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Risk Assessment of Fresh Agricultural Product Supply Chains: A Case Study of Freshippo

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Abstract: Fresh agricultural products are characterized by perishability, strict timeliness requirements, and significant demand fluctuations. Their supply chains face a high degree of uncertainty in production, cold-chain logistics, sales feedback, food safety, and quality control. To identify and evaluate supply chain risks associated with fresh agricultural products, this study constructs an indicator system based on a literature review. The system consists of seven dimensions: production risk, logistics risk, sales information risk, collaborative management risk, external environmental risk, policy and regulatory risk, and food safety and quality risk. By integrating the C-OWA operator with grey clustering analysis, this study conducts an empirical assessment of the fresh agricultural product supply chain of Freshippo. The results show that the comprehensive risk value of Freshippo's supply chain is 6.239, indicating a high-risk level. Food safety and quality risk, sales information risk, and external environmental risk are the main sources of risk. Excessive pesticide residues, customer trust crises, cold-chain equipment failures, and poor supplier management exert considerable influence on the overall risk level. Based on these findings, this study proposes several recommendations, including strengthening source control, improving cold-chain safeguards, enhancing digital collaboration, and establishing a continuous improvement mechanism. The findings are expected to provide a reference for supply chain risk governance in fresh food retail enterprises.

Keywords: Fresh agricultural products; Supply chain risk; Risk assessment; Grey clustering; Freshippo.

1. Introduction

With the upgrading of household consumption and the rapid development of instant retail, consumer demand for fresh agricultural products has continued to expand. Consumers have also placed increasingly high requirements on product freshness, safety, and delivery efficiency. Fresh agricultural products usually pass through multiple stages from origin to table, including planting and breeding, procurement, processing, warehousing, transportation, store sales, and online fulfillment. Failures in temperature control, information delays, inadequate quality inspection, or deviations in demand forecasting at any stage may lead to increased losses, higher costs, and even food safety incidents. Compared with ordinary commodities, fresh agricultural products have shorter life cycles, faster quality deterioration, and greater vulnerability to natural environmental factors. Therefore, risks in their supply chains are more transmissible and sudden.

In recent years, scholars have conducted extensive research on agricultural product supply chain security, cold-chain logistics risks, risk transmission, and early warning mechanisms [1–5]. These studies have provided a foundation for identifying risk factors and conducting quantitative evaluation. However, in the context of new retail, online orders, front warehouses, instant delivery, supplier collaboration, and consumer evaluation systems are highly coupled [6–7]. Traditional evaluations focusing on a single supply chain stage are no longer sufficient to fully explain the mechanism of risk formation. As a representative fresh food enterprise in the new retail sector, Freshippo has strong digital operational capabilities and a relatively complex supply chain network. At the same time, it faces multiple pressures related to food safety, cold-chain fulfillment, market competition, and customer trust. Therefore, conducting a supply chain risk assessment using Freshippo as a case is both representative and practically meaningful, as it can provide managerial implications for similar enterprises.

The research procedure of this study is as follows. First, risk factors in fresh agricultural product supply chains are identified through a review of the literature, and a hierarchical indicator system is constructed. Second, the C-OWA operator is used to process evaluation information from multiple subjects, thereby reducing the influence of extreme scores on the weighting results. Third, grey clustering analysis is applied to characterize the membership degree of each indicator across different risk levels. Finally, risk control recommendations are proposed based on the empirical results of the case study.

2. Risk Identification and Construction of the Indicator System

Supply chain risks associated with fresh agricultural products run through the entire process of production, circulation, and sales. Existing studies have frequently identified factors such as natural disasters, public health emergencies, agricultural input residues, cold-chain disruptions, improper supplier selection, information asymmetry, demand fluctuations, price volatility, and policy changes [8–11]. Based on Freshippo's operating model of "suppliers–warehousing and distribution system–stores/online consumers," this study classifies risk factors into seven primary indicators and twenty-one secondary indicators.

Production risk mainly includes agricultural product quality and safety, instability of production supply, and environmental pollution at the production site. Logistics risk includes cold-chain equipment failure, transportation delays, and warehousing management risk. Sales information risk includes deviations in market demand forecasting, price fluctuations, and customer trust crises. Collaborative

management risk includes poor supplier management, weak internal coordination, and information system failures. External environmental risk includes natural disasters, sudden public health events, and intensified market competition. Policy and regulatory risk includes changes in food safety regulations, tightening environmental protection policies, and adjustments to trade policies. Food safety and quality risk includes excessive pesticide residues, pathogenic microbial contamination, and violations related to packaging and labeling.

This indicator system considers both business processes and risk attributes. On the one hand, it covers the key stages of fresh product supply chains from source to terminal. On the other hand, it incorporates quality and safety, collaborative governance, external shocks, and compliance pressure into a unified evaluation framework, thereby providing a relatively comprehensive reflection of the risk structure of fresh food new retail enterprises.

3. Research Methodology

To improve the robustness of the evaluation results, this study combines the C-OWA operator with grey clustering analysis. Grey system theory emphasizes modeling and evaluation under conditions of incomplete information [12], making it suitable for multi-factor and weak-information problems such as fresh supply chain risk assessment. The C-OWA operator can sort and weight the importance scores assigned by multiple evaluation subjects, causing the scores to converge toward the middle and reducing the influence of individual extremely high or low values on the final weights. In this study, the importance scores of secondary indicators are standardized to obtain relative weights, which are then used in the subsequent comprehensive evaluation.

Grey clustering analysis is suitable for dealing with risk evaluation problems characterized by incomplete information and fuzzy judgment. This study divides risk levels into five categories: extremely high, high, medium, low, and extremely low. Corresponding whitening weight functions are then established. Evaluation subjects assess each indicator from two perspectives: occurrence probability and impact severity. The membership degree of each indicator across the five risk levels is then calculated. Compared with directly assigning a single risk level, grey clustering results can present the distribution of risks across different levels, which helps identify key risks that may have a low probability of occurrence but severe consequences.

In the comprehensive calculation, the clustering results of secondary indicators are first synthesized into primary indicator risk vectors according to their weights. The seven primary indicators are then synthesized into the overall risk vector. This study uses the values of 9, 7, 5, 3, and 1 as the central values corresponding to the five risk levels from extremely high to extremely low. The comprehensive risk value is calculated accordingly, and the overall risk level is determined based on the following criteria: a score above 8 indicates extremely high risk; a score from 6 to 8 indicates high risk; a score from 4 to 6 indicates medium risk; a score from 2 to 4 indicates low risk; and a score below 2 indicates extremely low risk.

4. Case Calculation and Result Analysis

Freshippo's supply chain is characterized by a high degree of digitalization, a wide range of product categories, and strict delivery timeliness requirements. Its operating model improves consumer convenience, but it also amplifies the pressure of supply chain collaboration and quality control. Based on case data and the scoring results of risk indicators, this study obtains the overall clustering vector of Freshippo's fresh agricultural product supply chain as follows: (0.178, 0.361, 0.368, 0.086, 0.007). This result indicates that its risks are mainly concentrated at the high and medium risk levels, which together account for more than 70 percent. The comprehensive risk value is 6.239, falling within the high-risk range. This suggests that although Freshippo possesses strong operational capabilities, its supply chain still faces significant systemic risks.

At the primary indicator level, food safety and quality risk has the highest score, with a risk value of 7.051. Sales information risk ranks second, with a risk value of 6.994, followed by external environmental risk, with a risk value of 6.574. All three dimensions reach the high-risk level. Among them, food safety and quality risk shows a relatively high membership degree in the extremely high-risk category. This indicates that once problems such as pesticide residues or microbial contamination occur, they may rapidly trigger regulatory penalties, public opinion diffusion, and declining consumer trust. Sales information risk is mainly affected by customer trust crises, demand forecasting deviations, and price fluctuations. In fresh food retail, quality and safety problems are often rapidly transmitted to the sales side through social media, evaluation systems, and platform feedback mechanisms, thereby affecting brand reputation and repurchase intention. External environmental risk is reflected in intensified market competition, disruptions caused by sudden events, and natural environmental uncertainty. Although these risks are not entirely controllable by enterprises, they directly affect procurement stability and fulfillment costs.

At the secondary indicator level, the risks of excessive pesticide residues and customer trust crises have relatively high weights, and both show a membership degree of 0.750 in the extremely high-risk category. They are typical "low-frequency, high-impact" risks. Cold-chain equipment failure, pathogenic microbial contamination, and poor supplier management also show prominent risk performance. Cold-chain equipment failure may lead to temperature-control failure, which in turn causes quality deterioration and microbial contamination. Poor supplier management may allow quality hazards at the source to spread downstream, making it an important antecedent of food safety risk. These findings indicate that the risks in Freshippo's supply chain do not exist in isolation. Instead, they demonstrate a chain-like transmission pattern from source quality to cold-chain fulfillment and then to customer trust.

5. Risk Control Recommendations

First, source quality control should be strengthened. Enterprises should implement hierarchical management for core suppliers and high-risk product categories, and improve supplier access, process audits, sampling reinspection, and exit mechanisms. For key categories such as fruits and vegetables, aquatic products, meat, and poultry, enterprises should clarify requirements related to pesticide and veterinary drug residues, microbial indicators, and production-site environmental conditions. Suppliers should also be encouraged to establish records of key control points.

Through batch management and traceability systems, information on production origin, inspection, warehousing, and transportation temperature can be integrated into a searchable chain, thereby improving the traceability of quality risks.

Second, cold-chain logistics safeguards should be improved. The cold chain is the foundation for the stable operation of fresh product supply chains. Enterprises should strengthen temperature and humidity monitoring for vehicles, warehouses, store freezers, and temporary holding equipment, and establish abnormality alarms and emergency response procedures. For high-value or highly sensitive product categories, backup vehicles, temporary refrigerated storage, and delayed-transfer plans may be established. Regular emergency drills should also be conducted to reduce the impact of cold-chain disruptions on product quality and safety.

Third, digital collaboration capabilities should be enhanced. Fresh product supply chains involve multiple actors, including suppliers, warehousing and distribution centers, stores, platforms, and consumers. Enterprises should reduce information delays through data sharing. Procurement, inventory, sales, and delivery data should be integrated within a unified system. Demand forecasting should be improved by considering seasonal factors, holidays, promotional activities, and regional consumption differences, so as to reduce both stockouts and overstocking. Early warning thresholds should be established for near-expiry products, slow-moving products, and abnormal complaints, allowing problems to be promptly fed back to procurement and quality control departments.

Fourth, customer trust and risk culture should be emphasized. The consequences of food safety incidents are not limited to single-event losses; they may also damage brand image. Enterprises should establish a regular risk review mechanism to classify and archive complaints, abnormal sampling results, cold-chain alarms, and supplier violations, and to optimize standard operating procedures in a timely manner. In addition, employee and partner training should be strengthened so that risk awareness is embedded throughout procurement, warehousing, delivery, and sales processes.

6. Conclusion

Taking Freshippo as a case, this study constructs a risk assessment indicator system for fresh agricultural product supply chains and conducts an empirical assessment using the C-OWA operator and grey clustering analysis. The results show that the comprehensive risk value of Freshippo's supply chain is 6.239, indicating a high-risk level. Food safety and quality risk, sales information risk, and external environmental risk are the main sources of risk. Excessive pesticide residues, customer trust crises, cold-chain equipment failures, pathogenic microbial contamination, and poor supplier management are the key risk factors. The study demonstrates that fresh agricultural product supply chain risks have a clear chain-like transmission pattern. Enterprises should enhance supply chain resilience from four aspects: source control, cold-chain safeguards, digital collaboration, and continuous improvement. Nevertheless, this study has certain limitations, including a limited sample scope and reliance on subjective judgment in indicator scoring. Future research may further verify the validity of the model by incorporating real enterprise operational data and consumer feedback data.

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