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Research on the Current Situation and Improvement Path of Green Cold Chain Packaging in Fresh Food E-commerce

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Abstract

With the promotion of the "dual-carbon" goals and the increasing consumer demand for fresh food quality, China's fresh food e-commerce industry has developed rapidly. However, the problems of resource waste and environmental pollution caused by cold chain packaging have become increasingly prominent. Promoting the green transformation of cold chain packaging has become a key issue for the sustainable development of the industry. This paper first briefly defines the core concepts, main characteristics, and common types of green cold chain packaging in fresh food e-commerce, then analyzes the current situation and problems through investigation, and finally proposes targeted suggestions and optimization strategies from different perspectives based on industry development needs. This study can provide practical guidance for fresh food e-commerce enterprises to promote the green transformation of cold chain packaging, and also offer references for improving industry standards and policy formulation, which is of great significance for promoting the green and sustainable development of the fresh food e-commerce industry.

Keywords

Fresh Food E-Commerce; Cold Chain Packaging; Green Transformation.

1. Introduction

The improvement of the national economy and the upgrading of residents' consumption level have brought development opportunities to the cold chain logistics industry. The market scale of fresh food e-commerce has surged, but the problem of cold chain packaging pollution has become increasingly severe. Statistics show that China's fresh food e-commerce market has grown continuously from 2019 to 2024 ,see Figure 1. Facing the increasing demand, the supply of cold chain logistics is difficult to meet the needs, outdated equipment leads to high product loss, and a large number of express packages cause resource waste and environmental pollution. Data show that 80% of green packaging products in China are exported, and only 20% are supplied to the domestic market; in the fast food industry, the penetration rate of green packaging is less than 10%. This phenomenon stems from multiple factors: on the one hand, consumers have limited awareness of green packaging and cannot distinguish between genuine and fake degradable products; on the other hand, price sensitivity is high, and most consumers are unwilling to pay a high premium for green packaging. Therefore, it is necessary to explore the mechanism and impact of green development in cold chain packaging logistics, and find a green, efficient, and sustainable development path for cold chain logistics.

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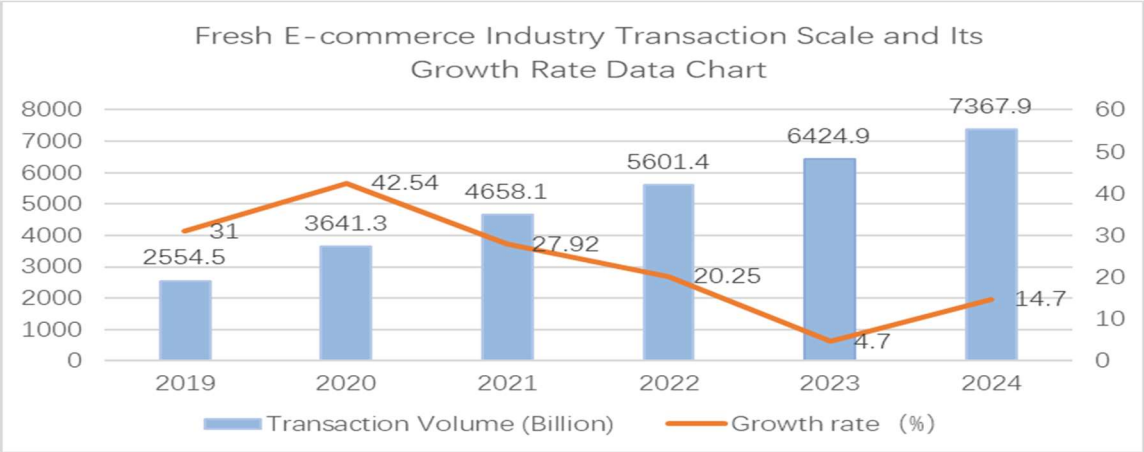


Figure 1. Fresh E-commerce Industry Transaction Scale and Its Growth Rate Data Chart

2. Research Status at Home and Abroa

2.1. Domestic Research Status

Domestic research on the green transformation of cold chain packaging in fresh food e-commerce shows a trend from in-depth problem research to proposal of solutions. Chen Fang, Guo Lichun et al. (2025), Li Zhengjun, He Junhua (2024) mentioned that food packaging accounts for more than one-third of the total packaging market, consuming a large amount of non-renewable resources and resulting in a higher carbon footprint. The green and sustainable development of fresh product packaging has become a consensus among countries, but China's current laws and policies on cold chain packaging for fresh food e-commerce are not perfect and were issued and implemented relatively late[3]. Therefore, when fresh food processing enterprises face the choice of multiple logistics packaging solutions, there is no complete and scientific evaluation standard for the advantages and disadvantages of the solutions and specific relevant indicators for reference. Huang Xin (2025) believes that adopting four strategies-dynamic coordination based on quality cycle, differentiated category coordination, technology-driven precise coordination, and supply chain coordination to reduce costs-can effectively eliminate the "cost-service" binary contradiction[1]. Liu Zhuozhuo, Duan Wenhao, Li Huan (2025) mentioned that due to lax temperature control and aging facilities and equipment, there are still many problems in China's fresh product cold chain logistics[6]. Zhao Ruijun, Lü Jingjing (2025), Xiang Mingyue (2023) mentioned that foam boxes and corrugated paper are the main packaging materials in cold chain logistics, and the increasing amount of such waste will cause serious harm to the protection of the natural environment[11].

2.2. Foreign Research Status

Foreign research in the field of green cold chain packaging has formed a promotion model from in-depth problem research to innovative technological innovation. Hossein Baniasadi, Roozbeh Abidnejad, Cristina D. Cruz; Ziba Fathi, Päivi Tammela (2025) pointed out that fresh products need to maintain the optimal temperature during storage and transportation to reduce the risk of temperature-sensitive products being affected by microbial growth, and studied new materials to replace the original materials[4]. Tianran Ren, Jun Ren, Dante Ben Matellini (2024) proposed a cold chain packaging risk management model based on a fuzzy Bayesian network. Through sensitivity experiments, they concluded that poor cold chain packaging will lead to safety problems and quality degradation[10]. Shen Chaoyi, Yang Zhichao, Rao Jingshan, Li Jiangkuo, Wu Di (2022) developed a new material-nanofiber mat-for fresh cold chain packaging, which has higher conductivity and hydrophobicity and has strong application prospects in sustainable fresh cold chain packaging[2].

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In summary, current research on the green transformation of cold chain packaging in fresh food e-commerce is good at analyzing macro systematic problems, proposing management strategies, and innovating new materials, but lacks implementable plans. Domestic research focuses on systematic challenges and strategic responses, with scholars clearly pointing out deficiencies in laws and policies, evaluation standards, waste disposal (such as the environmental pressure brought by foam boxes and corrugated cartons), and cold chain infrastructure. Foreign research shows a stronger technology-driven nature, actively exploring new materials, new technologies, and closed-loop recycling systems, and striving to fundamentally improve the environmental performance and fresh-keeping effect of packaging through innovations in materials science and circulation models.

3. Theoretical Basis for Green Cold Chain Packaging in Fresh Food E-commerce

3.1. Hierarchical Connotation of Green Packaging

The hierarchical connotation of green packaging presents a progressive structure. The basic layer focuses on compliance and reduction, meeting the bottom-line requirements of environmental protection through the use of environmentally friendly materials and streamlined structures. The advanced layer focuses on recycling and efficiency, relying on reusable packaging, standardized design, and intelligent tracking to improve the reuse rate and full-chain efficiency. The high-level layer achieves ecologicalization and coordination, requiring the industry chain to jointly promote the low-carbon transformation of the entire life cycle of packaging and combining consumer education to form a "production-consumption-recycling" closed loop. These three layers together constitute a green packaging system from basic compliance to systematic optimization[5].

3.2. Specificity of Fresh Cold Chain Packaging

In terms of functionality, cold chain packaging needs to meet three core requirements: maintaining a low temperature environment of 0-4°C for at least 48 hours to prevent microbial reproduction; anti-shock protection to avoid mechanical damage to fruits and vegetables; and breathable adjustment to control the gas composition inside the box. These functional requirements make traditional EPS foam boxes and chemical ice packs the mainstream choice in the industry, but also increase the environmental burden[7].

In terms of cost, cost sensitivity is another specificity of cold chain packaging. Data show that the unit price of degradable cold chain boxes is 28-35 yuan, while traditional foam boxes only cost 8-12 yuan; the cost of degradable ice packs is 2-3 times that of ordinary ice packs. The high cost makes small and medium-sized e-commerce enterprises hesitant. In the recycling link, cleaning and disinfection costs account for more than 60% of the total operating costs of the recycling system, further weakening enterprises' motivation to adopt green packaging[8].

4. Current Situation and Problem Diagnosis of Green Cold Chain Packaging in Fresh Food E-commerce

4.1. Low Standard Level of Fresh Food E-commerce Packaging

Since fresh agricultural products cover several categories such as fruits, vegetables, and aquatic products, and different types of fresh products have different requirements for packaging, the existing packaging standard system is difficult to take into account all types of fresh products. The content design of the standards is not reasonable enough, and a complete standardized system has not been formed. The existing standardized content of fresh food e-commerce packaging lacks practical value, simply copying the packaging standards of other products to

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the fresh food e-commerce packaging standards. With the rapid development of fresh food e-commerce, the existing fresh food e-commerce packaging standards have been difficult to meet the requirements of fresh product distribution[3].

4.2. Relatively Backward Packaging Technology in Fresh Food E-commerce

Improving packaging technology requires financial support, and many existing packaging enterprises are small enterprises, which face greater financial pressure to upgrade packaging technology. Secondly, due to the low level of fresh food e-commerce packaging standards, many enterprises only need to produce primary packaging that can simply meet the packaging needs of fresh products, lacking the motivation to upgrade packaging technology.

4.3. High Cost of Cold Chain Packaging in Fresh Food E-commerce

The cost of environmentally friendly materials such as bio-based tape and degradable plastic bags is more than three times that of traditional materials, and the huge price difference makes enterprises hesitant. Taking the mainstream degradable material polylactic acid (PLA) as an example, its raw material price is as high as 25,000-30,000 yuan/ton, while traditional polyethylene (PE) is only 8,000-10,000 yuan/ton. In addition, specialized treatment facilities for cold chain packaging are seriously insufficient, with only 12% of cities nationwide equipped with chemical ice pack treatment equipment, resulting in most ice packs being directly landfilled or incinerated[9].

4.4. Lack of an Ecosystem for Fresh Food E-commerce Packaging Recycling System

Cold chain packaging recycling faces threefold broken links at the consumer end, the recycler end, and the disposal end. At the consumer end, cold chain packaging recycling operations are complicated-ice packs need to be punctured and drained before recycling, and foam boxes need to be cleaned and dried. More than 90% of consumers choose to discard them directly due to the cumbersome operation, resulting in low recycling efficiency of express packaging. At the recycler end, the volume density ratio of foam boxes is extremely low, and the transportation cost is much higher than the recycling value, resulting in low enthusiasm among recyclers. At the disposal end, chemical ice packs contain propylene glycol and require professional treatment, but treatment sites are scarce and fees are high. Enterprises often choose the simplest way to dispose of them, which is to discard them, leading to problems such as high difficulty in express packaging recycling and environmental pollution[12].

5. Improvement Paths

5.1. Improving the Standardization System of Fresh Food E-commerce Packaging

Restraint and incentives should be implemented in parallel to restrict phenomena such as repeated and excessive packaging in fresh food packaging; necessary punitive measures should be taken against polluting enterprises through environmental protection laws; pilot projects should be carried out to provide certain policy and financial support for enterprises that carry out green packaging standardization, encouraging enterprises and the public to jointly build a green packaging standardization mechanism, and promoting the standardization and greening of fresh agricultural product packaging as soon as possible. A multi-channel supervision system should be built, giving play to the supervisory role of consumers, the media, etc., improving the market supervision mechanism, and publicly disclosing information on the handling of enterprises that do not meet the standards.

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5.2. Improving Fresh Food E-commerce Packaging Technology

5.2.1. Blockchain Traceability

Blockchain traceability technology can solve the problem of tracking the entire life cycle of packaging. By embedding NFC chips or UHF RFID tags in packaging, a "one object, one code" digital identity can be established, enabling full-chain traceability from raw material procurement, production and manufacturing, logistics and distribution to recycling and reuse ,see Figure 2: Fresh Food E-commerce Blockchain Traceability Diagram. Each package can be assigned a unique digital identifier, recording data such as material composition, number of cycles, and carbon emission reduction.

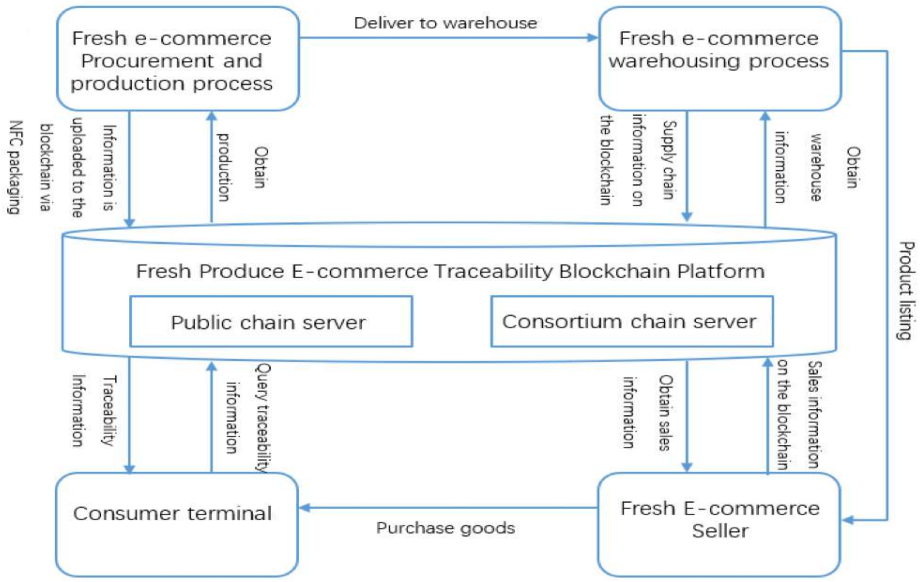


Figure 2. Fresh E-commerce Blockchain Traceability Diagram

5.2.2. AI Path Optimization

Artificial intelligence optimization systems have great potential in improving circulation efficiency. Path optimization algorithms can reduce the empty box return distance. For example, the "spatiotemporal grid path planning" algorithm developed by Meituan divides the geographical space into grids through path planning, and combines the time window constraints of orders to dynamically optimize the rider's path, realizing efficient large-scale path planning. The core formula is:

Minimize $\sum(d_{ij}\cdot x_{ij})+\lambda\cdot P_{timeout}+\mu\cdot P_{load}$

Where:

d_{ij}: travel distance from node i to j (based on grid distance or actual road network)

x_{ij}: binary decision variable, 1 if the rider travels from i to j, 0 otherwise

$P_{timeout}$: timeout penalty term, proportional to the deviation from the order's expected delivery time window

P_{load}: rider load penalty term, preventing a single rider from receiving too many orders

λ, μ: weight coefficients, dynamically adjusted through reinforcement learning (e.g., increasing λ during peak hours

5.3. Reducing the Cost of Fresh Food E-commerce Packaging

Promote reduction design, through classifying fresh products, achieve precise matching between packaging specifications and fresh products, so as to avoid the waste caused by using excessively large packaging boxes, and also reduce the need for additional filling materials due to excessive internal gaps, thereby reducing the weight of express packages.

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When plastic packaging must be used, lower-cost degradable materials can be considered, such as ordinary disposable plastic boxes made of PP material (unit price only 0.1-0.5 yuan). At the same time, natural materials such as bamboo fiber and rush weaving can be used as buffer layers, which are not only environmentally friendly, but sometimes can reduce costs by 20% compared with plastic.

5.4. Improving the Fresh Food E-commerce Recycling System

The standardization of green packaging for fresh food e-commerce should incorporate the concepts of energy conservation and environmental protection, and accelerate the construction of a green packaging recycling system. An effective way to improve the green packaging recycling system of cold chain logistics is to operate with regional stations as the core. To this end, it is recommended that the directly affiliated enterprises of all logistics distribution points (such as stations, cloud cabinets, etc.) carry out joint deployment cooperation with green packaging manufacturing enterprises of cold chain logistics. Specific measures include: setting up special independent green cold chain packaging recycling areas at these distribution points, and encouraging consumers to actively return packaging through incentive methods such as "active return with coupon gifts" or "accumulating a fixed number of returns/items to enjoy shipping discounts". This not only ensures that these special packages are uniformly and properly stored, but also enables timely maintenance, effectively reducing the damage rate and discard rate of green cold chain packaging[13].

6. Implementation Recommendations and Future Outlook

6.1. Implementation Recommendations

6.1.1. Establishing a Cross-Enterprise Recycling Alliance

The government should encourage leading enterprises in the industry to take the lead in establishing a fresh food packaging recycling fund, subsidizing enterprises according to the processing volume (e.g., subsidizing 800 yuan per ton of foam boxes). The fund sources include: 30% from financial appropriations, 40% from producer responsibility extension fees, and 30% from social capital. At the same time, formulate the "Green Packaging Management Regulations for Fresh Food E-commerce", clarifying the responsibility sharing ratio among platforms, merchants, and logistics parties.

6.1.2. Incorporation into the Carbon Trading Market

Include packaging carbon emission reductions into the national certified voluntary emission reduction (CCER) system, allowing enterprises to trade packaging emission reduction indicators. Initially, a conversion standard of 1 ton of recycled plastic = 0.8 tons of CO2 equivalent can be set, and later gradually connected to the international plastic credit mechanism.

6.1.3. Research and Development of Cutting-edge Technologies

Establish a special national key research and development program to support the development of revolutionary materials such as self-healing thermal insulation gels and photocatalytic antibacterial coatings. At the same time, fund community-level foam box crushing pretreatment equipment to achieve 90% volume compression and reduce transportation costs.

6.2. Future Outlook

Short-term (1-2 years): Focus on replacing highly polluting materials. Replace chemical ice packs containing propylene glycol with plant gel ice packs, and use starch-based buffer materials instead of EPS foam corners. This stage can reduce pollution complaints by 30% while controlling the cost increase within 5%.

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Medium-term (3 years): Establish a regional circulation system. Jointly build a circulation box sharing pool with 3-5 industry enterprises, set up centralized cleaning stations in regional distribution centers, and adopt a leasing model to share costs. The goal is to increase the box turnover rate to 80 times and reduce the cost per use by 40%.

Long-term (5 years): Build a full-chain digital system. Deploy a blockchain packaging traceability platform, connect to the carbon trading market, and achieve a 70% reduction in packaging carbon emissions. At this time, the "packaging as a service" model can be explored, transforming from a cost center to a profit center.

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