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Application of Blockchain Technology in Agricultural Product Traceability

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Abstract: In today's world, people's living standards have been gradually improving, and their health awareness has been constantly increasing; consumers need better quality and experience when shopping. The process of selling agricultural products needs to be further developed with digital transformation. The construction of an agricultural product traceability system based on blockchain technology enables full process tracking of the agricultural product supply chain for the integrity and transparency of traceability information; furthermore, because of its decentralized feature and immutability of transaction records, it provides a novel way for transforming and upgrading traditional agricultural product retail processes. In order to make clear the direction of this field, we attempt to summarize and review the existing domestic and international literature within the scope of blockchain technology and agricultural product sales: analyze the current research status, theoretical foundation of blockchain tech, case study and analysis as well as policy support, identify the shortcoming in current academic research (sample, method, depth, scenario).In doing so, it aims to clarify the research context and development status of the field, organize mainstream research perspectives, key technologies, and typical applications, analyze existing deficiencies and controversial issues, and thereby provide a forecast for future research directions. This offers theoretical references and insights for subsequent studies, promoting further deepening and improvement of related research.

Keywords: Agricultural Product Supply Chain; Blockchain; Quality Traceability; Case Study.

1. Introduction

1.1. Research Background

Chinese consumers' quality awareness has improved, and the varieties of products have been growing on the market. consumers need greater transparency and quality of agricultural product traceability badly. With the government's vigorous efforts, the safety and quality of food in China has been largely guaranteed [1]];meanwhile, consumers also put forward further requests besides healthy eating (such as freshness,deliciousness,or even having higher content of certain nutrients).The traditional centralized traceability system suffers problems including data tampering, information islands, and lack of transparency that cannot satisfy the market's need for trustworthy tracking of the whole agricultural product process. Blockchain tech,which possesses characteristics of decentralization, immutability, and traceability, provides new ways and tools to solve those problems, gradually becoming a research focus in the field of agricultural product traceability.The significance of this study is mainly reflected in the following aspects:

1. Theoretical level:Systematically review the current status of research on blockchain technology in the field of agricultural product traceability;build up a research framework that integrates supply chain management, information systems, and blockchain technology;identify shortcomings and frontier directions of existing research,and give references for further study.

2. Practical level: Investigate application models for blockchain technology on the food retail supply chain; optimize information sharing and flow mechanism; improve supply chain management efficiency and consumer trust; promote digitalization of agriculture.

This paper focuses on the application of blockchain technology in agricultural product traceability,with the following objectives:

1.Analyze how blockchain technology can improve precision, operational efficiency of food retail supply chain management; explore ways of integrating it with other technologies like Internet of Things and artificial intelligence.

2.Build a model of blockchain based agricultural product traceability system,model clearly using blockchain technology in different areas like supply chain management and financial services, smart contracts etc.,achieving digital upgrade.

3.Assess if consumers accept the blockchain traceability system, using it to promote the market.

4.Design incentive mechanisms of the food supply chain that promote enthusiasm for engaging in collaborative activities, while reducing operational costs.

The main research contents of this paper are as follows:

1. Sort out the relevant theories of blockchain technology, digital transformation, and business model innovation in order to establish a theoretical basis for this research.

2. In this paper, we review the current use of blockchain technology for agriculture at home and abroad, summarize the problems that exist in past researches, discuss future development directions.

3. According to literature analysis and case studies,a functional model for a blockchain-based agricultural product traceability system was built,optimizing its architecture and data flow mechanism.

4. Evaluate the practical impact of blockchain technology in enhancing supply chain transparency, consumer trust, etc., and provide policy recommendations and industry standards.

This study adopts the following methods:

1. Literature review method: systematically review related literature about blockchain technology and agricultural product traceability, clarify its current research status and

innovation points.

2. Case study method:Select typical agricultural product traceability cases for analysis,summarizing the advantages and limitations of blockchain technology application.

3. Empirical research method: pilot design and implement a blockchain based agricultural product traceability system,in order to assess its effectiveness and feasibility.

4. Policy Analysis Method: Analyze the impact of relevant policies on blockchain applications in agriculture and propose targeted industry development recommendations.

2. Relevant Theoretical Foundations

2.1. Theoretical Foundations of Blockchain

The blockchain was first introduced in 2008 by Satoshi Nakamoto, originally designed as the underlying technology of Bitcoin.Since then, blockchain has been used in different areas like supply chain, finance,and agriculture.Blockchain is a decentralized shared ledger technology that relies on cryptography and distributed consensus mechanisms.The data are encapsulated in chronological blocks linked together via a hash chain which makes the data immutable, traceable, and maintained by multiple parties in a peer-to-peer network,thus creating trust without the use of intermediaries [2].

As described in the "White Paper on China's Blockchain technology and Application Development (2016)" from the Ministry of Industry and Information tech,blockchain is a distributed ledger which is chronologically chained together with cryptography securing its immutability [3].The transactions will be verified by using asymmetric encryption and digital signature,and then they are grouped in blocks which are chained with each other based on their hash value.Tampering has an extremely high cost that ensures the authenticity and reliability of the data.

2.2. Foundations of Related Technologies

Blockchain technology system: The data layer,network layer, consensus layer, incentive layer, contract layer, application layer [4].

Data layer:Storage,encryption,and association with a chain (block structure, hash,timestamp,asymmetric encryption etc.).

Network Layer: Implements P2P networking,data transmission, node synchronization.Consensus layer: Ensuring that all nodes in the blockchain agree on the authenticity and validity of data,reaching an agreement on the bookkeeping rules.

Incentive Layer:Uses economics to encourage nodes for participating in maintenance,prevent malicious behaviors.

Contract layer: Encapsulate smart contracts,algorithms for automatic rule execution.

Application Layer:Provides application services for industry-specific scenarios, enabling technology implementation.

2.3. Application in Food Traceability

1.IBM Food Trust Blockchain Food Traceability Project [5]

Developed jointly with Walmart and IBM, this solution uses the IBM Hyperledger framework to provide complete process traceability on meat and produce. Allows fast detection of contamination sources, reduces waste and links the information chain from production through processing to retail.

2.EU's "Farm to Fork" Strategy

It was launched in 2020,covers the whole chain from production, processing, distribution, consumption and recycling, focusing on full traceability and sustainability standards.

3.AgriDigital in Australia

A multi-party collaborative operations and globally trusted trading platform that enhances transparency and efficiency of the agricultural supply chain.

2.4. Integration with Other Emerging Technologies

1.RFID Electronic Tag tech

The non-contact automatic identification technology can physically identify "one item,one code" and ensure the authenticity of source data.

2.QR Code tech

The low cost and high accessibility enable consumers to rapidly obtain full-chain traceability information.

3.Geographic Information tech

It is used for origin verification,traceability tracking,and regional supervision.It can be combined with blockchain in order to achieve a more accurate and visualized traceability process.

3. Review of Related Literature

3.1. IBM Food Trust

The IBM Food Trust uses a consortium blockchain based on the Hyperledger Fabric 2.0 architecture which is the world's most mature blockchain platform for food traceability.The network has multi-node permission management with different roles in the supply chain (e.g., "producers, processors, logistics providers, retailers, regulatory agencies, and consumers") having different data read/write permissions so that shared data maintains privacy as well [6].

In the IBM Food Trust system,each farm and processing plant functions as a blockchain node.The blockchain assigns a unique ID to every batch.Farmers sign the planting/breeding/process info of this batch (harvest/ slaughter/ shipment time, weight,packaging details etc.) through their mobile phone/handheld terminal device and upload them directly onto the chain,which cannot be tampered with but synchronized throughout the network.For products, from the processing end: After being segmented/packaged, a QR code will be generated on the packaging and link back to its original batch ID;during cold chain transportation, warehouse/refrigerated truck have temperature/humidity sensor + GPS for fully automatic data collection, uploading to the chain at every 10 minutes and cannot be manually changed.When the retail store node receive the product,they can be scanned and recorded in inventory. Consumers can scan the QR code on the packaging to obtain all information about the product's raw materials from the factory to the primary farm level.

At the end of 2025,IBM Food Trust connects more than 600 enterprises and 15,000 farms around the world covering more than 2,000 categories including meat,fruits and vegetables, seafood, and dairy products processing over 1.5 billion supply chain data records..

3.2. Alibaba AntChain

Currently Ant Chain is the most popular blockchain traceability platform for agricultural products in China.The

goal is to offer users/partners a one-stop application development platform service so they can rapidly develop blockchain applications for different business scenarios, which will support the growth of the real economy [7].as a retail application scene,Hema Fresh (Freshhema), integrates traceability function into their own supply chain and store system, making sure every record of fresh products from origin and processing through cold chain logistics until final sale are immutable, consumers could scan a QR code to get full traceability information about fresh products.

Farmer cooperatives will enter their data through Alipay or Hema merchant app (more lightweight than IBM). At the production side sensors could be placed inside greenhouses and orchards that would automatically upload soil quality and irrigation information onto the blockchain. Farmers may also upload more data with Alipay or the Hema Fresh app.On arrival at processing plants or sorting centers products get scanned and automatically retrieve production data from the blockchain. Once sorted,cleaned,packaged each product gets a Hema-exclusive "product traceability code",and it ships out to retail points throughout the country.In transport on refrigerated trucks temperature and humidity data are uploaded in real-time,automatic alerts trigger when there are any anomalies like temperature fluctuations directly identifying which truck/stretch of road has problems. Consumers can scan the code with Alipay or the Hema app to see information regarding where this product came from,how was processed, where did it go during logistics and what store they're sold by.

By 2025,the repurchase rate of Hema blockchain traceable products has increased by 38%,and the level of trust has risen by 52% [8].

3.3. Policy Support

The General Office of the State Council issued the "Opinions on Further Strengthening the Supervision of the Entire Food Safety Chain" in 2025,which stated that it was necessary to further clarify the responsibility for food safety regulation, establish and improve the collaborative mechanism,make joint efforts throughout the chain of supervision,firmly uphold the bottom line of food safety,and effectively safeguard the health and safety of the people.The national standards such as "General Principles for the Evaluation of Food Traceability Systems" unified the technical specifications for blockchain-based traceability in 2025 [9].With support from various policies,the use of blockchain technology for food traceability has received funding, policy support,and financial assistance from multiple levels,including both central and local authorities.

4. Existing Problems and Corresponding Countermeasures and Suggestions

Based on the earlier case analysis of IBM Food Trust and AntChain's Hema traceability system,along with the construction logic of blockchain-based food traceability networks,it can be observed that while China's blockchain food traceability technology has already established mature underlying architectures, policy support,and practical benchmarks, multiple issues of "disconnect between technological ideals and industrial realities" persist during actual industrial operation.Shortcomings at the technical, industry mechanism, and market application levels collectively hinder the widespread adoption of the traceability system.The specific issues are as follows.

4.1. The Problem of Data Falsification at the Source is Difficult to Avoid.

The main benefit of blockchain is that when the transaction record appears on the chain,it is collectively guaranteed by all nodes making it almost impossible to tamper with information already on the chain,furthermore,it cannot intervene in the data collection of offline farmers, warehousing,and transportation workers. While whether it is IBM Food Trust's cross-border traceability system or the Hema traceability system supported by Ant Chain in China,they both depend on manual input or simple IoT devices to collect source data,but have not yet realized full automation of data collection at every stage.Agricul-ture production (such as farming, breeding, and primary processing) some producers deliberately alter their original data including harvest times, quarantine records, medication logs,other raw data.When uploading false data to the chain and reaching consensus,it will become very difficult to change even after discovering potential risks through the enterprise's own inspection.To avoid this problem,the best way is for the government to take the lead to establish a reliable source data governance system.Manual data collection inevitably causes errors or data falsification.We should use tools like temperature and humidity sensors,GPS positioning modules,intelligent monitoring terminals etc.to replace manual entry as much as possible,to collect core information(production environment, harvest time,cold chain data,processing parameters),by machine so as not to allow humans to tamper with data; Secondly, set accountability for on-chain data to individuals clearly define the data responsibility of farmers, processing enterprises, logistics providers in the chain; Finally, strengthen government supervision, market regulation and agricultural and rural departments conduct regular spot check on source traceability data.Comparing on-chain data with actual offline production conditions,we can quickly identify and eliminate false traceability data.

4.2. Obstacles to Cross-Platform Data Interoperability

At present there are no unified technical standards and data specifications for blockchain-based food traceability platforms at home and abroad.IBM's Food Trust consortium blockchain platform using the Hyperledger Fabric architecture has its own data format and node access rules.The technical architectures and data interfaces of Chinese platforms like Ant Chain,JD's Zhen Intellectual Chain,various government traceability platforms are not uniform,cross-platform and cross-regional data exchanges are impossible.For instance,Hema Xiansheng's traceability system can only circulate within the Alibaba ecosystem but cannot link up with the local government public traceability platforms for agricultural products,data disconnect exists between regulatory and enterprise perspectives. [10] A number of independently operating traceability chains form information silos severely hinders the comprehensive and integrated development of the food traceability system, making it difficult to realize full lifecycle traceability and supervision of food products throughout the country.To solve these problems we can set up relevant industry standards according to the national standardization system unifying food traceability data formats interface standards,node access

rules,data interaction specifications,break through technical barriers among different enterprises and platforms seamlessly integrating commercial traceability platforms and government public traceability systems, solve the problem of commercial platform data (such as Hema Fresh) only circulating within their own ecosystems.Besides,build a national-level food traceability data sharing platform which integrates enterprise commercial traceability data and government regulatory data forming a comprehensive traceability data network spanning across regions,industries and entities achieving cross domain data interoperability and sharing.At the same time build a supervision mechanism for standard implementation urging all traceability platforms to upgrade their systems according to national standards gradually eliminate industry information silos,building an integrated national food traceability supervision system.

4.3. Cost Issues

Hardware equipment and post-maintenance costs involved in blockchain traceability systems are far beyond what most small and medium-sized farmers in China can afford. Abroad,platforms such as IBM Food Trust require high annual fees,which are available only for large multinational corporations. In Europe and the United States,farmers tend to be large-scale collective producers who can buy equipment in bulk making operations and maintenance fairly cost effective.Accordingly this problem does not occur here furthermore,in China agricultural products are mostly produced by small-scale farmers and individual households Although domestic companies have optimized blockchain deployment to some extent,the total cost of IoT collection devices,traceability code generation,and system maintenance remains a heavy burden for small-scale growers and individual breeders currently The primary beneficiaries of blockchain traceability are large supermarkets and leading agricultural enterprises Small and medium-sized producers, being the source of the food supply chain illustrate very low willingness to participate Most farmers still think that the costs are high while the return is low,thus making it hard for the traceability system to cover the entire industry chain To solve these problems regarding high costs in building and maintaining blockchain traceability systems and low willingness of small and medium-sized agricultural entities to participate Local governments can firstly introduce special subsidy policies together with relevant policies on digital agriculture and food safety Subsidies can be provided for equipment procurement,system maintenance and traceability code production to small farmers and micro-enterprises connecting to formal blockchain traceability platforms This will reduce their initial investment costs Secondly By using lightweight blockchain technology platform such as AntChain we simplify the system operation process and introduce more cost-effective and lightweight traceability solutions It abandons high barrier high-cost operational models like IBM Food Trust making it suitable for the reality of small and medium-sized agricultural entities in China Finally promote a cluster-based sharing model where blockchain nodes and IoT devices are deployed collectively at the level of agricultural cooperatives or industrial parks Multiple small and medium-sized entities share one traceability system and hardware resources Splitting the operation and maintenance costs.

4.4. Low Consumer Acceptance

In the current market environment,blockchain-based food traceability technology has already achieved mature and comprehensive applications.furthermore,the general public still lacks awareness of this tech,and its adoption rate remains low.Taking Hema Fresh as an example,the platform has implemented full-category fresh food traceability on the blockchain,yet only a small number of consumers actively scan QR codes to verify traceability information.Most consumers do not have the habit of proactively checking traceability details,making it impossible to use market choices to drive upstream production to standardize traceability practices.At the same time,the current traceability pages only display basic information such as origin and time,lacking core elements like risk warnings,as well as high-value-added content that can significantly stimulate consumer purchasing desire,such as weather conditions,medication usage,and farming environments during the breeding and cultivation process.This shortfall in effectively enhancing consumer trust has prevented blockchain-based traceability from fully realizing its market premium potential and social benefits.

To address the issues of low consumer awareness, underutilization of traceability functions,and market premiums,we can enhance the market penetration and recognition of blockchain-based traceability through platform guidance, social promotion,and content optimization. First, fresh food retail platforms should abandon homogeneous basic information display models when setting up information interfaces,highlighting food quality inspection reports,risk detection data,cold chain anomaly records,and origin certification information.This enriches the dimensions of traceability content and improves the reference value of traceability information. Second,various platforms should actively guide consumers to scan and verify traceability information through in-store pop-ups,app push notifications, and offline poster reminders,fostering a habit of proactive inquiry and quality-conscious consumption. Finally, collaborate with government departments and mainstream media to conduct science popularization campaigns on blockchain-based food safety traceability,promoting the technical advantages of blockchain,such as immutability and full traceability,to enhance consumer trust in traceable products.By increasing market awareness,a virtuous cycle can be established where "high-quality traceable products achieve favorable market returns," thereby incentivizing producers and distributors to actively standardize traceability practices and fully leverage the social role and market influence of blockchain traceability.

4.5. Data Privacy Issues

In order to resolve the contradiction in blockchain based traceability data sharing and privacy protection,we need to establish a three-in-one privacy security management system that integrates hierarchical permissions,data desensitization and security safeguards.Firstly we refine the permission hierarchy among consortium blockchain nodes.Based on the current multi-stakeholder governance model,strictly define the operational rights of production,logistics,sales,regulation and consumers. Sensitive commercial data of enterprises can only be accessed by regulatory nodes for verification while hiding business secrets from general consumers,balancing data traceability against commercial privacy protection; Secondly apply data desensitization technology completely. Prices, cooperation channels,production process etc.sensitive

data circulating on the chain are anonymized and obfuscated so that only essential traceability information about food safety is revealed preventing leakage of core commercial data.Last but not least strengthen the cybersecurity protection of the blockchain system. Regular upgrades of smart contracts and node server security firewall should be implemented along with establishing data anomaly monitoring and early warning mechanism to timely counter security risks like cyber attacks or data tampering ensuring the stability of the traceability network and fostering a safe compliant and trust-worthy food traceability data environment.

4.6. Summary of This Chapter

Overall,the multi-node sharing characteristic of blockchain consortium chains leads to the leakage of commercial data in the supply chain. The food supply chain involves sensitive information such as enterprise processing techniques,supply prices, and customer channels.Under the multi-node co-governance model, there is a contradiction and conflict between openly sharing supply chain data and protecting commercial privacy. Most current traceability platforms lack robust data desensitization mechanisms,permission divisions, and privacy encryption mechanisms.To protect commercial secrets, some enterprises may choose to conceal key data, resulting in incomplete traceability information. Additionally, some blockchain smart contracts and node servers are vulnerable to attacks, and the system security prevention system still needs further improvement. This will affect the secure operation of the traceability network.

5. Conclusion and Outlook

This study focuses on the application of blockchain technology in food traceability as its core research object. Through an in-depth analysis of the global benchmark case of IBM Food Trust and the localized practice of Hema Fresh supported by Ant Chain,it systematically examines the construction logic,operational processes,and policy support framework of blockchain-based food traceability networks.In response to the issues identified in current applications, optimization strategies are proposed, with the main conclusions as follows:

First: The application of blockchain in food traceability offers significant technological advantages and practical significance. The characteristics of consortium blockchains, such as multi-node collaborative governance, data immutability, and end-to-end traceability,can address various issues in traditional food traceability,including data tampering, information silos,and low regulatory efficiency. IBM Food Trust leverages second-level traceability to handle food safety incidents, while Hema Fresh uses the Ant Chain for precise supervision of fresh food cold chains.These examples demonstrate the value of blockchain technology in enhancing food safety management and increasing consumer trust.

Second: Currently,the application of blockchain technology in food traceability in China still faces several practical challenges. This includes not being able to collect authentic information in an off-chain manner,data silos due to inconsistent technical standards on platforms,lack of specific types of agricultural entity participation,consumer unawareness about blockchain tech,incomplete balance between privacy and security. The aforementioned barriers inhibit the widespread use of blockchain technology resulting in a polarized scenario where "leading enterprises implement the technology while grassroots scenarios remain blank".

Third:Policies and standards provide important protection for promoting the development of blockchain-based food traceability. Top-level design at the national level,specific policy guidance by ministries,unified national standards,and supportive measures locally provided relevant policies for blockchain food traceability with clear development direction and institution support on technology application.Further effort is needed in ensuring the implementation of policies and standards so that blockchain food traceability can move from pilot exploration to normal operation.

According to the current development trends of blockchain-based food traceability technology and limitations in our study, we propose some prospects regarding future research directions and application potential as follows:

First: Technological convergence and innovation is the mainstream of development.In the future,blockchain-based food traceability can be combined with other technologies like the Internet of Things, artificial intelligence,and big data so that automatic data collection and intelligent verification at all stages (production,processing,cold chain,sales) fundamentally solve the problem of "off-chain fraud". Meanwhile, the progress in lightweight consortium blockchain technology makes it easy for small and medium-sized entities to enter a blockchain platform which extends traceability to cover the whole industry chain.

Second: Gradually improve industry standards and data interoperability systems.Introducing national standards like the "General Guidelines for the Evaluation of Food Traceability Systems" unifies cross-platform and cross-regional data interoperability standards, solving the problem of data silos between government's public traceability platform and enterprises' commercial traceability platform, to build up a nationwide food traceability supervision system.

Third: The market value and social benefits will be highlighted. With the integration and improvements of measures like displaying traceability information and science popularization, consumers' awareness and acceptances towards blockchain traceability will greatly improve, creating a virtuous circle that "the high quality traceability products can command a higher premium," forcing producers to further standardize their traceability practices fully utilizing the function of blockchain traceability for improving food safety levels and driving high-quality agricultural development.

Fourth:The maturity of privacy protection and security governance mechanisms.In the use of technologies like data masking and tiered permission management,balance between blockchain traceability data sharing and commercial privacy protection will be improved.System's own security defense capabilities are strengthened,to provide some degree of security in large-scale application of blockchain-based food traceability.

In this paper we present our macro-level analysis regarding the current status and optimization strategies for blockchain-based food traceability applications.Future works can be conducted through empirical study of blockchain food traceability projects in certain areas/product category,more detailed work on cost-sharing mechanism, impact on consumer behavior etc.,to provide more targeted references for the practical implementation of blockchain food traceability.

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