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Research on Comprehensive Control and Traceability Management of Food Cold Chain Transportation

Sui Qing[1,2*], Amer Hamzah Jantan[1]

[1] City University Malaysia, Kuala Lumpur, Malaysia
[2] Shan Dong Institute of Commerce and Technology, Jinan, China

*Corresponding Author: 270879263@qq.com

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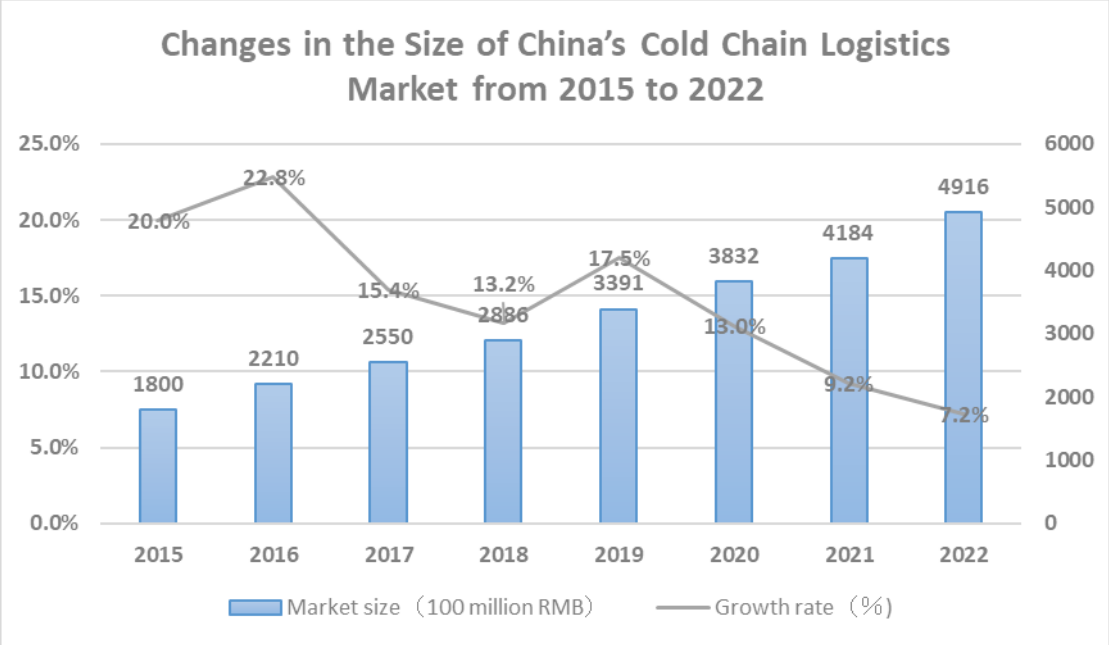
Abstract: *With the rapid development of economic globalization and cross-border e-commerce, the food import and export trade has encountered growth opportunities. Meanwhile, food safety has gained increasing attention from consumers worldwide. Most food products require cold chain transportation. However, in recent years, various safety hazards have emerged in the process of food cold chain logistics, with disruptions and food spoilage causing significant waste. Ensuring the safety and traceability of the entire food cold chain has become a critical factor limiting its development. This paper proposes strategies for the development of food cold chains, including the establishment of a comprehensive standard system, promoting orderly development of traceability systems, and enhancing traceability supervision platforms to achieve transparency in food cold chain safety.*

Keywords: Food Cold Chain, Modern Technology, Traceability

1. Introduction

In recent years, the impact of the COVID-19 pandemic in 2020 has drawn significant attention to the traceability of cold chain food products from various sectors of society. As an emerging industry, cold chain logistics is flourishing. As shown in Figure 1, the scale of China's cold chain logistics market has been consistently expanding from 2015 to 2022. In 2019, the market size of the cold chain logistics industry reached 339.1 billion RMB, with a year-on-year growth rate of 17.50%. In 2020, the overall market size saw the most substantial expansion in recent years, exceeding 400 billion RMB. Considering the continuous growth momentum, it is estimated that by 2025, the scale of China's cold chain logistics market will further increase to approximately 897 billion RMB.



In 2022, China's Central Government released Document No. 1, which emphasized the need to "improve the quality and safety traceability system throughout the entire industry chain." The State Administration for Market Regulation, in accordance with the deployment requirements of the Central Committee and the State Council to strengthen information-based traceability of imported cold chain food, adheres to the overall strategy of "preventing external importation and internal rebound." It is resolutely implementing the "prevention of goods" responsibility in the cold chain and accelerating the construction of centralized supervision warehouses. Continuous efforts are being made to build the traceability system for imported cold chain food. It is evident that traceability management is of utmost importance for the future development of the food cold chain industry. Optimizing and improving the traceability system for agricultural product cold chain logistics is a crucial prerequisite for ensuring the quality and safety of agricultural products and achieving standardization, scale, and industrialization in China's agriculture sector.

2. Definition and Importance of Food Cold Chain

2.1 Definition and Components of Food Cold Chain

The food cold chain is a logistics phenomenon established with the advancement of scientific technology and the development of refrigeration techniques. It is based on the principles of cryogenic science and employs refrigeration technology as a means. The cold chain ensures that perishable food products, from their origin, through processing, storage, transportation, distribution, and retail until reaching the hands of consumers, are consistently maintained at low temperatures necessary for preserving food quality, reducing losses, and preventing contamination. It represents a specialized supply chain system.

The food cold chain consists of four main components:
(1) Cryogenic Processing: This includes the cooling and freezing of meat, poultry, fish, eggs, and various food products, as well as processing operations carried out at low temperatures. It also involves pre-cooling of fruits and vegetables, low-temperature processing of various

frozen foods, and dairy products. This stage primarily relies on cold chain equipment with cooling, freezing, and rapid freezing capabilities.

(2) Cryogenic Storage: This encompasses the cooling and freezing storage of food products, including controlled atmosphere storage for fruits and vegetables. It aims to provide a low-temperature environment for preserving food freshness during storage and processing. Key equipment involved in this stage includes refrigerated storage facilities, cold storage cabinets, freezer cabinets, and household refrigerators.

(3) Refrigerated Transportation: This covers the low-temperature transport of food products over short and long distances, including local distribution. It primarily involves refrigerated railway cars, refrigerated trucks, refrigerated ships, refrigerated containers, and other low-temperature transportation vehicles. Temperature fluctuations during transportation are a significant factor affecting food quality, making temperature control critical, especially for long-distance transportation.

(4) Frozen Sales: This includes frozen storage and sales at wholesale and retail levels, and it is a collaborative effort involving manufacturers, wholesalers, and retailers. With the rapid development of various chain supermarkets in large and medium-sized cities, they have become the primary sales channels for cold chain food products. In these retail outlets, the use of refrigerated/freezer display cases and storage facilities has become an indispensable component of the complete food cold chain.

2.2 Importance of Food Cold Chain

The cold chain is a crucial means of preventing food spoilage and ensuring food quality. An efficient cold chain system can reduce food losses and waste, enhance compliance with food safety standards, minimize the risk of foodborne diseases, and slow down the growth of spoilage microorganisms.

Additionally, one of the most significant advantages of cold chain distribution is its ability to maintain product quality. For perishable products like fresh produce and frozen foods, improper preservation can lead to the loss of flavor, nutritional value, and overall quality, impacting consumer health and taste experiences. Cold chain distribution, through temperature control and rapid freezing, helps products remain fresh and maintain their quality throughout the entire transportation process.

3. Risks and Challenges of Food Cold Chain

3.1 Temperature Variations and Microbial Growth

All food products contain microorganisms that can lead to spoilage. Controlling food safety and quality throughout the production-to-transportation distribution process is primarily achieved by managing the growth of these microorganisms. Temperature control is critical in this regard. Different perishable products require specific storage temperatures, and even slight temperature fluctuations can affect product quality, taste, and shelf life. For example, strawberries should be stored at temperatures between 0°C to 3°C, with a storage duration of 7 to 10 days. The allowable temperature is 4.4°C, but it should not exceed this for more than 48 hours, or spoilage will begin. In general, for every 6°C increase in temperature, the growth rate of bacteria doubles, and shelf life is halved.

3.2 Challenges in Cross-Border Cold Chain Logistics

Cross-border cold chain logistics presents unique challenges due to the combination of "temperature control" and "cross-border" elements. "Cross-border" implies extended delivery cycles, multiple factors beyond control, adherence to international trade rules, and lengthy processes for the flow of goods, capital, and information. Food products demand high standards in terms of quality, timeliness, accuracy, and overall experience. Temperature control impacts every aspect of cross-border logistics, including foreign procurement, transportation, customs clearance, inspections, taxation, warehousing, and more. It requires expertise, experience, and language skills, given the diverse professional fields involved. Furthermore, temperature control during storage, transshipment, sorting, consolidation, and transportation imposes requirements for consistent temperature, monitoring, traceability, and transport times. Key challenges in cross-border cold chain logistics include:

i. Timeliness and Safety: Due to cross-border transport involving different countries or regions, transportation time and safety are top considerations.
ii. Complexity: Differences in customs, policies, regulations, and practices among different countries and regions make cross-border logistics operationally complex.
iii. High Costs: Cross-border logistics is relatively costly due to expenses such as transportation fees, tariffs, taxes, and more.
iv. Technological Challenges: Varying levels of information technology and technological methods in different countries and regions pose challenges for information management in cross-border logistics.

4. Comprehensive Cold Chain Food Safety Management Technologies

4.1 Modern Monitoring Technologies and Their Applications

Cold chain logistics monitoring systems primarily consist of sensors, data collectors, network communication devices, data processing centers, and management platforms. Sensors are mainly used to detect environmental parameters such as temperature and humidity and transmit these parameter data to data collectors. Network communication devices are responsible for data transmission and communication. The data processing center is the core of the cold chain logistics monitoring system, playing a crucial role in analyzing, processing, storing, and displaying data, providing data and decision support for the monitoring system. The management platform is responsible for remote monitoring and management of the cold chain logistics monitoring system.

Common information technologies used in cold chain food monitoring systems include RFID technology, sensor technology, internet technology, and artificial intelligence technology. In cold chain logistics monitoring systems, RFID technology is primarily used for tracking and managing goods, enabling real-time monitoring and control of goods for monitoring personnel. Sensor technology is mainly used for real-time monitoring of environmental parameters such as temperature, humidity, pressure, and real-time monitoring and control of equipment status. The application of internet technology provides technical support for the intelligence and digitization of cold chain logistics monitoring systems, while also offering more convenience and support to monitoring personnel. The application of artificial intelligence technology provides technical support for the digitization and intelligence of cold chain logistics monitoring systems and offers decision support and intelligent analysis tools for monitoring personnel.

4.2 Preservation Technologies and Strategies

Preservation technologies can be categorized into physical preservation technologies and chemical preservation technologies. Physical preservation technologies involve altering external factors such as temperature, pressure, and oxygen content to inhibit or eliminate harmful microorganisms, reduce oxidation, and inhibit enzyme activity, thereby extending the shelf life of food. In addition to traditional methods like ultraviolet sterilization, ultrasound, and radiation preservation, novel physical preservation technologies such as cryogenic temperatures, high-pressure electrostatic fields, ultra-high pressure, and modified atmosphere packaging have gained more research attention. Chemical preservation technologies involve adding preservatives to perishable foods through methods like immersion, spraying, or coating to inhibit microbial growth, slow down enzymatic reactions, and maintain the flavor, color, and nutritional content of the food.

Currently, China is taking various measures to enhance its cold storage capacity for food. This includes establishing sufficient cold storage and preservation warehousing spaces and promoting the radiation preservation of national warehousing facilities. Additionally, China is establishing a comprehensive refrigeration system in line with its national conditions, ensuring a more scientifically grounded food supply chain with the help of advanced technology and equipment. The commercialized processing industry for food products in China is gradually becoming more complete, with an increasing use of advanced technology in food processing. Advanced post-harvest processing techniques can reduce production costs and increase profits. For example, changing traditional manual processing methods to use techniques like infrared scanning can improve food processing efficiency and reduce unnecessary resource wastage.

5. Cold Chain Food Traceability Management

5.1 Traceability System and Its Significance

A food safety traceability system involves using technological means to track the production, distribution, and sales processes of food, ensuring end-to-end supervision from the source to the consumer. Such a system provides regulatory authorities with powerful tools to rapidly identify the source of food safety issues and take effective measures to protect the public from food safety risks.

Strengthening traceability system oversight is crucial not only for safeguarding a company's reputation but also for ensuring public safety and health. Accurate traceability information can help regulatory authorities quickly recall and handle products in the event of a food safety incident, reducing the risk of harm spreading. This emergency response mechanism allows food safety issues to be resolved more rapidly, ensuring the maximum protection of the public's interests and promoting the upgrading and development of the food industry. For businesses, establishing a robust traceability system can enhance production management efficiency and reduce production costs. For consumers, clear traceability information enables them to make more confident purchases and creates more market opportunities for businesses.

5.2 Current Status and Challenges of Global Cold Chain Food Traceability Systems

5.2.1 Traceability Standardization

As food traceability system development progresses, traceability standardization continues to evolve. Standards related to traceability coding specifications, traceability management requirements, traceability information recording specifications, traceability system construction standards, traceability technology requirements, blockchain application

guidelines, and specific requirements for enterprise food quality and safety management systems have been published.

At the international level, the International Organization for Standardization Technical Committee for Cold Chain Logistics Standardization (ISO/TC 315) released ISO 23412:2020, "Temperature-controlled transport service - Land transport of temperature-controlled packages with intermediate transfer," in May 2020. This standard recommends that temperature-controlled delivery service providers consider traceability in their workflows. Traceability in this context encompasses data capture, storage, and external provision throughout the entire temperature-controlled delivery service process, ensuring compliance with relevant laws and regulations.

At the domestic level, China has established a legal framework for food traceability, centered around the Agricultural Products Quality and Safety Law and the Food Safety Law. Since 2009, the Ministry of Agriculture and Rural Affairs has issued national standards for traceability requirements for major agricultural products, such as aquatic products, fruits and vegetables, and livestock and poultry meat. In August 2023, the State Administration for Market Regulation issued the "Requirements for Cold Chain Food Logistics Traceability Management (Draft for Solicitation of Comments)," outlining general guidelines for traceability management in cold chain food logistics. These guidelines cover key areas such as temperature data collection in critical processes, traceability information management, and implementation requirements, and they seek input from society as a whole. Under "Establishing a Traceability System," the guidelines specify that temperature information in cold chain food logistics should be the main focus of traceability content. They call for the establishment and improvement of end-to-end temperature monitoring management and inter-linkage mechanisms, ensuring complete temperature traceability throughout the process. These guidelines also outline the main tasks for establishing a cold chain food logistics traceability system.

5.2.2 Application of Traceability Systems in the Food Supply Chain

A traceability system integrates supervision of food production, processing, storage, transportation, and sales, providing a "from farm to table" traceability model. By collecting, centralizing, tracking, and uploading information from various supply chain stages, it establishes a food safety information database, allowing consumers to understand the entire process of food production and distribution that complies with food hygiene and safety standards. This transparency addresses the issue of severe information asymmetry in food safety and increases consumer confidence. For instance, during the 2008 Beijing Olympics, integrated sensors and electronic tags played a significant role in the fresh vegetable supply chain. Electronic tags on each vegetable recorded information about their origin and production processes. Additionally, temperature and humidity were automatically recorded on refrigerated transport vehicles, enabling source tracing and complete transparency in the supply chain, providing a detailed and unique perspective.

Following the principle of "blockchain as the core technology and food services as the development orientation," the China Food Supply Chain Alliance has implemented traceability throughout the entire process, from product cultivation, production, processing, packaging, transportation, to sales. The alliance conducts real-name authentication for enterprises and users. In cases of fraud or counterfeit goods, law enforcement agencies can locate, collect evidence, and hold parties accountable directly. For example, the "Chain Orange" system developed by the China Food Supply Chain Alliance utilizes the transparency, immutability,

and openness of blockchain technology to provide traceability services for citrus fruits. It offers a traceability query system from the field to the dining table, ensuring that consumers purchase genuine Jiangxi oranges. Alibaba Group's Cainiao Logistics and Tmall International have also ventured into the blockchain traceability field, utilizing blockchain technology to track, upload, and verify logistics information for cross-border imported goods throughout the entire supply chain, covering processes such as factory production, overseas warehousing, international transport, customs clearance, inspection reporting, and third-party inspection. Users can access comprehensive logistics and regulatory information through Alibaba's client applications.

5.2.3 Challenges and Implementation Barriers of Food Supply Chain Traceability Systems

Firstly, traceability standardization is incomplete. To achieve traceability for imported cold chain food, China has established national standards, local standards, and group standards. However, standards related to traceability for imported cold chain food are not yet well developed. Given the complexity of information collection in imported cold chain processes and the diversity of traceability data, data reported from various regions are automatically aggregated, posing challenges for system recognition. Currently, there is a lack of executable and referenceable national standards. Furthermore, some traceability standards mentioned in the standards are not truly traceability standards but are related to traceability, including information recording, information content, information management, and traceability implementation.

Secondly, traceability technology applications do not fully meet practical requirements, and information sharing is not smooth. Current agricultural product cold chain traceability efforts primarily use technologies such as RFID, barcodes, QR codes, GPS, and the Internet of Things to achieve end-to-end quality monitoring and information retrieval for products. However, current technology applications do not completely fulfill requirements. Ensuring the authenticity, accuracy, and effectiveness of information during traceability is challenging. Traditional RFID temperature detection electronic tags can provide real-time temperature monitoring but lack flexibility and cannot achieve real-time tracking. The cold chain food supply chain is vast and global, involving a wide range of processes from production and processing to storage, transportation, and sales. Traceability is a complex process that needs strict control at every step.

Lastly, traceability platform construction is incomplete, and oversight is inadequate. Traceability platforms use internet, Internet of Things, big data, and other technologies to store, process, and display traceability information. These platforms provide reliable end-to-end product information to consumers, enterprises, and government regulatory agencies, facilitating transparency in traceability information storage, processing, and display. Currently, traceability platform utilization is low, and consumers have limited awareness of the platform. On one hand, most consumers lack awareness of tracing food quality and safety during consumption, and their self-protection abilities are weak. On the other hand, consumers often do not know how to trace products through the platform, and there is a lack of knowledge dissemination. Traceability platforms face limitations in cross-regional integration, with existing platforms hampered by regional and technological disparities, making it difficult to achieve organic interconnection between traceability systems in different regions and information sharing among various traceability stakeholders. For imported cold chain food, traceability currently covers the information flow from customs entry to domestic sales, without comprehensive management of the entire process, including production, processing,

cold storage, logistics transportation, and sales in the country of origin. This limitation threatens the authenticity and integrity of internal data in the cold chain food logistics information system. In practice, traceability system oversight is insufficient, leading to difficulties in real-time monitoring and incomplete information for consumers seeking traceability information.

6.Future Trends and Recommendations in Food Cold Chain Transportation

6.1 Establishing a Robust Standard System to Promote the Orderly Development of Traceability Systems

In November 2020, the National Health Commission of China issued a notice titled "Improving Cold Chain Food Traceability Management." It emphasized the importance of implementing corporate responsibility for traceability management, advancing information-based traceability, strengthening overall planning, enhancing standards and regulations, innovating implementation models, improving interoperability, and accelerating the development of a nationwide, advanced, and applicable traceability system for key products. This initiative aims to enhance comprehensive quality and safety management, elevate product quality and safety, and enhance public safety. When establishing a national cold chain food traceability supervision system, it is essential to regulate and manage it with unified standards and regulations. This includes perfecting various management systems, implementing unified agricultural supply, unified technical guidance, unified production management, unified quality testing, and unified procurement and sales. Additionally, establishing cold chain logistics platforms and cold chain logistics monitoring platforms for end-to-end monitoring is imperative.

Strategies such as adopting standardized coding, improving traceability target information collection and management, upgrading packaging QR codes, adjusting traceability system compatibility, enhancing the standard system, and addressing information security concerns can optimize the prospects for the development of the cold chain food traceability industry. Local authorities should also intensify training, guidance, supervision, and enforcement efforts. Encouraging companies to use information technology for automatic product information identification, real-time reporting of critical cold chain food information, achieving forward traceability, backward traceability, and efficient issue resolution, as well as urging importers of cold chain food to strictly fulfill their traceability responsibilities, will collectively contribute to achieving the traceability goal of "source traceable and destination traceable."

According to an announcement from the National Standards Committee on September 14, 2023, China's first batch of national standards for "Imported Cold Chain Food Traceability," proposed by the National Logistics Information Management Standardization Technical Committee, was approved and published on September 7, 2023. These standards are set to be formally implemented on April 1, 2024. The primary objective of these national standards is to ensure the quality and safety of imported cold chain food and support the construction of a quality and safety traceability system for imported cold chain food. These standards cover various aspects, including traceability system construction, traceability information management, traceability system development, traceability data sharing and utilization, and traceability system data elements. The publication and implementation of these national standards will provide standard specifications for the construction of the imported cold chain food traceability system, establish basic requirements for relevant enterprises, offer insights into innovative approaches for quality and safety supervision of imported cold chain food, and

provide technical support to safeguard public welfare and promote the dual-cycle development pattern of the domestic and international markets. Furthermore, it will facilitate the alignment of domestic and international cold chain traceability standards, contributing to the formation of a global food cold chain traceability system.

6.2 Grasping Technological Innovation Directions to Promote End-to-End Traceability in Food Cold Chains

6.2.1 Building GSI Encoding Traceability Systems for Transparent and Effective Information Tracing

The GS1 system, an international organization for item coding globally, primarily addresses cross-border feedback control issues. This system encompasses multiple fields, including logistics, food, and raw materials, offering a standardized label and information exchange framework with specific global applicability. This system enables the monitoring and recording of product information within the supply chain in various regions worldwide, facilitating dynamic data tracking. It enhances the retrotranscription and accuracy of food information, enables rapid recalls of problematic products, and establishes uniform food safety traceability standards.

In the implementation of cold chain food traceability management, real-time data quality screening is crucial to identify and rectify traceability gaps promptly. The GS1 system, with its unified global product barcodes, serves as a global identity card system. By integrating relevant information of imported cold chain products into this system, it allows for the monitoring and recording of product information within the supply chain. Subsequent data consolidation and screening can generate traceability identifiers, enabling dynamic data tracking. This, in turn, enhances the retrotranscription and accuracy of food information, expedites product recalls, and standardizes food safety traceability. Government regulatory authorities can intelligently and transparently manage product information by querying the entire product-related process data within the imported cold chain food system using big data analytics. This approach enables precise management and supervision. Additionally, consumers can scan product information for traceability before purchase. It is imperative for China to establish a GS1 encoding traceability system to comprehensively track logistics information, refine traceability chain information, strengthen supervision of imported cold chain food safety, define relevant responsible entities, enhance food safety, and safeguard people's rights and safety.

6.2.2 Leveraging Modern Information Technology for Enhanced Safety Traceability Applications

The key to ensuring the quality and safety of agricultural products lies in source management and process control. Real-time monitoring and traceability within the fresh food cold chain framework make it easier for people to identify the origin of food products. Given the rapid development of the modern internet, it is essential to upgrade core technologies in logistics, including data collection, organization, and assessment. Combining information technology to design logistics schemes, actively introducing advanced information management systems and logistics tracking technologies, and achieving end-to-end monitoring and tracing are crucial. Emphasizing the application of information technology in cold chain logistics enhances controllability and safety. It is essential to promote the utilization of information technology for cold chain logistics, aligning it with current trends.

Establishing a source traceability database for agricultural products through electronic tag coding in the Internet of Things (IoT) can facilitate continuous and long-term monitoring of

the production and processing processes of agricultural products. The application of blockchain technology in the agricultural product traceability system can enhance the depth and breadth of food quality and safety traceability technology. Utilizing information technology and data resources to ensure transparency and traceability of agricultural product information through various channels effectively safeguards and enhances the quality and safety of agricultural products. Modern information technology, through the collection and recording of information at various stages and key points in agricultural product production, enables reverse querying. Gradually, it builds a traceability system that can trace the source, track the flow, and provide information queries. This approach accelerates digitized guidance, enabling quality and safety traceability in various stages of agricultural product production, from cultivation and breeding to the use of chemical inputs, disease and pest control, harvesting, storage, transportation, processing, and packaging. By establishing a secure monitoring system for cold chain logistics from the source to consumers, it enhances the supervision of the entire agricultural product cold chain logistics supply chain. This expands the scope of supervision from the source to the consumer endpoint, establishing comprehensive traceability, and strict standard supervision. Innovative institutional mechanisms ensure not only the quality and safety of agricultural products but also the protection of consumer rights. This approach allows for comprehensive and precise supervision and control of cold chain food in China, thereby promoting the development of cold chain food production and logistics. It realizes end-to-end digital traceability, restructuring the supply chain through data-driven high-quality development.

6.3 Improving Traceability Supervision Platforms for Transparent Food Cold Chain Safety

The "14th Five-Year Plan for Cold Chain Logistics Development" proposes the "National Cold Chain Food Traceability Supervision System Construction Project." Leveraging the existing national imported cold chain food traceability management platform, this project aims to gradually incorporate domestic cold chain food circulation into the traceability management scope. It seeks to promote data exchange and information sharing among national, provincial, and various market-oriented platforms, ultimately establishing a national cold chain food traceability management platform by 2025. The goal is to achieve multi-level, multi-system, cross-regional cold chain logistics traceability loops. By including both cold chain food and domestic cold chain food circulation in the traceability management system, it allows for comprehensive source tracking and problem resolution, promoting the full traceability of products. This comprehensive traceability ensures that products receive proper cold storage and preservation from their origin, maintaining temperature control throughout the entire transportation process. It also guarantees the safety and quality of products. Furthermore, it establishes a cold chain logistics safety supervision system from the source to consumers, improving the supervision of the agricultural product cold chain logistics supply chain. By broadening the scope of supervision and establishing comprehensive traceability from the source to the consumer, strict standard supervision, and innovative institutional mechanisms, it safeguards the quality and safety of agricultural products while protecting consumer rights. Consequently, the state can comprehensively and accurately supervise and control cold chain food, thereby promoting the development of cold chain food production and logistics. It enables end-to-end digital traceability and supply chain restructuring through data-driven high-quality development.

7. Conclusion

China has always prioritized food safety issues. While the country started relatively late in implementing comprehensive control and traceability management in food cold chains, the introduction of supportive policies, the increasing awareness of consumer safety, and rapid technological advancements in China are expected to lead to the realization of end-to-end traceability in cold chain food, creating a transparent and safe food supply chain in the near future.

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