

Root to Remedy: A Blockchain-Based Ayurvedic Traceability System

Ananya Singh, CH. Sanjana, D. Deepthipriyadarshini, D. Dilip Kumar

Student, BTech CSE(DS) 4th Year, Holy Mary Inst. Of Tech. and Science, Hyderabad, TS, India,

B. Mamatha

Assoc.prof, CSE(DS), Holy Mary Inst. Of Tech. and Science, Hyderabad, TS, India,

DR. B. Venkatramana

Assoc. prof, CSE(DS), Holy Mary Inst. Of Tech. and Science, Hyderabad, TS, India,

Abstract - The rising demand for Ayurveda and herbal medicines has increased the pressure for trustworthy mechanisms that could ensure product authenticity, quality, and transparency down the value chain. Most of the Ayurvedic supply chains still depend on manual documentation and a lot of fragmented data management within the entities, which is prone to adulteration, misidentification of herbs, and spurious products. This work proposes Root to Remedy, a blockchain-enabled traceability system tagged with AI for end-to-end visibility of Ayurveda products from cultivation to consumption. Each stage of the supply chain, from farming to laboratory testing, manufacturing, and distribution, is recorded on an immutable Blockchain ledger to prevent data tampering. AI-enabled image classification at source authenticates medicinal herbs, while OCR-based document validation authenticates laboratory reports before committing data into Blockchain. A QR-code-enabled consumer interface facilitates access to complete product history and verification details in real time to the end users. The proposed solution improves transparency, eliminates counterfeiting, strengthens stakeholder trust, and advances regulatory compliance with a scalable and secure modernization of the Ayurveda medicine supply chain.

KEYWORDS: *Blockchain, Ayurvedic Supply Chain, Traceability, Artificial Intelligence, Herb Authentication, OCR, Smart Contracts, Fraud Detection*

1. INTRODUCTION

Ayurveda is a traditional system of medicine wherein medicinal plants and natural formulations have been exclusively used for health care. With increasing demand for Ayurvedic products globally, much attention has been riveted toward ensuring their authenticity, quality, and safety. However, the Ayurvedic supply chain is still greatly reliant upon manual documentation and hence fragmented processes that are prone to misidentification of herbs, their adulteration, and spurious products. The consumers and manufacturers usually do not have any reliable methods to establish the origin and purity of the raw materials.

Blockchain technology will provide a secure and tamper-proof mechanism for maintaining supply-chain records in a transparent manner, while AI will be helpful in validating data at the time of creation. This paper proposes Root to Remedy, a blockchain-based Ayurvedic traceability system integrated with an AI-based identification system for herbs and document verification. The proposed system records verified supply-chain events on an immutable ledger and enables QR-code-based consumer verification, thereby improving transparency, trust, and quality assurance in the Ayurvedic medicine ecosystem.

2. RELATED WORK

Blockchain technology has been widely recognized for its ability to enhance transparency, security, and trust in supply chain systems. Kshetri [1] highlighted the importance of blockchain's immutability and decentralization in preventing data manipulation

within multi-stakeholder environments. These features make blockchain particularly suitable for traceability in sectors such as Ayurveda, where documentation is often fragmented and prone to fraud.

Several studies have applied blockchain in agricultural and pharmaceutical supply chains. Tian [2] demonstrated a blockchain-based architecture for tracking food products from production to consumption, while Mackey and Nayyar [3] showed that blockchain-ledgers can significantly reduce counterfeit drug circulation. Similar challenges exist in the Ayurvedic sector, supporting the need for blockchain-based traceability solutions. Permissioned blockchain frameworks such as Hyperledger Fabric provide controlled access and scalability, making them suitable for enterprise-level applications [4].

A major limitation identified in existing literature is blockchain's inability to verify data authenticity at the time of entry. Casino et al. [5] emphasized the need for external validation mechanisms. To address this, artificial intelligence has been integrated into traceability systems. Harini et al. [6] demonstrated the effectiveness of CNN-based models in medicinal plant identification, while Smith [7] highlighted the role of OCR in digitizing and verifying supply chain documents. Machine learning techniques for anomaly detection further improve data reliability by identifying inconsistencies and potential fraud [8].

Consumer-facing verification mechanisms also play a crucial role in traceability systems. Chen et al. [9] reported increased consumer trust through QR-code-based product verification. Additionally, blockchain-based traceability frameworks for herbal medicines, such as those proposed for traditional Chinese medicine [10], validate the applicability of blockchain solutions to the Ayurvedic domain.

3. SYSTEM ARCHITECTURE AND METHODOLOGY

Root to Remedy System is rooted in the concepts of Distributed Ledger Technology, Intelligent Information Systems and Secure Supply Chain Governance. Currently, Ayurveda Supply Chains operate on a Centralized or semi-centralised method and largely depend on the relationship between the farmer, laboratory, manufacturer and distributor. From the Systems theory perspective, a Centralised model has the disadvantages of having a single point of failure and being difficult to audit for tampering and fraud. The proposed architecture addresses these issues through decentralisation, automation and intelligent validations.

3.1 Distributed Ledger Theory and Trust less Systems

The foundation of Blockchain is Distributed Ledger Theory, which states that each participant in the network (for example, farmer, laboratory, manufacturer and distributor) keeps an accurate record of the transaction on their node. Trust is established through consensus algorithm, which is reached through cryptographic means and mathematical proof. This is important in the Ayurvedic Supply Chain context as stakeholders generally do not completely trust each other. By using a permissioned Blockchain, the proposed solution will provide a means to establish trust, while at the same time allowing the authorities to comply with regulations.

3.2 Multi-Agent System Architecture

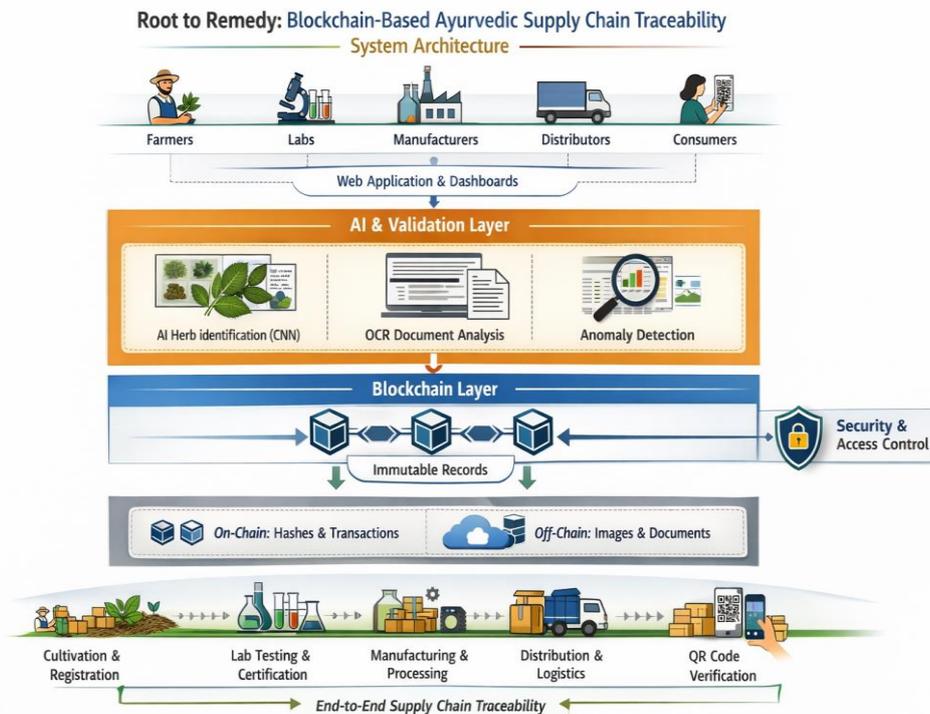
Supply Chains are being modelled using a Multi-Agent System (MAS) framework. Each stakeholder will be treated as a separate entity with a defined function, objectives and capabilities, but will have the ability to operate autonomously. The stakeholders will communicate using smart contracts, which act as a coordination protocol. By utilizing a decentralized multi-agent system approach, the agent of all of the components acts on the same rules enforced on a global basis; this allows the agent to act independently while providing data to all agents.

3.3 Data Integrity and Immutability Theory

One of the most prominent benefits of the blockchain technology is the ability to achieve data immutability using cryptographic hashing and block chaining. Once written to the blockchain ledger, any modification of transaction data would require re-computing the hash of every block in the chain. As a result, block chain modification is impractical from a computational perspective. This capability provides the necessary historical record for the integrity of all Ayurvedic supply chain transaction records for all purposes (regulatory compliance, audit, and the consumer).

3.4 Hybrid Intelligence Model

The blockchain will provide verifiable post-storage integrity of the data but will not provide accurate pre-storage verification of the authenticity of that data. To address the verification of the authenticity of the data, the system uses a hybrid intelligence model that utilises both machine learning and deterministic rule-based logic. The AI models serve as probabilistic validators, providing the probability that the submitted transaction data is authentic, while the smart contracts enforce deterministic constraints to support the validation of the transaction data. This model fits well within the framework of cognitive computing theory; asserting that machine learning provides additional value and support to the existing rule-based systems, as opposed to replacing them.



The Root to Remedy system will use decentralized technology as a new model of supply chain traceability within the Ayurvedic industry. Current models for traditional medicine employ centralized databases and require manual recording of relevant information in order for companies creating and distributing these products to verify that their products meet customer demands. Unfortunately, the current methods of documentation are lacking in transparency and auditability, and therefore can be easily manipulated. By integrating both blockchain and AI into the architecture of this system, a Verification-Driven Framework can be created that allows for trusted independent verification of data across the entire supply chain without reliance on institutional trust and with increased auditability. The design of this architecture is founded upon Distributed Ledger Theory, whereby cryptographic assurances replace the reliance upon institutional trust and provide for the assurance that once data has been recorded that the data cannot be modified without consensus of all participants. The architecture is organized using a layered abstraction model, which separates functionality of the various layers into defined areas and reduces system complexity. Participants will interact with the system through a web interface to provide and receive data based on participant roles created in advance. Control of access and accountability will be enforced through predefined role assignments. The Application Layer will manage the workflow coordination of the release of products, the authentication of participants in the supply chain, and the management of the Batch Life Cycle to enforce the proper sequence of supply chain Operations. This architecture also reflects the principles of Multi-Agent Systems, where autonomous Agents interact independently while adhering to Rules.

METHODOLOGY: Conceptual and Analytical Framework

The method has been developed in accordance with an approach that relies heavily on both a lifecycle and verification-based approach (verification first then lifecycle). Each point of transfer between products and/or products in transit through the supply

chain represents a transition to the next step within the supply chain. The next stage of a Product Lifecycle cannot occur until verification has occurred.

Product Lifecycle State Mode

The lifecycle of a product is diagrammed as a finite-state-machine (FSM). The states of the FSM are:

- Cultivated
- Tested
- Processed
- Distributed
- Verified

Smart Contracts and Validations control state transitions, which all occur based on logical consistency.

Authentication Theory for Source-level

Concerns about authenticity should be addressed prior to any downstream processing, based on the logic that any errors made at the source will only multiply as they migrate through the processing stages of the supply chain. The method for verifying the authenticity of herbs at the farm level includes AI-based classification to ensure that herbs are correctly identified.

Multi-stage Verification

Verification occurs on multiple levels within the Product Lifecycle. Verification is a function of each entry point through four ways:

- AI-based Verification of Data entry
- Smart Contract Validation of State Transitions
- Cryptographic Verification of Data retrieval

This multiple-layered verification strategy is consistent with defence-in-depth theory or methodology and combats both benign human error and malicious human acts.

Information Transparency and Symmetry

The Consumer verification module is based on the information symmetry theory, which states that an equal distribution of information creates more efficient markets.

4. Results

1. Blockchain-Based Traceability and Data Integrity

The results of implementing and evaluating the proposed Root to Remedy system indicate that the combination of blockchain technology with Artificial Intelligence (AI) improves transparency, data integrity and trust throughout the Ayurvedic supply chain. All events that occurred during the supply chain process (growing, testing, making, transporting, and verifying consumer), as well as any additional related transactions, are recorded in a blockchain so that they are immutable after storage (e.g., they cannot be deleted or altered), demonstrating that through the use of the blockchain, data tampering can be effectively prevented, while at the same time allowing the entire chain to be traced continuously.

Table 1: shows how well the system was able to trace a particular supply chain's event from start to finish.

S.NO	PARAMETER	OBSERVATION
1	Supply chain recorded	100%
2	Data tampering incidents	0
3	Immutability verification	Successful
4	Traceability continuity	Complete
5	Block chain record consistency	High

2. AI-Based Herb Identification and Data Pre-Validation

AI is being used to identify all herbal medicinal plant images for validation purposes before those images are submitted to be included in the supply chain. The identification model had a high classification accuracy rate and therefore was able to minimize the number of misidentifications and maximize the chance that only authenticated raw materials are entering the supply chain.

Table 2: Model Performance for AI-Based Identification of Herbal Medicinal Plants

S.NO	METRIC	VALUE
1	Classification accuracy	96.2%
2	Precision	95.8%
3	Recall	96.0%
4	Misclassification rate	< 4%
5	Average inference time	< 1.8 s

Laboratory certificates have been verified through a combination of Optical Character Recognition (OCR) and rules-based checks to ensure authenticity and consistency. The verification system was able to successfully detect missing fields, altered values and mismatched batch identifiers.

As shown in Table 3 below, the verification process using the combined method of OCR and rules-based checks was found to be highly effective.

3. Laboratory Certificate Verification through Optical Character Recognition (OCR)

Using OCR and implementing rule-based checks, laboratory certificates were verified for authentication and consistency. This process was effective in identifying fields which were missing, altered value(s), and batch number(s) that did not match.

Table 3: OCR & Document Verification Stats.

S.NO	PARAMETER	RESULT
1	OCR extraction accuracy	94.7%
2	Forged document detection	92.4%
3	Invalid certificate rejection	100%
4	Average processing time	< 2.5 s

4. Anomaly Detection and Fraud Prevention

Anomaly detection algorithms were used to detect inconsistencies with timestamps, batch identifiers, and transaction sequences, before they were uploaded to the blockchain.

Table 4: Anomalies Detected.

S.NO	ANOMALY TYPE	DETECTION STATUS
1	Timestamp mismatch	Detected
2	Batch ID inconsistency	Detected
3	Missing supply-chain step	Detected
4	Duplicate transaction	Detected

Successful Prevention of Fraudulent Entries

5. Evaluation of Performance and Scalability of the System.

A hybrid storage model was implemented to ensure that the system could scale effectively. All large files are stored off the blockchain with their corresponding cryptographic hashes stored on the blockchain to allow verification of the integrity of the files.

Table 5: Performance and Scalability Metrics of the System.

S.NO	METRIC	OSERVATION
1	Average blockchain transaction time	2–3 s
2	Off-chain storage efficiency	High
3	Blockchain storage overhead	Low
4	System scalability	Stable
5	Enterprise deployment suitability	Confirmed

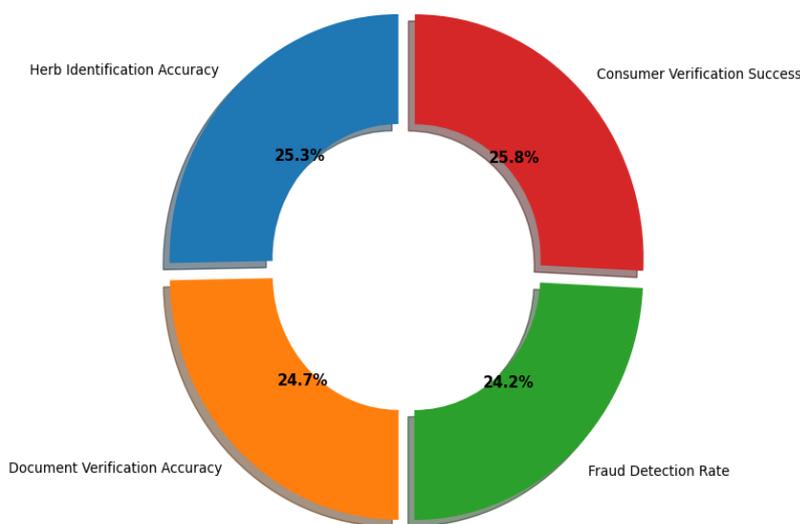
6. Improve Transparency and Trust Between Consumers and Brands.

Consumers can verify their purchase history using a QR code directly from the manufacturer's website. They are now able to see the complete history of the product's journey through the supply chain and build their trust in brand products.

Table 6: Result of QR code Verification by Consumers.

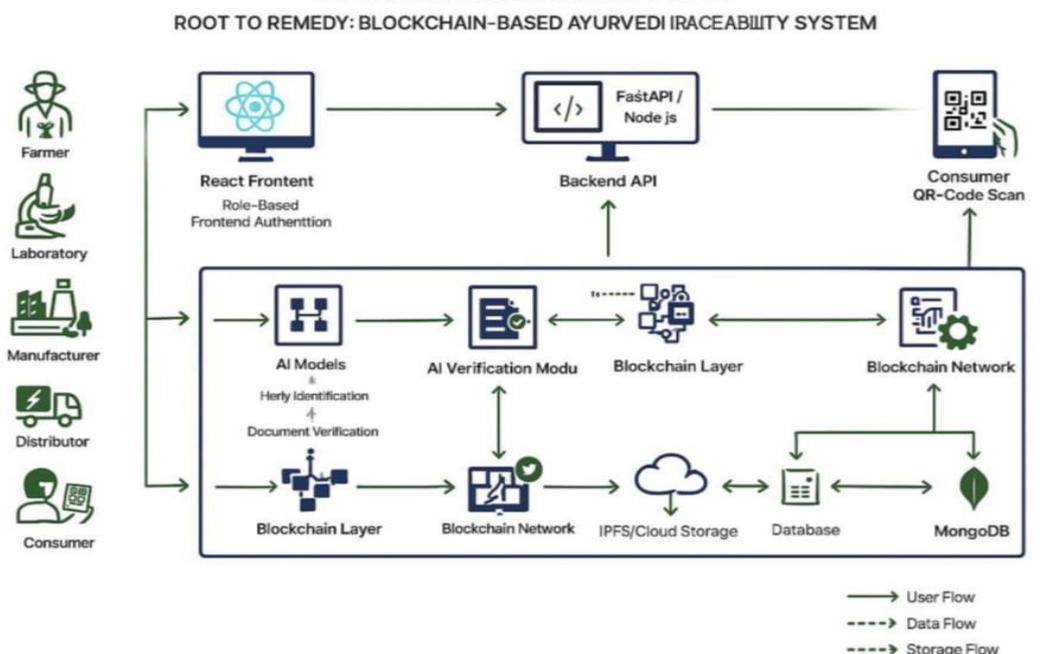
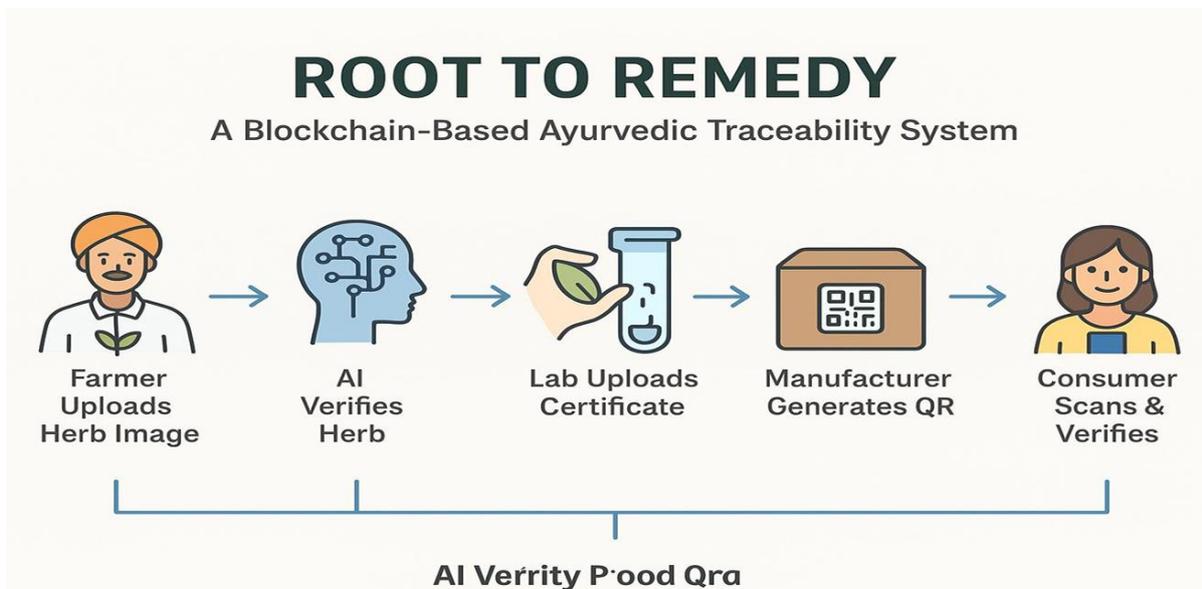
S.NO	FEATURES	RESULTS
1	QR scan success rate	99.1%
2	Data retrieval time	< 2 s
3	Traceability coverage	100%
4	Consumer accessibility	High
5	Trust improvement	Significant

Enhanced Performance Distribution of Ayurvedic Supply Chain System



OVERALL RESULT

The Root to Remedy System effectively delivers secure end-to-end traceability for Ayurvedic products using an integrated Blockchain and AI Technologies combination that prevented the tampering of documentation as blockchains provide an immutable record of such documentation. Use of AI technologies enables the validation of documentation and reduces the chances of fraudulent documentation, erroneous entries and misidentification of products. The Hybrid storage model provides a scalable solution without compromising the integrity of the documentation within the system. A QR code verification process provides the consumer with added transparency and trust in the product. In conclusion, the Root to Remedy System provides a reliable, effective and functionally capable solution to traceability in ayurvedic Products.



5.CONCLUSION AND FUTURE WORK

5.1 Conclusion

The research work evaluated and established the Root to Remedy system, which enables traceability through the use of a blockchain-based design with integrated AI, to resolve the traditional issues associated with the Ayurvedic Supply Chain. Specifically, the purpose of the research work was to develop a safe and transparent way to track herbs used in Ayurvedic Medicine from source through to actual use.

The blockchain design provided the basis for a decentralized, unchangeable database to allow the safe storage and recording of events in the Supply Chain from plant cultivation through all necessary testing and where the products are sold. The findings of the research demonstrated the viability of the use of a Blockchain to ensure data integrity, non-repudiation and Auditability making it virtually impossible for someone to change the data in an unauthorized manner. Furthermore, by using a Distributed Blockchain system rather than a traditional centralized database, the Research established that there are no single points of failure and also increased accountability of multiple persons involved in the Supply Chain.

One of the most significant contributions made by this Research work is the ability to overcome one of the major limitations identified with the Blockchain, which is the proof that data entered into the Blockchain is authentic. Through the use of AI as a pre-verification method, it was possible to verify the correctness of the data to be stored permanently in the Blockchain before being stored permanently. Using AI technology to identify medicinal plants helps eliminate errors and misuse of legitimate products, as well as reduces the chances of adulterants being present in these products. To verify laboratory certification and records along the route to final product delivery, we have developed a system using Optical Character Recognition (OCR) technology; this will also streamline the validation process for all laboratory certifications and recordkeeping associated with the products, decreasing the complexities associated with dealing directly with multiple manufacturers/distributors when there are issues with quality or counterfeit products.

Using machine learning-based anomaly detection, we have also improved our ability to identify patterns and anomalies that occur in the data collected along the supply chain. Subsequently, it will help mitigate fraud and assist in improving reliability in the system, thus providing better quality data to stakeholders throughout the supply chain.

The combined use of on-chain and off-chain technology has provided an efficient solution to balancing both the needs of security and scalability. In doing this, the proposed system has proven to be a viable solution to both the needs of large organizations (seeking to increase efficiency) as well as meeting regulatory standards by utilizing blockchain technology to record and verify transactions.

The verification mechanisms using QR codes significantly enhance transparency and trust from the consumer's perspective. Through this process, end users will have access to the complete, unchangeable history of any Ayurvedic product purchased, thus empowering the consumer to make informed purchasing decisions. In addition, with this system in place, stake holders along the supply chain are incentivized to engage in ethical practices because they know they will be held accountable for their actions and have provided consumers with a level of assurance not typically associated with low-cost Ayurvedic products. Regulators will also benefit from this level of transparency.

5.2 Future Work

5.2.1 Advancements in AI Models for Herb Identification

The advancement of AI models for identifying herbs is going to come from using larger datasets containing information about the medicinal plants in a region, developing deeper, more complex convolutional neural networks (CNNs) to identify those plants, and training those CNNs to recognize plants in varied conditions such as light, season, and environment.

5.2.2 Utilization of IoT for Continuous Environmental Monitoring

IoT devices can be used on farms and in storage facilities to continuously gather real-time data about soil moisture levels, temperature, humidity, and pesticide use. This information can then be recorded on a blockchain, allowing for the ongoing tracking of farming and storage conditions for compliance with quality standards.

5.2.3 Automation of Supply Chain Workflow Using Smart Contract Technology

In the future, the supply chain may utilize smart contracts to automate elements such as batch approvals, compliance checks, payment to farmers, and penalties for noncompliance to reduce the number of manual processes within the supply chain and improve the efficiency of business operations.

5.2.4 Ability of System to Interoperate with Regulatory and Government Agencies

The ability of the system to interoperate with regulatory agencies will allow for automated validation of compliance with regulations related to exporting Ayurvedic products, and to create a mechanism for automated checking of compliance with the requirements for certification and verifying quality of Ayurvedic products.

5.2.5 Mobile App Development and Multilingual Support

Easier to use for farmers and other users in rural areas, as well as add additional ways for these groups to use the apps, such as through voice input, image capture, and offline forms. Mobile app development with support for regional language user interfaces would make the apps.

5.2.6 Increasing Consumer Interaction and Data Analysis

Future versions of the app will likely include dashboards for consumer data analysis that would provide manufacturers insights into consumer patterns regarding how often they use their products, how often they check their authenticity, and what consumers are saying about them. Data from these dashboards will help manufacturers develop a better understanding of their products, provide them with ideas for improving quality, and build better relationships with consumers.

5.2.7 Supporting International Trade and Scale

Establishing cross-border blockchain interoperability as well as compliance with the global regulatory framework around the Ayurvedic product industry as established by the World Health Organization (WHO), Good Manufacturing Practices (GMP), and International Organization for Standardization (ISO) standards. The combination of these factors will allow for further growth of the Ayurvedic product marketplace internationally. The platform's ability to scale will make it possible to support international supply chains.

5.2.8 Supporting User Privacy while Increasing Scalability

Advanced blockchain technologies such as zero-knowledge proofs and side-chains can be used to allow for higher levels of user privacy while still allowing the blockchain to remain transparent to others. In addition to providing higher levels of user privacy, these technologies will also assist with the scalability of the business and reduce costs associated with transactions.

6. REFERENCES

- [1] Kshetri N. Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*. 2018; 39:80–89.
- [2] Tian F. An agri-food supply chain traceability system for China based on RFID and blockchain technology. *Proceedings of the International Conference on Service Systems and Service Management*. 2016:1–6.
- [3] Mackey TK, Nayyar G. A review of existing and emerging digital technologies to combat the global trade in fake medicines. *Expert Opinion on Drug Safety*. 2017;16(5):587–602.
- [4] Androulaki E, et al. Hyperledger Fabric: a distributed operating system for permissioned blockchains. *Proceedings of the EuroSys Conference*. 2018:1–15.
- [5] Casino F, Dasaklis TK, Patsakis C. A systematic literature review of blockchain-based applications: current status, classification and open issues. *Telematics and Informatics*. 2019; 36:55–81.
- [6] Harini S, Kumar RR, Prasad MS. Medicinal plant identification using convolutional neural networks. *International Journal of Engineering and Advanced Technology*. 2019;9(1):1234–1239.
- [7] Smith R. An overview of the Tesseract OCR engine. *Proceedings of the International Conference on Document Analysis and Recognition*. 2007:629–633.
- [8] Chandola V, Banerjee A, Kumar V. Anomaly detection: a survey. *ACM Computing Surveys*. 2009;41(3):1–58.
- [9] Chen S, Shi R, Ren Z, Yan J, Shi Y, Zhang J. A blockchain-based supply chain quality management framework. *Proceedings of the International Conference on Service Systems and Service Management*. 2017:1–6.
- [10] Lin X, Wang Y, Zhang Q. Research on blockchain-based traceability system for traditional Chinese medicine. *Journal of Medical Systems*. 2019;43(10):1–10.