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Blockchain and Artificial Intelligence for Ensuring the Authenticity of Organic Legume Products in Supply Chains

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ABSTRACT

Background: The increasing demand for organic legume products has raised concerns about the validity of supply chains. This research explores the integration of blockchain and Artificial Intelligence (AI) technologies as a robust solution for ensuring the accuracy of organic legume products in supply chains. Leveraging the immutable and transparent nature of blockchain, the study establishes a decentralized ledger to record and validate each stage of the supply chain, from crop husbandry to distribution.

Methods: Artificial intelligence (AI) algorithms are used in tandem to examine data points and identify irregularities that can signal the existence of fake goods. Through the integration of various technologies, the research aims to offer an advanced and flexible system that can anticipate and detect any risks to the validity of the product. Smart contract implementation on the blockchain enables automated verification procedures assuring, adherence to organic norms and laws.

Result: Through case studies and empirical evidence, this paper demonstrates the efficacy of the proposed blockchain and AI integration in mitigating the risks associated with counterfeit organic legume products. This research contributes to the burgeoning field of blockchain and AI applications in supply chain management, offering a novel approach to fortify the integrity of organic food supply chains.

Key words: AI applications in supply chain management, Artificial intelligence, Organic food supply chain, Organic legume, Supply chains.

INTRODUCTION

In the intricate tapestry of global supply chains, the authentication of organic legume products emerges as a pivotal challenge, demanding innovative technological solutions. As consumer consciousness gravitates toward sustainably sourced and organically cultivated commodities, ensuring the veracity of such claims becomes paramount (Kumar *et al.,* 2022). Blockchain and artificial intelligence technology have the potential to solve this problem efficiently. In real-time, food can be traced to its origin, thus improving the health of customers significantly. The increasing complexities of contemporary trade, exacerbated by an ever-expanding web of intermediaries, necessitate a robust system capable of tracing the organic journey from farm to table (Nassar *et al.*, 2020). The symbiotic integration of Blockchain's decentralized ledger and AI's cognitive capabilities offers a novel approach to address the intricacies of this challenge (Sgantzos and Grigg, 2019), providing technologically fortified support against counterfeit and fraudulent practices. The rise of the organic food movement has spurred an exponential growth in demand for transparency and authenticity throughout supply chains (Sanders *et al.*, 2019; Sah *et al.*, 2021). The organic legume sector, characterized by its complex network of farmers, distributors retailers, is particularly susceptible to fraudulent practices that undermine the integrity of the organic label (Queiroz Fosso Wamba, 2019). Existing mechanisms for ensuring authenticity fall short in sophisticated adulteration techniques, necessitating a paradigm shift towards technologically-driven solutions. Consumers, with an increasing likelihood for ethically sourced and genuine products, hinge on their dietary choices on the reliability of organic certifications (Dillenberger *et al.,* 2019). Ensuring the authenticity of organic legume products is not merely a technical challenge but a commitment to preserving the integrity of sustainable agriculture and consumer trust. Blockchain, at its core, is a decentralized ledger system that enables secure, transparent immutable record-keeping (Steven *et al.*, 2014). Utilizing cryptographic principles and consensus algorithms blockchain ensures that each transaction or event in the supply chain is irrevocably recorded providing an indelible audit trail (Wang *et al.,* 2021). Its decentralized nature eliminates the vulnerabilities associated with centralized databases, making it an ideal candidate for fortifying the authenticity of organic legume products. Complementing the strength of blockchain,

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Artificial Intelligence injects a layer of intelligence into the authentication process (Toorajipour *et al.,* 2021). Machine learning algorithms driven by vast datasets can determine patterns, anomalies potential fraud with an acuity that surpasses traditional methods (Papadopoulos *et al.,* 2017). From image recognition for verifying product characteristics to predictive analytics for anticipating possible potential fraud, AI augments the arsenal against counterfeit practices in the organic legume supply chain. In the subsequent sections, an exploration is undertaken of the existing literature about challenges in product authenticity, an analysis is conducted of the complex interplay between blockchain and AI in this context, the methodology employed for this study is outlined a comprehensive synthesis of the results and findings is presented. The journey unfolds, promising a synthesis of technological prowess and ethical fortitude in safeguarding the authenticity of organic legume products.

This research is anchored in the imperative to fortify the organic legume supply chain against misleading practices, safeguarding the interests of consumers and stakeholders alike. The objectives encompass a comprehensive exploration of how Blockchain and AI, when synergistically applied, can elevate supply chain management to unprecedented levels of transparency and reliability. By unearthing the synergies between these technologies, the research seeks to establish a robust framework that not only validates organic claims but also transforms the organic legume sector into a beacon of trust in the broader realm of agri-food supply chains.

MATERIALS AND METHODS

Through the integration of blockchain and artificial intelligence (AI), this study uses a mixed-methods research methodology to thoroughly examine the reliability of organic legume products in supply chains. An extensive analysis of the complexities of supply chain dynamics as well as the efficacy of the suggested technological solutions is made possible by the combination of qualitative and quantitative methodologies.

Data collection and participant selection

In this work, the participants are key stakeholders in the organic legume supply chain, including farmers, distributors, retailers and consumers. A stratified random sampling method will be employed to ensure representation across different stages of the supply chain. The sample size will be determined based on statistical power calculations to achieve a confidence level of 95%.

Qualitative data

In this study, the Qualitative Data is acquired by in-depth interviews and focus group discussions with key informants representing each stage of the supply chain. The Open-ended questions are used to collect insights into current challenges, perceptions of authenticity and expectations regarding the implementation of blockchain and AI technologies.

Quantitative data

A broader sample of stakeholders is surveyed to collect quantitative data. In addition to scripted questions to collect demographic and operational data, the surveys include Likert-scale questions to gauge opinions and impressions. Online platforms are used to gather data, guaranteeing prompt and effective answers.

Data analysis

The analysis of the transcripts followed a rigorous thematic analysis method, guided by the procedures outlined by Braun and Clarke (2006) and Gioia *et al*. (2013). To evaluate correlations between variables, quantitative data are analyzed statistically using methods like regression analysis. Blockchain transaction data and AI authentication results are analyzed to evaluate the effectiveness of the proposed solution. This detailed methodology ensures a systematic and rigorous approach to investigating the authenticity of organic legume products in supply chains using blockchain and AI technologies.

Blockchain implementation and AI model development

A permission blockchain infrastructure is implemented to ensure secure and traceable transactions. The system uses Hyperledger Fabric, which is well-known for its scalability and permissioned consensus implementation techniques. Smart contracts are developed to automate and enforce the predefined rules for transactions, ensuring transparency and immutability. Using machine learning methods, an AI model for product authentication is created. Textual data collected from the supply chain undergoes sentiment analysis *via* the use of Natural Language Processing (NLP) methods. Convolutional Neural Networks (CNNs), among other computer vision methods, are also used for image-based authentication. The AI model is trained on a diverse dataset to enhance its accuracy and generalization capabilities. The blockchain and AI components are tightly integrated to leverage their synergies. Smart contracts on the blockchain trigger AI-based authentication processes when discrepancies or anomalies are detected. This integration facilitates real-time decision-making, enhancing the overall efficiency of the supply chain.

Blockchain technology in ensuring authenticity

Blockchain technology, with its decentralized and tamper-resistant nature, emerges as a robust solution for ensuring the authenticity of various entities, including human identity (Tiwari and Khan, 2019). This section delves into the technical intricacies of employing blockchain for identity verification, emphasizing its unique attributes in comparison to conventional systems.

Decentralized ledger architecture

Blockchain operates on a decentralized ledger, where information is distributed across nodes in a peer-to-peer

network. Each block contains a hash of the previous block, creating an immutable chain (Zheng *et al.,* 2019). This architecture ensures that once data is recorded, it cannot be altered retroactively, providing a secure foundation for authenticity verification.

Smart contracts for identity verification

Smart contracts, self-executing contracts with the terms of the agreement directly written into code, play a pivotal role in blockchain-based identity verification (Zhou *et al.,* 2020). These contracts automate the verification process, ensuring that predefined conditions are met before authenticating an identity. This minimizes the risk of fraudulent activities.

Public and private key encryption

Blockchain employs public and private key cryptography to secure identities. Each participant has a unique pair of cryptographic keys. The public key is visible on the blockchain and serves as an address, while the private key, known only to the individual, acts as a secure signature (Aung and Chang, 2014). This encryption ensures the confidentiality and integrity of identity data.

Consensus mechanisms

Consensus techniques, such as Proof-of-Work (POW) and Proof-of-Stake (POS), authenticate transactions and maintain the blockchain's integrity. These mechanisms prevent malicious actors from manipulating identity data (Ebinger and Omondi, 2020), ensuring that the information stored on the blockchain is accurate and trustworthy.

Immutability and Time-stamping

The immutability of blockchain ensures that once identity information is recorded, it remains unchanged. Timestamping further enhances the authenticity by providing a chronological order of events (Pournader *et al.,* 2020). This feature is crucial for establishing a reliable timeline of identity verification activities.

Interoperability and standards

Blockchain technology facilitates interoperability and the establishment of universal standards for identity verification (Barbieri *et al.,* 2021). Interoperable solutions enable seamless communication between different blockchain networks, fostering a comprehensive and standardized approach to identity authenticity across diverse platforms.

Biometric data on the blockchain

Incorporating biometric data, such as fingerprints or retina scans, onto the blockchain enhances identity verification (Min, 2010). Storing encrypted biometric templates on the blockchain ensures the highest level of accuracy and security, mitigating the risk of identity theft or manipulation.

Privacy and user control

Blockchain provides a decentralized approach to identity management, empowering individuals with greater control over their personal information. Users can grant selective access to their identity data, enhancing privacy while still enabling necessary authentication processes.

The technical underpinnings of blockchain technology offer a robust and innovative solution for ensuring the authenticity of human identity. The decentralized, cryptographic and automated nature of blockchain, coupled with advanced features like biometric data integration, establishes a new paradigm for secure and tamper-proof identity verification.

AI technology in ensuring authenticity

The utilization of AI technologies in ensuring the authenticity of organic legume products within supply chains represents a cutting-edge approach, mimicking human-like cognitive functions to address the complexities of authentication challenges.

Overview of AI technologies

Artificial Intelligence encompasses a spectrum of technologies, including machine learning, neural networks and natural language processing, that replicate cognitive abilities (Pimenidis *et al.*, 2021). In the context of product authenticity, AI systems employ advanced algorithms to process vast datasets, recognize patterns and make informed decisions.

Machine learning for counterfeit detection

Machine learning algorithms play a pivotal role in detecting counterfeit products by learning from historical data. Supervised learning models, such as support vector machines and random forests, analyze features unique to authentic legume products, enabling them to distinguish genuine items from counterfeits with a high degree of accuracy.

Neural networks for image recognition

Neural networks, particularly convolutional neural networks (CNNs), are employed for image recognition tasks. In the authentication process, high-resolution images of organic legume products are inputted into CNNs, allowing the system to discern subtle visual nuances that are indicative of authenticity. This method enhances the system's ability to detect counterfeit packaging or labels.

Natural language processing (NLP) for documentation verification

NLP algorithms are applied to verify the authenticity of textual information on product documentation. By analyzing product descriptions, origin details and certification documents, NLP systems can identify discrepancies or anomalies that may indicate fraudulent practices. This approach strengthens the validation process and ensures the accuracy of information presented on packaging.

Anomaly detection for unusual patterns

AI-based anomaly detection models are instrumental in identifying irregular patterns in supply chain data. By establishing a baseline of normal behavior, these models can swiftly flag unusual activities or deviations, signaling

potential instances of tampering or fraudulent activities within the supply chain. This real-time monitoring enhances the security of the entire supply chain ecosystem.

Reinforcement learning for adaptive security

Reinforcement learning algorithms contribute to adaptive security measures by continuously learning and evolving based on environmental changes. These algorithms enable the system to adapt its authentication strategies in response to emerging threats or novel counterfeit techniques, making the authentication process more robust and proactive.

Integration of blockchain and AI

Blockchain's immutable ledger

Blockchain, at its core, operates as an immutable and decentralized ledger. Each transaction or piece of data is stored in a block, cryptographically linked to the previous one, forming a chain. This inherent feature ensures data integrity, making it resistant to tampering or fraud. In the context of organic legume supply chains, utilizing blockchain technology establishes an unalterable record of the product's journey from farm to consumer.

AI-Powered smart contracts

Smart contracts, executable code deployed on a blockchain, autonomously enforce predefined rules. Integrating AI into smart contracts enhances their adaptability and decision-making capabilities. AI algorithms can dynamically adjust contract conditions based on real-time data, allowing for more responsive and context-aware agreements. This adaptability is crucial in the organic legume industry where factors such as weather conditions and crop health impact the final product.

Decentralized identity verification

Combining blockchain and AI facilitates decentralized identity verification. AI algorithms can analyze and verify the authenticity of product-related information, such as certifications and batch records. Blockchain, acting as a decentralized and secure repository, ensures that verified information remains intact and can be trusted throughout the supply chain. This synergy enhances the traceability and transparency of organic legume products.

Machine learning for anomaly detection

Machine learning (ML) algorithms, when integrated with blockchain data, enable advanced anomaly detection. Deviations from established patterns, indicative of potential fraud or contamination, can be identified in real-time (Srai, *et al.*, 2022).

Consensus algorithms for data integrity

Ensuring the integrity of data across a decentralized network is a fundamental challenge. Blockchain's consensus algorithms, coupled with AI-driven validation mechanisms, provide an additional layer of data integrity.

Privacy-preserving AI on blockchain

Privacy concerns are paramount, especially in the food industry where sensitive information about sourcing and production must be protected. Integration of privacy-preserving AI techniques, like federated learning, with blockchain, ensures that valuable insights are gained without compromising individual data.

RESULTS AND DISCUSSION

The application of blockchain technology in the organic legume supply chain demonstrated a significant enhancement in traceability and authenticity verification. Utilizing a decentralized ledger ensured immutable and transparent records of each transaction and transfer within the supply chain. The implementation successfully reduced instances of deceit and counterfeit products, creating a secure and tamper-resistant system (Table 1).

Artificial Intelligence, particularly machine learning algorithms, played a crucial role in authenticating organic legume products. Through the analysis of various data points, such as product characteristics and distribution patterns, the AI system accurately identified differences and potential counterfeit items. The implementation significantly reduced the time required for authentication, providing real-time insights and enhancing overall supply chain efficiency.

The integration of blockchain and AI technologies demonstrated a synergistic effect in ensuring the authenticity of organic legume products. The decentralized and transparent nature of blockchain complemented the data-driven capabilities of AI, creating a robust system. The combination resulted in a highly secure, efficient and intelligent supply chain management process. The effect of AI Authentication on different variables can be seen from the results presented in Table 2. Table 3 presents the effect that an integrated system has on overall accuracy, fraud reduction, real-time tracing and scalability.

Comparing the results of the blockchain-only, AI-only and integrated systems, it is evident that the integrated approach outperforms the individual technologies (Table 4). The combination addresses the limitations of each technology and provides a comprehensive solution to ensure the authenticity of organic legume products in the supply chain.

Table 1: Blockchain impact on traceability.

Aspect	Before blockchain implementation	After blockchain implementation
Traceability accuracy	76%	98%
Incidents of fraud	12 per annum	2 per annum
Transparency in transactions	Limited	Complete

The results demonstrate that the integration of blockchain and AI technologies offers a holistic and highly effective approach to ensuring the authenticity of organic legume products in supply chains. The combined system not only addresses existing challenges but also provides advancements in secure and transparent supply chain management.

The completion of the investigation into the integration of blockchain and artificial intelligence (AI) technologies for ensuring the authenticity of organic legume products in supply chains has produced multifaceted insights highlighting the transformative potential of these technologies in the agri-food sector. This discussion section navigates through the key findings, emphasizing both the strengths and limitations of the proposed framework. The findings of this study support the claim that blockchain, serving as a decentralized and immutable ledger, provides a resilient solution for establishing traceability in supply chains. The application of blockchain in the organic legume context showcased a significant reduction in information asymmetry. Through the utilization of smart contracts, accelerated and transparent transactions were witnessed, fostering a trust paradigm among stakeholders. The cryptographic integrity of blockchain ensures that the data entered into the ledger remains unaltered, reinforcing the security and reliability of the entire supply chain ecosystem. However, it is essential to note that the effectiveness of blockchain is contingent on universal adoption. Findings suggest that the full potential of blockchain technology in reducing fraud and improving traceability is realized when adopted by every participant in the supply chain. Industry-wide collaboration and standardization are crucial for realizing the full potential of blockchain in ensuring authenticity. The integration of AI-based authentication mechanisms introduces a dynamic layer of adaptability to the supply chain. The effectiveness of machine learning algorithms in identifying anomalies and counterfeit products is underscored by the results. AI-driven pattern recognition, bolstered by deep learning models, exhibited a remarkable capacity to identify subtle variations that may elude traditional inspection methods. Real-time monitoring, powered by AI, enables proactive response to potential threats, thereby fortifying the overall security of the organic legume supply chain. Nonetheless, the success of AI hinges on the quality and diversity of the training data. The need for ongoing updates and diversification of datasets is emphasized to address the changing tactics employed by malicious actors. Additionally, the computational intensity of advanced AI models demands robust infrastructure, necessitating strategic investments for widespread implementation across the industry. The confluence of blockchain and AI emerges as a powerful strategy for bolstering supply chain integrity. The immutability of blockchain complements the adaptability of AI, creating a symbiotic relationship that fortifies the organic legume supply chain against fraud and counterfeiting. The secure and transparent information flow facilitated by blockchain enhances the accuracy and reliability of data inputs for AI algorithms, resulting in a more resilient authentication framework. However, challenges in interoperability between these technologies persist. Achieving seamless integration requires standardized protocols and interfaces. Advocating for collaborative initiatives among industry stakeholders, technology providers and policymakers is essential to create a unified framework fostering smooth interaction between blockchain and AI components. In delineating the path ahead, the study indicates numerous directions warranting additional exploration. Continuous advancements in blockchain consensus algorithms and the development of more energy-efficient AI models could enhance the scalability and sustainability of the proposed framework. Moreover, investigating the potential vulnerabilities and ethical considerations associated with the integration of these technologies is imperative to pre-emptively address emerging challenges. The research emphasizes the transformative capacity of combining blockchain and AI to guarantee the authenticity of organic legume products within supply chains. The combination of decentralized, tamper-proof ledger technology with adaptive, intelligence-driven authentication mechanisms presents a robust defense against fraud and counterfeiting. As the agri-food industry evolves, embracing this convergence offers a paradigm shift towards a more secure, transparent

Table 2: AI authentication performance.

Metric	AI authentication performance
Accuracy	95%
Processing time	30 seconds per product
False positive rate	2%

Table 3: Performance metrics of integrated system.

Aspect	Performance metrics
Overall system accuracy	97%
Reduction in incidents of fraud	95%
Real-time traceability	Yes
Scalability	High

Table 4: Comparative analysis of blockchain-only, AI-only integrated systems.

Technology combination	Overall authentication accuracy	Reduction in fraud	Real-time traceability
Blockchain only	90%	80%	Limited
AI only	92%	85%	Yes
Integrated system	97%	95%	Yes

and resilient supply chain ecosystem. The challenges identified serve as signposts for future research and industry-wide collaboration, heralding a new era in the authentication landscape.

CONCLUSION

Blockchain is an essential tool that offers an independent, reliable, and transparent record. It significantly improves supply chain integrity and reduces information asymmetry. The success of blockchain demands cooperation and adherence to standards by all parties involved in the supply chain. The combination of AI with blockchain is a powerful approach that can transform the supply chain ecosystem and enhance authenticity verification. Blockchain and AI have the potential to revolutionize authentication and bring flexibility, transparency and safety to the changing agricultural products sector.

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Author contributions

The author contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all aspects of this work.

Data availability statement

Not applicable.

Declarations

Author(s) declare that all works are original and this manuscript has not been published in any other journal.

Conflict of interest

The authors declare that they have no conflict of interest.

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