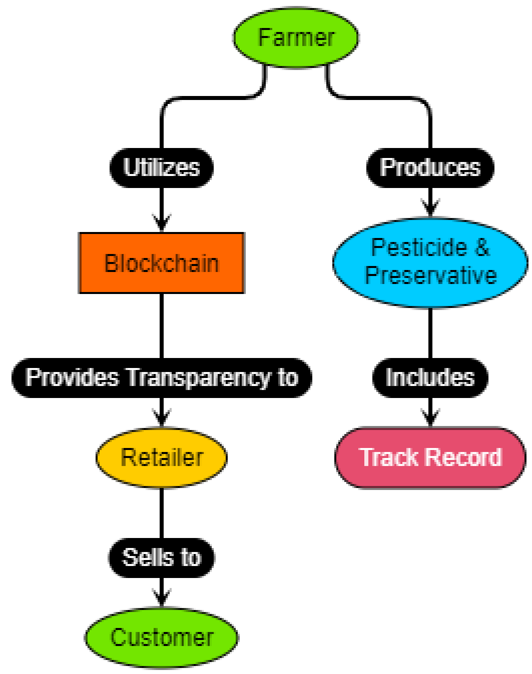

Fig. 1. Flowchart diagram of proposed model.

Transparency and Traceability in Agricultural Sup-ply Chains: Studies by Ren et al. (2019) and Kamilaris et al. (2019) underline the significance of transparency and traceability in agricultural supply chains for ensuring food safety and quality assurance. Blockchain technology provides immutable transaction records, enabling stakeholders to track agricultural products from farm to fork, mitigating risks related to foodborne illnesses, counterfeit products, and fraudulentpractices.

Decentralization and Data Integrity in Pesticide Man-agement: Blockchain's decentralized ledger ensures data in- tegrity and reliability, eliminating the need for central oversightand mitigating the risk of data manipulation. This fosters credibility and trust in pesticide usage data and encourages responsible management practices.

Smart Contracts for Compliance: Implementing smart contracts within blockchain can automate and enforce compli-ance with pesticide regulations. These contracts can prevent the sale of crops exceeding recommended pesticide limits,mitigating risks associated with misuse.

Mitigating Environmental Impact: Blockchain-enabled pesticide tracking can minimize environmental impact by regulating and reducing pesticide use, thus mitigating soil and water contamination, conserving biodiversity, and promoting sustainable agricultural practices.

Emerging Trends and Innovations in Blockchain-Based Agriculture: Research by Zhong et al. (2021) and Ma etal. (2019) explores integrating IoT devices, smart contracts, and AI algorithms with blockchain in agriculture. These tech- nologies enable real-time monitoring, automated compliance verification, and predictive analytics for optimized decision- making in pesticide tracking and smart farming practices.

Case Studies and Pilot Projects in Blockchain-Powered Agriculture: Initiatives like the IBM Food Trust platform (Caro et al., 2019) and the World Wildlife Fund's blockchain- powered traceability project (Ibrahim et al., 2020) demonstratehow blockchain improves transparency, traceability, and sus- tainability across agricultural value chains. Lessons from theseprojects inform the design and deployment of blockchain- powered pesticide tracking systems.

Challenges and Opportunities of Blockchain Adoption in Agriculture: While blockchain offers benefits, technical, regu-latory, and organizational barriers exist (Boerema et al., 2020; Malak et al., 2019). Addressing these challenges requires col- laborative efforts, standardization, and regulatory frameworks to promote innovation and adoption.

Consumer Awareness and Trust: Consumer concerns about pesticide residues drive demand for transparency and in-formation regarding pesticide usage in agriculture. Blockchain provides a transparent record, empowering consumers to makeinformed decisions aligned with their preferences for safe,sustainable, and ethically produced food.

Market Differentiation and Competitive Advantage: Blockchain-powered pesticide tracking differentiates products in the marketplace, meeting consumer expectations for quality, safety, and sustainability. Producers can position their offer- ings as premium, prioritizing consumer health, environmental stewardship, and ethical production.

Regulatory Considerations: Collaboration between regu- latory bodies, industry stakeholders, and technology providers is crucial for the successful adoption of blockchain-powered pesticide tracking systems, ensuring alignment with regulatory standards and industry practices.

III. PROBLEM IDENTIFICATION AND OBJECTIVES

A. *Problem Identification:*

In the context of smart farming, a significant problem arises from the absence of a robust, transparent, and tamper-proof system for tracking pesticide usage, leading to issues such as inadequate real-time monitoring, environmental harm through overuse, crop contamination, and compromised food safety. This lack of transparency and accountability among farmers, manufacturers, and regulators hinders the enforcement of safety standards and regulations, while also eroding consumer confidence in the food supply chain. Addressing these is-sues requires the development of a decentralized blockchain- powered pesticide tracking system that offers real-time visibil-ity, data-driven insights for optimized pesticide management, and compliance assurance, thereby reducing environmental impact and enhancing trust in the agricultural sector.

1) Lack of Transparency in Pesticide Usage: Traditional methods of pesticide tracking often suffer from a lack of transparency, making it challenging for stakeholders to access accurate and comprehensive information about pesticide usage throughout the agricultural supply chain. This opacity hinders efforts to monitor pesticide application practices, assess en- vironmental impacts, and ensure compliance with regulatory standards.

2) Inefficient Record-Keeping and Data Management: Manual record-keeping processes for pesticide usage data areprone to errors, inconsistencies, and data silos, leading to inefficiencies in data management and analysis. Fragmented data sources and outdated information systems exacerbate these challenges, impeding stakeholders' ability to access timely and reliable information for decision-making purposes.

3) *Limited Traceability and Accountability:* The inabilityto trace the origins of agricultural products and verify their authenticity poses risks to food safety, quality assurance, and consumer confidence. Without robust traceability mechanisms, stakeholders are unable to identify the sources of pesticide contamination, monitor product recalls, or hold accountable those responsible for pesticide misuse or fraudulent practices.

4) *Concerns About Pesticide Residues and Health Impacts:* Growing consumer awareness and concerns regarding pesti- cide residues in food products underscore the need for trans- parent and verifiable information about pesticide usage in agri- culture. Pesticide residues have been linked to adverse health effects, including chronic illnesses, reproductive disorders, and developmental abnormalities, raising public health concerns and prompting calls for stricter regulation and oversight.

5) *Environmental Sustainability and Ecosystem Resilience:* Improper pesticide management practices can have detri- mental effects on environmental sustainability and ecosystem resilience. Pesticide runoff and contamination can pollute waterways, harm non-target organisms, and disrupt ecolog- ical balance, posing threats to biodiversity, soil health, and ecosystem services essential for agricultural productivity andlong-term sustainability.

B. *Objectives*

The objectives of the blockchain-powered pesticide track- ing project are multifaceted, encompassing a range of goals aimed at addressing key challenges in pesticide management, transparency, and sustainability within the agricultural sector. These objectives serve as guiding principles for the design, development, and implementation of the system, with the overarching aim of enhancing accountability, traceability, and consumer confidence in agricultural practices.

1) *Establish Transparent and Traceable Pesticide Tracking:* The primary objective of the project is to establish a transpar- ent and traceable system for tracking pesticide usage through- out the agricultural supply chain. By leveraging blockchain technology, the system aims to provide stakeholders with access to an immutable and auditable record of pesticide application practices, enabling them to trace the origins of agricultural products and verify their authenticity.

2) *Enhance Data Management and Analysis:* A key ob- jective of the project is to enhance data management andanalysis capabilities related to pesticide tracking. By imple- menting a centralized database and user-friendly interface, the system aims to streamline data collection, storage, and analysis processes, facilitating informed decision-making and resource allocation for stakeholders across the agricultural value chain.

3) *Promote Accountability and Responsible Pesticide Man- agement:* The project seeks to promote accountability and responsible pesticide management practices among farmers, producers, and regulators. By establishing clear guidelines, protocols, and standards for pesticide usage, the system aimsto incentivize compliance with regulatory requirements, reduce the incidence of pesticide misuse or overuse, and minimize adverse environmental and health impacts.

4) *Empower Stakeholders with Access to Information:* Another objective of the project is to empower stakeholderswith access to transparent and verifiable information aboutpesticide usage in agriculture. Through the implementation of user-friendly interfaces and data visualization tools, the system aims to provide farmers, consumers, and regulatory agencies with real-time insights into pesticide application practices,crop origins, and production methods, enabling them to makeinformed decisions and take proactive measures to ensure foodsafety and environmental sustainability.

5) *Improve Consumer Confidence and Trust:* The project aims to improve consumer confidence and trust in agricultural products by enhancing transparency and accountability in pesticide management. By providing consumers with access to detailed information about pesticide usage, crop production methods, and supply chain traceability, the system aims to fos-ter trust, promote informed consumer choices, and strengthen brand reputation for producers and retailers alike.

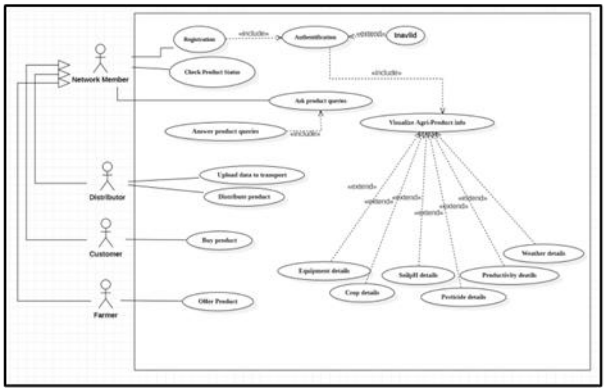

Fig. 2. Use Case diagram Blockchain Powered Pesticide Tracking in SmartFarming.

IV. SYSTEM METHODOLOGIES

A. System Methodology for Implementing IoT in Agriculture:

1) Needs Assessment:: Identify specific challenges and needs within the agricultural sector. Collaborate with farm- ers, agricultural experts, and stakeholders to understand their requirements and pain points.

2) Data Collection and Integration:: Establish robust data collection mechanisms, including wireless sensor networksand IoT gateways. Integrate data from diverse sources, such as IoT devices, satellite imagery, and external databases.

3) Data Processing and Analysis:: Develop data processingpipelines to clean, pre-process, and analyse the collected data. Utilize data analytics tools to extract actionable insights, such as soil moisture levels, weather patterns, and crop health.

4) Connectivity and Network Infrastructure:: Ensure re- liable connectivity through a suitable network infrastructure (e.g., Wi-Fi, cellular, LPWAN). Secure data transmission fromfield sensors to centralized systems.

5) Data Storage and Management:: Set up data storage solutions, like cloud-based platforms or on-premises databases.Implement data security measures and backup protocols to safeguard collected data.

6) Real-time Monitoring and Alerts:: Create real-time monitoring systems that provide farmers with immediate ac- cess to critical data and alerts. Generate alerts for events such as adverse weather conditions or irrigation requirements.

7) Sustainability and Maintenance:: Develop a plan for theongoing maintenance and support of the IoT system. Regularlyupdate hardware and software components to ensure system functionality and security.

8) Data Privacy and Security:: Implement robust data privacy measures to protect sensitive information collected by the system. Use encryption and access controls to secure data in transit and at rest.

9) Public Awareness and Trust Building:: Communicate the benefits of IoT in agriculture to the public, promoting transparency and building trust in technology's impact on foodproduction and sustainability.

V. OVERVIEW OF TECHNOLOGIES

A. Node.js v20.11.1:

Node.js is a JavaScript runtime built on Chrome's V8 JavaScript engine. It allows developers to run JavaScript code outside of a web browser, enabling server-side scripting and building scalable network applications.

B. React Native v0.73.6:

React Native is a framework for building native mobile applications using JavaScript and React. It allows developers to write mobile applications for iOS and Android platforms using a single codebase, speeding up development and reducing maintenance efforts.

C. Truffle v5.11.5 (core: 5.11.5):

Truffle is a popular development framework for Ethereum that simplifies the process of building, testing, and deploying smart contracts. Version 5.11.5 brings updates and improvements to the core framework, enhancing the developer experience for Ethereum developers.

D. Ganache v7.9.1:

Ganache is a personal blockchain for Ethereum development, providing a local testing environment for Ethereum smart contract development and debugging. It allows developers to simulate Ethereum blockchain behaviour, making it easier to test and deploy smart contracts.

H. MongoDB:

MongoDB is a popular, open-source NoSQL database system. It uses a document-oriented data model, makingit flexible and scalable for handling large volumes of data across distributed systems. MongoDB is known for its high performance, scalability, and ease of use. It is commonly used in modern web applications and provides features suchas high availability, horizontal scaling, and flexible data modelling.

I. Ethereum Blockchain:

Ethereum is an open-source, decentralized blockchain plat- form that facilitates the creation of decentralized apps (DApps)and smart contracts. It extends the capabilities of blockchain beyond simple transactions to support programmable con- tracts, which automatically execute when certain conditions are met. Ethereum uses its native cryptocurrency, Ether (ETH),as fuel for executing smart

E. Solidity v0.5.16 (solc-js):

Solidity is a programming language used for writing smart contracts on the Ethereum blockchain. It is statically typed and supports inheritance, libraries, and complex user-defined types. Solc-js is a JavaScript library for compiling Solidity code to EVM bytecode.

F. Web3.js v1.10.0:

Web3.js is a JavaScript library that allows interaction with Ethereum nodes using HTTP or IPC connections. It provides a convenient interface for developers to interact with Ethereum smart contracts, manage accounts, and send transactions programmatically from within their applications.

G. npm v8.19.4:

npm is the package manager for JavaScript, used to install, share, and distribute code libraries and applications. It simplifies the process of managing dependencies in JavaScript projects and facilitates the integration of third-party packages into development workflows.

A. Coding

1) Farmer:: This contract serves as a tool for farmers to efficiently manage and store essential information about

contracts and incentivizing network participants. Developers can build a wide range of applications on Ethereum, including decentralized finance (DeFi), non-fungible tokens (NFTs), and decentralized autonomous orga- nizations (DAOs). Ethereum's blockchain is secured by a con-sensus mechanism called Proof of Work (PoW), although thereare plans to transition to Proof of Stake (PoS) in Ethereum

2.0. Smart contracts on Ethereum are typically written in languages like Solidity and are executed on the Ethereum Virtual Machine (EVM). The Ethereum ecosystem comprises various tools and libraries like Web3.js for interacting with the blockchain, Ganache for local development, and Solidity for smart contract development.

VI. IMPLEMENTATION

their crops on the blockchain. It features functions for initializing default state variables, entering crop details including type, weight, and pesticide information, as well as retrieving this information when needed. This contract is highly adaptable, offering opportunities for extension to include additional crop details such as harvest date, farm location, and crop prices. Furthermore, it can be customized to support management of multiple crops by a single farmer, enhancing its versatility andutility within agricultural contexts.

2) Producer:: This contract offers functionalities crucial for farmers to effectively manage and document essential information about their harvested crops. Through the ”en- terCropDetails” function, farmers can input specifics such as the type of crop harvested, its weight, and details regarding pesticides used during cultivation. This data is stored withina structured ”CropData” associated with the farmer's address. Additionally, the contract facilitates the inclusion of preserva- tion information through the ”addPreservationInfo” function, enabling farmers to record details about chemicals employed for crop preservation. By leveraging the ”getCropDetails”

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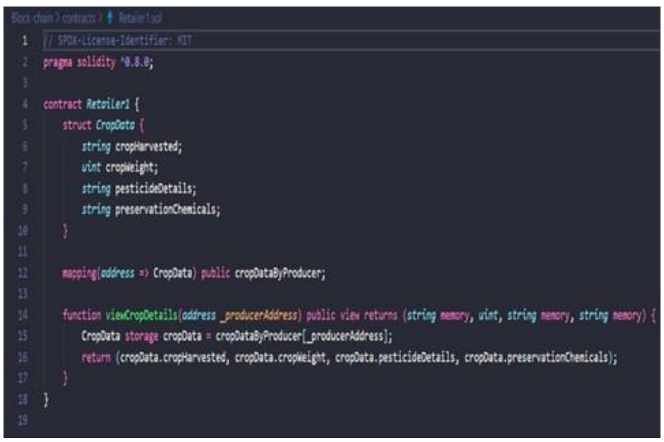


Fig. 3. This Solidity contract, named ”Farmer1”,is designed to store and manage information about crops harvested by a farmer. The contract has three public state variables: ”cropHarvested”, ”cropWeight”, and ”pesticideDetails”. These variables store the type of crop harvested,its weight, and details about the pesticides used.

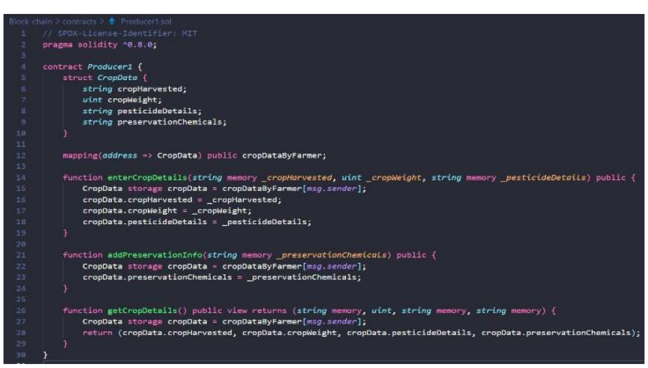


Fig. 4. : This Solidity contract, named ”Producer1”, is designed to store and manage information about crops harvested by farmers. The contract uses a struct called ”CropData” to store information about each crop, including the type of crop harvested, its weight, details about the pesticides used, and details about the preservation chemicals.

function, farmers can effortlessly retrieve the comprehensive set of information they’ve entered about their crop, including crop type, weight, pesticide details, and preservation chemical specifics. This streamlined approach to crop management empowers farmers with a robust system for maintaining crucialcrop-related data on the blockchain, thereby enhancing trans- parency and traceability throughout the agricultural supplychain.

3) *Retailer:* viewCropDetails: This function allows a user to view the details of a crop for a specific producer. The function takes one parameter: producerAddress. It returns a tuple containing the crop harvested, crop weight, pesticidedetails, and preservation chemical details.This contract can be used by retailers to view the details of a crop for a specific producer. This information can be useful for retailers who are interested in purchasing crops from producers. The contract can be extended to include additional information about the crops, such as the price of the crop, the date of harvest, andthe location of the farm. The contract can also be modified to

Fig. 5. This Solidity contract, named ”Retailer1”, is designed to store and manage information about crops harvested by producers. The contract usesa struct called ”CropData” to store information about each crop, including the type of crop harvested, its weight, details about the pesticides used, and details about the preservation chemicals.

allow producers to update the information about their crops, such as the weight of the crop or the preservation chemicals used.

B. Output:

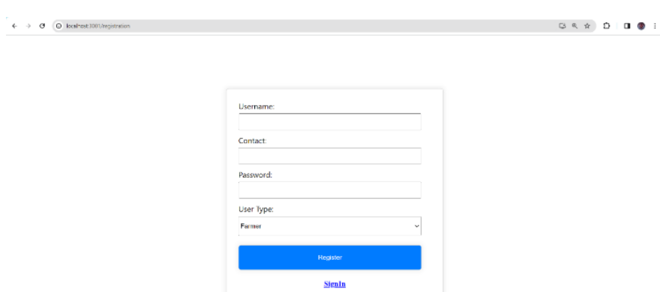
The development process, navigate to the project directory and execute the ”ganache-cli” command in the terminal, initi- ating a local Ethereum blockchain for testing and deployment of smart contracts. Subsequently, utilize ”truffle migrate” to seamlessly deploy contracts onto the Ethereum network, streamlining the deployment process and ensuring proper man- agement of migrations and blockchain state updates. Proceed to the backend directory and run ”node app.js” to launch the backend server, facilitating communication between the frontend application and the Ethereum blockchain. Finally,navigate to the frontend directory and execute ”npm start”to initiate the frontend application, enabling users to interact with the decentralized application through a web browser, thus completing the setup for development and deployment of Ethereum-based applications. This comprehensive workflow integrates various tools and processes to streamline the devel- opment lifecycle, empowering developers to efficiently build decentralized applications.

VII. RESULTS AND DISCUSSIONS

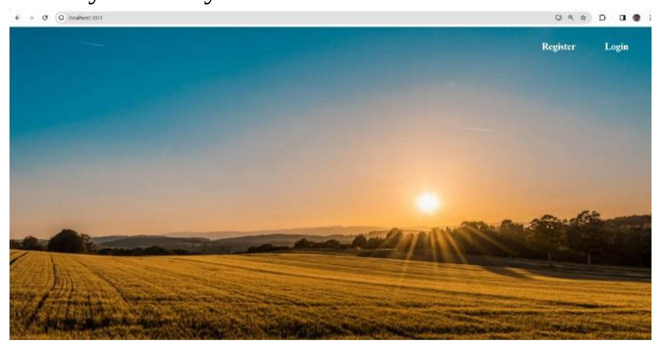
A. Results:

1. Registration and Authentication: The home page of the system offers a seamless registration and sign-in experience, allowing users to identify themselves among

Fig. 6. The homepage serves as the entry point for users, offering options to register or sign in as one of the four actors: farmer, producer, retailer, or consumer. Upon successful authentication, users are redirected to their respective dashboards



the four keyactors: farmer, producer, retailer, or consumer. Upon reg- istration, user details are securely stored in the database, ensuring confidentiality and data integrity. The sign-in process incorporates robust mechanisms for authentication, ensuring only authorized access to the system. In case of unsuccess- ful login attempts, appropriate error messages are displayed, maintaining the security of the system.



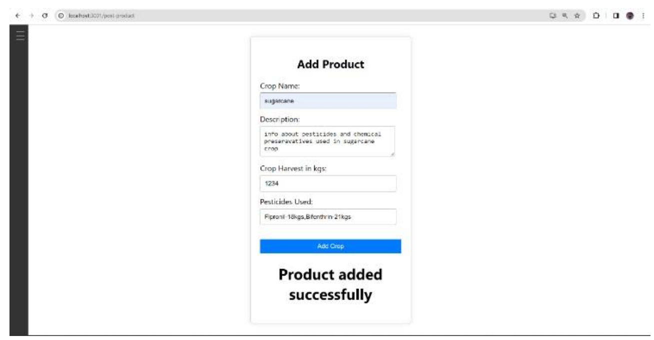


Fig. 7. The registration form for the web application, allowing users to create a new account with a username, contact information, password, and user type. Once registered, users can sign in to access the application’s features.

2. Farmer Interface: Farmers are empowered with a user- friendly interface to input crucial crop information including crop name, harvested amount, and associated pesticides along with their respective quantities. The system facilitates ease of data entry by providing dropdown menus for selecting weight units for both crop yield and pesticide quantities. Furthermore,farmers have the flexibility to add multiple pesticides for a single crop before saving the data. Once submitted, the

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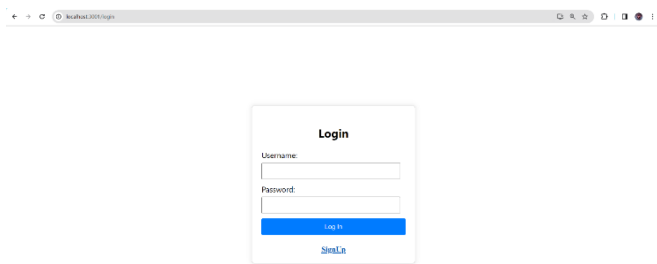

Fig. 8. Login form for the web application, allowing users to access the application's features and services by entering their credentials. Users who haven't registered yet can sign up for a new account by clicking the "SignUp" link or button.

Fig. 9. The farmer dashboard enables farmers to input crop cultivation data, including crop names, harvested amounts, and pesticide usage. The user interface features dropdown menus for selecting weight units and allows for the addition of multiple pesticides before saving the crop details

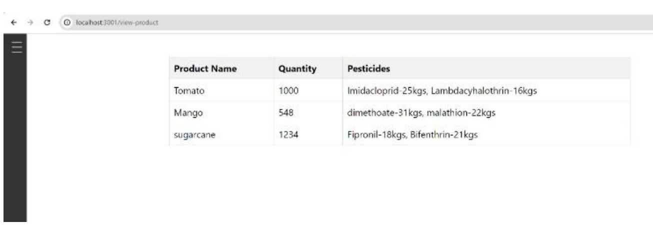

Fig. 10. Table of products, displayed in the Farmer's view product page. The table includes the product name, quantity, and the pesticides used for each product. The table has three products: tomatoes, mangoes, and sugarcanes, with quantities of 1000, 548, and 1234, respectively. The pesticides used for each product are also listed in the table entered data is immutably stored in the blockchain, ensuring its integrity and transparency throughout the supply chain.

3. Producer Interface: Producers gain access to a compre- hensive dashboard displaying all crops inputted by farmers. Upon hovering over individual crops, producers can seam- lessly add preservatives or chemicals along with their quan- tities. Similar to the farmer interface, dropdown menus are provided for selecting weight units, enhancing user experience and data accuracy. The additional information appended by

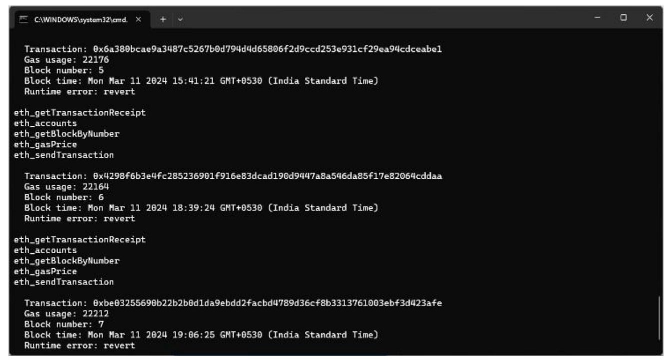

Fig. 11. The output of the ganache command-line interface displaying information related to transactions on the Ethereum blockchain. The output includes transaction hashes, gas usage, block numbers, block times, and error messages, as well as commands to retrieve transaction receipts, account information, block information, gas prices, and send transactions

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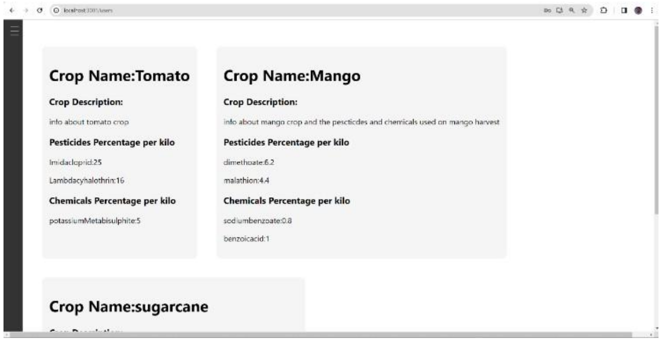

Fig. 12. The following page is where a producer can submit information about a chemical added when producer preserve the yield. The form includes sections for tomatoes, mangoes, and sugarcanes, where the user can enter information about the crop, quantity, pesticides, chemicals, and chemical preservatives used. The Producer can submit the form by clicking the "Submit" button, and the submitted chemicals will be displayed on the page.

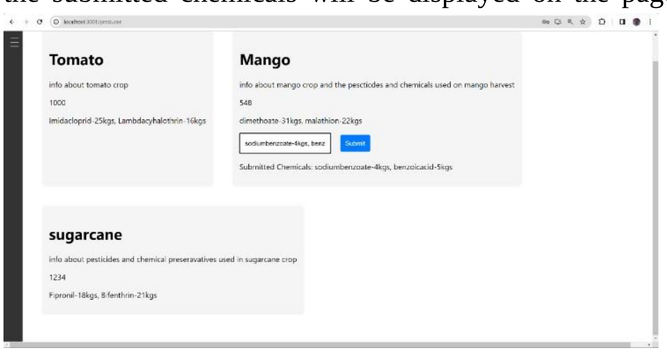

Fig. 13. The backend terminal shows information of the products submitted by the Farmer and the chemicals added by the Producer.

Fig. 14. The Retailer page displays all the products and their pesticides amount added by the Farmer and the amount of chemical preservatives added by the Producer.

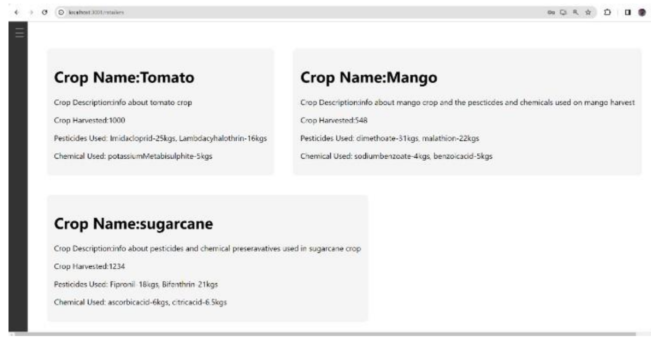

Fig. 15. The Customer page displays the crop along with the amount of pesticides and chemical preservatives added per kilo

producers is seamlessly integrated with the existing crop data, thus enriching the traceability and quality assurance aspects of the system. Each modification made by producers triggers a notification displaying the current number of blocks in the blockchain, fostering transparency and accountability.

4. Retailer Interface: Retailers are provided with a clean and intuitive interface showcasing detailed crop information including inputs from both farmers and producers. The in- tegrated view offers a comprehensive overview of the entire supply chain, enabling retailers to make informed decisions regarding product procurement and distribution. The interface emphasizes clarity and coherence, facilitating efficient naviga- tion and data analysis for retailers.

5. Consumer Interface: Consumers are presented with a user-centric interface displaying crop details in a consumer- friendly format. The system automatically converts the quanti-ties of crops and associated inputs into per kilo units, enabling consumers to make informed purchasing decisions based on product specifications and quality attributes. By providing transparent and accessible information, the system enhances consumer trust and confidence in the agricultural products theypurchase.

B. Discussions:

The development and implementation of the Blockchain-Powered Pesticide Tracking System in Smart Farming signify a pivotal advancement in agricultural technology, effectivelytackling crucial challenges within the supply chain while concurrently bolstering transparency, traceability, and account- ability. This innovative system introduces a radical shift in agricultural data management by harnessing blockchain tech- nology, guaranteeing unparalleled levels of data integrity and immutability. Through the utilization of distributed ledger technology, the system ensures the secure recording and timestamping of all transactions, ranging from crop inputs by farmers to additional annotations by producers, thereby signif- icantly mitigating the risks associated with data manipulationand fraudulent activities. Such advancements underscore the transformative potential of blockchain in instilling trust andreliability within the agricultural ecosystem, thereby heralding a new era of efficiency and security in agricultural operations. Additionally, the user-centric design of the system emerges as a key enabler in facilitating seamless interactions and enhancing user experience across diverse actor roles within the agricultural value chain. The provision of intuitive inter- faces tailored to farmers, producers, retailers, and consumersempowers them with the necessary tools and informationto make informed decisions at every stage of the supply chain. However, the continuous refinement and optimizationof the system's interface design remain imperative to ensureusability and accessibility for a broad spectrum of user groups. Moreover, the successful adoption of the system hinges uponits integration with existing agricultural practices and infras- tructure, necessitating collaborative efforts and stakeholder engagement to ensure seamless interoperability and adoption across the agricultural landscape.

VIII. CONCLUSION

In conclusion, the culmination of the blockchain-powered pesticide tracking project stands as a remarkable leap forward in agricultural technology, representing a fundamental shiftin the management and perception of agricultural data. This project not only embodies a technological innovation but also signifies a profound change in the governance and trans- parency of agricultural supply chains. By leveraging the unique features of blockchain technology—such as immutability, transparency, and decentralization—the system demonstrates its potential to redefine our understanding and management ofagricultural processes.

Through meticulous record-keeping and transparent trans- actional history, the system provides stakeholders with un- paralleled visibility into the journey of agricultural products, from their origin on the farm to consumption by end-users. This heightened transparency fosters consumer confidence in product safety and quality while offering invaluable in- sights for stakeholders across the supply chain. These insights empower stakeholders to optimize production, distribution, and sustainability efforts, leading to more efficient resource allocation and enhanced environmental stewardship.

However, realizing these benefits presents challenges, particularly regarding the scalability of blockchain technology within large-scale agricultural operations. Additionally, en- suring interoperability with existing agricultural systems and navigating complex regulatory frameworks remain ongoing challenges that require strategic planning and collaboration. Nonetheless, the potential impact of the blockchain-powered pesticide tracking system is profound, paving the way for a more resilient, efficient, and sustainable agricultural ecosystem. By facilitating data-driven decision-making, fostering trust among stakeholders, and driving innovation across the value chain, this system holds promise for unlocking new op- portunities for growth, resilience, and positive societal impact.

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