International Journal of Logistics Research and Applications
A Leading Journal of Supply Chain Management

ISSN: 1367-5567 (Print) 1469-848X (Online) Journal homepage: www.tandfonline.com/journals/cjol20

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To cite this article: Abadi Gugusa, Dante Benjamin Matellini, Ian Jenkinson, Chia-Hsun Chang & Rob Darlington (01 Apr 2026): A systematic review of cold chain logistics performance for fresh agricultural products: trends, gaps, and conceptual framework development, International Journal of Logistics Research and Applications, DOI: 10.1080/13675567.2026.2651844

To link to this article: https://doi.org/10.1080/13675567.2026.2651844

Published online: 01 Apr 2026.

INTERNATIONAL JOURNAL OF LOGISTICS: RESEARCH AND APPLICATIONS
https://doi.org/10.1080/13675567.2026.2651844

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A systematic review of cold chain logistics performance for fresh agricultural products: trends, gaps, and conceptual framework development

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ABSTRACT
The performance of Cold Chain Logistics (CCL) is crucial for preserving the quality, safety, and sustainability of perishable products. Although several reviews have discussed CCL performance, they have focused on food CCL. Therefore, a gap remains in the literature regarding performance measurement and evaluation of CCL for Fresh Agricultural Products (FAPs). The study used a Systematic Literature Review (SLR) employing a multidimensional approach encompassing descriptive, content, and thematic analyses, with a special emphasis on the floriculture sector. The findings highlight critical research gaps, including the absence of integrated performance metrics, limited focus on the floriculture sector, and insufficient consideration of real-world decision-making complexities. To address these gaps, a conceptual research framework is proposed integrating operational, economic, and sustainability dimensions of CCL, adapted for the unique challenges of the floriculture sector. It provides insights for the development of dynamic, comprehensive, and context-sensitive performance evaluation within logistical requirements.

ARTICLE HISTORY
Received 16 July 2025
Accepted 23 March 2026

KEYWORDS
Cold chain logistics; fresh agricultural products; floriculture sector; performance measurement; conceptual framework

1. Introduction

Cold Chain Logistics (CCL) is essential for maintaining quality, safety, and commercial value of Fresh Agricultural Products (FAPs) (Asante et al. 2019; Han et al. 2021; Zhao 2020). These products remain biologically active after harvest, making them highly sensitive to variations in temperature, humidity, and postharvest handling conditions (Imahori and Bai 2024; Schudel et al. 2023; Zaman et al. 2025). Even, during periods of socio-economic crisis, FAPs necessitate specialised handling to preserve their quality (Perdana et al. 2023). Variations in temperature and humidity accelerate respiration, moisture loss, and microbial growth, resulting in a rapid deterioration and a shorter shelf-life (Conradie, Goedhals-Gerber, and van Dyk 2022; Schudel et al. 2023). These risks increase along extended supply chains that involve multiple handling points, long distance transportation, and diverse economic conditions (Li and Li 2021). Jaelani et al. (2025) indicated that CCL is inherently vulnerable to various disruptions and inefficiencies due to its dependence on infrastructure, technology, geographically dispersed nature, and involvement of multiple stakeholders. In addition,

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Wei and Lv (2019) revealed that CCL often encounters disruptions during distribution, causing economic losses and safety concerns.

The global demand for processed and FAPs continues to grow and reached 1.17 trillion USD in 2024 (ITC 2024). The growth is driven by the changing lifestyle and expanding global trade for fresh produce (Han et al. 2021). This trend has raised the importance of Cold Chain Logistics (CCL) for meeting consumer demand and safety regulations (Khan, Imran Khan, and Haleem 2018). Effective cold chain management reduces postharvest losses and extends shelf-life, ensuring quality (Chen et al. 2023) and safety (Li et al. 2024). However, maintaining effective CCL requires coordinated development across links to reduce waste and maintain profitability (Han et al. 2021; Khan, Imran Khan, and Haleem 2018; Maestrini et al. 2017). Wei and Lv (2019) also showed implementation of efficient and effective CCL faces challenges in temperature regulation, route optimisation, and timely information feedback. The limitation and complexity of CCL (Chen et al. 2023) are further increased by the necessity for specialised equipment and monitoring systems (Han et al. 2021), and the involvement of multiple stakeholders operating under diverse standards and conflicting objectives (Bremer 2018; Fan et al. 2021). These challenges constrain the performance of CCL, which needs further investigation.

Performance measurement systems play a crucial role in supply chain management by ensuring that operations are aligned with strategic goals (Gunasekaran, Patel, and Tirtiroglu 2001; Hald and Mouritsen 2018). The performance of supply chain has become instrumental for maintaining competitiveness, resilience, and sustainability (Lizot et al. 2019; Singh and Acharya 2014; Stefanovic 2014). Despite the growth in research on supply chain performance measurement (Charkha and Jaju 2014), the identification of appropriate KPIs remains a challenge (Anand and Grover 2015). The literature is fragmented, lacking a comprehensive overview (Maestrini et al. 2017), and offers limited insights into the effective adoption of supply chain performance measurement systems for special supply chains such as fresh produce (Maestrini et al. 2018). This demonstrates the need for continued research to advance both theory and practice in the field.

The performance of agricultural cold chains encompass various factors that contribute to system success and sustainability (Fan et al. 2024). Han et al. (2021) have acknowledged the importance of improving CCL performance for minimising postharvest losses and ensuring food security. Evaluating CCL performance is also essential for setting objectives and determining future course of action (Gunasekaran et al. 2015), developing efficient supply chains (Defraeye et al. 2016), optimising cold chain operations, and implementing robust monitoring systems (Joshi, Banwet, and Shankar 2011). Despite its importance, the limitations of CCL performance measurement persist. These include the absence of standardised performance evaluation frameworks (Awad, Ndiaye, and Osman 2021; Han et al. 2021), the lack of harmonised metrics across actors and stages (Fan, Behdani, and Bloemhof-Ruwaard 2020), system complexity and conflicting interests (Fan et al. 2021; Wu et al. 2022; Xiao et al. 2015), limited access to monitoring technologies (Goedhals-Gerber, Fedeli, and van Dyk 2021; Kumar, Tyagi, and Sachdeva 2025), complexity in measuring energy use and emissions (De Keizer et al. 2015; Du Plessis, Van Eeden, and Goedhals-Gerber 2024; Wu et al. 2019), the absence of industry standards (Fan et al. 2024), product quality dynamics (De Keizer et al. 2015), and high operational costs (Zhang and Liu 2018). While these studies provide important insights, they often focus on isolated aspects of cold chain operations and lack a comprehensive performance measurement approach that integrates operational, economic, and environmental dimensions to central challenges.

Researchers are showing a growing interest in the area of cold chain logistics (Li et al. 2025), and CCL performance has been the subject of several reviews. To situate our research within existing body of literature, we examined prior review papers that at least partially address CCL performance. Previous reviews, as summarised in Table 1, provide an overview of various CCL issues discussed over the past five years. Awad, Ndiaye, and Osman (2021) called for integrated models linking transportation, quality, and environmental costs. Fan, Behdani, and Bloemhof-Ruwaard (2020) focus on trade-offs among costs, quality, and sustainability. Han et al. (2021) redirected the

Table 1. Review of reviews.

Reference	Review Theme	Sector	Review Method	Main finding	Limitations
Awad, Ndiaye, and Osman (2021)	Distribution modelling	Food	SLR	Identified dynamic vehicle route modelling, considering product quality and environmental impacts.	No unified framework exists for evaluating performance.
Fan, Behdani, and Bloemhof-Ruwaard (2020)	Efficiency & sustainability	Reefer Logistics	SLR	Reefer logistics faces trade-offs among cost, quality, and sustainability.	Lack of standardised metrics across different actors.
Han et al. (2021)	CCL dynamics	FAPs	CR	CCL maintains quality and safety of FAPs, reduces losses, and enhances farmer income.	Lack of comprehensive performance measurement frameworks for CCL.
Liao et al. (2024)	Cold chain sustainability	Food	SLR	Sustainability performance through the triple-bottom-line framework.	Highlight limitations regarding the performance measurement of CCL.
Akram et al. (2023)	Cold chain management	Food	SR	Indicated a significant shift towards sustainable food cold-chain management.	Lack of standardised performance indicators for comprehensive food cold chain management.

SLR: Systematic Literature Review, CR: Comprehensive Review, SR: Structured Review.

focus towards minimising losses and sustainable agriculture. Recent reviews emphasised sustainability, using frameworks such as the triple bottom line (Liao et al. 2024) and the structured conceptual model (Akram et al. 2023). While these reviews offer valuable insights, they focus primarily on food CCL, specific technologies, and cod chain operations. They do not fully synthesise how environmental factors, operational variability, and sustainability pressures interact to affect performance outcomes. As a result, a gap remains in performance measurement and evaluation of CCL for FAPs. The increasing complexity of CCL, the emergence of new technologies, the data-driven decision tool, and the sustainability pressure underscore the need for a systematic review that integrates these perspectives within a comprehensive performance framework. Thus, this systematic review aims to investigate current literature on the performance of CCL for FAPs, identify existing gaps, develop a conceptual framework, and propose future research directions. By synthesising evidence from articles published in peer-reviewed journals, this study will answer the following research questions:

RQ1: What are the emerging research trends and themes in CCL performance for FAPs?

RQ2: What research gaps exist in CCL performance literature on FAPs that require further investigation?

The remainder of this paper is structured as follows: Section 2 outlines the review methodology. Section 3 presents the results and findings, and a conceptual framework. Section 4 discusses major findings and research gaps. Finally, Section 5 presents conclusions, implications, and future research directions.

2. Method

2.1. Review framework

A SLR-based approach by Tranfield, Denyer, and Smart (2003) and Denyer and Tranfield (2009) was adopted to examine existing knowledge regarding CCL performance for FAPs. This approach supports synthesising knowledge in areas with conceptual fragmentation and methodological diversity through a transparent, replicable method (Denyer and Tranfield 2009; Tranfield, Denyer, and Smart 2003). It enables effective analysis of existing literature for knowledge generation (Cooper 2017; Fink 2019). It is becoming a systematic approach for evidence-based research (Martinic et al. 2019). It serves as a tool to evaluate studies related to a specific research question (Kitchenham et al. 2009), with increasing use in supply chain management research (Durach, Kembro, and Wieland 2017). This approach has also been applied in CCL reviews (Awad, Ndiaye, and Osman 2021; Fan, Behdani, and Bloemhof-Ruwaard 2020; Liao et al. 2024). Figure 1 illustrates the SLR framework.

2.2. Identification

As it is depicted in step 1 of Figure 1, a structured search was conducted in Scopus and Web of Science. These databases were chosen because both databases index peer-reviewed journals and mitigate indexing biases (Mongeon and Paul-Hus 2016). Search strings using an array of combined key words, including 'Cold Chain Logistics' OR 'Cool Chain Logistics' AND 'Performance', 'Temperature Controlled Logistics' OR 'Perishable Products' AND 'Performance', 'Cold Chain Logistics' AND 'Performance' OR 'Performance Measurement' were used. As shown in Table 2, the initial search generated 1,053 papers.

2.3. Screening

The screening process, step 2 of Figure 1, focused on filtering existing literature pertaining to CCL performance for FAPs. Using EndNote reference manager, 396 duplicate records were eliminated.

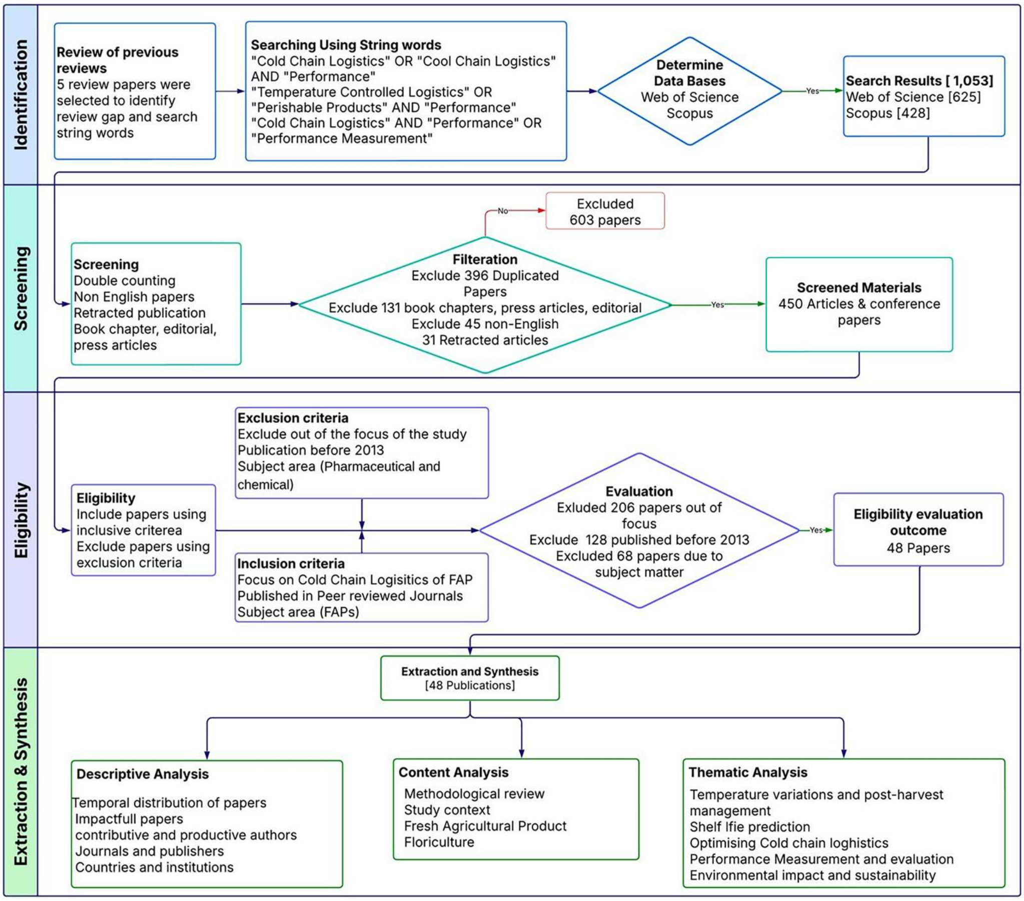

Figure 1. Systematic literature review framework adopted from (Denyer and Tranfield 2009).

A further 131 records were excluded based on publication type, including book chapters, press articles, and editorials. Finally, 45 English publications and 31 retracted records were also removed.

2.4. Eligibility

Full texts were reviewed using inclusion and exclusion criteria outlined in Table 3 to confirm eligibility. Studies were included if they focused on CCL for FAPs, published in peer-reviewed journals from 2013 onwards. Accordingly, 206 papers unrelated to performance measurement of CCL, 128 papers published prior to 2013, and 68 outside the domain of FAPs were excluded. Finally, 48 papers were found appropriate to be included in this systematic review. To ensure reliability, we adhere to a selection process guided by the protocol for the systematic review approach outlined

Table 2. Search string and materials identified.

	Database		
Searching string	Web of Science	Scopus	Total
'Cold Chain Logistics' OR 'Cool Chain Logistics' AND 'Performance'	292	188	**480**
'Temperature Controlled Logistics' OR 'Perishable Products' AND 'Performance'	187	128	**315**
'Cold Chain Logistics' AND 'Performance' OR 'Performance Measurement'	146	112	**258**
Total	**625**	**428**	**1053**

Table 3. Inclusion and exclusion criteria.

Inclusion criteria	Rationale
Research focused on CCL of FAP	To limit the vast area of CCL, less attention was given to FAPs by the previous review
Research articles published in peer-reviewed journals	To include studies that are widely accepted and of high quality
Studies published after 2013	Starting period of Floriculture Sustainability Initiative
Papers published in full-text English	To make the collected literature comprehensible to all members of the project
Exclusion criteria	
Pharmaceutical and chemical CCL	Out of the scope of the research objectives
Dissertation, seminars, workshop papers, and other grey literature	Lack of standardisation, consistency, and comparability

by (Denyer and Tranfield 2009; Tranfield, Denyer, and Smart 2003). Two reviewers assessed all studies independently and disagreements were resolved through structured discussion as recommended by (Briner, Denyer, and Rousseau 2012). This strengthened internal validity and ensured adherence to best practices recommended for evidence-based management and logistics research (Briner, Denyer, and Rousseau 2012; Seuring and Gold 2012).

2.5. Extraction and synthesis

A structured data extraction template was used to record publication details to capture descriptive, contextual, and thematic information (Table 4). We employed descriptive, content, and thematic analyses to summarise the findings, and narrative synthesis was used to integrate the results. Descriptive analysis facilitated the mapping of temporal trends and publication origins (Snyder 2019). Adopting contextual analysis assisted in situating findings within their sectoral, geographic and conceptual settings (Seuring and Gold 2012). Thematic analysis enabled the identification of performance-related themes and gaps across reviewed papers, enabling the development of conceptual insights (Nowell et al. 2017). Thus, this integrated approach strengthens the interpretive rigour and clarity of the analysis, thereby helping to effectively address the study's research questions.

3. Result

A standardised data extraction form was used to reduce human error and bias, in line with SLR protocols (Denyer and Tranfield 2009; Tranfield, Denyer, and Smart 2003). The extracted data were organised according to descriptive, contextual, and thematic dimensions. This structure

Table 4. Categories used to extract data.

Analysis	Category	Description
Descriptive	Temporal distribution Document type and subject area Impactful papers Productive authors, countries, and institutions	Annual distribution of publications, document types, citation indices, publishers and journals, countries and institutions of lead authors
Content	Methodological review Study context	Methodologies employed, geographic, sectoral, and conceptual contexts of reviewed studies
Thematic Analysis	Temperature variations and post-harvest management Shelf-life prediction and quality control Optimising CCL Performance measurement and evaluation of CCL Environmental impact and sustainability	The thematic focuses of the reviewed studies are categorised on similarity of the main themes.

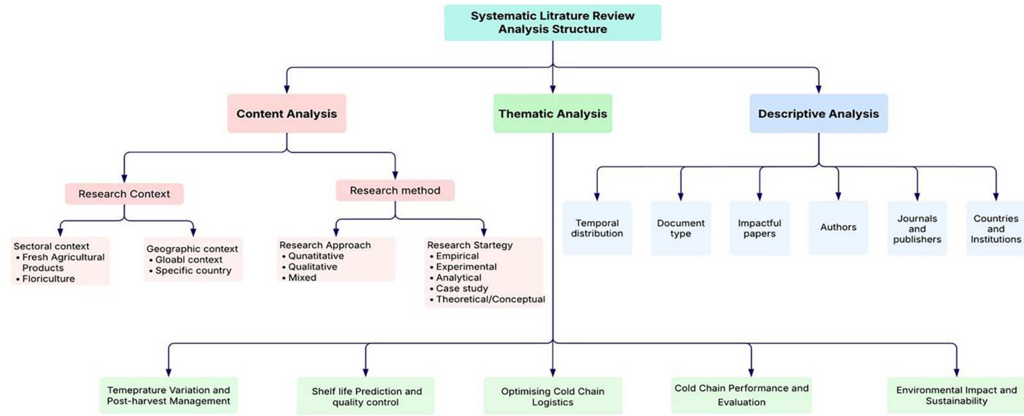

Figure 2. SLR analysis structure.

supported a comprehensive evaluation of publication trends, methodological diversity, research settings, performance themes, and conceptual developments. Figure 2 outlines the overall analytical framework of the review.

3.1. Descriptive analysis

The descriptive analysis supports transparency and ensures research replicability and traceability of findings (Akram et al. 2023; Chaudhuri et al. 2018). Research outputs are categorised by year of publication, document type, impactful papers, subject area, authors, journals, publishers, institutions, and countries. As illustrated in Table 5, the data set comprised 48 articles published between 2013 and 2024 across 37 journals, authored by 141 researchers. The average citation per article was 17.25, indicating consistent scholarly engagement in the field.

3.1.1. Temporal scientific production and citation of articles

As shown in Figure 3, research outputs increased steadily over the review period, indicating growing research interest in CCL. The annual number of publications exhibited fluctuations with the highest contributions occurring in 2022. This raise is attributable to the COVID-19 pandemic, during which research related to CCL intensified due to the increased demand for vaccines and other pharmaceuticals. Early publications (2013–2015) focused on postharvest physiology, storage conditions, and temperature management for FAPs (Ahmad, Tahir, and Shahri 2013; Rungruchkanont 2013; Van Meeteren, Schouten, and Woltering 2015). Subsequent studies from 2016 to 2018 moved towards optimisation and operational efficiency, reflecting growing interest in logistics planning and analytical models (Damrongpol et al. 2016; Liu, Zhao, and Zhang 2018; Xiao et al. 2017;

Table 5. Main information of the collection.

Description	Articles selected for analysis
Period	2013–2024
Articles	48
Sources	37
Average citation per article	17.25
Authors	141
Authors of single-authored articles	4
International co-authorship %	25
Author's Keyword	184
Co-authors Per Article	3.4

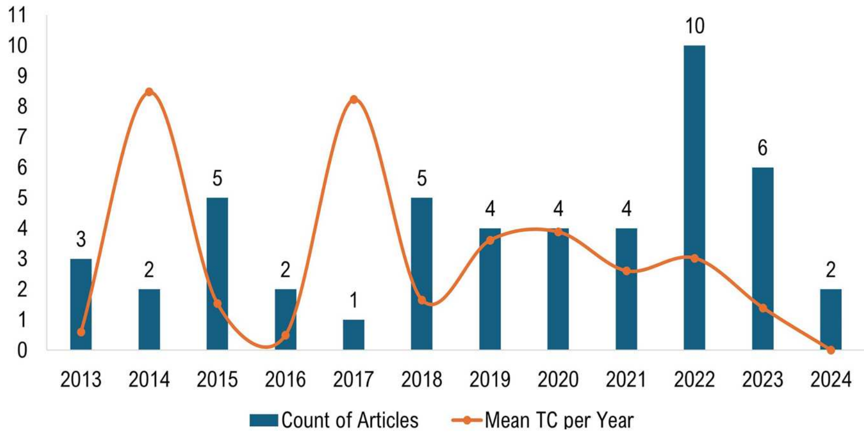

Figure 3. The trend of annual publication and citation.

Zhang and Liu 2018). Research conducted from 2019 to 2021 broadened into Internet of Things (IoT), sensor-based monitoring systems, and simulation (Fan et al. 2021; Wu et al. 2019; Yadav, Garg, and Luthra 2021). Post-2022, studies shifted to dynamic shelf-prediction, environmental analysis and sustainability (Chen et al. 2023; Du Plessis, Van Eeden, and Goedhals-Gerber 2022a; Rühlin and Scherrer 2023). These trends demonstrate a shift towards complexity, technology integration, and addressing environmental concerns in CCL. In terms of scope, earlier studies focused on specific products and local supply chains, whereas later publications expanded to global and multiproduct CCL across sectors.

3.1.2. Document type and subject area

The analysis of document type aims to assess the maturity of the knowledge base by demonstrating the proportion of studies published in peer-reviewed journals. As shown in Figure 4, the included publications consist mainly of journal articles (79%), while conference papers accounted for 21%. Cold chains have received increasing attention in practical applications and academic literature from different disciplines (Ndraha et al. 2018). The distribution reflects the CCL's multidisciplinary nature, with representation from Agricultural and Biological Sciences (18%), Engineering (15%), and Energy and Environmental Science (12%). This multidisciplinary spread demonstrates that CCL performance is conceptualised as a multi-dimensional challenge necessitating integrated perspectives.

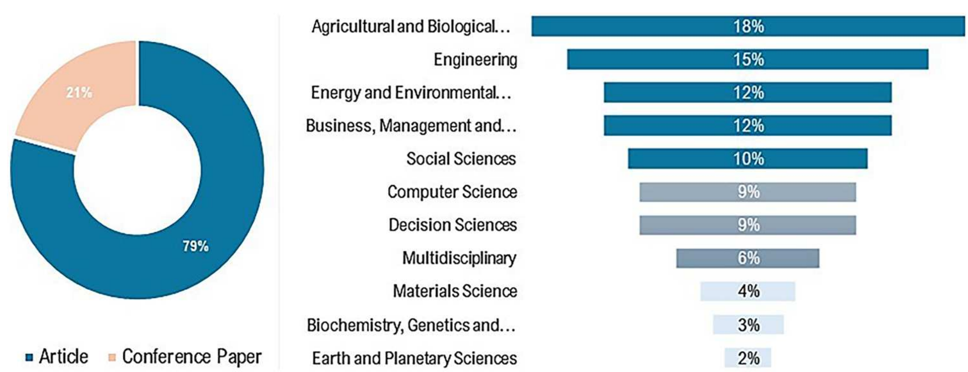

Figure 4. Distribution of publication by document type and subject area.

Table 6. Top 10 most cited publications.

Author	Topic	Total Citations	TC per Year	Normalized TC
Defraeye et al. (2014)	Forced-convective cooling of citrus fruit: cooling conditions and energy consumption	118	9.83	1.16
Qi et al. (2014)	A WSN-based perishable food shelf-life prediction and LSFO strategy decision support system in CCL	85	7.08	0.84
Xiao et al. (2017)	Improving the traceability and transparency of table grapes CCL	74	8.22	1.00
Wu et al. (2019)	Environmental trade-offs in fresh-fruit cold chains by combining virtual cold chains with LSA	71	10.14	2.81
Yadav, Garg, and Luthra (2021)	Development of IoT-based agriculture supply chain performance measurement	60	10.00	2.58
De Keizer et al. (2015)	Hybrid optimization and simulation to design a logistics network	51	4.64	3.04
Fan et al. (2021)	Trading off cost, emissions, and quality in CCL	32	6.40	2.46
Bin et al. (2022)	Selection of the cold logistics model based on the carbon footprint of fruits and vegetables in China	30	7.50	2.48
Bremer (2018)	Towards a reference model for the cold chain	29	3.63	2.20
Kassim and Workneh (2020)	Influence of postharvest treatments and storage conditions on the quality of Hass avocados	26	4.33	1.12

3.1.3. Impactful papers

Table 6 outlines annual citations of the top ten influential papers, including citation rates and normalised citation counts. CCL performance-focused studies that integrate real-time data, digital technologies, and environmental factors achieve high citation (Bremer 2018; Defraeye et al. 2014; Fan et al. 2021; Wu et al. 2019; Yadav, Garg, and Luthra 2021) and (Bin et al. 2022) addressed environmental trade-offs and carbon footprints in CCL, which attracted better attention. Shelf-life modelling and optimisation-focused studies, including (De Keizer et al. 2015; Qi et al. 2014), recorded high citation due to their contribution to advancing shelf-life prediction and CCL network design. Physiological and temperature focused studies (Kassim and Workneh 2020; Xiao et al. 2017) attracted academic interest due to their relevance across varied products. The citation distribution shows studies providing an integrated perspective, environmental consideration, predictive modelling, and physiological quality analysis receive the highest attention.

3.1.4. Productive authors, countries, and institutions

Table 7 presents the top ten most productive authors ranked by published articles and fractionalised contributions. Gerber L leads with five articles, and a fractionalised impact of 1.67 was the most productive author. Other key authors include Defraeye T, Guaita-Pradas I, Marques-Perez I, Van Eeden J, and Zhang X .… The data indicates balanced productivity among researchers. Bremer P, He X-D, and Rungruchkanont K achieved a fully fractionalised score of 1.00, despite fewer articles, implying independent research contributions.

Table 7. Top 10 most productive authors.

Author	No. of Articles	Author	No. of Articles Fractionalised
Goedhals Gerber L	5	Goedhals-Gerber L	1.67
Defraeye T	3	Guaita-Pradas I	1.00
Guaita Pradas I	3	Marques-Perez I	1.00
Marques Perez I	3	Van Eeden J	1.00
Van Eeden J	3	Bremer P	1.00
Zhang X	3	He X-D	1.00
Behdani B	2	Rungruchkanont K	1.00
Du Plessis Mj	2	Zheng L	1.00
Kumar N	2	Du Plessis Mj	0.67
Li J	2	Kumar N	0.67

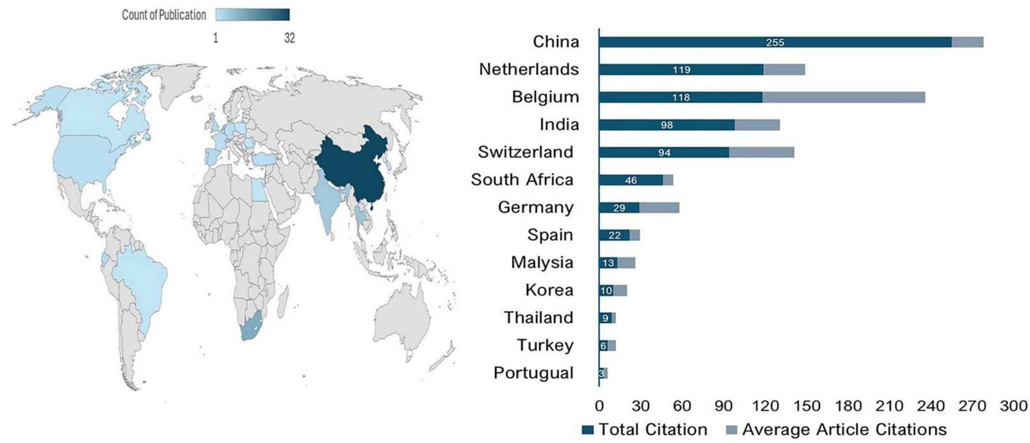

Figure 5. Annual production of publication by country and most cited countries.

As depicted in Figure 5, China leads with 32 publications and 255 citations, attributed to its large export sector of perishable products. South Africa follows with 12 publications focusing on horticulture supply chains. The Netherlands (119 citations) and Thailand (6 citations), each contributing 7 publications, showed active involvement in cold chain research. The Netherlands focuses on its agri-food export infrastructure, whereas Thailand emphasises its agriculture and seafood industries. As shown in Figure 6, Stellenbosch University produced 7 publications, underscoring South Africa's focus on horticultural exports. Wageningen University and Research contributed five publications and is known for its expertise in agricultural logistics and food supply chains. Universitat Politècnica de València, China Agricultural University, and Universidad Central del Ecuador each produced 3 publications. This geographic and institutional pattern reflects how product characteristics, cold chain structure, and level of advancement shape research output. The diverse geographical representation of the institutions also demonstrates the global scope of FAPs CCL research.

3.2. Content analysis

Content analysis was employed to systematically organise and classify the characteristics of reviewed studies on CCL performance for FAPs. Following Krippendorff (2018) methodological

Figure 6. Top 10 institutional affiliations of authors.

principles and (Seuring and Gold 2012) structured review approach, in this study, the content analysis is focused on descriptive and systematic organisation of patterns and their contextual relevance across reviewed studies. The content analysis provides a descriptive foundation for understanding the field's scope, including methodological approaches, geographic distribution, and underlying conceptual perspectives of CCL research. It highlights how product attributes and operational conditions influence performance related inquiries in CCL. The result of this stage provides a descriptive foundation for the subsequent thematic analysis, which interprets the deeper thematic patterns embedded in the literature.

3.2.1. Methodological review

Analysing methodologies employed in the reviewed studies facilitates our understanding of CCL performance from diverse perspectives. In line with the established research methodology literature, we categorised the methodologies adopted in the reviewed papers into quantitative, qualitative, and mixed methods. These designs are the main approaches for empirical investigation in the field of logistics and operations research (Golicic and Davis 2012; Ketokivi and Choi 2014). As shown in Table 8, quantitative studies dominate the field, accounting for 34 studies, showing a methodological bias towards quantitative approaches. Empirical analyses are extensively used to investigate temperature dynamics and logistics performance to gain insights into CCL (Chen et al. 2023; De Keizer et al. 2015; Liu, Zhao, and Zhang 2018). Experimental studies are adopted to evaluate physiological and quality responses to postharvest treatments, temperature effects, and packaging designs. Analytical strategies involving mathematical modelling, optimisation, and simulation are used to examine routing, temperature dynamics, and inventory decisions (Fan et al. 2024; Yadav, Garg, and Luthra 2021; Zheng 2015). Qualitative approaches (Bremer 2018; Du Plessis, Van Eeden, and Goedhals-Gerber 2022b) and case studies (Rühlin and Scherrer 2023; Viet et al. 2021) offered insights into real-world systems, allowing researchers to delve into human and organisational context. Mixed methods appeared in 12 studies, reflecting growing recognition of combining quantitative data-driven methods with contextual understanding. Despite their potential for analysing multidimensional logistics performance, mixed approach applications remain limited.

Table 8. Distribution of papers based on research strategy and approach.

Research approach	Research strategy	Count	Reference
Quantitative	Empirical	15	(Asante et al. 2019; Bin et al. 2022; Chen et al. 2023; Damrongpol et al. 2016; De Keizer et al. 2015; Fan et al. 2021; In et al. 2016; Jiayang, Linan, and Dongyan 2018; Li et al. 2023; Liu, Zhao, and Zhang 2018; Marques-Perez, Rodríguez-Mañay, and Guaita-Pradas 2022; Ruamsuke and Ongkunaruk 2021; Wu et al. 2019; Xiao et al. 2015; Zheng 2015)
	Experimental	11	(Ahmad, Tahir, and Shahri 2013; Cruz, Vieira, and Silva 2013; Defraeye et al. 2014; Kassim and Workneh 2020; Leite et al. 2015; Mohd Ali et al. 2022; Shoji et al. 2022; Van Meeteren, Schouten, and Woltering 2015; Woltering and Paillart 2018; Wu et al. 2022; Xiao et al. 2017)
	Analytical	6	(Du Plessis, Van Eeden, and Goedhals-Gerber 2022a; Fan et al. 2024; Guaita-Pradas, Rodríguez-Mañay, and Marques-Perez 2023; Xu et al. 2019; Yadav, Garg, and Luthra 2021; Zhang and Liu 2018)
	Case Study	2	(Rühlin and Scherrer 2023; Viet et al. 2021)
Qualitative	Conceptual	1	(Bremer 2018)
	Case Study	1	(Du Plessis, Van Eeden, and Goedhals-Gerber 2022b)
Mixed	Empirical	7	(Ksoll, Macchiavello, and Morjaria 2023; Qi et al. 2014; Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022; Secer, Guneser, and Guneser 2020; Titlo and Sopadang 2019)
	Experimental	1	(Rungruchkanont 2013)
	Analytical	1	(Kumar, Tyagi, and Sachdeva 2022)
	Case study	2	(Conradie, Goedhals-Gerber, and van Dyk 2022; Goedhals-Gerber, Fedeli, and van Dyk 2021)
	Conceptual	1	(He 2020)

Table 9. The geographic and conceptual context of reviewed studies on fruits and vegetables.

Geographic context	Study context	Reference
China	Perishability	(Xiao et al. 2015) (Xiao et al. 2017)
	Demand uncertainty & Perishability	(Zheng 2015)
	Environmental concerns	(Bin et al. 2022)
	Shelf-life prediction uncertainty	(Chen et al. 2023)
	Perishability	(Li et al. 2023)
	Economic cost & Environmental concerns	(Zhang and Liu 2018)
	Environmental concerns	(Jiayang, Linan, and Dongyan 2018)
	Environmental concern	(Du Plessis, Van Eeden, and Goedhals-Gerber 2024)
South Africa	Environmental concerns	(Defraeye et al. 2014)
	Perishability & Environmental concern	(Wu et al. 2019)
	Perishability, Economic cost & Environmental concerns	(Goedhals-Gerber, Fedeli, and van Dyk 2021)
	Temperature variations	(Conradie, Goedhals-Gerber, and van Dyk 2022)
	Perishability, Shelf-life prediction, Uncertainty & Environmental concerns	(Du Plessis, Van Eeden, and Goedhals-Gerber 2022a)
	Perishability & Shelf-life prediction	(Du Plessis, Van Eeden, and Goedhals-Gerber 2022b)
	Perishability	
	Environmental concerns	(Kassim and Workneh 2020)
		(Du Plessis, Van Eeden, and Goedhals-Gerber 2024)
Thailand	Perishability (post-harvest loss), Logistics variation, economic cost	(Damrongpol et al. 2016)
	Demand uncertainty & Perishability	(Titlo and Sopadang 2019) (Ruamsuke and Ongkunaruk 2021)
	Perishability	
Portugal	Temperature variation & Perishability	(Cruz, Vieira, and Silva 2013)
Switzerland	Environmental concern	(Rühlin and Scherrer 2023)
Malysia	Shelf-life prediction, Uncertainty & Perishability	(Mohd Ali et al. 2022)
Turkey	Perishability & Shelf-life prediction	(Secer, Guneser, and Guneser 2020)
Spain	Perishability	(Shoji et al. 2022)
Global context	Perishability	(Asante et al. 2019)
	Environmental concern	(Fan et al. 2021)
	Economic cost	
	Perishability	

3.2.2. Focus area

CCL performance varies widely across the geographical, sectoral, and conceptual contexts. Examining the study context is crucial to assess the generalisability of existing research (Ksoll, Macchiavello, and Morjaria 2023) and identify areas that require further exploration and framework development for future studies. Reviewed studies cover three sectoral contexts, fruits and vegetables, general perishables, and floriculture, each with distinct physiological and logistical characteristics that influence performance.

CCL research in the fruits and vegetables sector showed wide geographic diversity, reflecting the sectors' global importance (Table 9). Studies in China emphasises wireless sensor networks, predictive shelf-life modelling, neural network optimisation, and refrigerated transport performance to maintain product quality and efficiency (Bin et al. 2022; Chen et al. 2023; Du Plessis, Van Eeden, and Goedhals-Gerber 2024; Fan et al. 2024; Jiayang, Linan, and Dongyan 2018; Wu et al. 2022; Xiao et al. 2015; Xiao et al. 2017; Zhang and Liu 2018; Zheng 2015). Research from Thailand and Malaysia examines tropical fruit sensitivity to temperature and logistics delays using kinetic modelling to evaluate the temperature effect on product quality (Damrongpol et al. 2016; Mohd Ali et al. 2022; Ruamsuke and Ongkunaruk 2021; Titlo and Sopadang 2019). Studies conducted in Portugal and Switzerland focused on temperature deviations and sustainability in European logistics (Cruz, Vieira, and Silva 2013; Rühlin and Scherrer 2023). Studies conducted in South Africa examined fruit exports using Computational Fluid Dynamics (CFD) modelling for cooling efficiency (Du Plessis, Van Eeden, and Goedhals-Gerber 2022a; Kassim and Workneh 2020; Wu et

Table 10. The geographic and conceptual context of reviewed studies on general perishables.

Geographic context	Study context	Reference
China	Shelf-life prediction uncertainty	(Qi et al. 2014)
	Perishability & Economic cost	(Liu, Zhao, and Zhang 2018)
	Perishability & Demand uncertainty	(Xu et al. 2019)
	System complexity	(He 2020)
	Demand uncertainty & Environmental concerns	(Wu et al. 2022)
India	Perishability & Logistics variability	(Kumar, Tyagi, and Sachdeva 2025)
	Environmental concern & Perishability	(Yadav, Garg, and Luthra 2021)
	Environmental concern & Infrastructure challenges	(Kumar, Tyagi, and Sachdeva 2022)
Germany	Perishability	(Bremer 2018)

al. 2019). The literature on fruits and vegetables views CCL as a system that combines technical and ecological aspects where temperature regulation, kinetic modelling, and optimisation intersect. Research in this area integrates laboratory experiments with digital sensing and simulation to model quality degradation and energy efficiency (Jiayang, Linan, and Dongyan 2018; Li et al. 2023). Advanced methodologies such as CFD, LCA, and hybrid optimisation models have become important in assessing operational trade-offs, sustainability outcomes, and technological interventions (Chen et al. 2023; Defraeye et al. 2014; Du Plessis, Van Eeden, and Goedhals-Gerber 2024).

The general perishables category encompasses mixed fresh products focusing on system level modelling (Table 10). Research conducted in China employed simulation, neural networks, and coordination mechanisms to evaluate performance under uncertain demand and multi-stage logistics (Qi et al. 2014; Wu et al. 2022; Xu et al. 2019; Zhang and Liu 2018). India-based research focused on IoT-enabled frameworks, fuzzy multi-criteria evaluation, energy consumption and efficiency reflecting fragmented structures (Kumar, Tyagi, and Sachdeva 2022; Kumar, Tyagi, and Sachdeva 2025; Yadav, Garg, and Luthra 2021). German-based research develops a reference model that standardises the conceptualisation of cold chain systems (Bremer 2018). Research in this category considers CCL as an adoptive ecosystem that reflects interdependencies among various stakeholders (Bremer 2018; He 2020; Kumar, Tyagi, and Sachdeva 2025; Yadav, Garg, and Luthra 2021).

The floriculture sector displays distinct contextual features due to extreme perishability, sensitivity to temperature, aesthetic quality requirements, and dependence on fast transport. As shown in (Table 11), studies from India and Brazil examined storage temperature, chilling injury, and vase life (Ahmad, Tahir, and Shahri 2013; Leite et al. 2015). In Thailand, research explored logistics and temperature management for Dendrobium orchid exports (Rungruchkanont 2013). In the Netherlands, researchers emphasised on big-data and hybrid optimisation models for flower auction and distribution to improve logistics efficiency in Europe's flower market (De Keizer et al. 2015; Viet et al. 2021). Studies from Ecuador applied AHP and SCOR to link logistics

Table 11. The geographic and conceptual context of reviewed studies on floriculture.

Geography context	Study context	Reference
India	Perishability	(Ahmad, Tahir, and Shahri 2013)
Brazil	Economic cost & Perishability	(Leite et al. 2015)
Thailand	Perishability, Shelf-life prediction, & Uncertainty	(Rungruchkanont 2013)
Netherlands	Perishability	(De Keizer et al. 2015; Viet et al. 2021)
	Shelf-life prediction, Uncertainty, & Perishability	(Van Meeteren, Schouten, and Woltering 2015)
Ecuador	Demand uncertainty, Perishability, & Logistics variability	(Marques-Perez, Rodríguez-Mañay, and Guaita-Pradas 2022)
	Perishability &Economic efficiency	(Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022)
	Economic significance (competitiveness), Logistics (competitiveness)	(Guaita-Pradas, Rodríguez-Mañay, and Marques-Perez 2023)
Kenya	Uncertainty	(Ksoll, Macchiavello, and Morjaria 2023)
South Korea	Uncertainty	(In et al. 2016)

performance to national competitiveness for flower exports (Guaita-Pradas, Rodríguez-Mañay, and Marques-Perez 2023; Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022). Research from Kenya showed how supply chain disruptions affect logistics performance and exports (Ksoll, Macchiavello, and Morjaria 2023). These studies provide insights into managing perishability, demand uncertainty, shelf-life prediction, and sustainability in global floriculture logistics. The conceptual context highlights perishability and postharvest loss are central concerns of ornamental products, affecting profitability and consumer satisfaction. Literature addresses these through optimised handling protocols, storage, and packaging to mitigate quality degradation (Leite et al. 2015; Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022; Rungruchkanont 2013). Temperature breaks during transportation and handling affect shelf-life and economic return. Researchers have proposed simulation models to predict vase life under varying transport scenarios (De Keizer et al. 2015; Van Meeteren, Schouten, and Woltering 2015). Studies indicated assessing shelf-life under realistic logistical scenarios is essential for flower marketability (Leite et al. 2015; Rungruchkanont 2013). The literature also underscores the importance of sustainability contexts, addressing environmental impact and integrating into strategic decision-making frameworks like SCOR model (Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022; Viet et al. 2021).

3.3. Thematic analysis

Thematic analysis was conducted to identify recurring conceptual patterns in how CCL performance is framed and evaluated. The thematic analysis focuses on the interpretation of textual data and the development of themes (Braun and Clarke 2006; Nowell et al. 2017), and this review identified five core themes (Table 12) that show how existing studies conceptualise and evaluate CCL performance for FAPs. These themes reflect recurring performance issues and the understanding of interaction among physiological attributes, logistics operations, and environmental factors throughout the cold chain. The thematic analysis also illustrates system-level contradictions and conceptual gaps that facilitate the development of an integrated performance evaluation framework.

3.3.1. Temperature variations and postharvest management

Reviewed studies under this theme underscore how deviations in temperature and postharvest treatment present a significant challenge in the CCL of FAPs. Empirical evidence across fruits, vegetables, and flowers demonstrates that duration that products are exposed to insufficient cooling or temperature variation reduces shelf-life, firmness, colour stability, and marketability (Ahmad,

Table 12. Thematic categories of reviewed studies.

Themes	References
Temperature variations and postharvest management	(Ahmad, Tahir, and Shahri 2013; Conradie, Goedhals-Gerber, and van Dyk 2022; Cruz, Vieira, and Silva 2013; Damrongpol et al. 2016; Goedhals-Gerber, Fedeli, and van Dyk 2021; In et al. 2016; Kassim and Workneh 2020; Leite et al. 2015; Rungruchkanont 2013; Woltering and Paillart 2018; Xiao et al. 2015; Xiao et al. 2017)
Shelf-life prediction and quality control	(Chen et al. 2023; Mohd Ali et al. 2022; Qi et al. 2014; Secer, Guneser, and Guneser 2020; Van Meeteren, Schouten, and Woltering 2015)
Optimising cold chain logistics	(Asante et al. 2019; De Keizer et al. 2015; He 2020; Jiayang, Linan, and Dongyan 2018; Li et al. 2023; Shoji et al. 2022; Wu et al. 2022; Xu et al. 2019)
Performance measurement and evaluation of cold chain logistics	(Bremer 2018; Defraeye et al. 2014; Fan et al. 2021; Guaita-Pradas, Rodríguez-Mañay, and Marques-Perez 2023; Ksoll, Macchiavello, and Morjaria 2023; Kumar, Tyagi, and Sachdeva 2022; Kumar, Tyagi, and Sachdeva 2025; Liu, Zhao, and Zhang 2018; Marques-Perez, Rodríguez-Mañay, and Guaita-Pradas 2022; Ruamsuke and Ongkunaruk 2021; Titlo and Sopadang 2019; Viet et al. 2021; Yadav, Garg, and Luthra 2021; Zhang and Liu 2018; Zheng 2015)
Environmental impact and sustainability	(Bin et al. 2022; Du Plessis, Van Eeden, and Goedhals-Gerber 2022a, 2022b; Du Plessis, Van Eeden, and Goedhals-Gerber 2024; Fan et al. 2024; Rühlin and Scherrer 2023; Wu et al. 2019)

Tahir, and Shahri 2013; Cruz, Vieira, and Silva 2013). Studies further underscore the specificity of temperature tolerance of products. Some products display chilling injury, particularly tropical varieties (Leite et al. 2015), while others require lower temperature to maintain quality. Another focus area of the reviewed studies is the postharvest treatment of FAPs. Studies focused on fruit and vegetables indicated that improper storage temperatures can lead to significant quality losses, including reduced vitamin content and colour changes (Damrongpol et al. 2016; Kassim and Workneh 2020). Similar empirical evidence was presented in the floriculture sector. Cold chain functions, such as pre-export storage condition, transit time, and interplay between temperature variation and duration determine the vase-life of flowers (In et al. 2016; Woltering and Paillart 2018). Operational investigation revealed that early-stage temperature breaks in the cold chain resulted in significant quality losses (Conradie, Goedhals-Gerber, and van Dyk 2022; Goedhals-Gerber, Fedeli, and van Dyk 2021). Studies involving real-time monitoring using sensor-based and data-intensive approaches also indicated temperature abuses during pre-cooling, loading, handling, and storage (Xiao et al. 2015, 2017). Virtual and simulation studies confirm that early-stage temperature fluctuations propagate subsequent stages, exacerbating deterioration of quality (Wu et al. 2019).

The synthesis across the theme shows that temperature fluctuations and postharvest management are the main central challenges. Insights into physiological responses of perishable products under varying temperature were established by early investigations (Ahmad, Tahir, and Shahri 2013; Cruz, Vieira, and Silva 2013; In et al. 2016). Subsequent studies by Kassim and Workneh (2020) have expanded this understanding by examining the combination of postharvest functions and temperature control, demonstrating the importance of postharvest management in cold chains (Conradie, Goedhals-Gerber, and van Dyk 2022; Goedhals-Gerber, Fedeli, and van Dyk 2021; Leite et al. 2015). The integration of wireless sensor technologies, real-time data monitoring systems, and simulation enhanced the evaluation of temperature dynamics throughout the cold chain (Damrongpol et al. 2016; Wu et al. 2019; Xiao et al. 2015, 2017). However, operationalising optimal temperature with cold chain operations across different perishable products and cold chain stages remains challenging.

A recurring pattern across the reviewed studies indicates that temperature variations interact with other performance factors, such as handling practice, equipment efficiency, logistics timing, and environmental exposure. A methodological progress from manual observation of temperature to data-driven monitoring shows growing recognition of temperature dynamics as a systemic issue rather than a localised operational problem. The absence of models that link physiological freshness loss with logistical and environmental variables constrains the broader applicability of the findings from reviewed studies. A contradicting result is observed between maintaining strict temperature stability and managing energy consumption, particularly in extended cold chains where precise temperature control increases refrigeration load. In addition, actual temperature sensitivities varied significantly across specific products. This creates another tension between operational simplicity and physiological complexity that needs to be addressed.

3.3.2. Shelf-life prediction and quality control

This thematic area focuses on predicting and managing the shelf-life of perishable products through methodologies designed to forecast longevity, minimise waste, and ensure product quality. The findings of reviewed studies show advancements in shelf-life prediction for FAPs from static models to dynamic, data-driven, and uncertainty-aware models. Qi et al. (2014) introduced a decision support system integrating wireless sensor networks with predictive modelling to manage perishable products through Cold Chain Shelf-Life Decision Support System (C2SLDS). Van Meeteren, Schouten, and Woltering (2015) predicted the vase life of cut rose flowers using a simulation model based on temperature and storage duration. Secer, Guneser, and Guneser (2020) provided transferable insights for modelling perishability and quality changes in fresh products. Similarly, Mohd Ali et al. (2022) established a predictive model for pineapple based on critical quality indicators to predict the shelf-life under varying storage conditions. Chen et al. (2023) further advanced this approach by introducing a dynamic shelf-life prediction method that incorporates uncertainty. The model continuously updates predictions using real-time environmental data, reflecting the stochastic nature of temperature and humidity variations in actual logistics environments.

These studies represent advancements towards more data-driven cold chain management for FAPs. The studies indicated that accurate shelf-life prediction depends on reliable temperature data. However, the central challenge identified in the literature is the availability of real environmental data, especially in settings with limited sensor deployment or inaccurate data recording. Another limitation is the trade-off between prediction model accuracy and operational usability. The studies demonstrate the technical feasibility of the prediction models but lack decision rules that convert into operational actions. The evidence shows fragmented integration between prediction models and actual logistics decision-making processes, which limits operational application to CCL performance.

3.3.3. Optimising cold chain logistics

Optimisation research in CCL research has progressed from cost and time-based models towards multi-objective frameworks that incorporate quality loss, energy use, and emissions. CCL optimisation models incorporate freshness decay functions and environmental parameters into routeing and inventory decisions (Jiayang, Linan, and Dongyan 2018; Li et al. 2023; Wu et al. 2022). The other advancement is the shift towards hybrid and data-driven optimisation frameworks, to address real-world uncertainty and enhance predictive capability (De Keizer et al. 2015). Further progress in CCL optimisation is the integration of uncertainty and dynamic behaviour, demonstrating improved spoilage reduction and resource use, into multi-echelon optimisation models (Asante et al. 2019; Xu et al. 2019). He (2020) emphasises coordination and resilience, focusing on cooperation, benefit sharing, and risk mitigation to ensure a stable and sustainable cold chain system. Furthermore, simulation-based optimisation approaches integrate environmental factors and identify strategies for balancing freshness, cost and environmental impact (Li et al. 2023; Wu et al. 2022). Studies using digital-twin approaches also simulate interactions between temperature, humidity, and handling events, offering insights into operational vulnerability (Shoji et al. 2022).

The synthesis across the evidence demonstrates significant methodological advancement in cold chain optimisation, evolving from basic routeing heuristics optimisation to hybrid data-driven optimisation and digital twin simulation. While the reviewed studies contribute significantly to advancement in the field, they often remain disconnected from practical cold chain challenges. These studies focus on optimising individual components such as routeing and transport without considering the broader CCL system. In addition, there is limited consideration of contextual factors, such as infrastructural constraints in emerging markets, where cold chain inefficiencies often arise from a lack of power, storage, or skilled labour rather than inadequate routeing planning. Furthermore, the main challenge emerges between mathematical optimisation models and practical operational constraints. Many optimisation models require data precision and infrastructural stability. However, empirical evidence shows variable cooling efficiency, inconsistent handling, infrastructural limitations, and uncertainty in transport times. Another tension arises between local optimisation, such as improving packhouse cooling or roueting, and system level performance, where improvement in one stage does not necessarily improve overall performance and may shift bottlenecks elsewhere. This implies that optimisation research in cold chains requires integration with real world operational conditions and clear representation of system wide interaction.

3.3.4. Performance measurement and evaluation of cold chain logistics

Evaluating and improving cold chain performance remains unresolved in CCL of FAPs. The reviewed studies revealed various challenges and research gaps in performance measurement of CCL for FAPs. Cost management and environmental concerns pose significant challenges for performance evaluation. Studies indicated that balancing product freshness, logistics cost, carbon emission, and efficiency makes performance evaluation challenging in CCL (Defraeye et al. 2014; Liu, Zhao, and Zhang 2018; Zhang and Liu 2018; Zheng 2015). Absence of a comprehensive performance evaluation framework that considers the complexity of the CCL system is another limitation. Performance evaluation frameworks that adopt SCOR, AHP, Fuzzy-DEMATEL, and hybrid approaches highlight process weakness but they rarely represent the complexity of CCL (Bremer 2018; Titlo and Sopadang 2019). Further challenges include a lack of proper performance metrics (Ruamsuke and Ongkunaruk 2021), a focus on a deterministic approach (Fan et al. 2021), and the absence of a sector-tailored performance measurement framework (Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022). These research problems indicate the need for systematic approaches to enhance cold chain efficiency, comprehensive sector-level performance measurement, and empirical assessments of key performance indicators.

The reviewed studies on the performance measurement and evaluation of CCL for FAPs revealed key findings. Studies have adopted AHP and SCOR frameworks to identify KPIs that facilitate decision making and to examine the inefficiencies in CCL (Bremer 2018; Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022; Titlo and Sopadang 2019). Further, studies have developed technology-integrated evaluation frameworks and BP neural networks to enhance operational efficiency and effectiveness (Liu, Zhao, and Zhang 2018; Zheng 2015). However, these studies focus on specific processes and fail to integrate with system-level logistics and sustainability dimensions. Technological innovations, such as real-time monitoring systems, IoT, and sensor-based container designs have facilitated the development of an IoT-based performance measurement framework for agricultural supply chains (Defraeye et al. 2014; Yadav, Garg, and Luthra 2021). Balancing economic efficiency with environmental sustainability is a recurring concern, with researchers analysing factors such as transportation costs, carbon emissions, and energy consumption. Addressing this systemic challenge, researchers have employed system dynamics simulation, the ABS framework, and AH-Fuzzy TOPSIS approaches to demonstrate the trade-offs between operational cost, quality, and carbon emissions (Fan et al. 2021; Kumar, Tyagi, and Sachdeva 2022; Liu, Zhao, and Zhang 2018; Zhang and Liu 2018; Zheng 2015).

The literature reviewed across this theme collectively underscore that assessing the performance of CCL systems is not merely an operational concern but a strategic issue. Early studies primarily focused on cost efficiency and freshness loss as KPIs using analytical models (Bin et al. 2022; Liu, Zhao, and Zhang 2018). Over time, however, a multi-dimensional perspective has emerged. For example, Kumar, Tyagi, and Sachdeva (2025) integrated fuzzy-DEMATEL and MCDM approaches to map interdependencies among KPIs in agricultural cold chains. Additional works further advance this evolution by incorporating data-driven frameworks, particularly the use of big data analytics and IoT enabled systems (Fan et al. 2024; Zheng 2015). Viet et al. (2021) emphasised a multi-level decisions framework for evaluating the value of data in supply chain operations of FAPs. Moreover, methodological evolution was observed from single-criteria quantitative models (Titlo and Sopadang 2019), towards multi-criteria hybrid frameworks (Bremer 2018; Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022), reflecting the increasing complexity of cold chain systems. Likewise, studies employing a combination of SCOR and AHP (Rodríguez Mañay, Guaita-Pradas, and Marques-Perez 2022) or fuzzy-DEMATEL (Kumar, Tyagi, and Sachdeva 2025) have evolved to address the CCL performance evaluation challenges. A key challenge identified across the literature is that existing conventional performance measurement frameworks consider cold chain logistics systems as linear and stable system. As a result, the frameworks overlook dynamic variability, seasonality, disruptions, and interdependence identified in previous themes. As a result, the performance frameworks fail to capture the adoptive nature of cold chains. Despite the progress in CCL performance research, most studies adopt indicators tailored to specific products and logistics stages. The studies do not capture the interaction of temperature, quality, logistics operations, and energy use that characterise the CCL. As a result, existing frameworks could not adequately address the contradiction among cost, quality, and sustainability metrics. The thematic analysis reveals the need for multi-dimensional, adaptive, performance measurement systems that integrate operational, economic, and environmental indicators.

3.3.5. Environmental impact and sustainability

Environmental concerns are prominent in CCL owing to refrigeration, transportation, and packaging contributions to emissions and energy consumption. Environmental analysis in cold chain research has, thus, expanded in scope and complexity. Early studies focused on energy consumption in refrigerated transport and storage (Wu et al. 2019). Other studies examine transport emissions across modes and identify lower emission alternatives for certain routes (Bin et al. 2022). Research on short shelf-life products shows that transport often dominates emissions (Rühlin and Scherrer 2023). Another study quantifies greenhouse gas emission across entire cold chains and identifies that longer chains sometimes achieve lower per unit emissions through consolidation and efficiency (Du Plessis, Van Eeden, and Goedhals-Gerber 2024). In a different direction, geographic analysis demonstrates infrastructure disparities in sustainability performance (Fan et al. 2024), indicating that environmental performance is shaped by systemic constraints as much as operational choices. The synthesis on environmental analysis reveals tensions between quality preservation and emissions, short chains versus efficient long chains, and energy control versus cost pressure. Wu et al. (2019) demonstrated that improved temperature control reduces spoilage but often results in increased energy consumption and carbon footprint. The efficiency of sustainability strategies appears to vary by region. For example, Du Plessis, Van Eeden, and Goedhals-Gerber (2022b) highlight solar cooling as a viable solution in tropical regions, whereas Fan et al. (2024) advocate for national policy frameworks to facilitate energy transition in China. The absence of standardised environmental KPIs complicates cross-study comparisons and benchmarking. While some studies focus on carbon footprints, others emphasise energy intensity or food loss rate. Furthermore, gaps were observed that necessitate further research. There is a lack of integration with performance frameworks, as environmental indicators are rarely incorporated into mainstream CCL evaluation. In addition, assessments of cold chain stages were often made partial, frequently neglecting critical stages such as packaging, refrigeration leakage, or end-to-end emissions. Only a few studies have explored how sustainable CCL should be designed for resource-constrained settings, where emissions and food loss are both significant. This underscores the importance of moving beyond technical solutions to develop an integrated and comprehensive performance evaluation framework that captures all stages of cold chain, trade-offs, and contextual factors reflecting the realities of diverse cold chain contexts.

4. Conceptual framework

A review of CCL for FAPs was conducted to develop a conceptual framework, focusing on decision-making problems in performance measurement and contextual factors. As depicted in Figure 7, the framework comprises five dimensions derived from the thematic analysis. It reflects FAPs CCL systems' dynamic environment with complex adaptive systems, involving competitive objectives, process uncertainties, and environmental considerations. The framework addresses floriculture-specific contexts, such as perishability, postharvest losses, shelf-life sensitivity to temperature variations, sustainability, and supply and demand uncertainty due to seasonality, revealing limitations of existing performance measurement frameworks in capturing the cold chain systems' complexity. The framework outlines critical decision-making challenges in assessing CCL performance. Existing performance evaluation methodologies are reactive and rely on complex indictors applied in isolation. Performance assessments focus on specific objectives, neglecting trade-offs between speed, cost, and sustainability. Deterministic evaluations fail to account for the variability and uncertainty inherent in CCL operations. The dynamic nature of cold chains, influenced by disruptions, and seasonal fluctuations, further complicates development of performance indicators. These challenges impact existing frameworks' ability to guide real-time decisions, particularly in

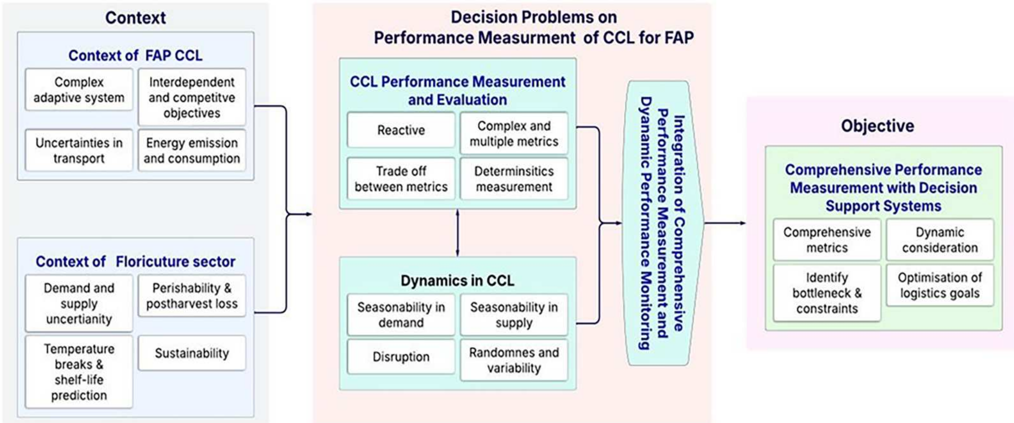

Figure 7. Conceptual research framework.

perishable sectors like floriculture. The proposed framework advocates the integration of comprehensive performance evaluation with dynamic performance monitoring and decision support systems.

The developed framework synthesise evidence from temperature variability, quality dynamics, cold chain logistics processes, performance evaluation, environmental conditions and connects with decision-making problems regarding CCL performance. It addresses the absence of an integrated perspective in the performance evaluation of CCL identified in the thematic analysis. It further moves beyond identifying the limitations of existing performance evaluation models. Based on Complex adaptive system theory, it conceptualises CCL as complex adaptive networks where performance emerges from interactions among perishability dynamics, operational process, environmental pressure, and decision-making response. In addition, it adopted dynamic capability theory by integrating the dynamic nature of CCL and how CCL actors should adopt dynamic performance monitoring to manage variability and uncertainty. The framework also introduces a new set of relationships that link contextual factors, performance measurement problems, dynamic environments, and performance decision-making processes. It consolidates previous research into an integrated structure that supports future empirical investigation and modelling in the CCL system. The framework also highlights the need for performance evaluation approaches that capture multiple dimensions and account for variability and uncertainty inherent in FAPs CCL. The conceptual framework was validated through the methodological rigour embedded in the systematic literature review. Its development adhered to PRISMA guidelines, ensuring transparent article selection, structured data extraction, systematic thematic synthesis, and the identification of cross-study patterns that collectively strengthen methodological validity. The constructs and relationships within the framework can be explicitly traced to the empirical evidence reported in the reviewed body of literature. The framework represents a synthesis of consistently observed constructs and empirically supported relationships documented across multiple independent investigations. The scope of the proposed framework is limited to the cold chain logistics context of the floriculture sector, and its components reflect the performance challenges and operational characteristics specific to this industry.

5. Discussion

A total of forty-eight peer-reviewed papers published between 2013 and 2024 were systematically reviewed to synthesise the current state of knowledge on CCL performance for FAPs. The study was motivated by the importance of cold chain systems in maintaining quality, minimising costs, and promoting sustainability within global fresh agricultural supply chains. Despite advancements in CCL research, a comprehensive perspective that integrates operational, economic, and environmental factors remains absent, limiting understanding of complex cold chain systems for FAPs and the floriculture sector.

5.1. Evolution and methodological orientation of CCL performance research

The descriptive analysis highlights growing academic attention towards CCL performance, particularly after 2018. Early publications focused on storage conditions, temperature control, and predictive tools for maintaining product freshness, while later studies shifted towards optimising and enhancing CCL efficiency, alongside data-driven solutions, integrating IoT and sensor-based monitoring systems. In addition, more recent research has delved into dynamic prediction and energy emissions of FAPs cold chains. These temporal trends reflect a shift from operational focus towards strategic and system-level CCL research. The evolution aligns with contemporary supply chain theory that conceptualise logistics networks as complex adaptive systems requiring an integral performance measurement framework.

The methodological review revealed most studies adopted quantitative approaches, primarily empirical and experimental quantitative strategies for performance assessment. These approaches have contributed to the advancement of knowledge in temperature dynamics, shelf-life prediction, cooling efficiency, and logistics optimisation. Nevertheless, the insufficient representation of qualitative and mixed approaches constraints the understanding of the human, organisational, and institutional dynamics that shape cold chain system performance. The dominance of purely quantitative approaches also leaves a methodological gap for mixed approaches that combine both quantitative and qualitative approaches. This methodological imbalance is a crucial challenge in the context of cold chains, where system failures in practice often stems from inadequate human decision making, lack of coordination among chain actors, and misaligned policies. In addition, in the floriculture sector, the application of dynamic simulations reflecting real-world uncertainties in cold chain systems in emerging economies remains relatively underexplored.

5.2. Geographic and sectoral contexts in CCL performance studies

While research focus in the field has increased, the distribution of publications remains uneven across regions and sectors. The geographic distribution of publications revealed that countries such as China, South Africa, the Netherlands, India, and Thailand dominate literature on CCL of FAPs, while major flower-exporting countries like Kenya and Ethiopia are underrepresented, showing a geographic bias. These countries are among the leading global flower exporters and face unique infrastructural, environmental, and socioeconomic challenges that merit contextual investigation to represent the upstream of the global floriculture supply chain. It also reflects that existing models are tailored to technologically advanced systems, limiting their applicability to developing contexts where most cold chain failures and postharvest losses occur. In addition, limited attention has been paid to cross-regional comparisons and the unique challenges faced by CCL operating across diverse climatic, regulatory, and infrastructural environments.

The contextual analysis underscores notable structural and conceptual distinctions among the fruits and vegetables, general perishables, and floriculture sectors. Research on fruits and vegetables dominates the literature, reflecting the sector's global expansion and its sensitivity to temperature and humidity variations. Studies in this area often focus on technical efficiency and optimisation. In contrast, the literature on general perishables adopts a more systemic perspective. These studies conceptualise cold chains as a complex adaptive system, and IoT-based monitoring frameworks and multi-echelon inventory models are utilised to assess performance. The floriculture sector remains less represented despite its global economic importance and distinct logistical challenges.

Existing studies focus on postharvest physiology and temperature control. The lack of integrated performance models hinders both scientific understanding and managerial decision-making within the sector. This gap calls for research given the unique logistical requirements of flowers, including temperature sensitivity, aesthetic quality, high perishability, short shelf-life, and demand volatility.

5.3. Thematic evolution in CCL performance research

The thematic analysis highlights the evolution of research priorities from temperature control and postharvest management towards optimisation and shelf-life prediction, energy efficiency and sustainability. These thematic transitions reflect a growing awareness of operational efficiency, data-driven decision making, and sustainability of CCL for FAPs. Temperature variation and postharvest management continue to be foundational to CCL, even minor deviations from optimal temperature can shorten shelf-life and increase waste. However, the operational implications for CCL, such as the management and control of temperature, are rarely explored. The findings revealed that majority of the studies have failed to link temperature monitoring and postharvest treatment practices to broader economic and environmental outcomes. Research on shelf-life predictions has shown notable methodological progress, transitioning from static kinetic models to adaptive and uncertainty-aware prediction systems. Nonetheless, the widespread application of these models across different perishable products remains limited, and they are not integrated into broader performance evaluation systems. Optimisation studies have also integrated optimisation with simulation models, representing an important shift towards practicability and adaptability. Despite this, the field still lacks a comprehensive system-level optimisation framework that connects postharvest handling, transport routeing, inventory control, and storage energy management. Moreover, existing studies overlook decision-making complexities faced by CCL managers in balancing quality, speed, cost, and sustainability under uncertain conditions. This fragmentation indicates a conceptual gap in the literature, especially in the floriculture sector, where product sensitivity and global supply chains necessitate effective logistics and continuous monitoring.

5.4. Performance measurement fragmentation and key research gaps

Performance evaluation studies employed multi-criteria frameworks like AHP, SCOR, and fuzzy-DEMATEL to design performance evaluation indicators for CCL. However, there is no consensus on standardised KPIs for CCL of FAPs, and performance measurement remains fragmented, often limited to few dimensions without a comprehensive framework. Thus, developing an adaptable and multi-dimensional performance framework, integrating operational, economic, and environmental dimensions, remains a priority. Studies focusing on environmental and sustainability themes present a conceptual advancement. The findings revealed that optimised longer cold chains can be efficient and reduce emissions, challenging the simplistic view that shorter supply chains are more sustainable. These insights suggest that evidence-based decarbonisation strategies, such as integrating renewable energy in cold storage and transport, should be designed to address the environmental concerns associated with CCL.

The literature review reveals several research gaps. The research output demonstrates a geographic imbalance, as many of the studies are conducted in developed regions with stable infrastructure and policy environments. However, emerging economies that are major exporters of FAPs and highly susceptible to cold chain failures are significantly underrepresented. A methodological gap, characterised by the underrepresentation of qualitative and mixed methods studies, limits insights into behavioural, managerial, and institutional determinants of performance. Conceptually, there is a lack of an integrated performance measurement framework for CCL of FAPs, particularly in the floriculture sector. Existing performance models fail to address the diverse decision problems encountered in practice, such as balancing speed with energy conservation, allocating cooling resources efficiently, and managing quality degradation while optimising costs. This limitation is critical for the floriculture sector, where product value is directly linked to logistics performance. The absence of cross-sectoral studies, standardised comprehensive performance metrics, and dynamic evaluation tools impedes efforts to benchmark and improve cold chain systems across cold chain stages and organisations.

5.5. Implications for an integrated conceptual framework in floriculture cold chains

To bridge the gaps identified above, this study proposes a conceptual framework for multi-dimensional and system-level analysis of CCL performance for FAPs, focusing on the floriculture sector. This framework integrates insights from the contexts of FAPs and floriculture into decision problems for CCL performance measurement. In addition, it connects micro-level disruption, temperature breaks or transport delays, to macro-level objectives such as sustainability. It also combines comprehensive performance indicators and dynamic performance evaluation to address the need for context-sensitive integrated performance measurement. The framework is particularly tailored for application in data-constrained and operationally complex settings, such as in the floriculture sector, but is also adaptable to other FAPs in emerging markets. It advances performance measurement of CCL by reframing CCL as a complex, adaptive, and context-dependent system rather than a linear logistics process. This conceptualisation aims to support the development of evidence-based policies, promote sustainability, and enhance the competitive advantages of floriculture exports.

6. Conclusion and implication

This systematic review synthesises research on CCL performance for FAPs, revealing key trends, methodological choices, thematic focus, and critical gaps in the literature. Although advancements have been made in temperature management and shelf-life prediction, the reviewed studies remain fragmented and often lack sectoral depth, geographic inclusivity, and methodological pluralism. The review highlights the need for integrated performance evaluation frameworks, particularly for sectors like floriculture, which have unique perishability challenges in complex global fresh agricultural supply chains. The conceptual framework developed can serve as a framework that facilitates performance analysis and informed decision-making in CCL systems, thereby contributing to bridging research gaps in the field.

6.1. Theoretical implications

This review extends performance measurement theory by demonstrating that the conceptual complexity in general supply chain management has not been adequately represented in special chains like cold chain logistics. The developed framework contributes to supply chain performance measurement theory by integrating insights from complex systems, dynamic capabilities, and contingency perspectives into a comprehensive performance model tailored for the distinct features of fresh agricultural cold chains. It adds a new theoretical perspective to reconceptualise performance measurement of cold chain management into context-specific, adaptable, and emergent behaviour of the system. The framework advances the field by guiding and offering a structure that incorporates sectoral characteristics and environmental uncertainties into the design of performance measurement systems. In addition, while complex adaptive systems and dynamic capabilities have been independently applied to supply chain contexts, the framework systematically integrates both perspectives into a comprehensive performance measurement framework for FAPs. Accordingly, it enhances the theoretical understanding of performance dynamics in fresh agricultural cold chains and establishes a foundation for future empirical testing. The review also contributes to the ongoing conversation about integrating sustainability into supply chain operations and performance measurement.

6.2. Conceptual implication

The conceptual implications of this study focus on redefining CCL performance assessment for FAPs and developing a comprehensive performance evaluation framework for the sector. This framework is based on real-world operational challenges and incorporates multiple performance dimensions, such as operational, economic, and environmental indicators. It goes beyond merely incremental refinement of existing performance approaches and represents a shift in how we conceptualise, measure, and manage CCL performance for FAPs. In addition, by explicitly demonstrating the relationship between small-scale disruptions like temperature breaks and transport delays and macro-level objectives such as sustainability, the framework operationalises and conceptually recognises a system level view. This dynamic and multilayered perspective allows for a thorough analysis of CCL performance for perishable and high-value products like flowers, where the extreme perishability and values sensitivity of the product make dynamic performance essential for commercial viability. It further serves as a foundation for developing models and metrics that connect theoretical concepts with practical applications.

6.3. Implication for policy makers

The framework guides policy makers to establish comprehensive and standardised performance frameworks and reporting requirements specific to the sector through engaging industry stakeholders. This facilitates the identification of best practices, enabling benchmarking, and creating accountability for performance improvement. In addition, in emerging economies, the development of a comprehensive performance framework assists policy makers in prioritise infrastructural investment decisions that address critical bottlenecks in high-value export sectors like floriculture. Moreover, it aids in guiding the design of regulatory frameworks and economic incentives to accelerate adoption of sustainable cold chain practices.

6.4. Managerial implication

The insights from the review and the developed conceptual framework will assist managers in designing adaptive performance frameworks that enable rapid adjustment of operations in response to changing conditions. It also offers practical tools and insights for managers to adopt multi-dimensional performance frameworks that balance quality, efficiency, and sustainability. It also supports managers in developing key performance indicators to evaluate their cold chain systems. Managers can use it to benchmark their operations, monitor performance, and make improvements to reduce losses and enhance product quality across the cold chain. In the floriculture sector, this integrated approach can help to enhance the competitiveness of cold chain systems, reduce post-harvest losses, and promote sustainable practices. In emerging economies, where infrastructural constraints and market volatility are pronounced, such frameworks are valuable for meeting international quality standards and strengthening competitive global market positions.

6.5. Limitations and future research direction

Despite its contributions, this study has several limitations. The review is limited to peer-reviewed journal articles indexed in Scopus and Web of Science, potentially overlooking valuable insights from regional studies and industry reports. The proposed conceptual framework, while grounded in literature synthesis, lacks empirical validation. Future research should prioritise empirical testing of an integrated simulation-based performance measurement approach for CCL and real-world cold chain system implementations, particularly in floriculture. Studies should explore how real-time monitoring and predictive analytics can be incorporated into dynamic decision support systems aligned with the structure of the framework. Furthermore, future studies should develop standardised performance metrics that capture operational, economic, and environmental objectives. Studies that combine real-time monitoring, stakeholder engagement, and scenario modelling are needed.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

This study is based on a systematic review of published literature. All data used in the analysis were obtained from publicly available peer-reviewed journal articles. The bibliographic dataset that supports the findings of this study is available from the corresponding author upon reasonable request.

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