Digital Technology Empowers Agricultural Supply Chain to Move toWards Sustainable Development

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Abstract. With the rapid development of information technology, digital technology has become an important driving force to promote the sustainable development of agricultural product supply chains. Based on the analysis of the constraints of sustainable development in the supply chain of agricultural products, this paper deeply discusses the application effect of digital technologies such as the Internet of Things, big data analysis, and blockchain in the supply chain through systematic literature review and case analysis. The results show that: (1) The Internet of Things technology can effectively alleviate the problem of information asymmetry between supply chain subjects and reduce logistics costs through real-time monitoring system and information transparency mechanism; (2) Big data analysis technology significantly improves the efficiency of supply chain decision-making with the help of demand forecasting models and operation optimization algorithms; (3) The distributed ledger and smart contract characteristics of blockchain technology provide technical support for the construction of a quality traceability system and enhance the flexibility of the supply chain, and reduce the incidence of quality disputes. Based on the above analysis, this paper proposes a sustainable development strategy to strengthen investment in digital infrastructure construction, deepen the application of key technological innovation, and improve the collaborative ability of the supply chain. This study not only improves the theoretical framework of digital technology to empower the supply chain, but also provides a practical reference for government departments to formulate industrial policies and enterprises to implement digital transformation.

Keywords: Agricultural product supply chain, Digital technology, Internet of Things, Big data, Blockchain

1 Introduction

With the rapid development and deep integration of 5G technology, big data, artificial intelligence, cloud computing, blockchain and other new generation digital technologies, the agricultural product supply chain is undergoing a profound transformation from Internet to intelligent and digital. The common pain points in traditional agricultural product supply chains, such as information asymmetry, high logistics costs, and

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difficult quality traceability, are being effectively addressed through innovative digital technology applications. The Internet of Things technology provides a solid foundation for the transparency and efficient operation of agricultural product supply chains through the deployment of intelligent sensors and devices. For example, the application of RFID technology in the field of agricultural product circulation has achieved real-time positioning, information sharing, and secure traceability of agricultural products, significantly improving the efficiency of agricultural product circulation and effectively reducing circulation costs. In practical applications, Maersk's Remote Container Management System (RCM) monitors the temperature, humidity, and carbon dioxide levels inside refrigerated containers in real-time through IoT sensors, significantly reducing the loss of perishable agricultural products during transportation and providing shippers with transparent and visualized data throughout the entire process. Big data analysis technology can extract deep value from massive amounts of data, revealing supply and demand patterns and operational bottlenecks. Climate FieldView under Monsanto (now Bayer Crop Science) ™ The platform integrates multi-source data such as meteorology, soil, and historical yield from farmland to provide accurate planting decision support for farmers. This not only optimizes resource utilization efficiency, but also indirectly improves the stability and quality of agricultural product supply.[1] Blockchain technology, with its decentralized and tamper proof characteristics, provides innovative solutions for the traceability of agricultural product quality. After the blockchain traceability system jointly developed by Wal Mart and IBM is applied to the global supply chain, every commodity will be certified on the blockchain system, forming a transparent and secure commodity record, which is expected to reduce the cost of enterprises by up to $1 trillion. [2] This system can shorten the time to trace the source of food safety incidents from days to seconds, greatly enhancing the transparency of the supply chain and consumer trust. Similarly, Ant Financial's blockchain traceability system for Wuchang Rice allows consumers to view detailed records of the entire process from planting land, seeds, fertilizers to logistics by scanning a code, effectively solving the problem of product authenticity identification. Therefore, in-depth research on how digital technology can help agricultural product supply chains achieve sustainable development can not only provide solid theoretical support and feasible practical guidance for the transformation and upgrading of agricultural product supply chains, but also effectively promote farmers' sustained income growth, accelerate the process of agricultural modernization, and effectively ensure the security of national agricultural product supply. This article will explore the key factors that constrain the sustainable development of agricultural product supply chains, analyze how digital technologies such as the Internet of Things, big data analysis, and blockchain technology can help promote the sustainable development of agricultural product supply chains, and propose sustainable development strategies for agricultural product supply chains under the background of digital technology development.

2 Overview of Relevant Research

2.1 Sustainable Development of Agricultural Product Supply Chain

Domestic and foreign scholars have achieved in-depth research results in the field of sustainable development of agricultural product supply chains. The research focus of foreign scholars mainly focuses on environmental impact analysis methods and supply chain optimization strategies for agricultural product supply chains. For example, Sonnino and Marsden[3]studied the environmental impacts in agricultural supply chains and proposed strategies to reduce greenhouse gas emissions and water resource consumption. In terms of supply chain optimization, research emphasizes improving the efficiency and resilience of the supply chain through technological innovation, collaborative mechanism design, and policy guidance, in order to achieve sustainable development goals.García-Martínez[4]We also explored the behavioral games and coordination mechanisms of stakeholders in the agricultural supply chain, as well as how to promote sustainable practices among supply chain members through incentive mechanisms. Domestic scholars focus on the development and implementation of sustainability strategies, the construction and optimization of green supply chains, as well as policy guidance and support.Ma Yuanhang[5]Propose to strengthen technological innovation to promote industrial upgrading, optimize resource allocation, and promote the sustainable development of agricultural product supply chains.Ma Kun[6]Studied the application of green technology in the agricultural product supply chain, and proposed the construction and practical path of a green agricultural product supply chain. At the same time, research has delved into the certification system, standard setting, and market promotion of green agricultural products.Zhao Xiaofei, Chen Xiulin[7]Studied the role of government policies in the sustainable development of agricultural supply chains and proposed corresponding policy recommendations.

2.2 Digital Technology and Sustainable Development of Agricultural Product Supply Chain

With the rapid development of digital technology, its application in the agricultural product supply chain has attracted increasing attention from both academia and practice. The Internet of Things, big data analysis, blockchain and other digital technologies provide new impetus and opportunities for the sustainable development of agricultural product supply chains.The Internet of Things technology has great potential for application in real-time monitoring, early warning and prediction, intelligent decision-making and other aspects of agricultural product supply chain management[8] (Lu Yuan,2021).It achieves real-time monitoring and tracking of the agricultural product supply chain through sensors, intelligent devices, and other means, improving the transparency and traceability of the supply chain. In addition, IoT technology can play a positive role in the warehousing and transportation processes of agricultural cold chain logistics.Big data analysis technology also plays an important role in the agricultural product supply chain. By mining and analyzing massive amounts of data, enterprises can more accurately understand consumer needs, optimize inventory management, and logistics distribution[9](Song Rong,2024).Big data analysis can identify consumer purchasing patterns and preferences, provide decision support for agricultural product production and sales, and achieve precise marketing and customized production. At the same time, through the analysis of historical data, big data technology can improve supply chain risk management capabilities, predict potential problems and develop response strategies, and enhance supply chain resilience. Blockchain technology, with its decentralized and tamper proof features, has shown great potential in fields such as agricultural product quality traceability and supply chain finance[10](Liu Tongjuan,Cai Xiaodong,2024).Through blockchain technology, information related to the production, processing, and transportation of agricultural products can be securely recorded and shared, creating a transparent and trustworthy traceability system that effectively addresses food safety issues. In addition, the integration of blockchain and IoT technology further enhances the real-time and accuracy of traceability systems, improves the transparency and integrity of agricultural product supply chains, enhances consumer trust in products, and provides technical support for supply chain finance.In summary, scholars at home and abroad have conducted in-depth research on the sustainable development of agricultural product supply chains and the application of digital technology, and have achieved rich research results. Foreign scholars mainly focus on sustainability assessment, environmental impact analysis, and supply chain optimization of agricultural product supply chains; Domestic scholars tend to focus more on sustainability strategies, green supply chain construction, and policy guidance. At the same time, the application of digital technology in agricultural product supply chains has become a research hotspot, and technologies such as the Internet of Things, big data analysis, and blockchain provide new opportunities for the sustainable development of agricultural product supply chains.There are still some key issues that need further exploration and resolution. The main research question of this paper is: How to enhance the sustainability of agricultural product supply chains through effective digital technology applications? Especially, how to use technologies such as the Internet of Things, big data analysis, and blockchain to break through the bottlenecks in information flow, logistics, and traceability mechanisms of agricultural product supply chains? In addition, how to balance technological innovation and policy support in the process of digital transformation to ensure the sustainable development of agricultural product supply chains?

3 Exploration of Key Factors Restricting the Sustainable Development of Agricultural Product Supply Chain

As a complex adaptive system, the sustainable development of the agricultural product supply chain is influenced by multidimensional and multi-level factors (see Figure 1). From a systems thinking perspective, the agricultural product supply chain is an organic whole formed by closely connected links such as production, processing, circulation, and sales, with close interactive relationships and feedback mechanisms between each link. This system characteristic determines that the factors affecting the sustainable development of the supply chain do not exist in isolation, but are interrelated and influence each other, forming a complex causal network.

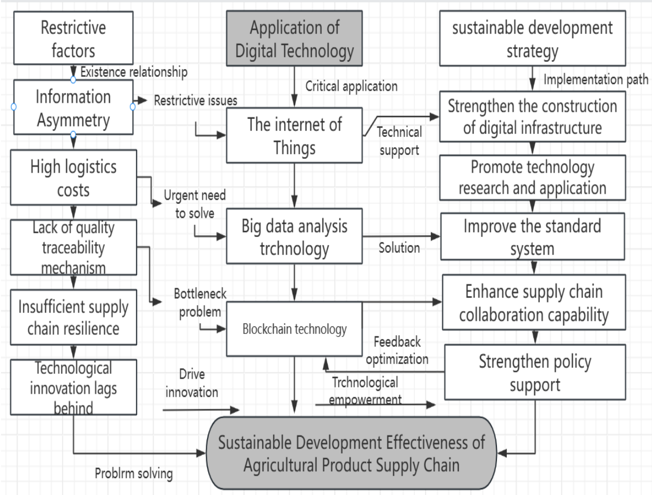

Fig. 1. Interactive Relationship Diagram of Constraints in the Agricultural Product Supply Chain System

3.1 Asymmetric Information: A Key Cause of Inefficient Supply Chain Operations

Asymmetric information is a core constraint factor in the agricultural product supply chain system, manifested as an unbalanced state of information acquisition, transmission, and application among various entities in the supply chain. This asymmetry is particularly prominent in the agricultural product supply chain, mainly manifested at three levels[11]: vertical information asymmetry, horizontal information asymmetry, and temporal information asymmetry.Vertical information asymmetry refers to the information barriers between upstream and downstream links in the supply chain. According to the Ministry of Agriculture and Rural Affairs of China “Survey Report on the Information Circulation Status of Agricultural Products Market in 2023” More than 70% of small farmers in the agricultural supply chain have difficulty obtaining accurate market demand information, while over 80% of consumers are unable to understand the actual production situation of agricultural products. This "two-way information blind spot" makes it difficult for producers to adjust their production layout according to market demand, and for consumers to make purchasing decisions that match their own preferences.Horizontal information asymmetry is reflected in the information isolation between different entities in the same supply chain link. For example, on the production side, farmers in different regions lack effective information sharing mechanisms, leading to regional supply-demand imbalances[12]; At the distribution end, information is not shared among logistics service providers, resulting in wasted transportation capacity and low efficiency. According to the China Federation of Logistics and Purchasing

"2024 Agricultural Product Logistics Operation Report" according to statistics, the empty driving rate of vehicles in China's agricultural product logistics field is as high as 40%, far higher than the level of 20% in developed countries. This is largely due to insufficient horizontal information sharing.Asymmetric information in the time dimension reflects the problem of lag in information transmission. The transmission of agricultural product price information from the terminal market to the production process usually takes 3-7 days, while the production cycle of agricultural products is usually several months or even longer. This time mismatch makes it difficult for farmers to make production decisions based on real-time market information. This time lag effect is an important cause of the "price cycle" phenomenon in agricultural products, exacerbating market volatility and resource misallocation.The impact of information asymmetry on supply chain systems is multifaceted. It directly affects farmers' production decisions, leading to a mismatch between supply and demand. According to the National Bureau of Statistics "Analysis Report on Supply and Demand Balance of Agricultural Products Market in 2023" Data shows that approximately 25% -30% of seasonal agricultural products in China experience oversupply or supply shortages each year, resulting in significant economic losses. Asymmetric information distorts the mechanism of market price formation, distorts price signals, and further strengthens supply-demand imbalances. In the highly asymmetric agricultural product market, the average price volatility is 30% higher, which not only increases the uncertainty of market participants but also reduces the efficiency of resource allocation. As shown in Figure 2, the problem of information asymmetry in China's agricultural supply chain is significantly higher than that of developed countries in multiple dimensions. Especially in terms of price information transmission delay and market demand forecasting error, China is 5-7 days and 15% higher than developed countries, respectively, which directly leads to production decision deviation and resource mismatch. The data in the figure clearly indicates that solving the problem of information asymmetry is the key to enhancing the sustainable development of China's agricultural product supply chain.

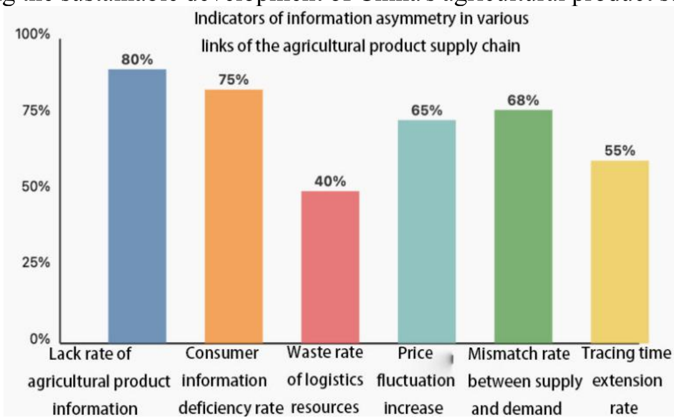

Fig. 2. Comparative data of information asymmetry in agricultural product supply chain

Data source: Institute of Rural Development, Chinese Academy of Social Sciences "China Agricultural Product Supply Chain Development Report 2024"

3.2 High Logistics Costs: an Important Constraint on the overall Efficiency of the Supply Chain

The problem of high logistics costs for agricultural products is not due to the low efficiency of a single link, but rather stems from the multidimensional constraints of the entire logistics system. From a system analysis perspective, the problem of high logistics costs for agricultural products can be analyzed from four aspects: insufficient infrastructure, outdated operational models, lagging technological applications, and imperfect institutional environments.At the infrastructure level, China's agricultural product logistics infrastructure faces problems of insufficient quantity, low quality, and uneven distribution. According to the China Cold Chain Logistics Association "2023 China Cold Chain Logistics Development Report", The cold storage capacity of agricultural products per 10000 people in China is only 30% of that in developed countries, and the coverage rate of specialized logistics centers for agricultural products is less than 50%. More importantly, these limited logistics infrastructure are mainly concentrated in economically developed areas, while agricultural production areas often have weak infrastructure, resulting in a clear phenomenon of "asymmetric infrastructure between production and sales". The insufficient infrastructure directly leads to a high loss rate of agricultural products in the logistics process. Data shows that the average loss rate of agricultural products in logistics in China is as high as 15%, while in developed countries, this proportion is usually controlled within 5%.In terms of operation mode, China's agricultural product logistics still relies mainly on traditional decentralized and small-scale operations, with insufficient scale and networking. According to the Market Operation and Consumption Promotion Department of the Ministry of Commerce "Statistical Bulletin on the Development of Agricultural Product Circulation Industry in 2023",The number of agricultural product logistics enterprises in China exceeds 200000, but more than 90% are small and medium-sized enterprises with an annual turnover of less than 10 million yuan. This decentralized operating model makes resource integration difficult and fails to generate effective economies of scale.

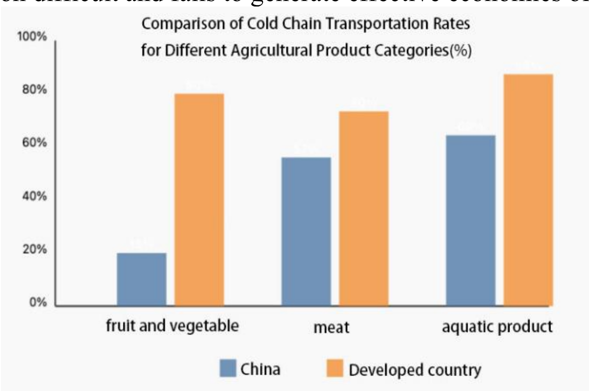

Fig. 3. Comparison of Cold Chain Logistics Coverage between China Developed Countries

Data source: China Cold Chain Logistics Association "2023 China Cold Chain Logistics Development Report"

At the level of technological application, the intelligence and informatization level of agricultural product logistics in China is relatively backward. The penetration rate of modern logistics technologies such as intelligent warehousing systems, automatic sorting technology, and temperature controlled logistics technology in the field of agricultural products is less than 30%, and most enterprises still adopt traditional manual operation and experience management methods. The insufficient application of cold chain logistics technology is particularly prominent, with a cold chain circulation rate of only 15% for fruits and vegetables, 57% for meat, and 69% for aquatic products in China, all significantly lower than the level of over 90% in developed countries. The insufficient application of technology directly leads to low logistics efficiency and high costs. As shown in Figure 3, there is a significant gap between China and developed countries in terms of cold chain logistics coverage. The coverage rate of cold chain logistics for various agricultural products is generally lower than that of developed countries, with the gap between fruit and vegetable products being the most significant. This is also an important reason for the high loss rate of 15% in the circulation of agricultural products in China[13]. The data in the figure intuitively reflects the lagging situation of China's agricultural cold chain logistics infrastructure and technology, and there is an urgent need to strengthen the construction and technological upgrading of cold chain logistics infrastructure.

3.3 Lack of Quality Traceability Mechanism: the Main Obstacle to Food Safety and Brand Trust

The difficulty in quality traceability is another key factor restricting the sustainable development of the agricultural product supply chain. It not only affects food safety assurance, but also hinders the establishment of consumer trust and the enhancement of brand value. From a system perspective, the difficulty in tracing the quality of agricultural products involves multiple aspects such as insufficient technical support, incomplete standard system, lack of main responsibility, and difficulties in data integration. At the level of technical support, the overall application of traceability technology for agricultural products in China lags behind. The current mainstream agricultural product traceability technologies include barcodes, QR codes, RFID, and blockchain[14], but in practical applications, traditional paper records and simple identification still dominate, and the coverage rate of efficient electronic traceability systems is less than 20%. Especially in the primary production stage of agricultural products, due to the dispersed production entities and limited economic capacity, the application proportion of advanced traceability technology is even lower, less than 10%. Insufficient technical support makes it difficult to effectively capture and record the entire process information of agricultural products from the field to the dining table, setting technical barriers for quality traceability. At the level of data integration, there is a serious problem of fragmentation and islanding of agricultural product traceability data[15]. At present, various levels of government departments, industry associations, leading enterprises, etc. have established different agricultural product traceability platforms, but the data sharing mechanism between these platforms is not perfect, and the information standards are not unified, which makes it difficult to effectively integrate and utilize traceability data.

According to the statistics of the Information Center of the Ministry of Agriculture and Rural Affairs on the construction of the agricultural product quality and safety traceability system in 2024, there are over 200 agricultural product traceability platforms established nationwide, but the interconnection rate between platforms is less than 15%, forming a large number of "data islands". As shown in Figure 4, there is a significant imbalance in the coverage of China's agricultural product quality traceability system. The figure clearly shows the differences in the coverage of traceability systems in different stages and regions. Among them, the application rate of traceability technology in the primary production stage is the lowest, only 20%, while in the product sales stage, the coverage rate of traceability systems reaches 65%. In terms of regional differences, the coverage rate of traceability systems in the eastern region is significantly higher than that in the central and western regions. This imbalance makes it difficult to achieve traceability of agricultural product quality throughout the entire chain and region. The chart data highlights the imbalance in the construction of China's agricultural product quality traceability system, and requires more attention to the coordinated development of the entire chain and region.

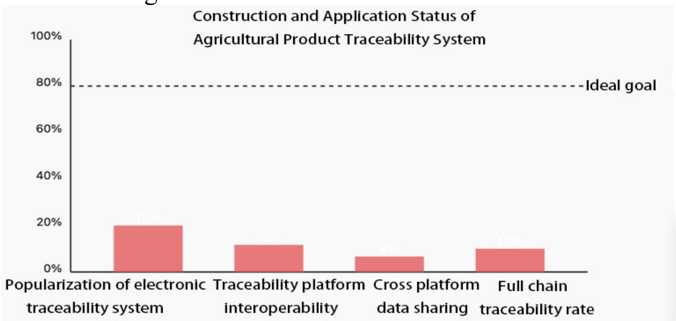

Fig. 4. Coverage of Agricultural Product Quality Traceability System

Data source: Ministry of Agriculture and Rural Affairs "Progress Report on the Construction of National Agricultural Product Quality and Safety Traceability System in 2023"

3.4 Insufficient Supply Chain Resilience: A Fragile Link in Response to External Shocks

As shown in Figure 4, comparing the resilience assessment results of China's agricultural product supply chain in five dimensions: shock resistance, recovery speed, resource elasticity, diversity of alternative solutions, and collaborative decision-making, it can be intuitively seen that the resilience of China's agricultural product supply chain is generally weak, especially in terms of collaborative decision-making and diversity of alternative solutions. In terms of structural vulnerability, China's agricultural product supply chain generally has the characteristics of "long chain, multiple links, and loose structure". From production to consumption, agricultural products usually go through multiple links such as farmers, cooperatives, buyers, wholesale markets, and retailers, each of which may become a vulnerable point in the system. Especially in the upstream production end, the production pattern dominated by small farmers has led to highly dispersed agricultural product production, insufficient economies of scale, and weak ability to resist risks. According to the National Bureau of Statistics “2023 National Agricultural Production and Operation Subject Census Data” The average planting scale of Chinese farmers is only 0.6 hectares, which is only 1/400 of that in the United States. This small-scale production lacks sufficient resource buffering and adjustment space when facing impacts such as natural disasters and market fluctuations. The radar chart in Figure 5 further confirms this point, as the scores of China's agricultural product supply chain in terms of shock resistance and resource elasticity are far below the ideal state, reflecting the inherent fragility of the current supply chain structure.

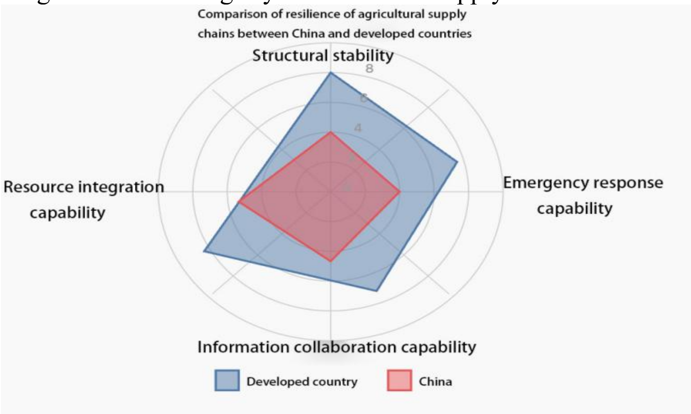

Fig. 5. Radar diagram of resilience assessment of agricultural product supply chain

Data source: China Logistics Society “China Agricultural Product Supply Chain Resilience Assessment Report 2024”

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3.5 Technological Innovation Lagging Behind: the Main Bottleneck of Supply Chain Modernization Transformation

Technological innovation is the core driving force for promoting the sustainable development of agricultural product supply chains, but there is still a significant gap in agricultural technological innovation in China, especially in the intelligent and precise application of production, processing, and logistics links, which lags behind developed countries. From a system perspective, the problem of lagging technological innovation involves multiple aspects such as insufficient innovation investment, lagging technology application, lack of talent support, and imperfect innovation environment.

Fig. 6. Comparison of Agricultural Science and Technology Innovation Indicators

Data source: China Association for Science and Technology “Comparative Study on Global Agricultural Technology Innovation 2024”

In terms of innovation investment, China's research and development investment in the field of agricultural product supply chain is insufficient. According to data from the Ministry of Science and Technology “2023 China Science and Technology Statistical

Yearbook",The proportion of agricultural technology research and development investment in China's agricultural GDP is less than 1%, far below the level of 2% -3% in developed countries. Most agricultural supply chain enterprises lack specialized research and development institutions and teams, with limited technical research and development capabilities, making it difficult to meet the technological needs of supply chain upgrading. As shown in Figure 6, by comparing the gap between China and developed countries in the main indicators of agricultural science and technology innovation, it can be clearly seen that China has significant deficiencies in research and development investment intensity, technology talent density, technology application rate, and patent output. In particular, the R&D investment intensity is only one-third of that of developed countries, which directly restricts the sustained innovation capability of agricultural technology. The data in the figure fully illustrates the lagging situation of agricultural scientific and technological innovation in China, which is also a key bottleneck restricting the modernization transformation of the agricultural product supply chain. In terms of technological application, the depth and breadth of modern agricultural technology in various links of the supply chain are insufficient. According to survey data from the Chinese Academy of Agricultural Sciences "Agricultural Science and Technology Development Report 2023"30%, the implementation area of precision agriculture technology is about 20%, far lower than the 70% and over 60% in the United States. In the processing stage, the conversion rate of agricultural products in China is less than 60%, far lower than the 80% in EU countries. In terms of logistics, the cold chain coverage rate of agricultural products in China is about 50%, far lower than Japan's 90%.In terms of talent support, there is a shortage of professional talents in the field of agricultural product supply chain. On the one hand, the total number of high-level agricultural technology talents is insufficient, and the proportion of agricultural college graduates engaged in agricultural related work is less than 30%; On the other hand, the number of grassroots agricultural technology extension personnel has decreased, and their professional quality varies greatly, making it difficult to meet the needs of modern agricultural technology promotion. Especially in rural areas, the proportion of new professional farmers is less than 20%, and most farmers lack modern agricultural technology training, which restricts the application and promotion of advanced technology.In terms of innovation environment, the policy support and market mechanism for agricultural product supply chain innovation are not perfect. The existing agricultural science and technology innovation policies are mostly focused on the production process, with insufficient support for processing, logistics, and other links; The incentive mechanism for the transformation of agricultural scientific and technological achievements is not sound, which makes it difficult for many advanced technologies to move from the laboratory to the field. In terms of the market, there is insufficient demand for innovation in the agricultural product supply chain, weak innovation motivation among enterprises, and imperfect mechanisms for sharing innovation risks, which restrict the release of innovation vitality.In summary, there are complex interactive relationships among the constraining factors of the agricultural product supply chain system, forming a causal network that is interrelated and mutually reinforcing. Asymmetric information, as a core constraint factor, directly leads to unreasonable allocation of logistics resources and drives up logistics costs; At the same time, it exacerbates the difficulty of quality traceability and reduces the transparency of the supply chain. There is a bidirectional constraint relationship between high logistics costs and the lack of quality traceability mechanisms - high logistics costs limit the application scope of traceability technology, while imperfect traceability systems increase the complexity and compliance costs of logistics management. These two factors together weaken the resilience of the supply chain, high logistics costs reduce the flexibility of resource allocation, and traceability difficulties prolong the identification and disposal time of risk events. The lag in technological innovation is a fundamental constraint that affects other factors. It not only strengthens information asymmetry, but also restricts the progress of logistics technology and the development of quality traceability systems. The insufficient resilience of the supply chain exacerbates the problem of information asymmetry, forming a vicious cycle. This systematic interaction forms multiple feedback loops: positive feedback exacerbates problems (such as information asymmetry and logistics costs reinforcing each other), while negative feedback provides improvement pathways (such as the mitigating effect of technological innovation on various problems). Understanding this complex interactive mechanism is key to developing systematic solutions.

4 Digital Technology Helps Promote Sustainable Development of Agricultural Product Supply Chain

4.1 Internet of Things Applications: Solving the Problems of Information Asymmetry and High Logistics Costs

Asymmetric information is a major pain point in the agricultural supply chain, and farmers often have difficulty obtaining accurate market demand information, leading to inaccurate production decisions. The Internet of Things technology, through intelligent sensors and wireless radio frequency identification (RFID) technology, can monitor real-time environmental parameters of farmland, such as soil moisture, temperature, light, etc., providing accurate production guidance for farmers. In addition, IoT platforms can also transmit market dynamics and weather forecasts in real-time, helping farmers make more scientific decisions based on market demand and environmental changes, reducing blind production, and optimizing supply and demand matching.High logistics costs, especially losses and management expenses in cold chain logistics, are also major issues in the agricultural product supply chain. IoT technology, through intelligent logistics systems, can achieve real-time tracking and monitoring of transportation vehicles, optimize transportation routes, reduce transportation time, and minimize losses. For example, temperature sensors and GPS positioning systems can monitor the temperature and environment of agricultural products during transportation, ensuring their freshness and avoiding losses caused by temperature fluctuations. In addition, intelligent warehousing systems can improve warehouse management efficiency, achieve automatic sorting, storage, and outbound of goods, thereby reducing warehousing costs.

4.2 Big Data Analysis: Optimizing Supply Chain Operations and Improving Decision-Making Efficiency

Big data analysis technology can accurately predict market demand through the processing of massive data and algorithm models, providing farmers with data-driven planting adjustment suggestions to avoid overproduction or shortage. At the same time, agricultural product processing enterprises and sellers can use big data analysis to understand consumer preferences, carry out customized production, and enhance market competitiveness. In the logistics process, big data analysis can optimize transportation routes, reduce empty driving rates, and improve vehicle loading rates by mining historical data. In terms of warehouse management, it is possible to predict inventory demand, implement precise inventory management, and reduce backlog and out of stock costs.Big data analysis can also help identify bottleneck links in the logistics process, provide directions for continuous improvement, and enhance the overall efficiency of the supply chain.

4.3 Blockchain Technology: Ensuring Quality Traceability and Enhancing Supply Chain Resilience

The difficulty in quality traceability is a long-term problem in the agricultural product supply chain, especially when quality issues arise, it is difficult to quickly identify the responsible party. Blockchain technology provides an effective quality traceability solution through its tamper proof and transparent features. Through blockchain, the information of agricultural products from production, processing to transportation, sales and other links can be recorded in real time and encrypted for storage, forming a transparent information chain. Consumers can view complete agricultural product information by scanning the QR code, thereby enhancing their trust in the product. If there are quality issues, blockchain technology can quickly trace the problematic links and improve processing efficiency.The supply chain of agricultural products is susceptible to external factors such as natural disasters and epidemics, resulting in poor resilience of the supply chain. Blockchain technology can build a more flexible and adaptive supply chain network through decentralized mechanisms. In the event of a supply chain interruption, blockchain can quickly identify and mobilize backup resources to ensure the continuity of the supply chain. In addition, through smart contracts, blockchain can automatically execute contract terms, reduce human intervention, improve supply chain response speed, and enhance its resilience.In summary, the Internet of Things, big data analytics, and blockchain technology do not exist in isolation. They work together to promote the sustainable development of agricultural product supply chains. The Internet of Things technology provides a real-time and accurate data foundation, making it possible for the application of big data analysis and blockchain technology. Big data analysis provides a scientific basis for optimizing and making decisions in the supply chain by deeply mining the data collected by the Internet of Things. Blockchain technology ensures the authenticity and immutability of data, providing technical support for quality traceability and enhancing supply chain resilience.

5 Sustainable Development Strategy of Agricultural Product Supply Chain under the Background of Digital Technology Development

5.1 Strengthen Digital Infrastructure and Technology Applications

The government should increase investment in digital infrastructure construction in rural areas, improve broadband network coverage and transmission speed, and provide necessary support for the application of digital technology. At the same time, enterprises and social capital should be encouraged to participate in infrastructure construction and promote the formation of diversified investment mechanisms. By accelerating the construction of rural digital infrastructure, narrowing the gap in technology application between urban and rural areas, ensuring the smooth application of technologies such as the Internet of Things, blockchain, and big data, promoting the digital transformation of agricultural product supply chains, and improving supply chain management efficiency and transparency. In addition, the improvement of technological level is also the key to promoting the digital transformation of agricultural product supply chains. Policies should encourage enterprises to increase research and application of these emerging technologies, especially the Internet of Things, big data, and blockchain, to solve problems such as information asymmetry, high logistics costs, and difficult quality traceability. At the same time, the government should support the cultivation of technical talents, promote cooperation between agricultural supply chain related enterprises, universities, and research institutions, and enhance the overall technical level of the industry. In addition, insufficient policy support is also one of the obstacles to digital transformation. Therefore, the government needs to introduce more targeted policies, including innovation incentive policies and improving digital transformation support policies, encouraging agricultural product enterprises to adopt digital technology through financial subsidies, tax incentives and other measures, and setting up special funds to support technological innovation of agricultural enterprises, especially in agricultural production, processing and logistics links, to help agricultural product enterprises improve overall efficiency, transparency and resilience, and promote the sustainable development of agricultural product supply chains.

5.2 Promote the Application of Big Data and Blockchain Technology in the Supply Chain

The government should guide enterprises to establish big data analysis platforms, deeply explore the massive data in the agricultural product supply chain, optimize market demand forecasting, inventory management, and logistics efficiency. At the same time, support enterprises to explore the application of blockchain technology in quality traceability and supply chain finance, ensuring the authenticity and integrity of information, and enhancing consumers' trust in agricultural products. Strengthen the research and promotion of technology, and improve the popularity and application level of technology in the supply chain.

5.3 Enhance Supply Chain Resilience and Collaboration Capabilities

The government should guide enterprises to strengthen the coordination and integration of the supply chain, form stable cooperative relationships, achieve resource sharing, complementary advantages, and risk sharing, and enhance the overall efficiency and competitiveness of the supply chain. By strengthening the resilience of the supply chain, enhancing its ability to respond to external shocks, promoting the establishment of supply chain risk management and emergency response mechanisms, and ensuring that the supply chain can quickly recover in the face of emergencies.

6 Conclusion

This article systematically reviews the research status of sustainable development of agricultural product supply chains and the application of digital technology in them, and deeply analyzes the core factors that constrain the sustainable development of agricultural product supply chains, including information asymmetry, high logistics costs, lack of quality traceability mechanisms, insufficient supply chain resilience, and lagging technological innovation. On this basis, it elaborates in detail how key digital technologies such as the Internet of Things, big data analysis, and blockchain can inject new momentum into the sustainable development of agricultural product supply chains by enhancing information transparency, optimizing operational efficiency, strengthening quality assurance, and enhancing system resilience. Finally, based on the current trend of digital technology development, sustainable development strategies covering strengthening digital infrastructure construction, promoting the deep application of key technologies, and enhancing supply chain collaboration and resilience are proposed. However, the widespread application of these digital technologies in rural areas still faces significant challenges. The key obstacles to technology promotion are the insufficient digital infrastructure in rural areas, limited technological acceptance capacity of small farmers, and high initial investment costs. Especially for rural areas in China, the small scale, high degree of decentralization, and uneven information literacy of farmers make the large-scale application of advanced digital technology face many difficulties. Looking ahead to the future, the following three in-depth research directions deserve special attention: firstly, the digital empowerment model for small farmers urgently needs to be further studied. The current application of digital technology is mostly targeted at large-scale business entities, and there is insufficient attention paid to small farmers who occupy the main position in agricultural production. Future research should focus on developing an economically feasible, technology friendly, and low acceptance threshold "digital empowerment model for small farmers", and explore in depth how to consider the cognitive level and economic situation of small farmers in the technology design stage to reduce application costs. At the same time, research should quantitatively analyze the investment return ratio of digital technology adopted by farmers of different scales, as well as the specific impact path and degree of different technology combinations on small farmers' production decisions and income levels, providing scientific basis for the government to formulate differentiated digital technology promotion strategies. Secondly, there is an urgent need to break through the standardization and interoperability issues of digital technology. At present, the application of digital technology in the agricultural product supply chain often presents an "information island" state, and the lack of uniformity in the technical standards and data formats adopted by different entities and links seriously restricts the sharing of information and collaborative decision-making throughout the entire chain. Future research should focus on exploring the technical path and governance mechanism for establishing a unified digital standard system for agricultural product supply chains, including information collection standards, transmission protocols, data formats, privacy protection mechanisms, etc., and designing a multi-party incentive model based on consensus mechanisms to address the lack of willingness and rights protection issues of different stakeholders in the information sharing process, achieving seamless integration between technical systems and efficient flow of data. Thirdly, research on the adaptability of digital technology to rural social structure urgently needs to be strengthened. Existing research focuses more on the technology itself, while neglecting the social environment in which the technology is applied. The complex social relationship network, traditional business habits, and cultural psychological characteristics in rural areas will significantly affect the acceptance and application effectiveness of digital technology. Future research should adopt a multidisciplinary approach to deeply analyze how digital technology affects the trust mechanism, power structure and interest distribution pattern of rural society, and how to organically combine the wisdom of traditional rural governance with modern digital technology to design digital solutions that are both technologically progressiveness and conform to the reality of rural society, so as to ensure inclusiveness and fairness in the process of technology promotion. These in-depth and focused research directions will help solve the core problems faced by digital technology in the application of agricultural supply chains, promote the development of agricultural supply chains towards a more sustainable direction, and ultimately achieve the strategic goals of agricultural modernization and rural revitalization.

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