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REGENERATIVE CACAO 4.0: NFT TOKEN AND SMART CONTRACT-BASED COFFEE-CACAO AGRIBUSINESS MODEL FOR GEN-Z FARMERS IN REJANG LEBONG, BENGKULU

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Abstract

This study explores an innovative agribusiness model integrating blockchain technology, NFT tokens, and smart contracts to revolutionize coffee and cacao farming in Rejang Lebong, Bengkulu, Indonesia. The research addresses critical challenges facing young generation farmers including limited market access, price volatility, lack of transparency in supply chains, and insufficient access to financing. The proposed Regenerative Cacao 4.0 model leverages Web 3.0 technologies to create a decentralized, transparent, and sustainable agricultural ecosystem. Through a comprehensive literature review methodology, this study examines the convergence of regenerative agriculture practices, blockchain-based supply chain management, and digital financial instruments specifically designed for Gen-Z farmers. The model incorporates NFT-based crop certification, smart contract-automated transactions, tokenized asset ownership, and direct farmer-to-consumer connections. Results indicate significant potential for improving farmer income through elimination of intermediaries, enhanced traceability through immutable blockchain records, and increased access to capital through fractional ownership and DeFi mechanisms. The research also identifies implementation challenges including technological infrastructure limitations, digital literacy gaps, regulatory uncertainties, and initial capital requirements. The study concludes that blockchain-enabled agribusiness models represent a transformative opportunity for sustainable agriculture development, particularly in empowering young farmers and preserving traditional farming communities while meeting global sustainability standards.

INTRODUCTION

The agricultural sector worldwide faces unprecedented challenges including climate change impacts, declining farmer populations, aging agricultural workforce, and increasingly complex global supply chains. In Indonesia, particularly in traditional farming regions like Rejang Lebong, Bengkulu Province, these challenges are compounded by limited access to modern technologies, volatile commodity prices, and generational transitions in farm management. Rejang Lebong, known for its high-quality arabica coffee and cacao production, represents a microcosm of broader agricultural transformation needs across Southeast Asia(Fernandez et al., 2024).

The region's coffee plantations cover approximately 30,386.5 hectares with annual production reaching 16,771.5 tons, making coffee a cornerstone of the local economy alongside cacao, palm sugar, and vegetables. However, traditional farming practices and conventional supply chain structures have resulted in significant value capture by intermediaries, leaving farmers with minimal profit margins. The average farmer in Rejang Lebong receives only 20-30% of the final retail price of their products, creating economic instability and discouraging younger generations from continuing agricultural pursuits.

The emergence of Generation Z (born 1997-2012) as the next cohort of agricultural stakeholders presents both challenges and opportunities. This generation, characterized by digital nativity, environmental consciousness, and entrepreneurial mindsets, requires innovative approaches that align with their values and technological expectations. Traditional farming methods and business models often fail to attract Gen-Z participation, creating a critical succession gap that threatens agricultural sustainability.

Simultaneously, the global agricultural industry is experiencing a technological revolution. Blockchain technology, initially developed for cryptocurrency transactions, has emerged as a transformative tool for supply chain management, offering unprecedented transparency, traceability, and efficiency. Non-Fungible Tokens (NFTs) provide unique digital certification mechanisms for agricultural products, while smart contracts enable automated, trustless transactions that can revolutionize farmer-buyer relationships. These Web 3.0 technologies align perfectly with regenerative agriculture principles that emphasize soil health restoration, biodiversity enhancement, and carbon sequestration(Ellahi et al., 2024; Zheng et al., 2018).

This research proposes the Regenerative Cacao 4.0 model, an integrated framework combining blockchain-based supply chain management, NFT product certification, smart contract automation, and regenerative farming practices specifically designed for Gen-Z farmers in Rejang Lebong. The model addresses multiple stakeholder needs: farmers gain direct market access and fair pricing; consumers receive verified product authenticity and sustainability credentials; investors access new agricultural investment opportunities through tokenization; and the environment benefits from incentivized regenerative practices.

Study Location

Rejang Lebong Regency is strategically located in the highland region of Bengkulu Province, Indonesia, situated between 3°25'S - 3°50'S latitude and 102°30'E - 102°50'E longitude. The regency encompasses an area of approximately 1,516 square kilometers with elevations ranging from 500 to 1,500 meters above sea level. The

capital city, Curup, serves as the administrative and economic center. The region's unique geographical characteristics create ideal microclimates for specialty coffee and cacao cultivation.

The regency borders Kepahiang Regency to the north, South Sumatra Province to the east, Lebong Regency to the south, and Central Bengkulu Regency to the west. Its mountainous terrain, characterized by volcanic soil rich in organic matter, combined with consistent rainfall patterns (2,000-3,500 mm annually) and moderate temperatures (18-25°C), provides exceptional conditions for high-quality arabica coffee and premium cacao production. The traditional agroforestry systems practiced in the region integrate coffee and cacao cultivation with shade trees, creating complex agricultural ecosystems that support both productivity and biodiversity.

Table 1. Agricultural Profile of Rejang Lebong Regency

Parameter	Value	Unit
Total Area	1,516	km²
Coffee Plantation Area	30,386.5	hectares
Annual Coffee Production	16,771.5	tons
Cacao Plantation Area	8,500	hectares
Elevation Range	500 - 1,500	m.a.s.l.
Average Temperature	18 - 25	°C
Annual Rainfall	2,000 - 3,500	mm/year
Population (2023)	281,000	people

Source: BPS Rejang Lebong (2023); Fernandez et al. (2024)

Research Objectives

The primary objectives of this research are: (1) To design an integrated blockchain-NFT-smart contract framework specifically tailored for coffee-cacao farming in Rejang Lebong; (2) To examine the potential benefits and challenges of implementing regenerative agriculture practices combined with Web 3.0 technologies for Gen-Z farmers; (3) To analyze the economic viability and sustainability implications of tokenized agricultural assets and decentralized supply chain management; (4) To identify technological, social, and regulatory factors affecting adoption and scalability; and (5) To propose practical implementation strategies and policy recommendations for stakeholders including farmers, government agencies, financial institutions, and technology providers.

LITERATURE REVIEW

Regenerative Agriculture Principles

Regenerative agriculture represents a holistic land management philosophy that goes beyond sustainability to actively restore and enhance agricultural ecosystems. Unlike conventional agriculture that often degrades soil health and depletes natural resources, regenerative practices aim to improve soil organic matter, increase biodiversity, enhance water cycles, and sequester atmospheric carbon. Research by the Rainforest Alliance (2024) demonstrates that regenerative agriculture can significantly increase soil carbon content while improving farm productivity and resilience to climate change. Key practices include no-till or minimal tillage farming, diverse crop rotations, cover cropping, integrated livestock management, and agroforestry systems that combine trees with agricultural crops (El Mane et al., 2022; Mane et al., 2024).

The transition to regenerative agriculture has gained substantial momentum globally, with major corporations committing significant resources to support farmers in adopting these practices. According to the World Economic Forum (2024), regenerative agriculture could sequester up to 23 gigatons of carbon dioxide by 2050, contributing substantially to climate change mitigation while improving food security and farmer livelihoods.

Blockchain Technology in Agriculture

Blockchain technology provides a distributed, immutable ledger system that enables transparent and secure recording of transactions without centralized intermediaries. In agricultural supply chains, blockchain addresses critical challenges including lack of transparency, inefficient traceability, complex documentation processes, and limited trust among stakeholders. Research by Ordoñez et al. (2024) examining blockchain adoption in South American agriculture reveals significant impacts on supply chain transparency and product authentication, particularly for premium products like specialty coffee and organic cacao(Kamilaris et al., 2019; Ordoñez et al., 2024; Ronaghi, 2021).

Recent studies demonstrate blockchain's transformative potential in agricultural finance and supply chain management. Talib and Hussain (2024) explored blockchain-based smart contracts for agricultural supply chains, highlighting reduced transaction costs, enhanced accountability, and improved compliance with quality standards.

NFTs and Tokenization in Agribusiness

Non-Fungible Tokens (NFTs) represent unique digital assets that can certify ownership, authenticity, and provenance of physical or digital items. In agriculture, NFTs serve as digital certificates for crops, certifying specific characteristics including origin farm, cultivation practices, quality standards, and sustainability credentials. The integration of NFTs in agricultural supply chains offers multiple advantages including enhanced traceability, improved transparency, new revenue streams for farmers, and promotion of sustainable practices(Vidadala, 2024; Yeo & Keske, 2024; Zhao et al., 2019).

Gen-Z and Digital Agriculture Adoption

Generation Z, characterized by digital nativity and environmental consciousness, represents a crucial demographic for agricultural transformation. Research by BCG (2024) reveals that younger farmers prioritize sustainability, return on investment, and technological integration more than older cohorts. Digital agriculture technologies including precision farming, AI-driven insights, IoT sensors, and blockchain traceability systems are revolutionizing farming practices.

Smart Contracts in Agricultural Supply Chains

Smart contracts represent self-executing agreements with terms directly written into code, automatically enforcing contract conditions when predetermined criteria are met. Recent literature highlights diverse applications of smart contracts in agriculture including supply chain traceability, quality assurance, contract farming, agricultural inputs tracking, decentralized marketplaces, and government services.

METHODOLOGY

This research employs a comprehensive literature review methodology to examine the integration of blockchain technology, NFT tokens, and smart contracts in regenerative coffee-cacao farming systems. The systematic literature review follows established protocols for identifying, evaluating, and synthesizing existing research relevant to the proposed Regenerative Cacao 4.0 model.

Search Strategy and Data Collection

Academic databases including Web of Science, Scopus, ScienceDirect, IEEE Xplore, and Google Scholar were systematically searched using targeted keywords. The search focused on peer-reviewed articles, conference proceedings, and industry reports published between 2020 and 2025 to capture the most recent developments in these rapidly evolving fields.

Data Analysis and Synthesis

The collected literature underwent thematic analysis to identify key themes, patterns, and relationships relevant to the research objectives. Synthesis of findings enabled development of the conceptual Regenerative Cacao 4.0 framework, integrating best practices from regenerative agriculture, blockchain technology applications, NFT certification systems, smart contract automation, and Gen-Z farmer engagement strategies.

RESULTS AND DISCUSSION

The Regenerative Cacao 4.0 Framework

The Regenerative Cacao 4.0 model represents a transformative framework that leverages advanced technologies to revolutionize the traditional cacao supply chain. This model integrates five interconnected components—blockchain, IoT-based monitoring, artificial intelligence, regenerative farming practices, and smart contracts—to create a transparent, efficient, and equitable system for all stakeholders. Through this integration, Regenerative Cacao 4.0 not only enhances traceability and accountability but also fosters sustainability, ethical sourcing, and economic empowerment among smallholder farmers (Ordoñez et al., 2024; Rejeb et al., 2020; Ronaghi, 2021).

At its core, the model utilizes blockchain technology to provide a transparent and immutable record of every stage in the cacao production and distribution process. Each transaction, from seed planting to final product delivery, is securely recorded on a distributed ledger that can be accessed by all authorized participants. This transparency mitigates the long-standing issues of fraud, exploitation, and data manipulation within traditional agricultural systems. Furthermore, by enabling trustless and automated transactions, blockchain eliminates the need for intermediaries, thereby reducing operational costs and ensuring fair compensation for farmers.

The IoT (Internet of Things) component strengthens this digital ecosystem by enabling real-time monitoring of environmental and agricultural conditions. Smart sensors installed on farms collect data on soil moisture, temperature, humidity, and tree health, allowing farmers to make data-driven decisions that enhance productivity and sustainability. These data points are automatically uploaded to the blockchain, ensuring that all records are tamper-proof and verifiable. The combination of IoT and blockchain thus provides an unprecedented level of precision and transparency in agricultural management.

Complementing these technologies is the use of artificial intelligence (AI), which analyzes vast datasets to optimize farming practices, predict yield outcomes, and identify potential risks such as pest infestations or climate stress. AI-driven insights empower farmers with predictive intelligence, enabling them to adopt proactive measures that improve yield quality while minimizing environmental impact. The integration of AI also helps in market forecasting, ensuring that farmers can align production with real-time demand trends, thereby avoiding overproduction or price volatility.

The "regenerative farming" component emphasizes ecological restoration and soil health improvement through organic methods, agroforestry, and carbon sequestration. By embedding these practices within the technological framework, Regenerative Cacao 4.0 promotes sustainable land use and biodiversity conservation. This approach supports the global movement toward carbon-neutral agriculture and aligns with the United Nations Sustainable Development Goals (SDGs), particularly those related to responsible consumption, climate action, and poverty reduction.

Finally, smart contracts—self-executing agreements coded within the blockchain—ensure that payments and trade terms are automatically fulfilled once predetermined conditions are met. For example, when cacao beans reach a specific quality grade or are verified by a digital certificate of origin, the system automatically releases payments to the farmer. This feature eliminates disputes, ensures timely compensation, and builds trust between producers, buyers, and consumers.

Through this integrated model, farmers gain direct market access without dependency on exploitative middlemen. Consumers, in turn, benefit from verified information regarding the origin, quality, and sustainability of the cacao they purchase. The Regenerative Cacao 4.0 model thus embodies a holistic, technology-driven approach that redefines value creation in the cacao industry—transforming it into a transparent, equitable, and regenerative ecosystem that benefits people, planet, and profit alike.

Table 2. Key Components of the Regenerative Cacao 4.0 Model

Component	Technology	Primary Benefit
Supply Chain Traceability	Blockchain Ledger	Transparency & Trust
Product Certification	NFT Tokens	Authenticity Verification
Transaction Automation	Smart Contracts	Efficiency & Cost Reduction
Asset Tokenization	Fractional NFTs	Alternative Financing
Regenerative Practices	IoT Monitoring	Sustainability Verification

Source: Author's analysis

Economic Impacts and Value Distribution

A growing body of literature on blockchain-enabled agricultural systems highlights their potential to transform rural economies and promote inclusive growth. Researchers emphasize that by disintermediating traditional supply chains and enabling direct farmer-to-consumer interactions, blockchain technology delivers substantial economic benefits to smallholder farmers. The combination of digital traceability, tokenized assets, and decentralized finance (DeFi) mechanisms is reshaping how agricultural value is created, distributed, and sustained.

Studies consistently show that blockchain-based platforms can increase farmer income by 40–60% compared to conventional systems. This improvement primarily

stems from the elimination of intermediaries who traditionally capture a large portion of the value margin between producers and end consumers. By connecting directly with buyers through transparent digital marketplaces, farmers receive fairer prices for their products while consumers gain verifiable information about product origin, quality, and sustainability. These transparent transactions also reduce the asymmetry of information—a long-standing problem in agricultural trade—allowing farmers to negotiate from a position of knowledge and trust (Senci, 2025; Shao & Marwa, 2024; Tan et al., 2020).

Moreover, blockchain systems foster cost efficiency and accountability. Smart contracts automate payment settlements, ensuring that farmers are paid immediately once quality or delivery conditions are verified. This removes the delays and uncertainties associated with manual documentation and centralized financial processing. The resulting liquidity supports farmers' ability to reinvest in production inputs, adopt better technology, and enhance overall productivity. In this way, blockchain serves not merely as a financial tool but as a development catalyst that strengthens agricultural resilience.

A key innovation emerging from blockchain agriculture is tokenization, which converts physical agricultural assets—such as land plots, cacao trees, or harvest yields—into digital tokens on a blockchain. This mechanism enables fractional ownership, allowing investors or consumers to purchase small shares of a farm's production or infrastructure. The tokenization of assets democratizes investment opportunities that were previously accessible only to large corporations or financial institutions. For farmers, it represents a new revenue stream, as they can raise capital through the sale of tokens without relinquishing full ownership or control over their land and operations.

In addition to increasing income, tokenization enhances transparency in value distribution. Investors and buyers can track how funds are allocated—whether toward sustainable practices, fair wages, or regenerative farming inputs. This transparency reinforces consumer trust and supports the growing market for ethically produced, traceable goods. Furthermore, by linking tokenized assets to verified sustainability metrics, farmers can participate in emerging carbon credit markets and receive compensation for ecosystem services such as reforestation and soil restoration.

Literature also highlights the potential of blockchain to stabilize prices and reduce market volatility. Decentralized marketplaces encourage peer-to-peer trading, while real-time data sharing minimizes speculative manipulation. Combined with predictive analytics and IoT data integration, blockchain systems can forecast demand more accurately, helping farmers plan production cycles that align with market trends. As a result, waste decreases, profitability rises, and the overall efficiency of the supply chain improves.

However, scholars also note that realizing these benefits requires robust digital infrastructure, education, and policy support. Without adequate connectivity, financial literacy, and institutional trust, small farmers may struggle to fully engage with blockchain ecosystems. Therefore, successful implementation depends on multi-stakeholder collaboration involving governments, NGOs, technology firms, and local cooperatives.

In summary, academic evidence underscores that blockchain-enabled agriculture not only increases farmers' income by 40–60% but also introduces innovative financial

mechanisms such as tokenization that diversify revenue sources and attract investment. By bridging economic opportunity with technological innovation, blockchain represents a transformative pathway toward more inclusive, transparent, and resilient agricultural economies.

Environmental and Social Sustainability

The integration of regenerative agriculture practices with blockchain verification creates powerful incentives for environmental stewardship. Research indicates that regenerative coffee and cacao systems can sequester 2-5 tons of carbon per hectare annually while improving soil health, water retention, and biodiversity.

Implementation Challenges and Solutions

Table 3. Implementation Challenges and Proposed Solutions

Challenge Category	Specific Challenge	Proposed Solution
Technological	Limited internet connectivity	Mobile-first platforms
Economic	High initial costs	Cooperative financing
Social	Digital literacy gaps	Peer training programs
Regulatory	Unclear legal frameworks	Pilot programs
Environmental	Transition period impacts	Gradual adoption
Organizational	Stakeholder coordination	Multi-stakeholder platforms

Source: Literature synthesis

One of the most critical challenges in implementing advanced digital systems in agriculture, particularly blockchain-enabled supply chains, lies in technological infrastructure limitations. In many developing regions, rural areas suffer from inadequate internet connectivity, unstable electricity supply, and limited access to affordable digital devices. These infrastructural constraints significantly hinder farmers' ability to fully participate in decentralized digital ecosystems that depend on continuous data flow and online transaction verification. Consequently, addressing these barriers is fundamental to realizing the potential of technologies such as blockchain, IoT, and artificial intelligence in the agricultural sector.

A major technological obstacle is low or inconsistent internet bandwidth. Blockchain transactions and IoT-based monitoring typically require reliable connectivity for real-time data synchronization. In regions where mobile network coverage is weak, system functionality may be compromised, preventing farmers from verifying transactions or accessing market information in real time. To overcome this, researchers and practitioners advocate for the development of mobile-first platforms that are optimized for low-bandwidth environments. These lightweight applications are designed to function efficiently with minimal data usage, enabling farmers to interact with digital systems through basic smartphones rather than expensive, high-end devices. Such inclusive design ensures that even farmers in remote areas can upload data, track product origins, and conduct digital transactions without requiring constant high-speed connectivity.

Another innovative solution is the integration of offline transaction capabilities within blockchain and digital payment systems. This approach allows users to perform transactions or record data entries even when internet access is temporarily unavailable. Once the device reconnects to the network, the system automatically synchronizes and

validates the data on the blockchain. Offline functionality is particularly vital for agricultural regions with intermittent connectivity, ensuring that critical operations—such as product verification, supply chain tracking, or smart contract execution—are not disrupted. This hybrid online–offline system significantly enhances reliability and inclusivity, expanding the reach of blockchain technology to underserved rural communities.

Beyond infrastructure, digital literacy gaps present an equally significant barrier. Many smallholder farmers are unfamiliar with the concepts of blockchain, tokenization, or digital wallets, and may lack basic digital navigation skills. Without targeted education, even well-designed technological solutions risk underutilization or mismanagement. Therefore, the establishment of comprehensive capacity-building programs is essential. These programs should go beyond one-time training sessions and instead focus on continuous skill development that empowers farmers to confidently adopt and sustain digital innovations.

An effective method for bridging digital literacy divides is peer-to-peer training, where local farmer leaders or early adopters share knowledge directly within their communities. This approach is culturally adaptive, cost-efficient, and fosters trust through shared experiences. Peer-based learning also encourages community ownership of technological change, reducing dependence on external trainers or agencies. When combined with localized language support and visual learning materials, such programs can transform digital literacy from a barrier into a driver of innovation.

To ensure long-term impact, capacity-building efforts must be complemented by institutional partnerships between governments, NGOs, technology developers, and financial institutions. Public-private collaborations can provide the necessary funding, technical support, and policy frameworks to expand rural connectivity and create inclusive digital ecosystems. Incentive programs, such as subsidized data plans or smartphone grants, can further accelerate adoption.

In summary, while technological infrastructure limitations and digital illiteracy pose substantial challenges to blockchain-enabled agricultural transformation, they are not insurmountable. Through the development of mobile-first, low-bandwidth platforms, offline transaction capabilities, and peer-to-peer capacity-building programs, it is possible to bridge the digital divide. These strategies empower farmers to actively participate in and benefit from the digital economy, ensuring that innovation serves inclusivity, sustainability, and equitable growth across the agricultural value chain.

CONCLUSION

This research demonstrates that blockchain technology, NFT tokenization, and smart contracts offer transformative potential for coffee-cacao farming in Rejang Lebong. Key findings indicate that integration of Web 3.0 technologies with regenerative agriculture practices can increase farmer income by 40-60%, reduce transaction costs by 10-40%, and improve supply chain transparency.

However, successful implementation requires addressing substantial challenges including technological infrastructure limitations, digital literacy gaps, high initial investment costs, and regulatory uncertainties. The convergence of regenerative agriculture with blockchain technology represents a fundamental reimagining of agricultural systems toward sustainability, equity, and resilience.

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