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Technology and Equipment for Cold-Chain Storage and Transportation of Fresh Agricultural Products

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Abstract: Technology and equipment for cold-chain storage and transportation are critical for maintaining the quality and improving the circulation efficiency of fresh agricultural products, and they are strategically important for ensuring food safety and increasing agricultural income. In this article, the demand for cold-chain storage and transportation technology and equipment in China is analyzed, the current status is summarized, and the gaps between China and more-developed countries in this regard are discussed. Moreover, the essential technologies, most-important tasks, and major projects for the development of cold-chain storage and transportation technology and equipment for fresh agricultural products are clarified based on the Delphi method and field research. The major problems faced by technology and equipment include a lack of specialized precooling facilities in places of production, lack of refrigerated transportation equipment, limited quick-freezing technology and equipment, lagging research and development of the necessary technologies, nonstandardized construction of refrigeration and cold-storage facilities, and insufficient cold-chain infrastructure. A three-step technical route is proposed for the development of technology and equipment: achieving high efficiency and standardization by 2025, informatization and intelligence by 2035, and intelligence and autonomation by 2050.

Keywords: fresh agricultural products; cold-chain storage and transportation technology; cold-chain equipment; Delphi method

1 Introduction

In recent years, with increasing attention in China to food quality and safety and the strong support of all levels of government, cold-chain storage and transportation technology and equipment for fresh agricultural products have developed rapidly. The rapid rise of cold-chain storage and transportation has also exposed several problems, such as a low technical level, many potential safety hazards, lack of refrigerated transportation equipment, and the logistics information "broken chain." In addition, the outbreak of COVID-19 poses new challenges to the development of the cold-chain industry. To ensure food safety in cold-chain circulation, the study of cold-chain technology with antiviral and antibacterial functions and the development of a safe and efficient whole-process cold-chain technology and equipment system are urgently needed.

Cold-chain storage and transportation technologies and equipment are mainly divided into cold-processing, refrigeration, refrigeration transportation, and refrigeration sales technologies and equipment. With regard to the cold processing of fruits and vegetables, immersion and spray precooling are still the main methods in China at

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present, whereas spiral precooling machines are mainly used for meat precooling. In the quick-freezing process, direct-contact quick-freezing equipment based on liquid nitrogen is most widely used. In China's early refrigeration technology and equipment development, fruit and vegetable refrigeration automation is higher than that of meat refrigeration, but there are still many problems. The lack of refrigerated transportation equipment technology is the main factor restricting the development of cold chains in China. The main refrigerated transportation mode is land transportation. With the implementation of the Belt and Road Initiative, the rise of fresh e-commerce, cross-border food trade and other markets, railway, water, air, and other refrigerated transportation modes will play a greater role [1].

The development of cold-chain storage and transportation technology and equipment for fresh agricultural products is necessary for implementing high-quality development in the new era and is important for realizing a healthy China. Research on the development of cold-chain storage and transportation technology for fresh agricultural products in China is still limited. In this article, the demand for cold-chain storage and transportation technology and equipment for fresh agricultural products in China is analyzed, along with the current development situation, the gap between China and the world's most advanced level and the main problems China faces. The essential technologies, most-important tasks, and major projects for the development of cold-chain storage and transportation technology and equipment are summarized to provide support for the development of the industry until 2050.

2 Demand analysis of cold-chain storage and transportation technology and equipment

2.1 Macro demand

With its large population, China is a large consumer and producer of fresh agricultural products. The western region has unique natural conditions and a production base for high-quality agricultural products. To solve the problems of unsalable waste of agricultural products in the western region and shortage and high price in the eastern region, China has formed a typical circulation pattern of sending fruits from the west to the east. The northern region has a cold climate in winter, which makes it impossible to cultivate normal crops; however, it has a large population and a large demand for fruits and vegetables. To alleviate the disparity between the supply of and demand for fruits and vegetables in the off-season of winter and spring, Guangxi, Hainan, Yunnan, and other provinces actively support the development of transporting vegetables from the south to the north. According to a survey, the total transportation volume of fresh agricultural products in China exceeds 3×10^8 t, and the comprehensive cold-chain circulation rate is only 19%. The loss of food in circulation is a serious problem. Taking fruits & vegetables, meat, and aquatic products as examples, the corrosion rates in circulation are 0%–30%, 12%, and 15%, respectively. The loss and deterioration of a large number of fresh agricultural products in the production and marketing process have caused a huge waste of social resources, and the direct economic loss is as high as 680 billion RMB every year [2,3]. To reduce the decay rate in the circulation process, the temperature of fresh agricultural products during production, processing, storage, transportation, sales, and other links must be strictly controlled. The cold-chain storage and transportation technical equipment is important for reducing the circulation loss rate of fresh agricultural products and ensure food quality and safety.

2.2 Technical requirements

2.2.1 Cold-chain environment precise control technology and equipment

Refrigerated storage and transportation environments have a significant impact on the quality of fresh agricultural products. The main parameters characterizing the environment include temperature, humidity, gas concentration, wind speed, pressure, light intensity, and fluctuations in related parameters. The refrigerated storage and transportation environments of different types of fresh agricultural product vary. It is necessary to conduct quality research on fresh agricultural products under a refrigerated storage and transportation environment and explore the quality change law of fresh agricultural products under different refrigerated storage and transportation conditions, different degrees of maturity of fruits and vegetables, and different processing technologies to provide a theoretical basis for the research and development of frozen storage technology and cold-chain equipment. Comprehensive regulation of refrigeration system capacity, uniform cooling end equipment, air distribution optimization, and other technologies are necessary to develop cold-chain storage and transportation equipment with accurate control of storage and transportation environmental parameters.

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2.2.2 Cold-chain environmental protection and energy-saving technology and equipment

Developing environmentally friendly, efficient, and sustainable cold-chain storage and transportation equipment is important in the current cold-chain industry. While seeking environmentally friendly refrigerants with zero ozone depletion potential and low global warming potential, one must also focus on the basic research on thermal cycles corresponding to new refrigerants to improve the energy efficiency of refrigeration systems. Such technologies as enhanced heat exchange in low-temperature environments, frost suppression and defrosting of evaporators in low-temperature environments, physical field assisted freezing, variable capacity refrigeration, integration of cold and heat, utilization of renewable energy and natural cold energy, and development of high-efficiency cold-chain equipment in all links of the entire cold chain should be developed vigorously.

2.2.3 Cold-chain automation, informatization, and intelligence technology and equipment

With the rapid development of big data and artificial intelligence (AI), automation, informatization, and intelligence will be the development direction of cold-chain storage and transportation technology and equipment. Developed countries have advanced technology and management experience in cold-chain storage and transportation technology and equipment. For example, the United States, Japan, and some European countries have developed intelligent cold storage that combines intelligent technology with traditional cold-storage technology to realize intelligent, unmanned, and efficient production and operation management. China has a great need for cold-chain automation, monitoring, and management of all links and has certain technical advantages in fifth-generation (5G) mobile communication, big data, AI, and other directions. It should seize the opportunity and strive to reach a world-leading level.

2.2.4. Cold-chain antivirus and antibacterial technology and equipment

In June 2020, the COVID-19 epidemic appeared in the Xinfadi agricultural products wholesale market, which made food safety issues a serious concern and brought new challenges to China's cold-chain industry. The low-temperature conditions required for freezing and quality preservation of meat and aquatic products objectively provide favorable conditions for the survival of SARS-CoV-2 virus. Therefore, there is an urgent need to study cold-chain technology with antiviral and antibacterial functions, develop a safe and efficient whole-process cold-chain technology and equipment system, and kill viruses while assuring the quality of fresh agricultural products to control the spread of epidemics through the cold chain and improve the level of food safety and public health.

3 Development status of cold-chain storage and transportation technology and equipment in China

3.1 Cold-processing technology and equipment for fresh agricultural products

China is the world's largest producer and consumer of fruits and vegetables. After fruits and vegetables have ripened and been picked, they are often transported directly at room temperature without precooling treatment, which causes serious circulation loss. According to a survey, Jiangsu Province, Tianjin City, Hainan Province, and other places use the method of placing ice into the cold pool to keep the water temperature close to 0°C, and then manually immerse a plastic basket with vegetables into the ice pool to precool vegetables. The Guangzhou Conghua Hualong Fruit and Vegetable Preservation Co., Ltd. uses contact cold water cooling equipment (Fig. 1) to precool litchi in cold water at the origin. Yantai City, Shandong Province, uses spray cold water precooling equipment to precool cherries and constantly improves the precooling technology and equipment, which has become popular in Wulian County, Lijiazhai, Taian City, Henan Province, Shaanxi Province, Sichuan Province, and other cherry-producing areas [4].

Fig. 1. Fruit and vegetable ice water precooling equipment.

With the continuous growth of the national economy, the total annual output of livestock and poultry in China has remained at 8×10^7 t [5]. The engineering field focuses on equipment technology related to the cooling process of meat and poultry, such as the segmented cooling technology of pig carcasses, which can reduce dry consumption in the cooling stage by 30%–50%. The equipment, materials, and technology required for the construction of conventional cooling rooms have been localized, but some equipment and components must be imported to improve the automation level and further reduce material and energy consumption. With further improvements in the production efficiency and quality requirements of meat and poultry, along with the continuous reduction in cost caused by the localization of equipment, most newly built factories use spiral precoolers (as shown in Fig. 2).

Fig. 2. Screw precooling machine.

3.2 Quick-freezing technology and equipment of fresh agricultural products

Quick-freezing devices used in China are roughly divided into blast-type, indirect-contact-type, and direct-contact-type quick-freezing equipment. Blast-type quick-freezing equipment includes tunnel-type, spiral-type, and fluidization quick-freezing equipment. Indirect contact quick-freezing equipment involves plate, steel belt, and rotary types, among which plate-type quick-freezing equipment is the most widely used. Direct contact quick-freezing equipment includes immersion and spray types, among which direct contact quick-freezing equipment based on liquid nitrogen is the most widely used. Liquid-nitrogen spray and liquid-nitrogen impregnation are applied to strawberry, Ling Bai, green bean, broccoli, and other fresh-keeping plants, which can significantly affect the activity of polyphenol oxidase and peroxidase [6,7]. However, it is not economical to freeze fruits and vegetables completely with low added value using liquid nitrogen. Combined liquid-nitrogen and mechanical refrigeration should be considered. Different types of food have different requirements for quick-freezing technology and equipment. It is necessary to conduct in-depth research on quick-freezing technology for fruits and vegetables, aquatic products, animals and poultry, and convenience foods and scientifically determine the optimal quick-freezing technology for specific types of food.

3.3 Technology and equipment for freezing and refrigerating fresh agricultural products

Frozen storage technology and equipment are mainly used in the meat, aquatic product, and fruit and vegetable processing industries. The design temperature for productive cold storage in meat processing plants is mostly 0°C or −18°C to −20°C. The former is used for temporary storage of chilled meat or low-temperature meat products, and the latter is used for storage of frozen products. The design temperature of the productive cold storage of aquatic processing plants is usually less than −20°C, and the products are often set to −23°C to −25°C when they are used for export. Fruit and vegetable processing can be divided into fresh marketing and deep processing. The processing process of fresh marketing generally includes raw material sorting, graded picking, packaging, warehousing, cooling, and refrigeration. Deep processing mainly includes quick freezing and clean vegetable production, among which quick freezing involves cleaning, blanching, cooling, and other processes before quick freezing, whereas clean vegetable production involves cleaning, sometimes even disinfection, and fresh cutting, among other processes. Fresh fruit and vegetable processing plants mainly use two modes: cooling and refrigeration. The cooling mode is used for short-term temporary storage of varieties, mainly for the rapid cooling of seasonal fruits and vegetables after picking, or to provide thermal insulation packaging based on ice bottles and ice bags to reduce losses in the subsequent transportation process. The freezing and refrigeration facilities for fruits and vegetables are similar to those of meat joint processing plants. The difference is that the cooling link of quick-frozen-vegetable processing plants utilizes ice water, all quick-frozen links adopt quick-freezing machines, and the degree of automation is generally higher than that of meat freezing.

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3.4 Technology and equipment for refrigerated transportation of fresh agricultural products

At present, China's cold-storage transportation mode is mainly land transportation, the road cold-chain transportation market demand is strong, and transportation cargo turnover is increasing yearly. The increase in market demand and national policy support, under the condition of the entire railway refrigerated transport development in the country, has achieved a breakthroughs in railway refrigerated transport infrastructure construction, the opening of new railway refrigerated transport routes, optimization of railway refrigerated transport time, etc. Improvements in railway transport capacity, cold-chain logistics and long-distance refrigerated transportation have become increasingly apparent. In 2016, the *13th Five-Year Development Plan of Railway Cold Chain Logistics Network Layout* issued by China National Railway Group Co., Ltd. predicted that, by 2020, the railway refrigerated transport volume would be approximately 2×10^7 t, the cold-storage capacity would be approximately 3×10^6 to 5×10^6 t, and the total revenue of cold-chain logistics would be approximately 50–70 billion CNY. These development goals were achieved. With the implementation of the Belt and Road Initiative, the rise of fresh e-commerce, cross-border food trade, and other markets, the railway, water, air, and other refrigerated transportation modes will play a greater role, and the combination of a variety of refrigerated transportation modes will play a more important role in the cold-chain logistics market.

4 Main problems in the development of cold-chain storage and transportation technology and equipment in China

4.1 Lack of specialized precooling facilities at origin

According to statistics, the precooling rate of fruits and vegetables in China is approximately 20%, most of which is achieved through cold storage. The cold storage is not equipped with professional precooling facilities, most of which are built in the wholesale market, resulting in untimely precooling, a long precooling time, and a low precooling efficiency. For example, the average turnover rate of the precooling and refrigeration of vegetables in Hainan Province is nine days. High temperature, failure to precool after harvest, long precooling time, and other factors seriously affect the quality of vegetables. At present, the specialization and quantity of precooling equipment in producing areas are far from meeting the precooling needs of fruit and vegetable producing areas. The low degree of automation, high energy consumption, and high production cost of the precooling equipment are the main factors that restrict the development of precooling technology and equipment.

4.2 Lack of refrigerated transportation equipment

Heat preservation vehicles and refrigerated vehicles account for 85% of the total amount of refrigerated road transportation equipment in China, while fresh-keeping vehicles account for only 15%, and the proportion shows a downward trend. With the improvement in living standards, the requirements for the quality of fresh agricultural products are increasing, and the corresponding demand for refrigerated transportation is increasing. The reasonable proportions of heat preservation vehicles, fresh-keeping vehicles, and refrigerated vehicles should be 20%, 30%, and 50%, respectively [8]. At present, China has approximately 1.8×10^5 refrigerated transport vehicles. Although the number of refrigerated vehicles is increasing annually, there is still a large gap in the number of refrigerated vehicles (especially per capita) compared with more-developed countries. With the growth in production and sales of fresh agricultural products, the refrigerated transportation industry will create high-speed development opportunities; however, the insufficient number of refrigerated transportation vehicles restricts the development of the industry to some extent.

4.3 Immature quick-freezing technology and equipment

In recent years, to meet domestic market demand, China's quick-freezer manufacturers have developed various forms of quick freezers, accounting for more than 90% of the domestic market share. However, there is still a large gap between domestic quick freezers and advanced international products in terms of manufacturing and design levels, which is reflected in manufacturing processes, automatic control, materials, reliability, cleaning devices, and so on. The main problems of domestic quick-freezing equipment are high energy consumption and a high failure rate. The energy consumption of refrigeration systems accounts for most of the energy consumption of food refrigeration enterprises, whereas the energy consumption of quick-freezing equipment accounts for approximately 30%–50% of the total energy consumption of frozen food processing plants [9].

4.4 Underdeveloped research and development of key technologies

China's cold-chain system has both late development advantages and late development traps. "Late development advantage" refers to the ability to learn and apply the mature technologies of developed countries, which together with market demand, capital investment, and a complete industrial manufacturing and engineering construction system, constitute the material basis for the rapid development of China's cold-chain construction. The existence of a "late development trap" means that technology path dependence may have formed instead of exploring a technology development system that is more in line with national conditions. China's refrigeration industry is facing rare development opportunities, but, apart from individual technical links, such as carbon dioxide refrigeration systems, there has been no technical breakthrough matching the total development [10]. This has become a key factor restricting the development of the industry from quantitative change to qualitative change.

4.5 Lack of standardization in construction of refrigeration facilities

China's refrigeration industry uses steam compression refrigeration technology, and most related refrigerants are dangerous chemicals. A large number of multistory civil cold storages adopt ammonia cold exhaust pipes, and the charge amount of ammonia refrigerant is often as high as dozens or even hundreds of tons [11]. If there are problems, such as substandard construction, old facilities, or poor management, the risk of accidents is high [12]. Driven by economic interests, the proportion of actual facilities that fully meet the requirements of the whole-process cold chain is not high, and such phenomena as unqualified refrigeration temperature, cold-chain "breaking," and no health protection measures can be found everywhere. Even if there are no food safety accidents, the food quality is damaged.

4.6 Insufficient construction of cold-chain infrastructure

The circulation efficiency of the cold chain and the whole-process cold-chain system depends on complete cold-chain infrastructure construction. At present, the construction level of cold-chain transportation facilities in China is not high, and it is difficult to realize seamless connections between highways, railways, and water transportation networks. The lack of a modern logistics equipment technology system with information technology as the core and supported by storage and transportation equipment mechanization and packaging automation [13] makes the phenomenon of the chain breaking of cold chains serious and difficult to avoid.

5 Development planning and major projects of cold-chain storage and transportation technology and equipment in China

5.1 Development plan

The development of cold-chain storage and transportation equipment depends on breakthroughs in key technologies. According to the survey results obtained using the Delphi method, a list of key technologies of cold-chain storage and transportation equipment for fresh agricultural products in China was statistically formed (as shown in Fig. 3), including five primary technologies (refrigerated processing at origin, refrigerated storage, refrigerated transportation, refrigerated sales, and the whole-process cold chain), as well as 29 specific secondary technologies.

In the next 30 years, the development of cold-chain storage and transportation technology and equipment for fresh agricultural products in China is divided into three stages: 2020–2025, 2025–2035, and 2035–2050. Each stage has corresponding development plans, essential technologies, important tasks, and major projects (as shown in Fig. 4) that can support the steady, orderly, and sustainable development of cold-chain storage and transportation technology and equipment for fresh agricultural products.

5.1.1 Development plan for 2025

In view of the problems facing the cold-chain storage and transportation technology and equipment of fresh agricultural products, such as large temperature and humidity fluctuations, high energy consumption, and low degree of automation and standardization, the following technologies should be developed by 2025: (1) typical cold-processing technology of fresh agricultural products, high-efficiency differential pressure precooling technology, and rapid-freezing technology of low-temperature natural working medium; (2) technology that can accurately guarantee temperature and humidity in the refrigeration environment of agricultural products, technology to control dry consumption of fresh agricultural products, and technology to control the ice temperature environment of agricultural products; (3) technology to monitor the quality of agricultural products during refrigerated transportation,

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cold-storage technology for refrigerated transportation, and refrigerated transportation technology based on pure electric/fuel-cell vehicles; (4) natural working medium low-energy-consumption freezer technology, fresh distribution cabinet technology, and mobile fresh vending technology; and (5) whole-process cold-chain information technology based on 5G communications. To achieve these breakthroughs, the creation of a standardized and intelligent cold-processing equipment development system is planned for fresh agricultural products. In addition, a low-energy and low-cost cold-storage equipment development system and an automatic cold-chain logistics park will be developed. Finally, the preliminary development of highly efficient, standardized, and intellectualized cold-chain storage and transportation technology and equipment for fresh agricultural products is required.

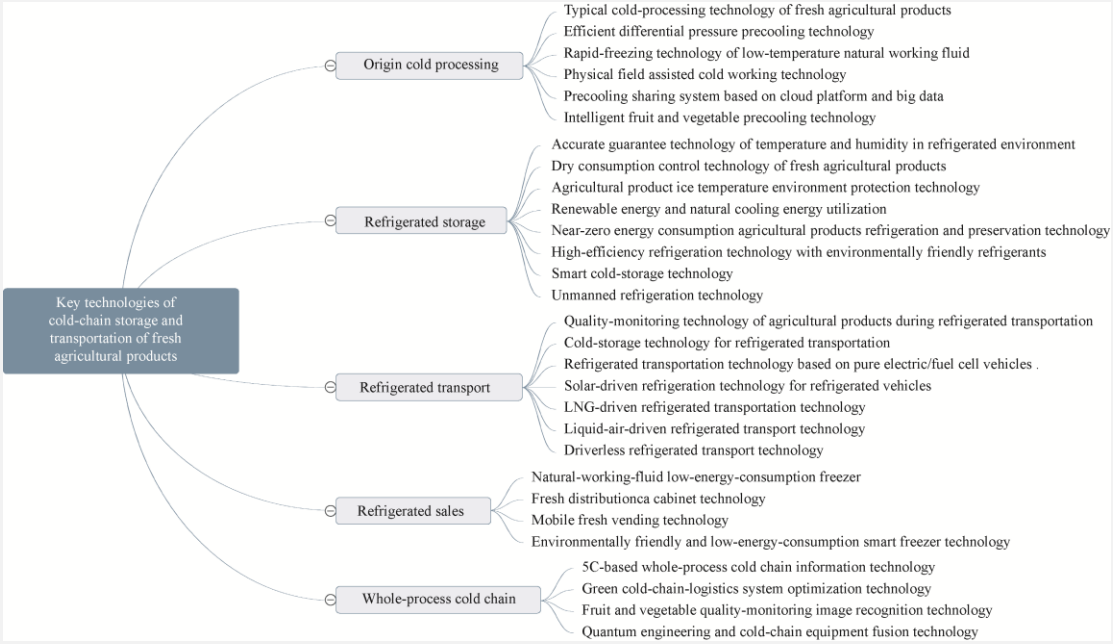

Fig. 3. Key technologies of cold-chain storage and transportation equipment for fresh agricultural products in China.

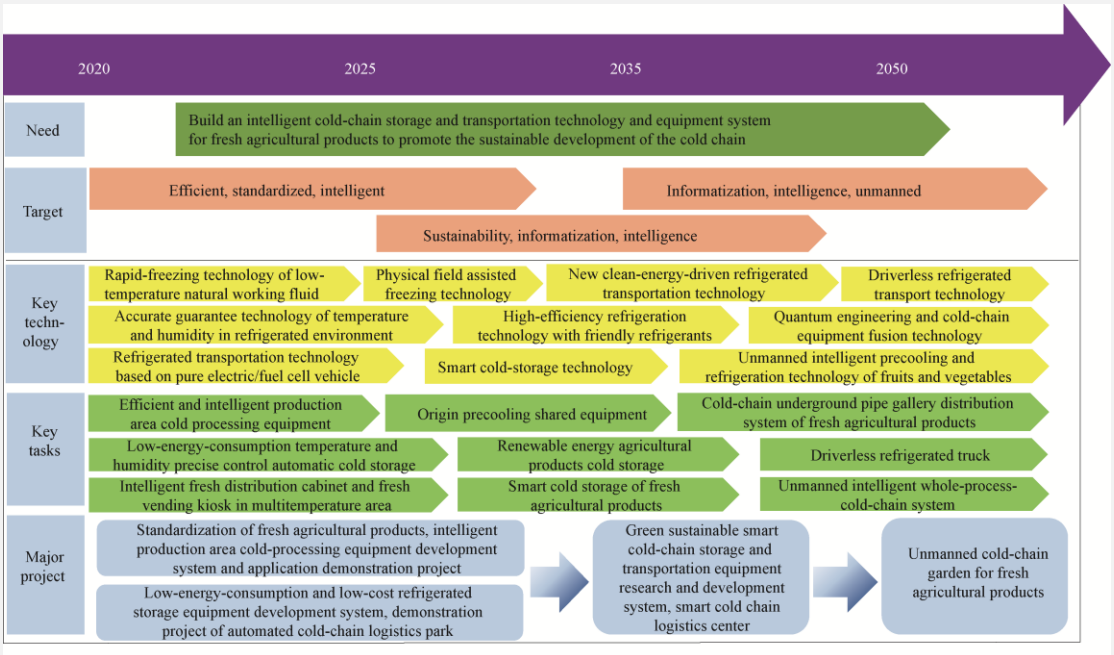

Fig. 4. Technical development route of cold-chain storage and transportation equipment for fresh agricultural products in China.

5.1.2 Development plan for 2035

Based on the progress of technology and equipment in the previous stage, the interaction of temperature flow,

energy flow, quality flow, and value flow was analyzed. It was determined that the following technologies will be required: (1) physical field assisted cold-processing technology, and a precooling sharing system based on a cloud platform and big data; (2) renewable-energy and natural-cold-energy utilization technology, near-zero-energy-consumption refrigeration and preservation technology for agricultural products, efficient refrigeration technology using environmentally friendly refrigerants, and smart cold-storage technology; (3) solar-driven refrigeration technology, liquefied-natural-gas-driven refrigeration transportation technology, and liquid-air-driven refrigeration transportation technology applied to refrigerated vehicles; (4) environmental protection and low-energy-consumption smart freezer technology; and (5) green cold-chain logistics system optimization technology, fruit and vegetable quality-monitoring image recognition technology. Accordingly, a green and sustainable smart cold-chain storage and transportation equipment research and development system and smart cold-chain logistics center should be established to develop a whole-process smart green cold-chain system for fresh agricultural products and realize the sustainability, informatization, and intelligence of cold-chain storage and transportation technology and equipment for those products.

5.1.3 Development plan for 2050

Based on previous research on the sustainability, informatization, and intelligence of cold-chain storage and transportation technology and equipment for fresh agricultural products, the following technologies will be required: unmanned intelligent precooling technology for fruits and vegetables, unmanned refrigeration technology, driverless refrigeration and transportation technology, and the technology for the integration of quantum engineering and cold-chain equipment. Accordingly, an unmanned cold-chain park for fresh agricultural products and an unmanned intelligent whole-process cold-chain system must be established to realize informatization, intellectualization, and unmanned operation of the cold-chain storage and transportation technology and equipment for fresh agricultural products in China.

5.2 Major projects

5.2.1 Construction of intelligent management and control platform for cold-chain storage and transportation

To address the problems of the high cold-chain loss rate, complex storage and transportation environment, and opaque information in the upstream and downstream of the supply chain in the intelligent supply chain for agricultural products, it is necessary to develop in-depth sensing of intelligent cold-chain data, intelligent and trusted blockchian technology for quality-maintained storage and transportation, a cold-chain logistics intelligent supervision cloud service platform, an intelligent regulation system for quality-maintained storage and transportation of agricultural products, and a blockchian cloud platform for supply chain credit evaluation and supervision of agricultural products.

The following issues must be studied: the quality change law under the coupling of time, environment, and quality; intelligent quality prediction technology for quality-assured storage and transportation; real-time environmental perception and regulation technology in the storage and transportation process; and the whole-process quality and safety control system. This is essential for solving emerging problems in current cold-chain logistics information construction and intelligent equipment research and development. The new agricultural product supply chain coordination platform based on the application of big-data technology will make remarkable progress. It will guide the formation of a complete set of intelligent technology systems for quality-assured storage and transportation and provide technical support for the construction of a system for circulation quality control of perishable agricultural products, as well as a cold-chain logistics big-data application platform and application demonstrations. The result is a reasonable reduction of dependence on imported products, making China’s cold-chain unmanned supervision level close to that of more-developed countries.

5.2.2 Construction of environmental protection storage hub

In terms of green cold-chain logistics, increasing the proportion of new-energy-based refrigerated transport vehicles, improving the utilization rate of cold-storage areas, adopting recyclable cold-chain packaging, carrying out green comprehensive tests of cold-chain logistics, reducing carbon dioxide emissions from cold-chain logistics, and improving resource utilization are needed. A backbone cold-chain logistics base should be built in essential areas of agricultural products. A regional cold-chain logistics hub should be established for agricultural products. Finally, the supply capacity of fresh agricultural products, such as meat, milk, vegetables, and fruits, should be improved.

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5.2.3 Standardizing the construction of cold-chain logistics

China's cold-chain standards system should summarize common circulation conditions based on clarifying the main body of the cold chain. According to the freshness-preserving needs of cold-chain circulation entities, the existing standards system should be comprehensively upgraded, and technical standards for cold-chain equipment and facilities that meet the needs of modern circulation must be developed. Great importance should be attached to the classification formulation/revision of relevant product standards. Existing national and industrial standards should be revised, and a standards system for cold-chain equipment should be established.

6 Suggestions on the development of cold-chain storage and transportation technology and equipment in China

6.1 Implementing special projects for scientific and technological research and development

6.1.1 Developing efficient and accurate environmental-control cold-chain equipment

To support the sustainable development of the cold-chain logistics industry in China, basic research on the heat and mass transfer process and airflow organization optimization of fresh agricultural products and different cooling media is recommended. A mixed working medium inner cascade, variable capacity refrigeration, and high-precision control core technologies (such as temperature control and various kinds of adaptive temperature regulation) are required. High-efficiency heat exchangers suitable for low-temperature quick freezing, high-efficiency vegetable precooling equipment, multitemperature storage and transportation equipment, controlled atmosphere storage equipment, ultralow-temperature freezing and quick-freezing equipment, and fresh food distribution cold-chain logistics equipment, such as cabinets and portable refrigerators, should be studied and developed. From basic theory to equipment design and development, the technical level of cold processing, freezing and refrigeration, refrigerated transportation, and other links must been improved in many ways from multiple perspectives.

6.1.2 Developing essential cold-chain logistics informatization technology

To eliminate the restrictions on the development of the cold-chain logistics industry, research on a circulation quality control method and system for fresh agricultural products is recommended. Based on the characteristics of cold-chain logistics, sensors of machine vision, spectrum, electronics, mechanics, ultrasound, and biology should be used to realize rapid, nondestructive, and real-time monitoring and detection of fresh agricultural products. Research on the application of environmental parameters and location-sensing technology in the storage and transportation of fresh agricultural products should be strengthened. Moreover, whole-process information traceability of fresh agricultural products should be realized by using sensors for temperature, humidity, light, air oxygen content, ethylene content, and hydrogen sulfide content, as well as the GPS and Beidou satellite navigation and positioning systems, to promote the information sharing and collaborative operation of all links of the logistics industry and the efficient allocation of social resources.

6.2 Improving the policy guarantee system

6.2.1 Vigorously supporting the construction of cold-chain facilities

A logistics base should be constructed for agricultural products. Enterprises engaged in agricultural product processing, cold-chain logistics, and circulation should be encouraged to speed up the construction of cold-chain logistics facilities, such as preservation, refrigeration, freezing, precooling, transportation, and inspection facilities. Economical and practical cold-chain storage facilities should be constructed on an appropriate scale according to local conditions. Long-distance and short-distance cold-chain transportation vehicles should be equipped to save energy and protect the environment. Temperature control facilities for the commercialization of agricultural products and the temperature control capacity of the mobile chain must be improved. A combined railway, highway, waterway, and air transportation network for agricultural products should be established. Cooperative intermediary service organizations for the transportation of agricultural products should be developed, and a refrigerated multimodal transportation system should be gradually introduced to improve the comprehensive benefits of transportation.

6.2.2 Actively supporting cold-chain enterprises

A bank–enterprise cooperation mechanism should be established and improved. Credit support for the cold-chain logistics industry should be increased appropriately, and reasonable capital needs of enterprises should be met. Given the challenging shortcomings restricting the development of the cold-chain logistics industry, social capital is encouraged to participate in investment and construction by establishing industrial development funds and by other

means. The costs of water, electricity, and gas should be subsidized for cold-chain enterprises, and a “green channel” policy for cold-chain transportation of fresh agricultural products should be implemented.

6.2.3 Maintaining necessary supervision

Fresh-keeping technology and refrigeration standards and thermal insulation technology standards must be strictly implemented for raw material treatment, sorting, processing and packaging, cooling and freezing, cold storage, refrigeration and transportation, wholesale distribution, distribution, and retail for all kinds of fresh products. Relevant enterprises should be encouraged to establish cold-chain logistics data collection, processing, and release systems, strengthen the analysis and utilization of cold-chain logistics big data, and gradually realize the informatization, digitization, transparency, and visualization of the entire process of cold-chain logistics. Regular spot checks of operations should be conducted in accordance with laws and regulations in terms of temperature control and preservation of relevant market-responsible processes, such as production, acquisition, processing, warehousing, transportation, retail, and distribution, and timely announcements should be made to society.

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