Knowledge graph analysis of domestic research on cold chain logistics for fruits and vegetables based on CiteSpace

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Abstract. In recent years, the field of cold chain logistics for fruits and vegetables has emerged as a significant topic in academic research. This study adopts a bibliometric approach and utilizes the visual analysis tool CiteSpace to systematically investigate the progress of domestic research in this area. Based on 209 core articles retrieved from the CNKI (China National Knowledge Infrastructure) database from January 2007 to May 2024, the study constructs multi-dimensional knowledge graphs—including discipline co-occurrence networks, author collaboration networks, and keyword timezone maps. The analysis reveals several key findings: there is a marked upward trend in the annual number of publications, research hotspots have evolved in phases, and core research areas concentrate on the optimization of cold chain logistics systems, innovations in preservation technologies for fruits and vegetables, and the construction of agricultural product logistics networks. It is worth noting that quality control of fruits and vegetables, along with related technological challenges, may become prominent directions for future research.

Keywords: cold chain logistics for fruits and vegetables, CiteSpace, knowledge graph analysis

1. Introdution

With the increasingly complex and evolving global landscape and the rapid, healthy development of China's national economy, the public's aspiration for a better life continues to rise. As a result, higher demands are being placed on the quality and safety of fresh agricultural products—such as fruits and vegetables—in daily life. Currently, China ranks first globally in terms of both the cultivation area and production volume of fruits and vegetables. However, according to the latest research findings from the Institute of Food and Nutrition Development, Ministry of Agriculture and Rural Affairs, significant losses occur during the circulation of major agricultural products in China. Using a weighted average method, the study estimates that the overall loss rate for seven categories of agricultural products—vegetables, fruits, aquatic products, grains, meat, dairy, and eggs—reaches as high as 22.7%, with an annual loss totaling approximately 460 million tons. This alarming figure highlights the urgent need to optimize the cold chain logistics system for agricultural products. Statistics further show that the spoilage rate for vegetables can be as high as 20%, while the rates for meat, aquatic products, and fruits reach 8%, 10%, and 11%, respectively. Each year, around 400 million tons of fresh agricultural products enter circulation, of which nearly 80 million tons—or about one-fifth—of fruits and vegetables are lost due to spoilage, making China's annual fruit and vegetable spoilage rate the highest in the world. The high perishability, seasonality, and storage difficulties of fruit and vegetable products, combined with market price volatility and supply-demand imbalances, significantly increase the risks associated with cold chain operations. In light of these challenges, ensuring the smooth supply and demand of fruit products, guaranteeing quality and safety, and improving farmers' incomes have become urgent goals. Consequently, many scholars and experts have devoted their efforts to research in fruit and vegetable cold chain logistics.

This study aims to systematically review the progress of research on cold chain logistics for fruits and vegetables in China and to clarify the developmental trajectory of this technology through a bibliometric approach. By employing the visual analysis tool CiteSpace, this study conducts a multi-dimensional analysis of relevant literature from the CNKI database, focusing on the identification of research hotspots, the evolution of knowledge structures, and the prediction of emerging trends. The goal is to provide a theoretical reference and guidance for future research in this field.

2. Knowledge graph analysis method and data source

2.1. knowledge graph analysis method

CiteSpace is a visual knowledge mapping software developed by Dr. Chaomei Chen at Drexel University in the United States. It innovatively integrates visualization technology with scientometrics, drawing upon citation analysis, co-citation analysis, and other bibliometric methods, as well as technologies such as computer graphics and data mining [1]. CiteSpace can be used to generate knowledge graphs depicting the development of scientific and technological domains, providing an intuitive panorama of scientific knowledge, and identifying key literature, research hotspots, and emerging trends within a given scientific field. In China, the software has been primarily applied in the fields of management and technical sciences [2], but it has not yet been widely used in research on cold chain logistics for fruits and vegetables.

2.2. Data source

The data for this study were obtained from the China National Knowledge Infrastructure (CNKI), the most authoritative digital publishing platform for Chinese academic journals, which encompasses core journal literature across various disciplines. Literature related to cold chain logistics for fruits and vegetables began to emerge in China after 2005. Therefore, the retrieval period was set from 2005 to 2024. Using the subject term "fruit and vegetable cold chain logistics" as the search criterion, a total of 230 journal articles were initially retrieved. To ensure the effectiveness of the data analysis, further screening was conducted to exclude irrelevant materials such as conference papers, newspapers, yearbooks, books, patents, and book reviews. Ultimately, 209 articles published between 2007 and 2024 were selected as the final sample for analysis.

3. Current status and analysis of fruit and vegetable cold chain research

3.1. Research fields and distribution of source journals

Based on visualized analysis of the CNKI database regarding the source journals and publication frequency in the field of fruit and vegetable cold chain logistics, the core journal cluster and disciplinary breadth of this research domain can be identified. As shown in Figure 1, the majority of research in this field in China falls under agricultural economics, accounting for more than half of all publications (52.25%). This is followed by macroeconomic management and sustainable development at 18.34%. Other involved disciplines include light industry and handicrafts, market research and information science, computer software and applications, trade economics, industrial economics, automation technology, telecommunication technology, and business economics. These findings indicate that research on fruit and vegetable cold chain logistics in China is primarily concentrated in two key domains: agricultural economics and cold chain technology.
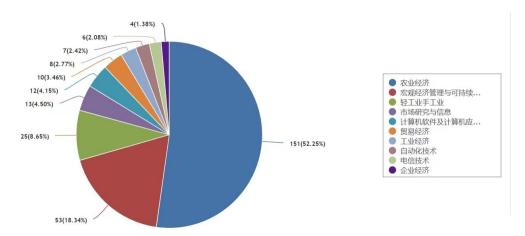

Figure 1. Discipline distribution of domestic fruit and vegetable cold chain related research

In addition, Table 1 lists the top 20 domestic journals by number of publications on fruit and vegetable cold chain logistics. The distribution of publications across journals reflects a degree of concentration. The top two journals—Preservation and Processing and Logistics Technology—account for 20.48% of all articles in this field. The top 10 journals collectively contributed 81.90% of the total literature, and these are primarily research-oriented journals focusing on logistics, commercial economics, and logistics technology. This indicates that a relatively stable core cluster of journals has emerged for research on fruit and vegetable cold chain logistics in China. This cluster not only facilitates in-depth and sustainable development of the field but also provides a stable communication platform for the academic community engaged in this research.

Table 1. Top 20 domestic literature sources for fruit and vegetable cold chain related research

No.	Journal Name	Number of Articles	Percentage	No.	Journal Name	Number of Articles	Percentage
1	Preservation and Processing	9	10.84%	11	Science and Technology Information	3	3.61%
2	Logistics Technology	8	9.64%	12	Hubei Agricultural Sciences	3	3.61%
3	Logistics Engineering and Management	7	8.43%	13	China Storage & Transportation	3	3.61%
4	Logistics Technology	7	8.43%	14	Modernization of Shopping Malls	3	3.61%
5	China Fruits and Vegetables	6	7.23%	15	Dalian University of Technology Journal	2	2.41%
6	Logistics Technology and Application	5	6.02%	16	Food and Machinery	2	2.41%
7	Modern Business and Industry	5	6.02%	17	China Market	2	2.41%
8	Rural Economy and Science	5	6.02%	18	China Agricultural Resources and Zoning	2	2.41%
9	Modern Marketing (Late Edition)	4	4.82%	19	Chinese and Foreign Entrepreneurs	2	2.41%
10	Jiangsu Agricultural Sciences	3	3.61%	20	Agricultural Product Processing	2	2.41%

Source: Compiled based on statistics from the CNKI database.

3.2. Visualization analysis of author distribution

3.2.1. Co-authorship network analysis

High-frequency authors and their collaboration networks play a critical role in shaping a research field [3]. By constructing an author co-occurrence knowledge network, we can identify the core researchers in the field and assess the degree of scholarly collaboration [4]. Using CiteSpace software, the analysis was set for the period from 2007 to 2022 with a time slice of one year. The node type was set as "Author," and the Top50 threshold was applied, meaning only the top 50 authors by annual publication count were included in the co-occurrence network analysis. The resulting network comprised 344 nodes and 369 links, with a network density of 0.0063, indicating a large number of researchers in the fruit and vegetable cold chain logistics field and a relatively close collaborative network among scholars, with a high level of communication awareness. The co-authorship knowledge network map, sorted by betweenness centrality, is shown in Figure 2.
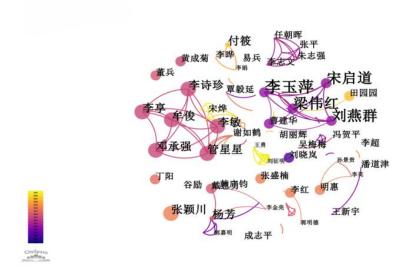

Figure 2. Map of co-occurrence knowledge network of domestic authors

In this map, node size (font size) represents the frequency of an author's appearance or number of publications, while the thickness of lines between nodes reflects the closeness of collaboration between authors. The network reveals collaborative relationships among 344 authors from 2007 to 2024, with more connections indicating broader collaboration. Three major research collaboration groups are clearly observable within the domestic research community: The largest research group centers around Li Yuping from the Institute of Scientific and Technical Information, Chinese Academy of Tropical Agricultural Sciences, whose primary research interests include agricultural economics, macroeconomic management and sustainable development, and plant protection. Li Yuping collaborates closely with Liang Weihong, Song Qidao, Liu Yanqun, and Cao Jianhua, all affiliated with the same institute. The second group includes Mu Jun, Li Shizhen, Li Min, Guan Xingxing, Deng Chengqiang, and Li Xiang, all from Yangtze University. The third major collaboration group is composed of Zhang Ping from Beijing University of Posts and Telecommunications, Ren Zhaohui and Zhu Zhiqiang from the National Agricultural Products Fresh-Keeping Engineering Research Center (Tianjin), and Li Zhiwen from Tianjin Agricultural University. These collaborative groups form a divergent network structure, indicating the emergence of large-scale research teams in the fruit and vegetable cold chain logistics field. The study shows a clear trend of "intra-group cohesion," meaning that collaboration within teams is strong, whereas inter-institutional cooperation across different research teams remains limited. Most high-yield authors belong to these three core groups. However, the majority of other researchers appear to be scattered, suggesting that collaboration and communication across institutions remain insufficient. There is an urgent need to strengthen academic exchanges and cooperation among researchers in this field.

3.2.2. Core author analysis

Based on the number of publications, the top 10 high-yield authors are listed in Table 2. The most prolific author is Li Yuping, with six publications, followed closely by Liang Weihong, Song Qidao, and Liu Yanqun, each with five publications. Other high-yield authors include Deng Chengqiang, Yang Fang, Zhang Yingchuan, Guan Xingxing, Li Xiang, and Li Shizhen, each with fewer than five publications. These scholars have established significant influence in this field. Collectively, the top 10 authors contributed 39 publications, accounting for 18.67% of all articles, indicating the preliminary formation and gradual expansion of a core research team in the field of fruit and vegetable cold chain logistics. According to Price's Law, the formation of a high-yield author group in a discipline must meet specific quantitative characteristics, namely, that this group should produce more than half of the total literature in the field. The formula for identifying core authors is as equation (1) [5]:

$$M = 0.748\sqrt{Nmax} \tag{1}$$

Where M is the minimum number of publications required to be considered a core author, and Nmax is the number of publications by the most prolific author.

When the number of publications is higher than M, the author is considered as a core author. Substituting Nmax = 6 (number of papers by Li Yuping), we calculate M ≈ 1.832, and by rounding up, M = 2. Therefore, any author with two or more publications is classified as a core author in the field of fruit and vegetable cold chain logistics in China. A total of 31 authors have published 2 papers, and 9 authors have published 3 papers, resulting in 45 core authors with at least two publications.

Table 2. High-yield authors and core authors of domestic research

Publications	High-Yield Author	Rank	Publications	High-Yield Author	Rank
6	Li Yuping	1	3	Yang Fang	6
5	Liang Weihong	2	3	Zhang Yingchuan	7
5	Song Qidao	3	3	Guan Xingxing	8
5	Liu Yanqun	4	3	Li Xiang	9
3	Deng Chengqiang	5	3	Li Shizhen	10

4. Research hotspots and frontiers in fruit and vegetable cold chain logistics

4.1. Keyword co-occurrence analysis

As a condensed expression of the core content of academic papers, keywords serve as a highly abstract summary of research themes. Through bibliometric analysis of keywords, it is possible to effectively identify academic hotspots and key directions within a specific research field. The frequency of high-frequency keywords is significantly positively correlated with the popularity of research topics. The visual knowledge map constructed based on keyword co-occurrence analysis provides researchers with an intuitive representation of the domain's knowledge structure, as shown in Figure 3. Based on an analysis of 209 domestic research articles on fruit and vegetable cold chains, this study utilized the g-index (k=25) as the data filtering criterion. Specific parameters were set as follows: node type was set to "Keywords," the time span was from January 2007 to May 2024, and the time slicing interval was one year. Other parameters were kept at the default values of the CiteSpace software. After running the analysis, a keyword co-occurrence network was generated. In the visualization, keywords are represented by circular nodes, with node

diameter proportional to keyword frequency. The font size of keyword labels is directly related to their frequency. In Figure 3, the larger the font, the more frequently the keyword appears, indicating popular topics and key concepts in fruit and vegetable cold chain logistics research. The network contains N = 272 nodes and E = 429 edges, with a network density D = 0.0116, indicating a relatively strong correlation between keywords.

Analysis of the knowledge map reveals that high-frequency keywords exhibit a clear clustering pattern. Keywords such as "cold chain logistics," "fruits and vegetables," "fruit and vegetable cold chain," "cold chain," "fruit and vegetable products," "agricultural products," "countermeasures," "fresh fruits and vegetables," and "fruit and vegetable logistics" appear with high frequency. Among them, "cold chain logistics" appears 110 times and has a centrality of 0.56, indicating its status as a high-centrality node and core hub in the network. Other key terms, such as "fruits and vegetables" and "fruit and vegetable cold chain," are closely associated with the central node, reflecting a high degree of relevance to the research theme.
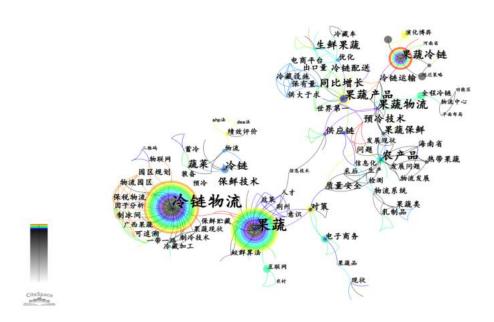

Figure 3. High-frequency keyword knowledge map of fruit and vegetable cold chain

After running the CiteSpace software, a total of 272 keywords were obtained. Using a threshold of at least four occurrences, high-frequency keywords were extracted. These high-frequency terms not only represent the core conceptual system within the field but also reflect the current focal issues in research. An analysis of the evolutionary trend of these keywords can further forecast the direction of academic development and provide researchers with a cognitive framework and optimization basis for research orientation. Table 3 lists and ranks the top 20 high-frequency keywords in the field of fruit and vegetable cold chain research.

Table 3. Keywords frequency of fruit and vegetable cold chain (Top 20)

Frequency	Centrality	Keyword	Rank	Frequency	Centrality	Keyword	Rank
110	0.56	Cold chain logistics	1	6	0.53	Supply chain	11
51	0.92	Fruits and vegetables	2	5	0.02	Tropical fruits	12
16	0.14	Fruit and vegetable cold chain	3	4	0.04	Current situation	13
12	0.07	Cold chain	4	4	0.10	Optimization	14
11	0.27	Fruit and vegetable products	5	4	0.36	Cold chain transport	15
9	0.17	Agricultural products	6	4	0.00	Development strategies	16
9	0.31	Countermeasures	7	4	0.11	E-commerce	17
7	0.09	Fresh fruits and vegetables	8	4	0.01	Hainan Province	18
7	0.48	Fruit and vegetable logistics	9	4	0.14	Vegetables	19
6	0.05	Logistics	10	4	0.10	Fruit and vegetable preservation	20

Compared with the development trajectory of international cold chain logistics, China's cold chain practices only began in the 1950s. Despite this late start, with the dual drive of policy support and academic research, Chinese scholars have recently

developed distinctive research directions in agricultural cold chains. These include the development of low-temperature preservation technologies, innovations in supply chain models, and improvements in distribution network efficiency.

In the early stages of China's cold chain logistics industry, development primarily relied on the introduction of foreign cold chain technologies. However, in recent years, as the "Internet+" continues to integrate with various industries, the cold chain logistics industry has undergone continuous technological innovation, addressed shortcomings and promoted a shift in growth drivers. For example, Wang et al. combined RFID technology with cold chain temperature monitoring to achieve real-time temperature tracking during the transportation of tilapia, meeting consumers' demand for cold chain temperature records [7]. Although the government has increased efforts in R&D for cold chain logistics, weak foundations in technological innovation and outdated equipment usage have resulted in high spoilage rates and low preservation integrity in the transportation of agricultural products.

Fruit and vegetable cold chains are a significant subfield within agricultural cold chain logistics, with distinct characteristics compared to other product types. Fruits and vegetables are highly diverse, require complex storage processes, have high freshness demands, and involve longer industrial chains. Feng, Wu, et al. developed a real-time online monitoring system for fruit and vegetable cold chains based on ZigBee technology to monitor temperature and humidity during transportation [8]. Liu Lu analyzed the current state of domestic and international fruit and vegetable cold chain transportation and reviewed the application of phase change materials (PCMs) in cold chain logistics. She pointed out that PCMs can effectively save energy and achieve peak load shifting. However, current research mostly focuses on supercooling phenomena, with limited attention paid to hysteresis effects.

4.2. Research trend analysis

In scientific knowledge mapping, the burst characteristics of keywords hold significant indicative value for research trends. When certain terms show a sudden increase in frequency within a short period, it often signals the emergence of new research directions. A systematic analysis of the temporal distribution and co-occurrence relationships of burst keywords can help construct predictive models for frontier developments in a given field. In the study of fruit and vegetable cold chain logistics, research frontiers and development trends are primarily determined by keyword bursts and changes in frequency. By constructing a visual map of burst keywords, the frontier trends in this research domain can be presented more intuitively and clearly.

Based on the co-occurrence and clustering maps of keywords generated by CiteSpace, the "Burstness" detection function was employed with the following parameter settings: the tuning coefficient γ was set to 0.1, and the minimum burst duration was set to 2 years. The top 25 burst keywords and their corresponding temporal distributions were extracted from the visualization interface. In the generated keyword burst map, "Year" refers to the initial year the keyword appeared in CNKI-retrievable documents; "Strength" quantifies the intensity of the burst—a higher value indicates a more significant burst; "Begin" and "End" refer to the start and end years of the burst period, respectively. The red bars indicate the burst time span, while the blue bars represent time slices by year. For example, the keyword "fruit and vegetable logistics" began its burst in 2007 and ended in 2009, meaning its popularity sustained from 2007 to 2009. The keywords were sorted by three criteria—starting year, burst duration, and burst strength—to generate the burst keyword spectrum shown in Figure 4.

The observation shows that the average burst duration for keywords is approximately two years, with the time spans of different keywords occurring consecutively without interruptions. Keywords such as "fruit and vegetable logistics," "tropical fruits and vegetables," "logistics," "optimization," and "fruit and vegetable products" exhibited relatively high burst intensities, all exceeding 1.5. Notably, "tropical fruits and vegetables" reached a burst intensity of 2.26, indicating that this area received considerable scholarly attention during its active period. Furthermore, the data indicate a shift in research focus: before 2014, the emphasis was mainly on specific technical topics such as refrigeration technology, preservation, and cold storage. Since 2014, however, researchers have increasingly focused on regional development status, logistics models, and informatization. It is also worth noting that keywords such as "fruit and vegetable products" (burst strength 1.87) and "strategic issues" (burst strength 1.04) have emerged as new hotspots within the past three years. These keywords represent current key topics and may serve as valuable references for guiding future research directions in the field of fruit and vegetable cold chain logistics.

op 25 Keywords with the Strongest Citation Burs

Keywords	Year	Strength	Begin	End	2007 - 2024
果蔬物流	2007	1.64	**2007**	2009	
制冷技术	2009	1.26	**2009**	2010	
果蔬现状	2009	1.26	**2009**	2010	
保鲜贮藏	2009	1.26	**2009**	2010	
冷藏加工	2009	1.26	**2009**	2010	
冷藏运输	2010	0.98	**2010**	2012	
流通模式	2011	1.05	**2011**	2012	
策略	2011	1.05	**2011**	2012	
热带果蔬	2012	2.26	**2012**	2014	
海南省	2012	1.1	**2012**	2014	
包装工艺	2012	1.03	**2012**	2013	
农超对接	2013	1.11	**2013**	2014	
大湘西区	2014	1.06	**2014**	2015	
物流模式	2014	0.91	**2014**	2016	
物流	2012	1.76	**2015**	2016	
现状	2012	1.13	**2015**	2017	
信息化	2015	0.91	**2015**	2017	
优化	2016	1.52	**2016**	2017	
发展策略	2016	1.12	**2016**	2019	
生鲜果蔬	2013	1.41	**2017**	2020	
果蔬产业	2014	1.1	**2017**	2019	
冷链配送	2018	1.03	**2018**	2019	
蓄冷	2015	1.02	**2019**	2020	
果蔬产品	2013	1.87	**2020**	2023	
问题	2011	1.04	**2021**	2023	

Figure 4. Mutation mapping of keywords in fruit and vegetable cold chain research

5. Conclusion

This study systematically analyzes 209 domestic research articles on fruit and vegetable cold chain logistics published between 2007 and 2024 and indexed in the CNKI database, using the CiteSpace software. By constructing multidimensional knowledge maps such as author collaboration networks and keyword co-occurrence networks, the paper investigates the distribution of disciplinary knowledge structures, core author collaboration relationships, and the evolution of research themes. The main conclusions are as follows:

First, in terms of disciplinary distribution and literature sources, the majority (52.25%) of the research falls within the field of agricultural economics, followed by macroeconomic management and sustainable development, light industry and handicrafts, market research and information, and computer software. The research disciplines involved in fruit and vegetable cold chain logistics are relatively concentrated. Second, regarding core authorship, Li Yuping is identified as the most prolific author in the field, followed closely by Liang Weihong, Song Qidao, and Liu Yanqun. Within research teams, members maintain close collaborative relationships. However, cross-institutional cooperation among different academic teams remains relatively limited. Researchers from different institutions tend to work independently, showing a lack of collaborative awareness, and a core group of authors has yet to form.

Through keyword co-occurrence network clustering analysis, three major core research hotspots were identified in the field of fruit and vegetable cold chain logistics: cold chain logistics, fruits and vegetables, and fruit and vegetable logistics. These topics display a high degree of diversification. The clustering structure of keywords presented in this study is both significant and convincing, offering high practical research value. In terms of research trends, the keyword time-zone map reveals that since the emergence of the field, the average burst duration of keywords has been about two years. The research frontiers in domestic fruit and vegetable cold chain logistics have evolved over time. From the initial focus on "fruit and vegetable logistics" to recent interests in "cold chain distribution," "thermal energy storage," "fruit and vegetable products," and "issues," each stage has been marked by representative keywords. The burst time spans of keywords are continuous and show no evident gaps.

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