Journal of Engineering and Technology for Industrial Applications

ITEGAM-JETIA

Manaus, v.11 n.52, p. 112-125. March / April, 2025.

DOI: https://doi.org/10.5935/jetia.v11i52.1553

ISSN ONLINE: 2447-0228

RESEARCH ARTICLE OPEN ACCESS

POTENTIAL ADOPTION OF BLOCKCHAIN IN FOOD COLD SUPPLY CHAIN: A BIBLIOMETRIC STUDY AND FUTURE RESEARCH AGENDA

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ARTICLE INFO

Article History
Received: January 11, 2025
Revised: February 20, 2025
Accepted: March 15, 2025
Published: March 31, 2025

Keywords:
Blockchain,
Cold chain,
Digitalization,
Supply chain.

ABSTRACT

The food cold chain represents a crucial aspect of the highly sensitive food industry. Insufficient supervision can give rise to a range of adverse consequences, including conta mination, fraud, and food waste. In line with technological advancement, the implementation of cold chains is becoming increasingly integrated with digital solutions, with blockchain technology representing a notable example. However, some bibliometric analyses have not focused on the cold supply chain, limiting their scope to the supply chain in general. Consequently, further studies are required to gain a more comprehensive understanding of this complex and evolving field. The objective of this analysis is to provide a bibliometric examination of the potential implementation of blockchain technology in the context of food cold chains. This will facilitate the identification of the most recent developments, prevailing trends, and research gaps that require further investigation. This research uses the combination of PRISMA and bibliometric analysis method through Biblioshiny and Vosviewer using 201 scientific articles. The results show that this topic has an annual growth of 96.77%, and there are 3 interesting research clusters, namely 1) blockchain technology transformation in improving traceability and reducing food waste, 2) blockchain technology in improving the competitiveness of cold supply chain companies, and 3) blockchain that can improve food safety, leading to increased consumer confidence. Based on the major themes obtained and strategic diagram, there are various future research opportunities, including capability freight transportation, deteoritation, food contamination, storage and transportation, carbon emissions, competitiveness, delphi analysis, agricultural products and sales.

I. INTRODUCTION

Agricultural, livestock, and fishery commodities are products that are used to fulfill daily needs by humans. However, agricultural, livestock, and fishery commodities have characteristics that are sensitive, perishable, and have a relatively short shelf life [1]. Some commodities that are sensitive and perishable include milk, fish, meat, fruits, and vegetables, so they need to be distributed in a cold storage called a cold supply chain [2]. Cold supply chain is a supply chain management for commodities, especially agriculture, livestock, and fisheries, which have perishable properties by maintaining their temperature and humidity from the production process to reach consumers to remain in optimal conditions [3], [4]. The application of cold supply chains is a very good thing because the quality and selling value of these commodities can be well maintained from upstream to downstream [5]. The cold supply chain can also prevent the delivered agricultural commodities from becoming food waste and food loss.

However, in its implementation, there are still various problems faced in the cold supply chain process that occurs. The crucial problem encountered is the poor handling of the cold supply chain which causes a decrease in the quality of commodities during the process to become food waste. Referring to the United Nations Environment Programme, the cold supply chain is the highest contributor to food loss and food waste in the world with a total of 526 million metric tons of waste or 12% of the total food waste in

the world [6]. Poor handling of the cold supply chain is caused by the incompetence of workers, the occurrence of violations or fraud, and the lack of traceability in the cold supply chain implemented [7]–[9]. This certainly has a negative impact on the course of the supply chain and has the potential to cause chain damage [10]. Therefore, research on cold supply chain traceability is very important to be carried out, one of which is through blockchain technology.

Blockchain is decentralized data that involves a credentialed block chain that cannot be changed, deleted, or removed [11]. Blockchain is a system that is chronologically connected to one another [12]. This makes blockchain a technology that can anticipate the occurrence of fraud or falsification of data. In its implementation, blockchain has a very broad application in various fields including government [13], economy [14], health [15], [16], automotive [17], and supply chain [18]–[20]. Based on the characteristics and advantages of blockchain, it has great potential to be applied to the cold supply chain to increase consumer confidence, preserve consumer rights, and maintain quality [21].

Several studies applying blockchain to cold supply chains are currently being favored by researchers as it provides a positive multiplier effect. Research by Ma et al. applied blockchain technology to the cold supply chain to detect contamination in products distributed to consumers [22]. On the other hand, Ali et al. applied blockchain to trace the traceability of the halalness of an agricultural product [23]. Liu et al. also conducted similar research by utilizing blockchain to trace the freshness of an agricultural product from upstream to downstream [24].

The bibliometric study in this research will provide a new perspective on the application of blockchain in the cold supply chain and is different from previous studies that discuss digital supply chains in general.

This study will discuss in depth and specifically the implementation of blockchain in the cold supply chain starting from the latest developments, trends that are in vogue, to potential research opportunities so that the hope is that it can provide new knowledge for agro-industry players to academics. In more detail, this research aims to answer several research questions that are presented as follows:

Q1: What is the current state of research on the application of blockchain to the cold food supply chain?
Q2: What are the most prolific and influential articles, sources, and countries in research on blockchain applications in the cold food supply chain?
Q3: What are the favored research trends on the application of blockchain to the cold food supply chain?
Q4: What are the gaps and potential future research opportunities in the application of blockchain to the cold food supply chain?

II. THEORETICAL REFERENCE

II.1 BLOCKCHAIN

Blockchain can be described as a technology in the form of interconnected blocks of blocks containing transactions with a decentralized system and cannot be modified in the system [25]. In its implementation, blockchain has four main attributes, namely decentralized structure, cryptographic system, consensus mechanism, and smart contract [26].

A decentralized system means that all parties involved have equal access and visibility of data, a cryptographic system is a random code that records or tracks a chain of data over time through a block that contains a hash and cannot be modified, a consensus mechanism is the principle of retrieving some important information from cryptographic data, while a smart contract is an agreement feature in a transaction that can be recorded in data [27].

In its application in the supply chain system, blockchain has great potential to be applied because there are several factors that support it. According to Wang et al., these supporting factors include the creation of a supply chain based on full trust, simplifying the complexity of a more visible supply chain, product security and authenticity, and finally increasing the fight against fraud and fraud [28].

Some of the broad uses of blockchain include digitizing transactions, improving data security, and implementing smart contracts in the process. Blockchain is also often combined with other technologies to optimize its performance such as sensors and the internet of things [29], [30]

II.2 FOOD COLD SUPPLY CHAIN

The cold supply chain of food commodities is the process of transforming raw products into semi-finished or finished materials but at low temperatures [31]. Cold supply chains aim to maintain the quality of food products during the production, storage or shipping process while reducing the food waste created [32], [33]. In addition, the cold supply chain of food for some time also serves to prevent food products from contamination that threatens food safety [4].

In its implementation, cold supply chains in the food sector often use several modes of transportation such as refrigerated trucks, refrigerated trains, or refrigerated ships [34]. Based on the literature review, food cold supply chains have the main disadvantage of difficult monitoring of temperature, humidity, and traceability. Poor monitoring will lead to various frauds or cooling temperature errors that result in a decrease in the quality of food products and create food waste.

The food cold supply chain is the largest contributor to food waste in the world with a proportion of 20%. It is necessary to combine the cold supply chain with technologies such as the internet of things, machine learning, artificial intelligence, deep learning, RFID, and blockchain to facilitate monitoring activities carried out [35], [36].

III. MATERIALS AND METHODS

This research uses the preferred reporting items systematic review and meta analysis (PRISMA) and combines it with bibliometric analysis to find out the research trends that occur in a sector so that it can be known which research is often done and which research gets less attention.

The combination of PRISMA systematic literature review and bibliometric analysis is often used because it successfully helps researchers find research gaps and potential topics [37], [38]. In the analysis conducted, several software tools were used, including Vosviewer and Biblioshiny through R. Vosviewer and Biblioshiny are useful software for summarizing previous research both qualitatively and quantitatively. In addition, the software helps in the data visualization process so that the data collected is easier to understand.

There are several steps that need to be applied in conducting combination PRISMA method and bibliometric analysis, including conducting literature studies, identification and screening data collection (open acces and english articles), screening data selection through eligibility literature, and conducting bibliometric analysis (qualitative synthesis, quantitative synthesis, research gap,

and further research agenda). As for the details regarding the research framework using PRISMA in this study it is presented in Figure 1.

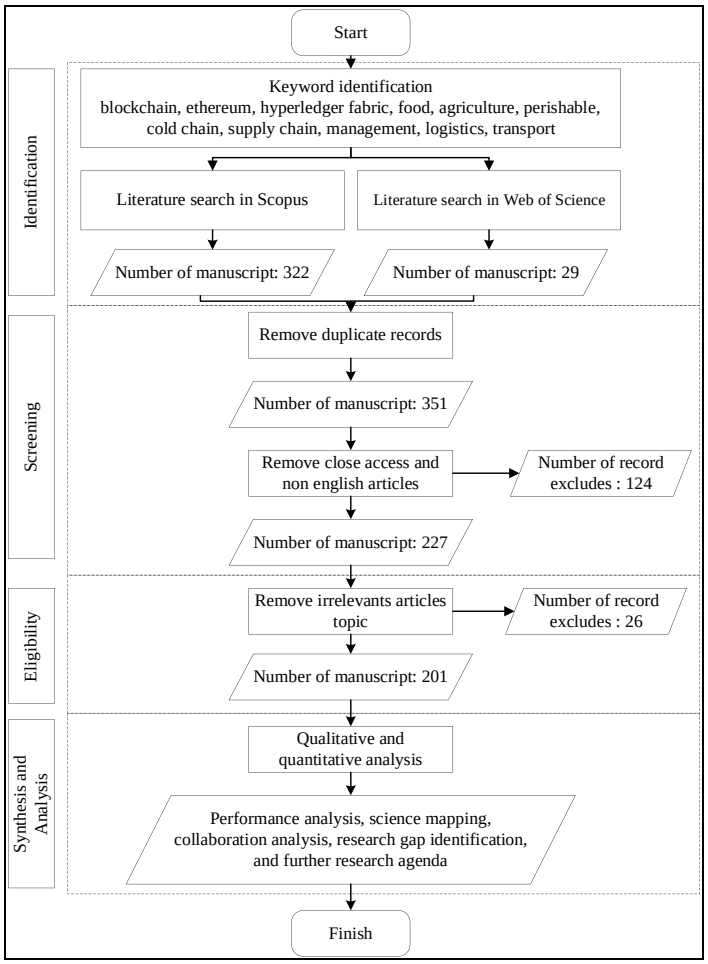

Figure 1: PRISMA research framework.
Source: Authors (2025).

In the literature study stage, a literature search related to blockchain and cold supply chain was conducted through credible international sources, namely Scopus. In the identification and screening data collection, several rules were used in accordance with the criteria of the topic being analyzed. Some of the criteria set are research publications using English, published in 2019-2024, publications in the form of experimental articles, publication must open acces, and using several keywords combination to obtain accurate analysis using logic gate including “blockchain”, “ethereum”, “hyperledger fabric”, “food”, “agriculture”, “perishable”, “cold chain”, “supply chain”, “management”, “logistics”, “transport”. The results of the literature search through scientific databases that have been carried out managed to get 351 scientific articles related to the application of blockchain technology in the cold supply chain.

The data that has been collected is then screening data to eliminate close access literature and do not meet the criteria so that 201 articles are ready to be analyzed. Bibliometric analysis will provide a comprehensive, coherent, and broad explanation of the application of blockchain and cold supply chains. In more detail, bibliometric analysis will provide information on the distribution of research fields, the distribution of researchers, and the productivity of a research field [39].

This is certainly useful for finding the latest trends and providing knowledge for the industry to develop. In this bibliometric analysis, the results will be presented quantitatively, qualitatively, and visually because there are several things that will be analyzed, including research trend analysis, research distribution, keywords, and research gaps.

IV. RESULTS AND DISCUSSIONS

IV.1 PERFORMANCE ANALYSIS

Research performance analysis is the first thing that is done to identify developments and provide an overview of blockchain research in the cold supply chain. The topic of blockchain research on the cold supply chain is an interesting new field and is experiencing very rapid development. In the 2019-2024 period there were 201 research publications produced by 639 researchers and obtained from 113 sources publisher.

Blockchain research on the cold supply chain also has a very good impact and development with an average citation of 22.51 per document and an annual growth rate of 96.77%. This shows that blockchain research on the cold supply chain is something interesting with significant growth year on year, but further identification is needed to find out the current trends and gaps that need to be filled for the future. The summary of research performance in the field of blockchain in the cold supply chain is presented in Table 1 and Figure 2.

Table 1: Descriptive analysis of research performance

Component	Description	Result
Publication	Total number of research publications	201
Publication Period	Active period of research publications	2019-2024
Productivity	Publication/period	33,5
Source	Total number of journal sources in related fields	113
Total Citation	Total number of citations in related fields	4.525
Average Citations per Document	Total citation/publication	22,51
Average Citations per Year	Total citation/period	754
Total Author	Total research authors contributing to the field	639
Single Author Publication	Individual research publications	6
Group Author Publication	Group research publications	195
Collaboration Index	Total author/publication	3,18
Collaboration Coefficiency	(1- (publication /total author)	0,69

Source: Authors (2025)

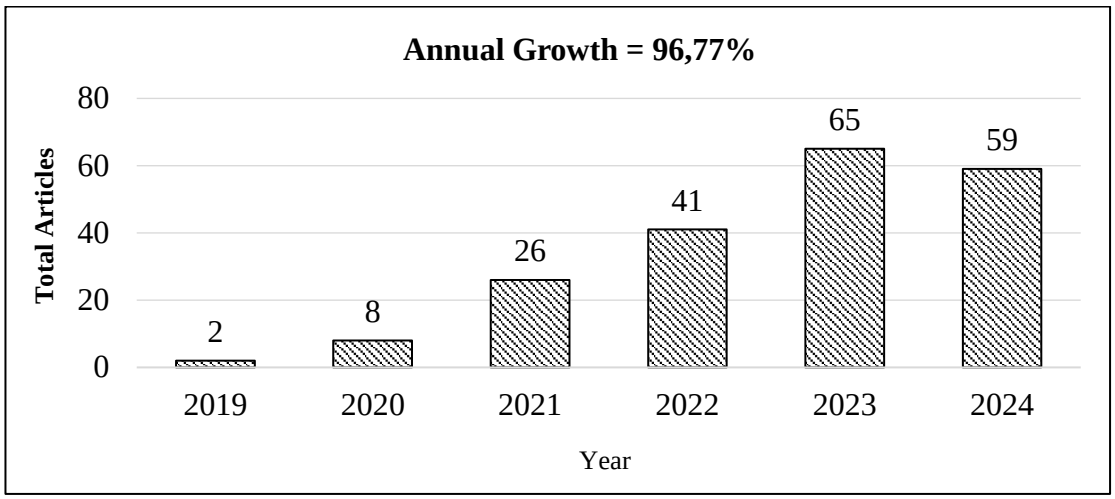

Figure 2: Year on year research trends
Source: Authors (2025)

IV.2 SCIENCE MAPPING

Research mapping is a section that will explain the distribution of research on the application of blockchain in the cold supply chain in a structured manner by analyzing several things such as the distribution of researchers, the distribution of sources, the distribution of countries, and the distribution of keywords. Some of these things will be analyzed for their impact through the number of publications and citations.

Citation is often used as an indicator in measuring the quality and impact of a study because it shows the usefulness and relationship of one study with another [40]. In more detail, citations are divided into two types in bibliometric analysis, namely global citation and local citation. Global citation is defined as citations obtained from various studies on the internet, while local citation is a citation obtained from 201 studies involved in bibliometric analysis.

Based on the analysis conducted on total global citations, the research on the application of blockchain in the cold supply chain with the title of "A Systematic Literature Review on Machine Learning Applications for Sustainable Agriculture Supply Chain Performance" by Sharma et al. [41] received the highest total global citations with 427 global citations. Followed by the research of Rejeb et al. [42] titled "Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management" with 280 total global citations. Meanwhile, the research of Tsang et al. [43] titled "Blockchain-Driven IoT for Food Traceability With an Integrated Consensus Mechanism" received the third highest global citations with 216 total global citations.

In total local citations, the study by Tsang et al. [43] titled "Blockchain-Driven IoT for Food Traceability With an Integrated Consensus Mechanism" received the highest total local citations with 15 total local citations. Followed by the research of Aamer et al. [44] with the title "The Internet of Things in The Food Supply Chain: Adoption Challenges," which received 5 total local citations. Meanwhile, the research of Masudin et al. [45] titled "The

Effect of Traceability System and Managerial Initiative on Indonesian Food Cold Chain Performance: A Covid-19 Pandemic Perspective" is in third place with 4 total local citations. The complete analysis of the top 10 scientific articles on blockchain implementation in the cold supply chain based on global and local citations is presented in Table 2 below.

Table 2: Top 10 best scientific articles based on global and local citations.

Articles	TGC	Articles	TLC
Sharma, 2020, Compt Ops Res	427	Tsang, 2019, IEEE	15
Rejeb, 2019, Future Internet	280	Aamer, 2021, Benchmarking	5
Tsang, 2019, IEEE	216	Masudin, 2021, Global J Flex Sys Man	4
Ali, 2021, Tech Forecast Soc Change	153	Kumar, 2020, Benchmarking	4
Golpîra, 2021, J Ind Infor Integr	120	Kayikci, Int J Log Manag	4
Ali, 2022, J Bus Res	118	Feng, 2020, IEEE	3
Wu, 2023, Int J Prod Res	116	Afreen, 2021, IEEE	2
Liu, 2021, Trans Res Part E Log Trans Rev	88	Kumar, 2022, Ops Manag Res	2
Kumar, 2020, Benchmarking	86	Kashyap, 2023, Benchmarking	1
Mishra, 2022, Int J Logist Manag	83	Gupta, 2024, Benchmarking	1

Note: TGC = Total Global Citation; TLC = Total Local Citation
Source: Authors (2025).

Further analysis to determine the impact of researchers also included co-citation analysis. In simple terms, co-citation can be defined as a shared citation in a third article from other researchers [46]. In the co-citation analysis, the researchers were divided into two clusters based on the similarity of research topics, namely cluster 1 with red color and cluster 2 with green color. In cluster 1, Zhang X is the most dominant researcher, followed by Zhang J, Wang X, Wang Y, Liu Y, and Ruiz-Garcia L. In cluster 1, the topics discussed are directed towards the application of blockchain that can impact to sustainable aspects especially about the environment, such as the reduction of carbon emissions and the reduction of food waste produced in food cold chain.

Meanwhile, in cluster 2 with the green color, Gunasekaran A is the most influential researcher, followed by Mangla SK, Kumar A, Sarkis J, and Govindan K. In cluster 2, the topics discussed revolve around the adoption of blockchain technology in food cold

supply chain and its impact from others sustainable perspective especially on economic and social aspects such as cost minimization, long-term investment, and social welfare. As for the visual representation of the co-citation in this study, it is detail presented in Figure 3.

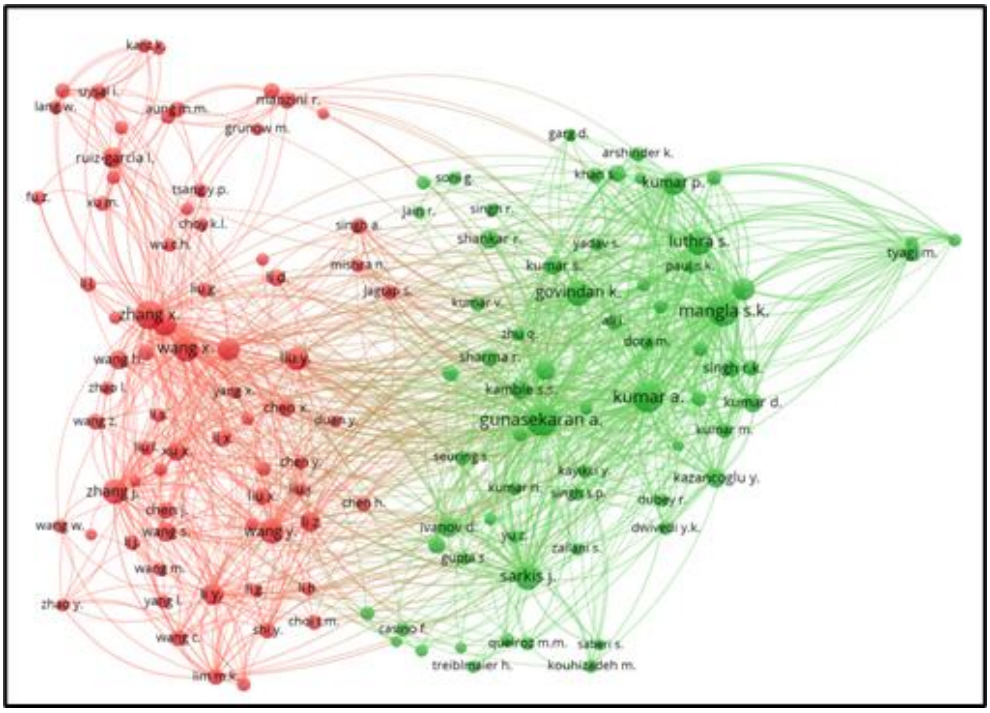

Figure 3: Cocitation analysis.
Source: Authors (2025).

This research also analyzes the sources that publish studies on the application of blockchain in cold supply chains. Based on the collected data, there are 113 sources that will be analyzed for their impact by measuring several indicators, including H-index, G-index, total citations, and total articles. The H-index is an indicator used to measure the impact of a source based on the total number of articles and total citations it has. Meanwhile, the G-index is an indicator that not only measures the total number of articles and total citations but G-indeks also measures about the distribution of citations to other research articles, making it considered more accurate in measuring impact.

Analysis of publication sources is conducted to identify potential sources that can be targeted for publishing articles on the application of blockchain in cold supply chains. Based on publication sources with the topic of blockchain application in cold supply chains. If viewed from the H-index, the Journal of Cleaner Production (6), IEEE Access (6), and Sustainability (5) are the best. If viewed from the G-index, Sustainability (11), Journal of Cleaner Production (9), and IEEE Access (8) are the best. If viewed from total citations, IEEE Access (445), Benchmarking (213), and Computers and Industrial Engineering (189) are the highest. Meanwhile, if viewed from total publications, Sustainability (11), Journal of Cleaner Production (9), and IEEE Access (8) are the most compared to other publication sources. The top 10 publication sources based on the various indicators mentioned above are presented in Table 3.

Table 3: Top 10 best publication sources based on index.

Rank	Sources	H-Index	G-Index	Cite	Articles
1	Sustainability	5	11	160	11
2	Journal of Cleaner Production	6	9	175	9
3	IEEE Access	6	8	445	8
4	Benchmarking	5	6	213	6
5	Annals of Operations Research	4	6	175	6
6	Environment, Development and Sustainability	3	5	68	5
7	Computers and Industrial Engineering	4	4	189	4
8	Foods	4	4	122	4
9	Expert Systems with Applications	3	4	61	4
10	Operations Management Research	2	4	17	4

Source: Authors (2025).

The next analysis conducted is a distribution analysis to determine the spread of blockchain research in the cold supply chain. In total, there are 33 countries that have conducted research on the application of blockchain in cold supply chains, spread across the world. The continents that dominate this field are Asia and Europe. This can happen because both continents that is Asia and Europe continent have concerns to cold supply chain of food because its have correlation with economic.

Based on the analysis conducted, if we look at the number of publications, it was found that China is the most productive country in producing research with 51 scientific articles, followed by India with 44 scientific articles, and Italy with 12 scientific articles.

Meanwhile, if we look at the number of citations, China ranks highest with 812 citations, followed by India in second place with 745 citations, and the United Kingdom in third place with 664 citations. China has become the dominant country in blockchain application research in the cold supply chain because China is a leader in blockchain research across various fields, including food and cold supply chains [12]. The 10 most countries based on total publications and the most impactful based on citations are presented in Figures 4 and 5.

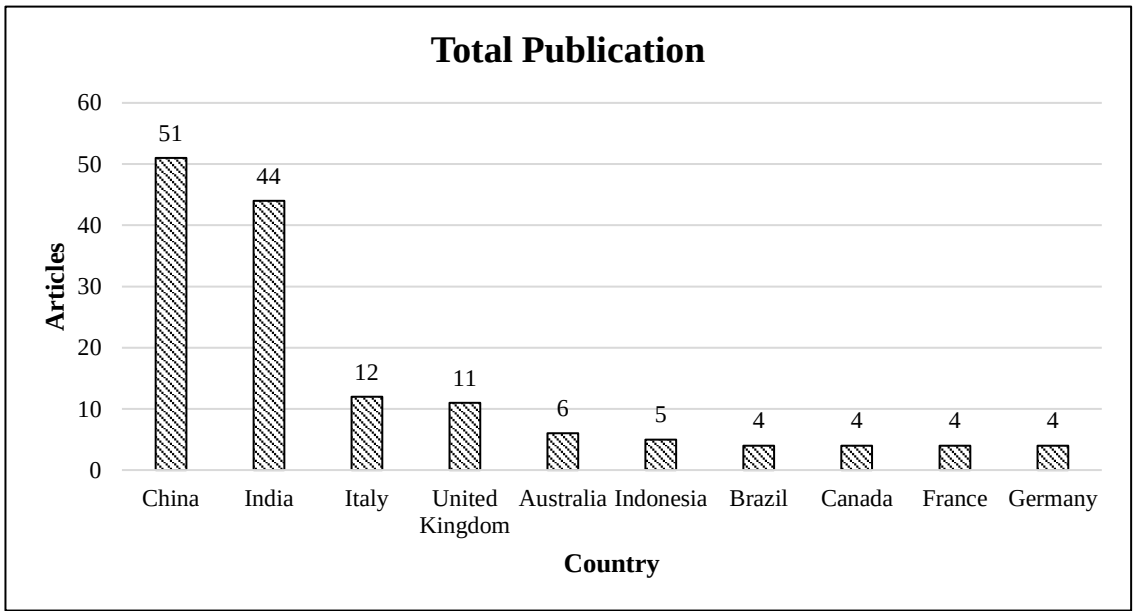

Figure 4: Distribution of the 10 most productive countries based on publications.
Source: Authors (2025).

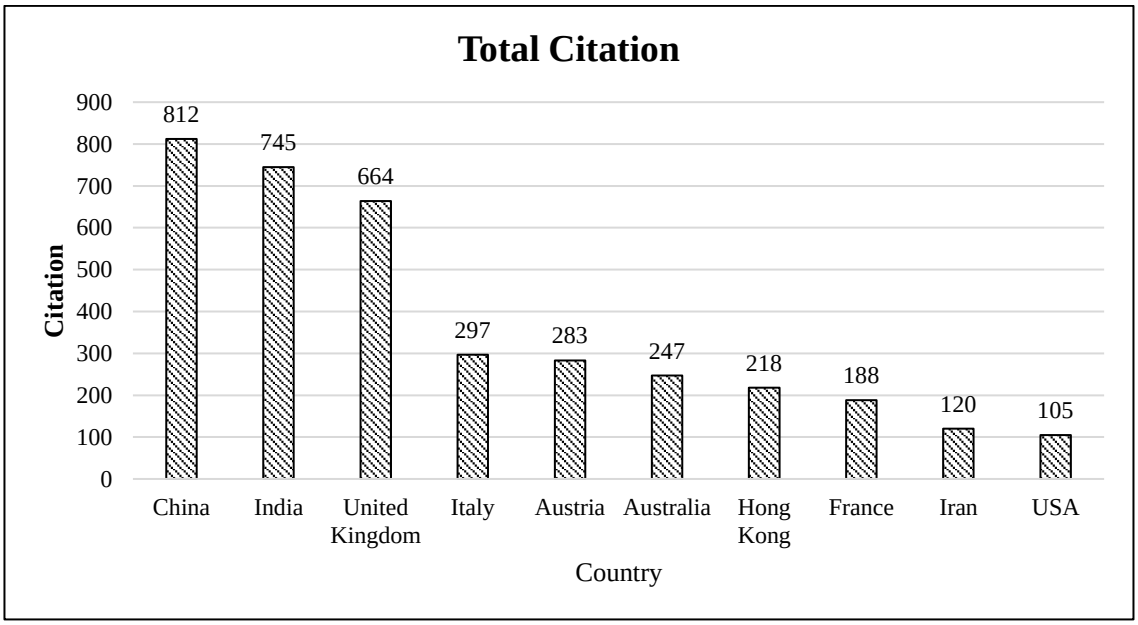

Figure 5: Distribution of the 10 most impactful countries based on total citations.
Source: Authors (2025).

Keyword analysis was also conducted in this study because it serves the function of understanding the relationships that occur between one keyword and another. Keyword analysis was conducted using the Vosviewer software. Through keyword analysis, research gaps and potential future research can also be identified. The selected keywords must appear 3 times in the chosen scientific articles to obtain accurate and interrelated keywords. Based on the keyword analysis conducted, the results showed that 39% of the keywords are in cluster 1, 37% of the keywords are in cluster 2, and 24% are in cluster 3.

The distribution of keywords in the bibliometric analysis conducted shows something interesting because several frequently keywords were identified in this part. Some of the most frequently appearing keywords include "supply chains" appearing 57 times, "blockchain" appearing 51 times, "food supply" appearing 48 times, "internet of things" appearing 28 times, "decision making" appearing 26 times, "sustainability" appearing 25 times, "food safety" appearing 21 times, "traceability" appearing 18 times, "food waste" appearing 12 times, and "logistics" appearing 12 times.

Based on word analysis, it can be concluded that blockchain is one of the potential technologies applied in cold supply chain logistics to support the creation of a sustainable cold supply chain. Some benefits that can be obtained from the application of blockchain in the cold supply chain include facilitating decision-

making, enhancing food safety, improving product traceability, increasing consumer trust, boosting product sales, and even in some cases, being implemented to minimize food waste. for more detailed visual representation of the keyword, it is presented in Figure 6.

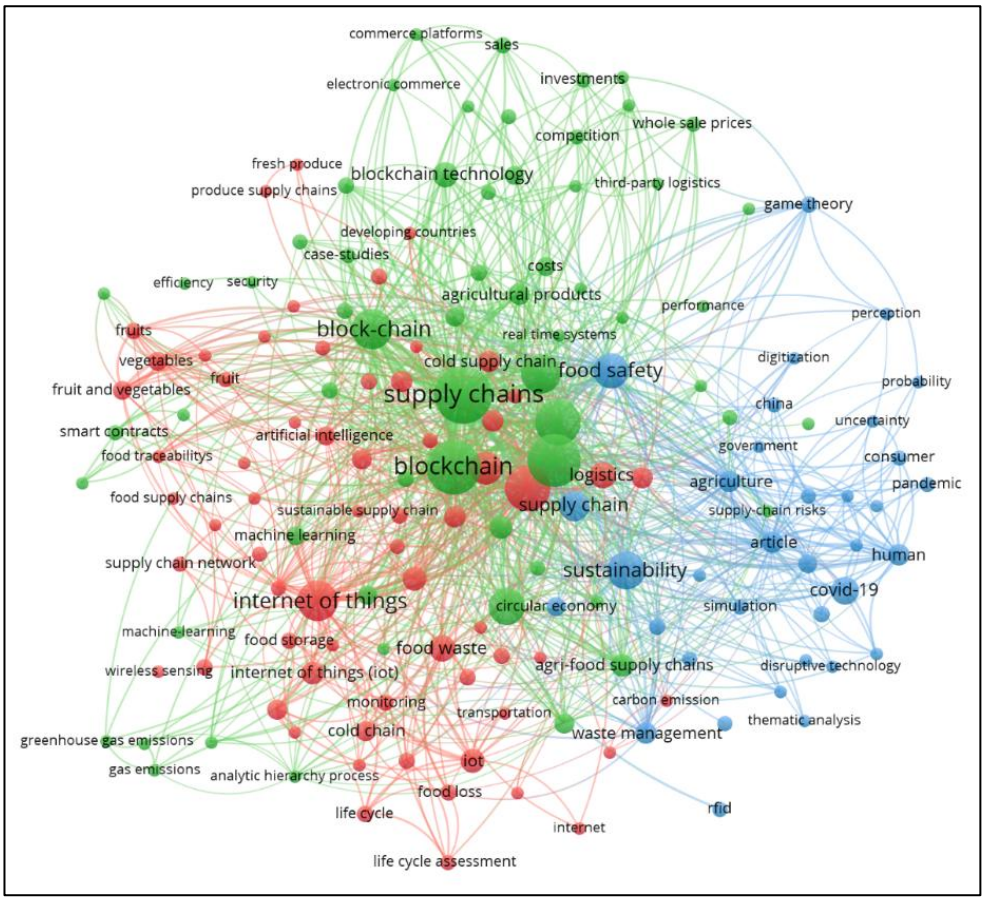

Figure 6: Keyword analysis and its development.
Source: Authors (2025).

Based on the results obtained above, it can be concluded that the research topic on the application of blockchain in the cold supply chain currently aims to enhance the sustainability of the cold supply chain by optimizing sustainability aspects such as the environment (minimizing food waste and greenhouse gas emissions), economy (increasing competitiveness and sales), and social factors. (minimize uncertainty and increase food safety for consumers). In the keyword analysis, the analysis was conducted by dividing it into three major thematic clusters. Cluster 1, marked in red, discusses the internal agro-industry, specifically the use of blockchain technology transformation in improving traceability and reducing food waste. Cluster 2, marked in green, discusses the impact of blockchain technology on enhancing the competitiveness level of cold supply chain companies. Meanwhile, in cluster 3 with the blue color, it discusses in detail the presence of blockchain that can enhance food safety, thereby impacting the increase in consumer trust.

IV.3 COLLABORATION ANALYSIS

In this study, the collaboration between researchers and between countries will be analyzed to understand the latest developments in blockchain research in the cold supply chain. The collaboration analysis was conducted with the condition that the document must be written by at least 2 researchers in 1 document. Based on the analysis results, it was found that 97.01% of the research was conducted collaboratively by the researchers, while the remaining 2.99% was done individually. Based on collaboration and their relationships with each other, the researchers were divided into 4 clusters. The cluster division was based on the collaborations that had been conducted, the documents produced, and the similarity of themes discussed together with other researchers. Cluster 1 in red consists of 9 researchers, cluster 2 in green consists of 7 researchers, cluster 3 in blue consists of 7 researchers, and cluster 4 in yellow consists of 3 researchers. In cluster 1 with the red color, there is Mangla SK as the researcher who has collaborated the most and produced research with 9 collaborations and 5 published documents. In cluster 2 with the green color, there is Kumar A with 12 collaborations and 9 published documents. In cluster 3 with the blue color, there is Kazancoglu Y with 7 collaborations and 3 published documents. Meanwhile, in cluster 4 with the yellow color, there is Singh RK with 3 collaborations and 3 published documents.

The analysis results show that researchers are still mapped based on their countries of origin, and international collaboration has not yet been realized effectively. To gain a more detailed understanding of the collaboration conducted by the researchers, a visualization will be presented in Figure 7. When viewed by country, the majority of researchers who dominate the collaboration are fairly evenly distributed across several continents such as Asia, Europe, and America. To gain further insight into this matter, it will be discussed in detail in the next section.

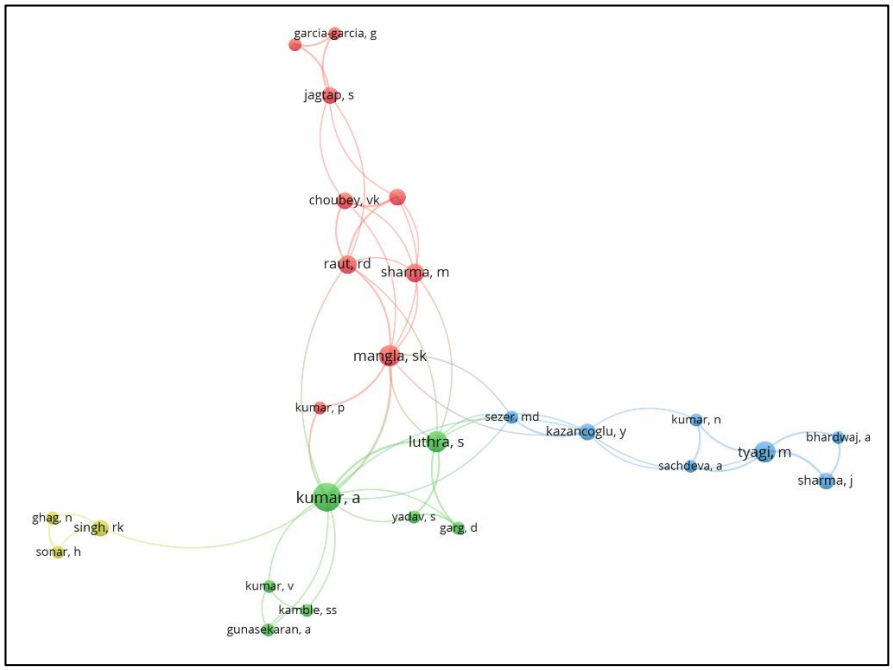

Figure 7. Collaboration among researchers.
Source: Authors (2025).

After understanding the spread of collaboration among researchers, the next step will be to analyze the spread of collaboration among the countries involved. Interesting findings were obtained in this research, as there are several agrarian countries (China, India, Indonesia) and non-agrarian countries (United Kingdom, Germany, Italy) that significantly dominate the blockchain research in cold supply chains. In the analysis of the spread of collaboration between countries, clustering was also performed, dividing them into 3 clusters. In terms of distribution, cluster 1 consists of 16 countries, cluster 2 consists of 16 countries, and cluster 3 consists of 5 countries.

In cluster 1, marked in red, the United Kingdom is the most dominant country in research on blockchain in cold supply chains, having successfully collaborated with 26 other countries and produced 32 publication documents. In cluster 2, marked in green, India is more dominant than China, with 19 international collaborations and 61 publication documents produced. Meanwhile, in cluster 3, Finland slightly outperformed Indonesia with 7 international collaborations and 3 published documents. The United Kingdom and India have become the largest because both countries are technology nations that easily adapt to new technologies and implement them in the food sector, which is considered crucial [47]. The collaboration between countries certainly signifies something positive because the issues of blockchain and cold supply chains have become crucial topics to discuss together. The mapping of international collaboration is presented in Figure 8.

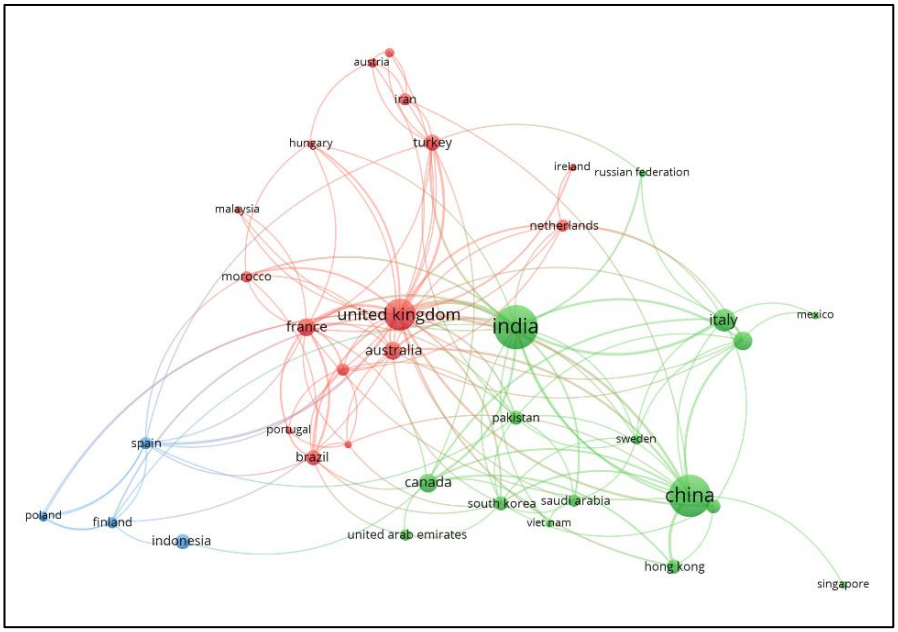

Figure 8: Collaboration between countries.
Source: Authors (2025).

IV.4 REPORT FINDING IMPLEMENTATION BLOCKCHAIN IN COLD SUPPLY CHAIN

The application of blockchain in the cold food supply chain has become a recent trend with its extensive implementation and positive impact on the cold supply chain industry. Based on the conducted study, it was found that the majority of research discusses conceptual models, influencing factors, and their application in the cold supply chain-based food industry. To provide a clearer picture, an extraction was conducted from several literatures available in the database that focuses on the contribution of blockchain in the cold supply chain-based food industry. As for more detailed information on this matter, it is presented in Table 3.

Table 3: Contribution of literature to application of blockchain in cold supply chains.

No.	Authors	Contribution	Type
1	Munir et al. [48]	Provided recommendations on how to adopt blockchain in the cold supply chain from an environmental, economic, social, perspective.	Journal
2	Li et al. [49]	Created intelligent distribution system based on blockchain to establish operations that are green logistics.	Journal
3	Feng et al. [50]	Created multisensor blockchain-based monitoring system for frozen shellfish quality.	Journal
4	Zhang et al. [51]	Created recording system from upstream to downstream for frozen aquatic products using a combination of blockchain and internet of things.	Journal
5	Gao & Li [52]	Created a high quality data for coordination and pricing system in the cold supply chain to minimize miscoordination using blockchain and neural networks.	Journal
6	Xue & Li [53]	Created a multichain blockchain system for fruit and vegetable with more efficient queries.	Journal
7	Zuo et al. [54]	Created a decentralized system combined with internet of things and neural networks for optimizing the delivery routes of cold agricultural products.	Journal
8	Wu et al. [55]	Analyzed the adoption of blockchain in the cold chain of fresh products and comparing it with several scenarios.	Journal
9	Tsang et al. [43]	Created a more practical food product traceability by combining fuzzy logic, internet of things, and blockchain.	Journal
10	Khanna et al [56]	Created a blockchain based traceability system specifically for the dairy agro-industry.	Journal
11	Patidar et al. [57]	Identified critical factors and finding that blockchain can enhance the fresh supply chain.	Journal
12	Jo et al. [58]	Created a blockchain system for the cold supply chain of meat commodities and measuring environmental impact.	Journal
13	Ma et al. [22]	Identified strategies to anticipate contamination in fresh or chilled food products by utilizing blockchain.	Journal
14	Ahmad et al. [59]	Analyzed the current needs and challenges in the implementation of blockchain in the food industry.	Journal
15	Nayal et al. [60]	Identified mediating factors that influence the adoption of blockchain in the cold food supply chain.	Journal
16	Morales et al. [61]	Analyzed consumer trust in perishable products through a blockchain system.	Journal
17	Ali et al. [23]	Formulate a blockchain framework for halal-based cold supply chains to enhance supply chain integrity.	Journal
18	Wang et al. [62]	Designing a blockchain framework combined with radio frequency identification in food cold chain.	Journal
19	Majdalawieh et al. [63]	Created a combination system blockchain and internet of things in the poultry agroindustry.	Journal
20	Bai et al. [64]	Designing a blockchain system for the cold supply chain of fresh agricultural products and analyzing the tripartite behavioral strategy.	Journal

Source: Authors (2025).

Based on the above contribution study, researchers agree that the presence of blockchain in the cold supply chain can provide a good multiplier effect and can be applied in various sectors and under various conditions. In its implementation, blockchain can also be combined with various other synergistic technologies such as the Internet of Things, digital twin, and radio frequency identification. The presence of blockchain can facilitate agro-industries with cold supply chains to identify discrepancies, make quick decisions, streamline several operations, and easily determine the root of problems. In the long term, the adoption of blockchain technology can certainly provide various benefits, especially in increasing consumer trust and making the agro-

industry more adaptive. This illustrates that blockchain has a very wide potential to be implemented in to optimize the food cold chain

IV.5 TREND ANALYSIS AND IDENTIFIED POTENTIAL FUTURE RESEARCH

A trend analysis and an investigation of prospective topics will furnish readers with new knowledge, thereby facilitating further research in the domain of blockchain applications in cold supply chains. The trend analysis indicates that the field of blockchain in cold supply chains is undergoing rapid development with a multitude of applications. This is substantiated by the annual growth in research, which has consistently increased year on year. The advancement can be attributed to blockchain becoming a transformative technology that generates a positive multiplier effect, particularly in the context of cold supply chains.

In examining the evolution of blockchain applications in the context of cold supply chains, a strategic diagram is employed to discern current trends, dominant themes, unique themes, emerging themes, and fundamental themes. As evidenced by the trend diagram, several topics have recently emerged as subjects of discussion in the context of blockchain applications within the cold supply chain. These include concerns related to contamination of cold supply chain products, the minimization of carbon emissions, the assurance of cold supply chain product freshness, and increased cold chain product sales.

The issue of contamination in cold supply chain products has become a matter of great urgency, as it bears directly on the safety of the products in question, particularly foodstuffs. A number of studies have employed blockchain technology to identify contamination in livestock products and other foodstuffs within the cold supply chain [65]. The utilisation of blockchain within the context of the cold food supply chain offers a number of advantages, including the expedient detection of contamination, the identification of contamination sources, the determination of contamination timing, and the streamlining of product recalls from the market [22], [56], [66]–[68].

The second point pertains to the topic of carbon minimization within the context of blockchain. Given the relative scarcity of research on this subject, it represents an intriguing topic for further investigation. The research by Chen & Yin [69] is noteworthy for its proposal of a blockchain-based supply chain model for fresh food items such as dairy products. Shakhbulatov et al. [70] also developed a carbon tracking system for the distribution of cold chain food products, given that the cold chain is regarded as a significant contributor to carbon emissions. The integration of blockchain technology in carbon minimization can facilitate the assessment and decision-making processes for subsequent stages by stakeholders [7].

In addition to being able to identify contamination and carbon, blockchain in the cold supply chain can indirectly maintain product freshness. This can happen because with a transparent and trustworthy system, all actors involved in the cold supply chain from upstream to downstream will strive to maintain the freshness of the product [49]. Another advantage that consumers will gain is that they will be much more interested and have a much higher inclination to buy if there is a system that shows the transparency of product freshness [71].

From an economic standpoint, the implementation of blockchain technology in cold supply chain management is poised to bolster sales of associated products implemented blockchain technology and subsequently measured the sales levels of the product, demonstrating a notable increase due to the emergence of consumer trust [72]. Conversely, Chen et al. [73] assessed consumer preferences in the Jiangxi province of China. This study evaluated comparable fresh products and contrasted consumers' willingness to pay between fresh products that utilize blockchain technology, fresh products that employ conventional systems, fresh products with rigorous credit monitoring, and fresh products with international certification. The findings indicate that consumers are willing to pay a premium for fresh products that implement blockchain technology due to their perceived assurance of security for buyers. Detailed the trend diagram presented in Figure 9.

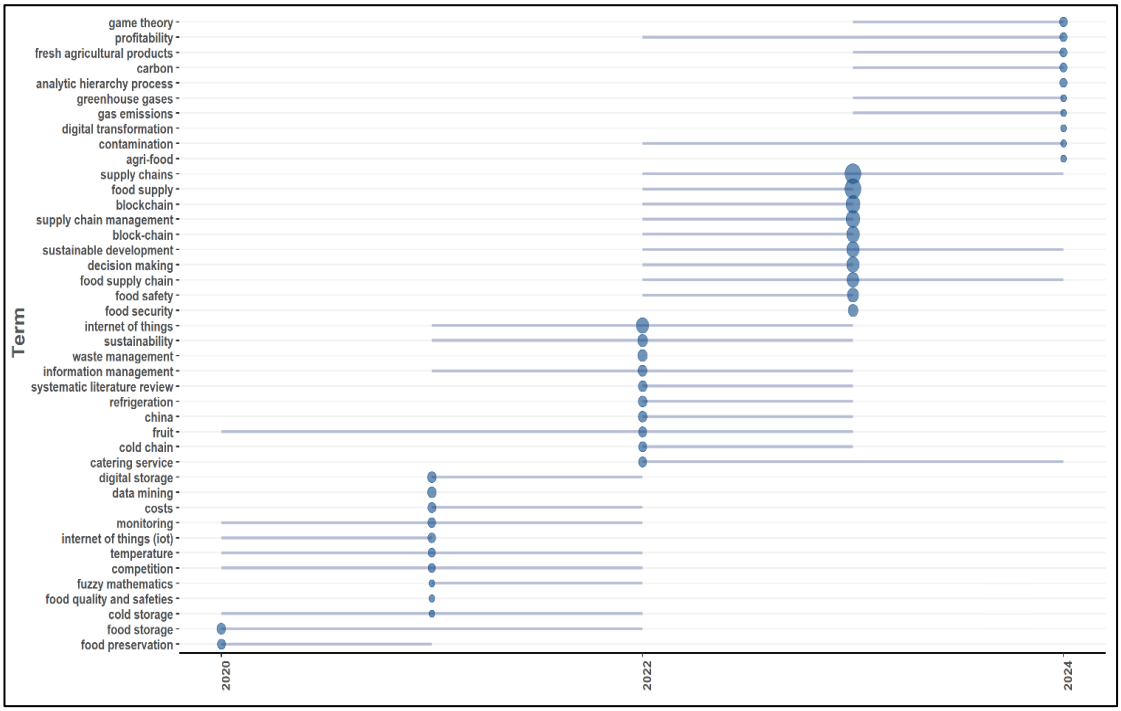

Figure 9: Research trend diagram.
Source: Authors (2025).

After conducting a research trend analysis, the next step is to analyze potential topics on the application of blockchain in the cold supply chain. Potential topic analysis was conducted using a strategic diagram and dividing potential topics into four quadrants. Topics in quadrant 1 are those that act as drivers due to their large number and high influence. Quadrant 2 is filled with highly developed topics that are specific and isolated. Quadrant 3 contains topics that are either developing or declining with still low numbers and centrality. Quadrant 4 is filled with topics that underpin blockchain research in the cold supply chain [74], [75].

The results of the strategic diagram correlate with the results of the previous research trend diagram. In quadrant 1, there are several keywords including sustainability, commerce, vegetables, and fruits. In quadrant 2, there are keywords such as capability freight transportation, deterioration, and food contamination. In quadrant 3, it consists of storage and transportation, carbon emissions, competitiveness, delphi analysis, agricultural products, and sales. Meanwhile, quadrant 4, which serves as the basis for research, consists of supply chains, blockchain, digital storage, and the internet of things. Based on the results obtained above, quadrants 2 and 3 can be an interesting focus for further research development considering they still have relatively low density, thus offering significant potential for further exploration. Regarding the strategic diagram on the topic of blockchain in the cold supply chain, it is presented in Figure 10.

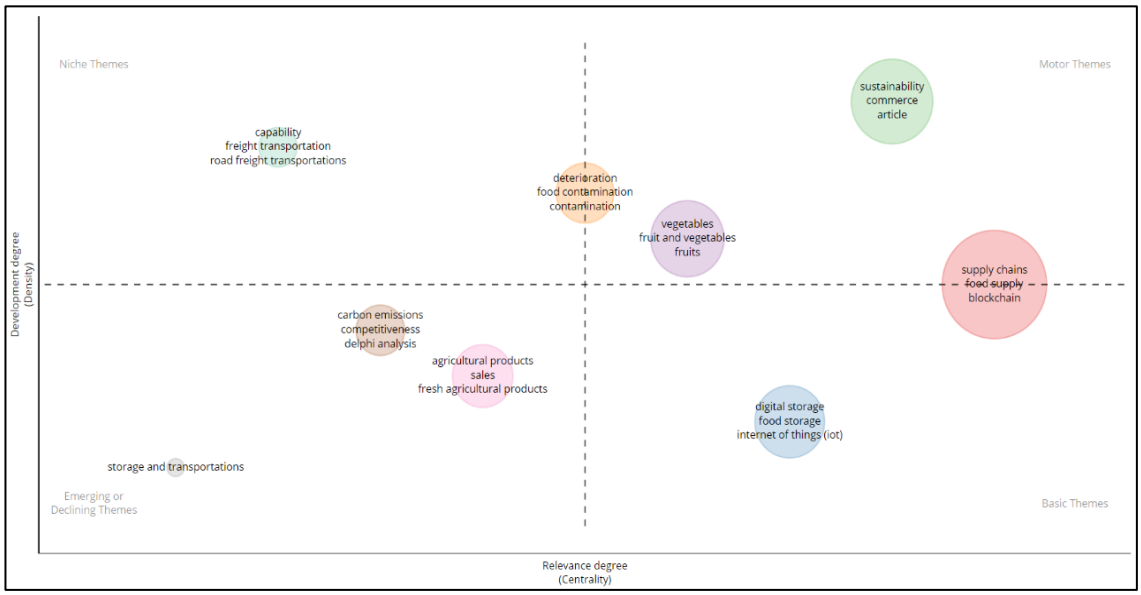

Figure 10: Identify potential future research with a strategic diagram.
Source: Authors (2025).

V. CONCLUSIONS

Based on the systematic literature review and bibliometric analysis that has been conducted, several conclusions have been drawn, including the following:

1. Research on the application of blockchain in the cold food supply chain has been rapidly developing year by year, evidenced by an annual growth rate of 96.77%.
2. The productivity and impact of blockchain research in the cold food supply chain are measured by articles, sources, and countries. From the perspective of article productivity and impact, the article titled "A Systematic Literature Review on Machine Learning Applications for Sustainable Agriculture Supply Chain Performance" ranks highest in total global citations. Meanwhile, the article titled "Blockchain-Driven IOT for Food Traceability With an Integrated Consensus Mechanism" ranks highest in total local citations. In terms of source productivity and impact, Sustainability, Journal of Cleaner Production, and IEEE Access are the best. Whereas, when viewed from the perspective of productivity and the impact of countries, China, India, and Italy rank highest in total publications, while in terms of total citations, China, India, and the United Kingdom rank highest.
3. The trend analysis results indicate that there are several interesting topics to discuss further regarding blockchain in food cold chain, namely contamination of cold supply chain products, minimization of carbon emissions, assurance of freshness of cold supply chain products, and increased sales.
4. The results of the gap analysis using strategic diagram indicate that there are several topics filling quadrants 2 and 3, namely capability freight transportation, deterioration, food contamination, storage and transportation, carbon emissions, competitiveness, delphi analysis, agricultural products, and sales.

VI. AUTHOR'S CONTRIBUTION

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VII. ACKNOWLEDGMENTS

The authors are grateful for the scholarship support provided by the Ministry of Education, Culture, Research and Technology of Indonesia and IPB University. The authors would also like to thank Prof. Marimin, M.Sc. for his guidance and direction in carrying out the research.

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