Focusing on Characteristic Industries: Research on the Optimization of the Value Chain of Hainan's Tropical High-Efficiency Agriculture Driven by Big Data

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Abstract: Against the backdrop of the Hainan Free Trade Port construction, this paper delves into how big data technology drives the optimization and upgrading of the value chain of Hainan's tropical characteristic and efficient agriculture. Through an analysis of the current development status of Hainan's tropical agriculture, it reveals the bottlenecks existing in various segments of its value chain. By integrating practical cases such as the "Digital Platform for Technology Integration in Industrial Chains," the Wenchang Chicken industry, and the industrialized seedling cultivation base at the Yazhou Base of the Sanya Tropical Agricultural Science Research Institute, this paper systematically elaborates on the application mechanisms and empowerment pathways of big data technology in agricultural production, management, marketing, and service links. Research indicates that big data technology, through methods like precision planting, smart management, brand building, and traceability supervision, can effectively enhance the value chain efficiency and industrial added value of Hainan's tropical agriculture, providing new momentum for promoting rural revitalization and high-quality agricultural development in Hainan.

Keywords: Big Data; Tropical Agriculture; Value Chain; Smart Agriculture; Hainan Free Trade Port

1. Introduction

1.1 Research Background and Significance

Against the backdrop of the vigorous advancement of the Hainan Free Trade Port construction, tropical characteristic and efficient agriculture, as one of Hainan's four leading industries [1], is facing unprecedented development opportunities and transformation challenges. Leveraging its unique tropical climate resources and geographical location advantages, Hainan has developed characteristic agricultural industries represented by tropical fruits, winter melons and vegetables, the Nanfan seed industry, and natural rubber, forming a highly localized agricultural system. However, with rapid changes in domestic and international market environments and continuous upgrades in consumer demand, long-standing issues in Hainan's tropical agriculture—such as a fragmented industrial chain, low value chain levels, and slow market response—have become increasingly prominent, severely constraining the further improvement of industrial efficiency and competitiveness [2].

Currently, new-generation information technologies represented by big data, artificial intelligence, and the Internet of Things are rapidly integrating into the agricultural sector, providing powerful momentum for the modern transformation of traditional agriculture. Big data technology, through the collection, analysis, and application of massive data, enables the optimal allocation of agricultural resources, precise management of production processes, intelligent matching of market supply and demand, and collaborative integration of industrial chains, thereby effectively enhancing the overall efficiency of the agricultural value chain. In the favorable environment of continuously released policy dividends from the Hainan Free Trade Port, fully utilizing data as a new factor of production and promoting the deep integration of big data technology with tropical agriculture are of great significance for breaking the bottlenecks in Hainan's agricultural development, cultivating new drivers for rural industries, and achieving the strategic goals of rural revitalization.

This research is based on the strategic context of the Hainan Free Trade Port construction, focusing on the pathways and mechanisms of big data technology enabling the optimization of the tropical high-efficiency agricultural value chain. It aims to provide theoretical references and practical guidance for promoting the digital transformation of Hainan's agriculture and constructing a modern agricultural industrial system. The research results will not only help enrich the theoretical system of agricultural informatization development but also serve as a decision-making basis for government departments formulating agricultural digital policies and enterprises promoting digital practices, possessing significant theoretical and practical value.

1.2 Research Objectives and Methods

This research aims to deeply analyze the application status, mechanism, and realization pathways of big data technology in optimizing the value chain of Hainan's tropical high-efficiency agriculture. The specific objectives are as follows: first, to systematically sort out the constituent links and current problems of Hainan's tropical agricultural value chain; second, to explore the internal logic and pathways of big data technology enabling agricultural value chain optimization; third, to summarize and analyze typical cases and practical experiences of big data technology application in Hainan's tropical agriculture; fourth, to propose policy recommendations and development strategies for big data-driven optimization of Hainan's tropical agricultural value chain.

2 Theoretical Basis and Literature Review
2.1 Agricultural Value Chain Theory

The concept of the agricultural value chain originates from Porter's value chain theory and refers to a series of value-added activities that agricultural products undergo from production, processing, circulation, to final consumption [3]. In the agricultural field, the value chain includes not only the physical transformation process of agricultural products but also the information flow, capital flow, and value flow accompanying the logistics. Agricultural value chain management aims to reduce transaction costs and enhance overall efficiency and added value by optimizing the connection and coordination of various links in the chain.

In recent years, with the rapid development of digital technology, the theory of the agricultural value chain has been continuously enriched and improved. The traditional agricultural value chain exhibits linear characteristics, with low correlation between links and prominent information asymmetry problems. In contrast, the modern digital agricultural value chain emphasizes the networking of the chain, transparency of information, and synergy of entities. As the core production

factor in the digital era, big data technology empowers various links of the value chain, effectively addressing pain points such as information asymmetry and low resource allocation efficiency, thereby realizing the optimization and reconstruction of the value chain [4].

In the context of Hainan's tropical agriculture, value chain optimization should not only focus on technological upgrades in individual links but also pay more attention to the synergistic efficiency improvement of the entire chain. This requires starting from all links, including pre-production planning, in-production management, post-production processing, circulation and sales, and even brand building, to construct a big data-driven closed-loop optimization system and achieve a fundamental shift from production orientation to market orientation [5].

2.2 Theoretical Framework of Big Data Empowering Agriculture

Big data empowering agriculture refers to the process of enhancing the decision-making ability and operational efficiency of agricultural entities through the application of big data technology, thereby realizing value creation in the agricultural industry. Its theoretical framework mainly includes three levels: data collection, data processing, and data application, covering the complete process from data resourceization to data valorization.

At the data collection level, agricultural big data sources are extensive, including remote sensing data, sensor data, transaction data, meteorological data, and multiple other types of data sources. With the popularization of IoT technology, the coverage, accuracy, and frequency of agricultural data collection have been greatly improved, laying a solid foundation for big data applications. For example, the research team from the Aerospace Information Research Institute, Chinese Academy of Sciences, by integrating multi-source remote sensing data, innovatively proposed a "two-step" monitoring framework, overcoming the difficulty of accurately estimating the annual planting area of rice in tropical regions [6].

At the data processing level, big data analysis technologies such as machine learning, data mining, and visual analysis can extract valuable information and patterns from massive data, providing support for agricultural decision-making. The "Digital Platform for Technology Integration in Industrial Chains" constructed by the Chinese Academy of Tropical Agricultural Sciences (CATAS) comprehensively displays the development status of leading industries through multi-dimensional and visual methods, connecting the industrial chain [7], and realizing the effective integration and utilization of data.

At the data application level, big data technology can be widely used in multiple scenarios such as precision production, market prediction, supply chain optimization, and financial services, empowering the optimization and upgrading of various links in the agricultural value chain. Taking the Hainan Wenchang Chicken industry as an example, by integrating technologies such as the Internet of Things, big data, and artificial intelligence, a whole-industry-chain smart breeding standard system has been established, providing a replicable model for intelligent livestock breeding in tropical regions [8].

3 Analysis of the Current Development Status of Tropical Agriculture in Hainan
3.1 Resource Endowment and Industrial Scale

As China's only tropical island province, Hainan possesses unique climatic conditions and biological resources, providing natural advantages for the development of tropical agriculture. Hainan has sufficient sunlight, abundant rainfall, an annual average temperature of 22-27° C, and no

frost throughout the year, making it the largest tropical crop production base in China. These unique natural resource endowments make Hainan an ideal area for developing tropical characteristic and efficient agriculture, and also provide an important guarantee for the national winter "vegetable basket" and "fruit basket" supply.

In recent years, Hainan's tropical agriculture has maintained a stable development trend with continuous growth in industrial scale and economic benefits. According to statistics, Hainan has established 17 key agricultural industries including lychee, dragon fruit, mango, durian, winter melons and vegetables, coffee, the Nanfan seed industry, and pineapple [9], forming a relatively comprehensive tropical agricultural industrial system. Particularly, Hainan's lychee industry demonstrated strong market competitiveness, with off-island shipments reaching 207,000 tons in 2025, generating an off-island output value of 3.8 billion RMB, while prices increased by 20% to 30% year-on-year [8]. Furthermore, characteristic agricultural products such as Wenchang Chicken, natural rubber, and Qiongzhong Green Orange have earned nationwide reputation, establishing unique regional brand advantages.

In terms of industrial layout, Hainan has gradually formed a regionalized, specialized, and clustered development pattern. Southern cities and counties such as Sanya, Lingshui, and Ledong focus on developing the Nanfan seed industry and tropical fruits; eastern coastal areas focus on developing winter melons and vegetables and marine aquaculture; central mountainous areas focus on developing underforest economy and high-mountain characteristic crops. This industrial layout based on resource endowment and comparative advantages has effectively enhanced the specialization level and scale benefits of Hainan's tropical agriculture.

3.2 Analysis of the Current Situation and Problems of the Tropical Agricultural Value Chain

Although Hainan's tropical agriculture possesses unique resource advantages and an industrial foundation, the overall level of its value chain remains relatively low, with bottlenecks and problems existing in various links to different degrees. As can be seen from Table 1: Analysis of Main Problems in Various Links of Hainan's Tropical Agricultural Value Chain.

At the production level, low refinement and insufficient application of technology are the main problems. Although Hainan has national-level scientific research platforms such as the National Nanfan Scientific Research and Breeding Base, the promotion and application rate of advanced technologies still needs to be improved. Many areas still rely on traditional experience for production management, leading to low production efficiency and unstable product quality. For example, in rubber planting, traditional tapping methods are inefficient, and there is a lack of effective early warning and prevention mechanisms for diseases and pests, making it difficult to improve industrial efficiency [7].

At the processing level, insufficient deep processing capacity and low added value are prominent problems. Hainan's tropical agricultural products are still mainly sold fresh, the processing proportion is relatively low, and most processing is primary, with insufficient development of deep processing and high-value-added products. Taking the mango industry as an example, most mangoes are sold directly after simple packaging, lacking deep-processed products such as pulp, dried mango, and mango wine, making it difficult to fully exploit the product's value potential.

At the circulation level, an imperfect cold chain logistics system and information asymmetry lead to high loss rates and low profitability. Located in the tropics, Hainan's agricultural products are highly perishable and require high cold chain logistics standards. However, the existing cold chain

facility coverage is insufficient, leading to serious post-harvest losses of fruits and vegetables. To address the pain point of high post-harvest loss in the lychee industry, the platform recommends preservation technology and connects with cold chain logistics experts [7], but the overall cold chain guarantee capacity still needs strengthening.

At the marketing level, limited brand influence and insufficient market development capacity restrict the realization of industrial value. Although Hainan has many high-quality characteristic agricultural products, except for a few well-known brands, most products have limited brand influence and low market recognition, making it difficult to form brand premiums. At the same time, due to the lack of accurate grasp of market demand, there is severe information asymmetry between production and sales, leading to frequent supply-demand imbalances and price fluctuations.

Table 1: Analysis of Main Problems in Various Links of Hainan's Tropical Agricultural Value Chain.

Value Chain Link	Main Problems	Manifestations
Production Link	Low refinement, insufficient tech application	Dominated by traditional experience, low production efficiency, untimely pest control
Processing Link	Insufficient deep processing capacity, low added value	Primarily primary processing and fresh sales, few deep-processed products
Circulation Link	Imperfect cold chain logistics, information asymmetry	High post-harvest loss, poor supply-demand connection, large price fluctuations
Marketing Link	Limited brand influence, insufficient market development	Low brand premium, frequent market supply-demand imbalances

4 The Internal Logic and Pathways of Big Data Empowering the Agricultural Value Chain

4.1 Optimization of the Production Link Empowered by Big Data

In the production link, big data technology effectively improves agricultural production efficiency and resource utilization rate by achieving precision planting and intelligent management. Specifically, big data empowers the production link mainly through the following pathways:

First, precise monitoring of the production environment. By deploying data collection equipment such as field sensors, drones, and remote sensing devices, soil moisture, nutrient status, meteorological conditions, crop growth, and other data are monitored in real time, providing a data foundation for precision agriculture. For example, the digital planting project for wax apples at the "Longzhou No.1" family farm in Lingao County deployed smart agricultural facilities such as soil multi-parameter sensors, meteorological monitoring stations, pest monitoring instruments, and high-definition cameras, achieving all-weather monitoring and data collection of the production environment [10].

Second, scientific production decision-making. Based on historical data and real-time monitoring data, decision support systems such as crop growth models and pest prediction models are constructed to provide scientific guidance for agricultural production. The "Digital Platform for Technology Integration in Industrial Chains" constructed by CATAS can accurately identify industrial bottlenecks, scientific problems, and technical needs in various links and match expert team solutions [7], making production decision-making more scientific and precise.

Third, automation of the production process. Combining big data analysis with intelligent equipment realizes the automation and refinement of agricultural production operations. In the industrialized seedling cultivation base at the Yazhou Base of the Sanya Tropical Agricultural Science Research Institute, automatic seeders operate efficiently, seedling trays move uniformly on conveyor belts, accurately completing a series of processes such as soil filling, hole pressing, seeding, soil covering, and watering [10], greatly improving production efficiency and standardization.

The application of big data technology in the production link effectively solves the uncertainty and high loss problems in traditional agricultural production, achieving a transformation from "depending on heaven for food" to "knowing heaven and acting accordingly," laying a solid foundation for the high-quality development of tropical agriculture.

4.2 Innovation in the Management Link Empowered by Big Data

In the management link, big data technology promotes innovation and change in agricultural business models by improving resource allocation efficiency and risk management capabilities. Specific manifestations include the following aspects:

First, supply chain collaborative optimization. Big data technology achieves transparency and collaboration in the supply chain by breaking down data barriers between various links of the industrial chain. Taking Tunchang Black Pig as an example, by constructing an industrial map, it deeply integrates the entire chain of agricultural production, management, and services, realizing a new agricultural form characterized by visualized agricultural data, intelligent production, precise decision-making, and convenient services [7], greatly improving the collaborative efficiency of the supply chain.

Second, quality and safety traceability management. Using big data and blockchain technology, a whole-process traceability system from farm to table is constructed to enhance product quality and safety assurance capabilities. Chengmai Fu Orange empowers its brand digitally, uses intelligent sorting lines to accurately grade fruit size and sugar content, each box of oranges carries an "ID card," and scanning the QR code allows viewing of traceability information such as the grower and test results [10], effectively improving the product's quality and safety assurance level and market reputation.

Third, innovation in agricultural financial services. Big data technology innovates agricultural financial products and service models by accurately assessing agricultural production risks and credit status. CATAS is exploring the systematic innovation of data value transformation paths relying on the advantages of the Hainan Free Trade Port's cross-border data policies, further leveraging and revitalizing data assets, and promoting the high-quality development of the tropical crop industry through financial leverage [7], providing more precise financial service support for agricultural management.

The innovation in the management link empowered by big data effectively reduces agricultural operating costs and management risks, improves resource allocation efficiency and market response speed, and promotes the transformation of traditional agricultural business models towards modernization and refinement.

4.3 Breakthroughs in the Marketing Link Empowered by Big Data

In the marketing link, big data technology helps agricultural enterprises better understand market demand and maximize product value through precise market positioning and personalized

marketing strategies. The main pathways for big data empowering the marketing link include:

First, precise insight into consumer demand. By analyzing sales data from e-commerce platforms, consumer review data, etc., consumer preferences and changes in market demand are accurately grasped, providing a basis for product development and marketing strategy formulation. In the case of Chengmai Fu Orange, by using intelligent sorting lines to accurately grade fruit size and sugar content, the differentiated needs of different consumer groups were met [10], achieving precise product marketing.

Second, brand building and value enhancement. Big data technology can help enterprises accurately position their brand image, effectively communicate brand value, and enhance brand influence and market competitiveness. Chengmai Fu Orange, through digital brand empowerment, not only achieved product traceability but also effectively communicated the brand story and quality commitment, enhancing consumers' sense of identity and loyalty to the brand.

Third, precise matching of sales channels. By analyzing consumer behavior data and channel sales data, product channel strategies are optimized to achieve precise matching of supply and demand. Changjiang sweet potatoes, through high-temperature healing technology treatment, achieved a healthy tuber rate of 94.7% and a loss rate reduction of 3 percentage points. With this technology, Changjiang sweet potatoes were successfully exported to Canada and reached cooperation intentions with merchants from the UK, the Middle East, etc. [10], achieving effective expansion into the international market.

The application of big data technology in the marketing link effectively solves problems such as information asymmetry in the agricultural product market, low brand premium, and single sales channels, helping Hainan's tropical agricultural products achieve a transformation from "produced well" to "sold well," enhancing product added value and market competitiveness.

4.4 Support Service System Empowered by Big Data

The optimization of the agricultural value chain empowered by big data cannot be separated from a perfect support service system, mainly including data platform construction, technical standard formulation, and talent team building:

In terms of data platform construction, Hainan is actively promoting the integration and sharing of agricultural data resources. The "Digital Platform for Technology Integration in Industrial Chains" for tropical characteristic and efficient agriculture constructed by CATAS comprehensively displays the development status of leading industries from three dimensions: provincial, county, and township, covering all links of "cultivation, planting, harvesting, storage, processing, and sales," achieving unified data aggregation, unified management, centralized analysis, and information sharing [7], providing important platform support for big data empowering agriculture.

In terms of technical standard formulation, Hainan actively promotes the formulation and promotion of standards related to agricultural big data. The "Hainan Haikou Wenchang Chicken Whole Industry Chain Intelligent Breeding Standardization Pilot" project declared by Hainan (Tanniu) Wenchang Chicken Co., Ltd. was successfully selected into the list of national standardization pilot projects in 2025 by the National Standardization Administration Committee [8]. By integrating technologies such as the Internet of Things, big data, and artificial intelligence, a whole-industry-chain smart agriculture standard system is established, providing a replicable model for intelligent livestock breeding in tropical regions.

In terms of talent team building, Hainan strengthens the cultivation of agricultural big data

talents and technology promotion through various channels. The "Longzhou No.1" family farm in Lingao County conducts skills training for 270 person-times annually, radiating to farmers in surrounding cities and counties. Everyone is highly motivated to learn new technologies [10], providing talent guarantee for the promotion and application of big data technology in the agricultural field. As can be seen from the table below, Table 2: Main Pathways of Big Data Empowering the Optimization of Hainan's Tropical Agricultural Value Chain.

Table 2: Main Pathways of Big Data Empowering the Optimization of Hainan's Tropical Agricultural Value Chain.

Value Chain Link	Big Data Empowerment Pathways	Typical Cases
Production Link	Precise environmental monitoring, Scientific production decision-making, Automated production processes	Digital Wax Apple Planting in Lingao, Factory-based Seedling Cultivation in Sanya [10]
Management Link	Supply chain collaboration and optimization, Quality and safety traceability, Innovation in agricultural financial services	Whole Industry Chain Management of Tunchang Black Pig, Traceability System for Chengmai Fu Orange [7-10]
Marketing Link	Consumer demand insight, Brand building and value enhancement, Precise matching of sales channels	Export of Changjiang Sweet Potatoes, Brand Marketing of Chengmai Fu Orange [10]
Service Support	Data platform construction, Technical standard formulation, Talent team building	"Science and Technology Integration Map" Platform, Wenchang Chicken Smart Breeding Standard [7-8]

5 Analysis of Typical Cases of Big Data Driving the Optimization of Hainan's Tropical Agricultural Value Chain

5.1 Case One: Wenchang Chicken Whole Industry Chain Smart Breeding Model

As the top-ranked of Hainan's "Four Major Famous Dishes," Wenchang Chicken boasts a long history and profound cultural heritage. Under the traditional breeding model, the Wenchang Chicken industry faced challenges such as low standardization, fluctuating quality, and difficulties in brand protection. To address these issues, Hainan (Tanniu) Wenchang Chicken Co., Ltd. actively explored a whole industry chain smart breeding model [8]. By empowering various stages of the industrial chain with big data technology, it has achieved value enhancement and innovative development for the industry.

In the breeding stage, the company utilizes big data technology to establish a breeding chicken genetic evaluation system. By analyzing data on breeding chicken production performance and offspring quality, it optimizes selection and mating plans, improving breeding efficiency and accuracy. Simultaneously, it uses gene sequencing technology to construct DNA fingerprints, providing technical assurance for the conservation of Wenchang Chicken genetic resources and purebred breeding [8].

In the farming stage, the company, in collaboration with universities, introduces IoT devices and

big data analysis technology to monitor environmental parameters in the chicken houses (such as temperature, humidity, and air quality) in real-time, automatically adjusting the environment to ensure healthy chicken growth. Through an intelligent feeding system, feed is precisely allocated according to the growth stage and health status of the chickens, improving feed utilization efficiency. Notably, the company has also established a chicken behavior analysis system. Using video surveillance and AI recognition technology, it monitors chicken activity in real-time, promptly identifies abnormal behavior, issues warnings, and effectively prevents disease outbreaks.

In the processing and circulation stages, the company, collaborating with universities, has built a full-process traceability system. Each chicken is fitted with a leg ring that records information from hatching, breeding, slaughtering, to sales. Consumers can access all product information by scanning a QR code, significantly enhancing product quality transparency and consumer trust. Concurrently, based on historical sales data and market trend analysis, the company can accurately predict market demand, optimize product mix and inventory management, and reduce operating costs. The "Wenchang Chicken Project" led by a faculty team from the School of Information Engineering, Hainan Vocational University of Science and Technology, serves as a vivid example.

The practice of the Wenchang Chicken whole industry chain smart breeding model in Hainan demonstrates that big data technology empowerment not only enhances production efficiency and product quality but also strengthens brand value and market competitiveness. This model was selected as a National Standardization Pilot Project for 2025 [8], providing valuable, replicable, and scalable experience for the digital transformation of the tropical livestock and poultry breeding industry in Hainan and across the nation.

5.2 Case Two: Big Data Empowerment Practice in the Hainan Mango Industry Chain

Mango is one of Hainan's important tropical fruits, with extensive cultivation area and large yield. However, it has long faced issues such as a singular variety structure, significant market price fluctuations, and insufficient brand influence. The Chinese Academy of Tropical Agricultural Sciences (CATAS), through its "Science and Technology Integration Map" platform [7], provides comprehensive data empowerment for the mango industry chain, achieving notable results.

In the production stage, the platform integrates data from Hainan's main mango producing areas, including soil, climate, and phenology, providing growers with precise guidance for farming operations. By analyzing historical meteorological data and patterns of disease and pest occurrence, it builds predictive and early warning models for diseases and pests, helping growers take preventive measures in advance and reduce production risks. The platform also matches growers with expert teams, providing targeted technical solutions and enhancing the scientific level of production management.

In the harvesting stage, the platform provides growers with optimal harvest timing recommendations by monitoring fruit maturity and market supply and demand, avoiding price drops caused by concentrated market entry. Simultaneously, it classifies and grades fruits based on quality data, enabling differentiated sales to meet the needs of different consumer groups.

In the sales stage, the platform integrates diverse sales data from online and offline channels, analyzes consumption trends and regional market demand characteristics, providing market decision support for growers and distributors. Through sentiment analysis of consumer review data on e-commerce platforms, it accurately grasps consumer preferences regarding mango taste, quality, packaging, etc., guiding product improvement and marketing strategy adjustments.

The practice of big data empowerment in the mango industry demonstrates that data integration and analysis based on the entire industry chain can effectively resolve the contradiction between small-scale production and the large market, enhance the industry's ability to cope with market risks, and drive the industry's transition from quantity expansion to quality and benefit improvement. This provides a useful reference for the digital transformation of Hainan's tropical fruit industry.

5.3 Case Three: Digital Transformation and Upgrading of the Natural Rubber Industry

Natural rubber is an important tropical economic crop and strategic material in Hainan. However, in recent years, affected by international market fluctuations and rising costs, the industry's development has faced severe challenges. To address this, Hainan is actively promoting the digital transformation and upgrading of the natural rubber industry, empowering various segments of the industry value chain through big data technology to enhance industrial efficiency and competitiveness.

In the planting stage, the "Science and Technology Integration Map" platform built by CATAS integrates new tapping technologies and deep processing techniques to increase industrial added value [7]. By monitoring the growth status and latex yield of rubber trees, it provides precise tapping guidance for rubber farmers, improving tapping efficiency and profitability. The platform also provides timely warnings for diseases and pests, helping rubber farmers take preventive and control measures to reduce losses.

In the harvesting stage, the "Jiao Yi" rubber tapping software and rubber plantation management system independently developed by the Yunnan Mengla County Agricultural Reclamation Group optimized the rubber harvesting process and enabled refined management of rubber plantations [11]. The software system, through key steps like data entry, process control, and data analysis, effectively addressed issues such as information opacity and low efficiency in traditional rubber harvesting.

In the processing stage, big data technology improves product quality and production efficiency through real-time monitoring and optimization of production process parameters. Concurrently, based on the analysis of market demand and inventory data, it optimizes product structure and production plans, reducing inventory costs and operational risks.

In the sales stage, the platform integrates price information and supply-demand data from domestic and international natural rubber markets, providing market analysis and price forecasting services for producers and rubber farmers. Through the data platform, the Xilian Branch of Hainan Rubber Group can fully grasp the overall supply and demand situation, price fluctuation trends, and development differences across cities and counties in the province. Through historical data tracing and real-time market monitoring, it accurately predicts market trends, providing precise support for enterprise production [7].

The practice of digital transformation and upgrading in the natural rubber industry shows that big data technology can effectively enhance the modernization level and market competitiveness of traditional agricultural industries, exploring a new path for the sustainable development of the natural rubber industry in Hainan and across China.

6 Challenges and Countermeasures for Applying Big Data in Hainan's Tropical Agriculture
6.1 Main Challenges

Although big data technology shows great potential in driving the optimization of Hainan's tropical agricultural value chain, it faces multiple challenges in practical application:

Data Collection and Sharing Barriers. Agricultural data is characterized by multiple sources, heterogeneity, and fragmentation, making data collection difficult and costly. Simultaneously, due to departmental barriers and interest fragmentation, data silos are prevalent, and data sharing mechanisms are imperfect. When constructing the "Science and Technology Integration Map" platform, CATAS encountered prominent problems such as dispersed data, poor data quality, insufficient openness and sharing, and inadequate development and utilization of data related to tropical characteristic and efficient agricultural industries at provincial and county levels in Hainan [7], which somewhat constrained the overall effectiveness of big data empowerment.

High Technology Application Costs. The implementation of big data technology necessitates significant investment in hardware equipment, software system development, and talent team building. The substantial upfront capital required, coupled with a prolonged return on investment cycle, places a heavy financial burden on small-scale farmers and agricultural enterprises with limited resources. For instance, the digital wax apple cultivation project in Lingao County involved the deployment of sophisticated smart agricultural facilities, including soil multi-parameter sensors, automated weather stations, pest monitoring devices, and high-definition cameras [10]. The costs associated with such technological infrastructure are prohibitively high for ordinary farmers.

Severe Shortage of Professional Talent. The application of agricultural big data requires interdisciplinary talents who are proficient in both agricultural technology and data science. Currently, there is a severe shortage of such talents, which has become a major bottleneck constraining big data's empowerment of agriculture. Although Hainan has established 10 provincial-level modern agricultural industry technology systems covering various characteristic fields like areca nut, grouper, and local chicken, with nearly a hundred experts working on the front lines providing technical services to farmers [10], the professional talent pool still falls short of actual needs.

Limited Participation from Farmers. Due to traditional production habits and low digital literacy, many farmers have limited acceptance and ability to apply big data technology, hindering its promotion. Hainan has recognized this issue and conducts skills training at bases like the "Longzhou No. 1" family farm in Lingao County [10], reaching farmers in surrounding cities and counties. However, overall, farmer participation still needs improvement.

6.2 Countermeasures and Suggestions for Promoting Big Data Application

Addressing the challenges above, the following countermeasures and suggestions are proposed to promote the in-depth application of big data technology in Hainan's tropical agriculture:

Strengthen Data Infrastructure Construction. Build data collection, transmission, storage, and analysis platforms covering the entire agricultural industry chain, break down data barriers, and promote data sharing. CATAS is striving to consolidate the digital foundation for tropical agriculture, aiming to develop the "Map" platform into a digital agricultural platform based in Hainan, serving China's tropical regions, and expanding globally [7]. This approach deserves promotion and further development.

Innovate Technology Promotion Models. To address the limited funds and technical capabilities of smallholder farmers, explore diversified promotion models involving "government guidance, enterprise leadership, and farmer participation" to lower the threshold for technology application. The Hainan Provincial Government has introduced the 2025 agricultural incentive and subsidy policy, offering rewards and subsidies ranging from 100,000 to 10 million RMB to eligible tropical

characteristic and efficient agricultural projects that establish benefit-linking mechanisms for farmers [12]. Such policies should be continuously optimized and implemented more vigorously.

Strengthen Cultivation of Interdisciplinary Talents. Foster interdisciplinary talents skilled in both agriculture and data science through various channels like industry-academia cooperation and practical training bases. Simultaneously, enhance digital skills training for existing agricultural technicians to improve their big data application capabilities. Hainan already conducts skills training at some agricultural bases, such as the annual 270 person-times training at the "Longzhou No. 1" family farm in Lingao County [10]. Such training should be expanded in scope and depth.

Promote Deep Integration of Industry, Academia, and Research. Strengthen cooperation between research institutions, universities, and agricultural enterprises to drive the innovative application and commercialization of big data technology in agriculture. The 2025 Hainan Agricultural Science and Technology Innovation Exchange Event and the Agricultural Science and Technology Market Construction Promotion Event held at the Nanfan Academy aimed precisely to build a platform for sharing agricultural sci-tech resources and achieving win-win cooperation, boosting both the vitality of agricultural sci-tech innovation and the effectiveness of industrial integration development in Hainan [13]. Such events should be regularized and institutionalized.

Fully Utilize the Policy Advantages of the Free Trade Port. Leverage the policy advantages of the Hainan Free Trade Port, such as cross-border data flow, to systematically innovate data value realization paths, further leverage and revitalize data assets, and promote the high-quality development of the tropical crop industry through financial instruments [7]. Simultaneously, use the Free Trade Port's open platform to introduce international advanced technologies and management experience, enhancing the international competitiveness of Hainan's tropical agriculture.

7 Conclusion and Outlook

7.1 Main Conclusions

Through theoretical analysis and case studies, this research thoroughly investigated the pathways and mechanisms by which big data technology drives the optimization of Hainan's tropical high-efficiency agricultural value chain, arriving at the following main conclusions:

First, big data technology, by empowering various segments of the agricultural value chain, can effectively address the bottleneck issues hindering the development of Hainan's tropical agriculture. In the production segment, it enables precision planting and intelligent management, improving production efficiency and resource utilization. In the management segment, it optimizes supply chain coordination and quality management, reducing operational costs and risks. In the marketing segment, it facilitates brand building and market expansion, enhancing product added value and market competitiveness.

Second, Hainan has actively explored the application of big data in empowering tropical agriculture and has accumulated various beneficial experiences. Typical cases, such as CATAS's "Science and Technology Integration Map" platform, the whole industry chain smart breeding of Wenchang Chicken, and the digitalization of the natural rubber industry, demonstrate that big data technology has yielded significant results in practical applications, providing replicable and scalable models and experiences for the digital transformation of Hainan's tropical agriculture.

Third, the application of big data technology in Hainan's tropical agriculture still faces numerous challenges requiring collaborative efforts from multiple stakeholders. Issues like data collection and sharing barriers, high technology application costs, shortage of professional talent, and limited farmer

participation restrict the breadth and depth of big data empowerment. It necessitates coordinated efforts from the government, enterprises, research institutions, farmers, and other entities to collectively advance the deep integration and widespread application of big data technology in the agricultural sector.

7.2 Future Outlook

With the deepening construction of the Hainan Free Trade Port and continuous innovation in digital technologies, big data-driven optimization of the tropical agricultural value chain will embrace broader development prospects:

Technology integration and application will deepen. As new-generation information technologies like artificial intelligence, blockchain, and 5G deeply integrate with big data technology, agricultural digital transformation will accelerate, enabling more precise, efficient, and transparent value chain optimization. For instance, the "Fan-Future Agriculture Intelligent Hub" co-created by the Yazhou Bay National Laboratory and Huawei establishes an AI data foundation for agricultural breeding [8], heralding revolutionary changes brought by technological integration to agriculture.

Value chain integration will become more comprehensive. Big data technology will extend beyond optimizing single links or industries towards integration across the entire industry chain, region, and even the global value chain, achieving more extensive and profound resource integration and value creation. CATAS's commitment to developing the "Map" platform into a digital agricultural platform rooted in Hainan, serving China's tropical regions, and expanding globally [7] reflects this trend.

The policy framework will become increasingly comprehensive. As data's status as a key factor of production becomes more established, institutional arrangements concerning data property rights, data security, and data transactions will be progressively refined. This will provide stronger institutional safeguards for big data's role in empowering agriculture. Hainan Free Trade Port's pioneering policy explorations in areas such as cross-border data flow will yield valuable insights for national-level agricultural big data applications.

In summary, as a crucial engine driving agricultural transformation and upgrading, big data technology will play an increasingly important role in developing Hainan's tropical high-efficiency agriculture. By strengthening technology application and innovation, and improving policy support and institutional safeguards, big data technology will vigorously promote the optimization and upgrading of Hainan's tropical agricultural value chain, inject new momentum into rural revitalization and high-quality agricultural development in Hainan, and contribute Hainan's wisdom to building agricultural modernization with Chinese characteristics.

Acknowledgments

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