Value Generation of Ecological Agricultural Products in Jilin Province under Digital Twin Technology

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Abstract: *Digital twin technology has opened up a new technological pathway for value creation in ecological agricultural products. As a major agricultural province, Jilin Province possesses abundant ecological agricultural resources; however, the mechanisms for transforming these resources into economic value remain underdeveloped. By establishing bidirectional mapping between physical entities and virtual models, digital twin technology enables full-process digital control of ecological agricultural products. Analysis shows that value enhancement is primarily achieved through three pathways: intelligent management and control of production processes, systematic development of quality traceability systems, and digital transformation of brand promotion. The application of this technology significantly improves production efficiency, quality control capability, and market recognition of ecological agricultural products, providing strong support for the advancement of agricultural modernization.*

Keywords: *Digital Twin Technology; Ecological Agricultural Products; Value Generation; Jilin Province; Smart Agriculture*

1. Introduction

The cultivation of value in ecological agricultural products is a critical component of deepening supply-side structural reform in agriculture and advancing the rural revitalization strategy. Located in the heart of the Northeast China Plain, Jilin Province enjoys inherent advantages for the development of ecological agriculture. Nevertheless, existing value cultivation models are constrained by low levels of production standardization, weak quality traceability systems, and insufficient brand outreach capacity. As a representative frontier information technology, digital twin technology can construct digital replicas of physical agricultural systems, enabling real-time monitoring and intelligent decision-making across the entire value chain of ecological agricultural products. This provides a novel pathway for overcoming the limitations of traditional agricultural development models. The mature application of digital twin technology in manufacturing and other sectors also offers solid technical foundations for its expansion into the agricultural domain.

2. Theoretical Mechanisms by Which Digital Twin Technology Drives Value Generation in Ecological Agricultural Products

2.1 Core Characteristics and Application Advantages of Digital Twin Technology

Digital twin technology is characterized by real-time mapping, virtual-physical interaction, and predictive optimization. Through high-precision digital modeling, it can fully reconstruct physical agricultural systems in a virtual environment. Relying on Internet of Things (IoT) devices to continuously collect agricultural environmental data and intelligent algorithms to generate virtual models with dynamic feedback capabilities, the technology realizes bidirectional linkage between the physical and digital worlds. Compared with traditional approaches to agricultural informatization, digital twin technology overcomes temporal and spatial constraints, providing continuous, all-dimensional system monitoring. Its data-driven decision-making mechanisms significantly enhance the precision of agricultural production [1]. The application value of digital twin technology is mainly reflected in the visualization and control of production processes, which help reduce labor input and optimize management efficiency; predictive analytics that shift agricultural production from passive response to proactive prevention; and standardized digital architectures that provide technical support for large-scale deployment, thereby comprehensively promoting the upgrading of agricultural

modernization.

2.2 The Internal Logic of Value Generation in Ecological Agricultural Products

The value generation of ecological agricultural products follows a progressive logic of "ecological attributes - quality perception - value realization". At its core, this process transforms ecological resource advantages into market competitiveness. The value system of ecological agricultural products consists of three dimensions: use value, environmental value, and brand value. Use value is reflected in nutritional composition and safety attributes; environmental value arises from the positive contributions of production processes to ecological protection; and brand value is generated through price premiums based on consumer recognition of environmental attributes. Value formation proceeds through four key stages: quality cultivation, information transmission, value recognition, and price realization. During the quality cultivation stage, environmentally friendly production technologies are adopted to ensure intrinsic product quality. In the information transmission stage, full-chain traceability systems are employed to convey environmental attributes to consumers. The value recognition stage relies on precise brand promotion to enhance consumers' purchase intentions, while price realization converts environmental value into tangible economic returns through market mechanisms.

2.3 Coupling Mechanisms between Digital Twin Technology and Value Generation

Digital twin technology forms a deeply coupled relationship with the value generation of ecological agricultural products, enabling coordinated optimization across all segments of the value chain. In terms of quality construction, digital twin systems ensure ecological quality through precise environmental monitoring and production control. In information transmission, the integration of blockchain technologies and IoT devices establishes tamper-proof and traceable mechanisms, enhancing consumer trust in the ecological attributes of products. In value perception, virtual reality technologies allow consumers to experience ecological agricultural production processes immersively, strengthening brand awareness and attachment. In value realization, big data analytics assist producers in accurately identifying changes in market demand and optimizing product pricing strategies [2]. This technology-value linkage creates a positive reinforcement loop: technological application enhances product value, while value realization provides financial support for further technological advancement, driving the overall system toward higher levels of development and ultimately achieving the integrated unity of ecological, economic, and social benefits.

3. Current Status of Value Generation and Digital Transformation Needs of Ecological Agricultural Products in Jilin Province

3.1 Resource Endowments and Industrial Foundations of Ecological Agricultural Products in Jilin Province

Jilin Province is located within the high-quality agricultural planting belt between 41° and 46° north latitude and lies at the core of one of the world's three major golden corn belts. Its black soil resources account for approximately 22% of the national total, providing exceptional natural endowments for the cultivation of green and ecological agricultural products. The province's forest coverage rate reaches 45.04%, wetlands account for 5.35% of total land area, and the proportion of surface water bodies meeting good-quality standards remains consistently above 85%. In terms of industrial performance, total grain output reached 4.764 billion kilograms in 2024, while the gross output value of agriculture, forestry, animal husbandry, and fisheries amounted to RMB 38.49 billion, representing a year-on-year increase of 5%. Distinctive green agricultural products such as Chagan Lake Rice, Changbai Mountain Ginseng, and Wangqing Black Fungus have established notable brand recognition. Among these, the annual cultivation volume of Wangqing Black Fungus has reached 650 million cultivation bags, generating an output value of RMB 3.4 billion. The province has developed more than 50 standardized production bases for green food raw materials, over 200 agricultural enterprises have obtained organic certification, and the edible fungi industry has surpassed 1.2 billion cultivation bags in scale, with an output value of RMB 4.7 billion. Together, these factors provide a solid industrial foundation for the large-scale development of ecological agricultural products.

3.2 Limitations of Traditional Value Generation Models

The existing value formation mechanisms for ecological agricultural products exhibit several inherent shortcomings that constrain the growth of overall industrial benefits. During the production stage, limited levels of standardization lead to significant fluctuations in product quality. The absence of unified production guidelines and quality control standards makes it difficult to meet the homogeneity requirements of high-end markets. In the circulation stage, information silos are prevalent, creating barriers between producers and consumers. As a result, consumers are unable to clearly identify the ecological attributes and quality indicators of products. Brand development lags behind industrial expansion, with most ecological agricultural products still positioned at the raw material supply stage. Insufficient deep processing and brand cultivation weaken their capacity for economic value addition. Sales channels remain relatively narrow, relying primarily on traditional wholesale markets and physical retail outlets, while digital marketing and promotion tools are underutilized. Moreover, the construction of full-process traceability systems remains underdeveloped. Traditional manual record-keeping methods cannot support end-to-end traceability, resulting in limited transparency regarding product origins and production processes. Collectively, these factors hinder the effective transformation of ecological benefits of ecological agricultural products into economic returns.

3.3 Assessment of Practical Conditions for Digital Transformation

Jilin Province possesses favorable conditions for digital transformation, creating a supportive environment for digitally enhancing the value of ecological agricultural products. In terms of infrastructure, mobile broadband coverage has reached 98%, and rural network facilities continue to improve. The policy environment has been steadily optimized, with the provincial government implementing initiatives such as the Ten-Billion Grain Production Increase Plan, introducing 32 high-efficiency cultivation technologies, establishing modern agricultural industry-education alliances, and building a comprehensive policy support system. Initial results have already been achieved in technological application. For example, the integrated air-space-ground satellite monitoring system established in Yongji County covers 322 hectares of rice fields and has enabled a doubling of farmers' incomes. In Shulan City, an intelligent rice noodle processing line with an annual processing capacity of 50,000 tons has reduced grain losses by 30%, with an investment of approximately RMB 8 million and a payback period of around three years. Talent cultivation mechanisms are also becoming increasingly well developed, with more than 30 doctoral researchers participating in enterprise-based industry-university-research collaboration through the modern agricultural industry-education alliance. Meanwhile, market demand continues to grow steadily, as rural per capita disposable income has reached RMB 20,804, reflecting an increase of 6%.

3.4 Key Demand Orientations for Enhancing Value Generation

Enhancing the value of ecological agricultural products requires a systematic digital approach centered on four core demands. First, the demand for intelligent agricultural production management is particularly prominent. Traditional experience-based models lack sufficient precision. In Wujia Village, Yongji County, for instance, the application of smart agriculture technologies enabled refined management across 322 hectares of rice fields, achieving simultaneous improvements in yield and quality while reducing fertilizer and pesticide use by 30%. Second, the demand for transparency in quality traceability systems is highly significant. The beef cattle industry in Huadian City has already implemented full-process traceability through QR code-based digital records; however, such models remain limited in the ecological agricultural product sector. There is an urgent need to establish digital traceability mechanisms covering the entire industrial chain [3].   Third, the demand for precision in brand communication is increasingly evident. Although Chagan Lake Rice has maintained organic certification for seven consecutive years, its brand influence remains insufficient and requires digital tools to enable targeted marketing. Finally, the demand for efficient production-marketing linkage is clear. The successful case of the Huadian cattle market, with an annual transaction volume of RMB 745 million, demonstrates the importance of digital trading platforms. Similarly, the ecological agricultural product sector needs to develop efficient production-marketing docking platforms, which are expected to improve circulation efficiency by more than 25%.

4. Implementation Pathways for Digital Twin Technology-Empowered Value Generation of Ecological Agricultural Products in Jilin Province

4.1 Building an Intelligent Production Management System

An intelligent production management system should establish a complete closed-loop framework of "perception - analysis - decision-making - execution" to ensure refined management throughout the production of ecological agricultural products. At the perception stage, diversified sensing devices, including soil pH sensors, chlorophyll detection instruments, and automated pest and disease recognition camera systems, should be deployed to enable real-time acquisition of production environment data. A representative case is the smart agriculture demonstration park in Yongji County, which has established a comprehensive monitoring network based on 168 temperature control points. At the data processing layer, edge computing technologies are employed to construct a virtual farmland mapping system that integrates soil nutrient data, historical meteorological records, and crop growth stage parameters, thereby enabling the development of scientific crop growth prediction models. The decision-support layer relies on intelligent algorithm systems to provide farmers with precise recommendations on water-fertilizer ratios, early warnings of pest and disease outbreaks, and optimal harvest timing. At the execution layer, production instructions are automatically implemented through intelligent irrigation systems, drone-based crop protection operations, and automated harvesting machinery. By constructing three-dimensional dynamic crop growth models, the system simulates growth outcomes under different management strategies and offers intuitive decision-making references for farmers, achieving management outcomes such as the 30% loss reduction realized by intelligent production lines in Shulan City.

4.2 Establishing a Full-Chain Quality Traceability System

The construction of a full-process quality traceability system can be based on blockchain technology to create a distributed data storage architecture that ensures the authenticity, reliability, and tamper resistance of traceability data. During the production stage, intelligent data collection devices automatically capture key information such as planting locations, sowing specifications, fertilization timing and dosage, and plant protection operations. Drawing on the blockchain-based traceability practices used for Changbai Mountain Ginseng, a unique digital identity can be generated for each production batch. In the processing stage, barcode scanning technologies are used to record details including raw material sources, processing parameters, quality inspection results, and packaging dates, with reference to the twelve-step digitalized process management experience of Jiangwan Rice Industry [4]. In the circulation stage, Internet of Things technologies are applied to monitor temperature, humidity, vibration, and other conditions in real time during transportation, thereby ensuring product quality stability throughout circulation. At the consumer end, scanning the QR code on the product packaging enables access to a complete product profile, including origin environmental data, visual records of the production process, third-party inspection reports, and logistics trajectories. The system should also incorporate quality anomaly monitoring functions that automatically trigger alerts when product indicators deviate from standards, facilitating precise identification and rapid recall of problematic products and strengthening consumer confidence in the safety of ecological agricultural products.

4.3 Enhancing the Effectiveness of Brand Value Communication

Improving the effectiveness of brand value communication requires the development of a diversified digital marketing system to achieve optimal dissemination of brand value through data-empowered precision marketing strategies. At the content creation level, panoramic photography technologies can be used to present ecological agricultural production scenarios, while drone imagery captures seasonal variations in farmland landscapes, thereby creating compelling brand narratives. Wangqing Black Fungus, for example, can leverage its natural advantage of an 88.79% forest coverage rate to transform ecological strengths into distinctive brand identity. The digital communication system should integrate multiple online touchpoints, including WeChat mini-programs, Douyin live streaming, and Tmall marketplaces, to build an omnichannel brand communication matrix. Intelligent marketing systems can construct user profile models based on data such as browsing histories, consumption records, and social interaction behaviors, enabling differentiated and targeted content delivery. The digital transformation of brand storytelling should further explore regional cultural characteristics and ecological attributes of products, conveying ecological brand values through short videos, graphic

content, and interactive live-streaming formats [5]. A brand influence evaluation mechanism should be established to dynamically track communication outcomes using indicators such as online public opinion heat, user engagement levels, and conversion efficiency, providing data support for iterative optimization of marketing strategies and promoting the sustained growth of brand value for ecological agricultural products like Chagan Lake Rice.

4.4 Optimizing Production-Marketing Docking Service Platforms

Production-marketing docking service platforms should develop centralized digital trading systems to facilitate precise matching of supply and demand information and coordinated optimization across the industrial chain. The information service module utilizes web crawling technologies to collect price data from major agricultural product wholesale markets nationwide. By integrating external data such as meteorological variations, policy orientations, and consumer preferences, the system provides users with interpretive analyses of market dynamics and forward-looking price trend forecasts. The transaction matching system relies on intelligent analytical models to achieve smart matching based on dimensions such as product specifications, transaction scale, geographic distribution, and historical trading performance. The Huadian cattle market's achievement of an annual transaction volume of RMB 745 million through a professionalized platform offers a valuable reference. The logistics integration module should connect with leading cold-chain service providers such as SF Express and JD Logistics to deliver end-to-end temperature-controlled logistics solutions for ecological agricultural product from production sites to end consumers, ensuring product freshness and nutritional quality. The financial service module should incorporate a combination of tools, including supply chain finance, agricultural futures, and price protection mechanisms, to help producers effectively manage market volatility and capital turnover challenges. In addition, the platform should establish credit evaluation and quality assurance systems. Through third-party quality inspection verification, user feedback collection, and dispute resolution mechanisms, a reliable trading environment can be cultivated, fostering a virtuous operational ecosystem and facilitating the full realization of value in Jilin Province's ecological agricultural products.

5. Conclusion

Digital twin technology has opened up new pathways for value generation in ecological agricultural products in Jilin Province. The construction of an integrated digital twin system encompassing production management, quality traceability, brand communication, and production-marketing docking across the entire value chain can effectively address key challenges in traditional agricultural development, including information asymmetry, low levels of standardization, and insufficient exploitation of brand value. Jilin Province should seize the opportunity presented by the development of smart agriculture and accelerate the deep integration of digital twin technology into the green agricultural product sector. By improving infrastructure, refining policy frameworks, and cultivating specialized talent, the province can comprehensively enhance the efficiency of value transformation for green agricultural products, injecting strong momentum into agricultural modernization and comprehensive rural revitalization. Future efforts should continue to deepen advancements in areas such as technical standard formulation and cross-regional collaboration.

Acknowledgment

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