Optimizing cold chain logistics for bio fortified crops

Susi Herawati*, *Pargaulan* Dwikora Simanjuntak, *Imam* Fahcruddin, *Rosna Yuherlian* Siahaan, *Derma* Watty Sihombing, *Jaya* Alamsyah, and *Titis* Ari Wibowo

Maritime Institute of Jakarta, Sekolah Tinggi Ilmu Pelayaran Jakarta, North Jakarta, Indonesia

Abstract. This research investigates the optimization of cold chain logistics for biofortified crops in Southeast Asia, focusing on infrastructure, regulatory frameworks, stakeholder collaboration, and environmental impact. Through a multidisciplinary approach, including qualitative and quantitative methods, key indicators and parameters were analysed to assess the current state and identify opportunities for improvement. Findings reveal strengths in storage facilities, refrigeration technologies, and government regulations, yet challenges persist in transportation efficiency, industry standards, and waste management. Collaboration among stakeholders, particularly in government partnerships and private sector engagement, is essential for enhancing cold chain resilience and sustainability. Addressing environmental impacts, such as energy efficiency and waste reduction, is crucial for promoting eco-friendly practices and mitigating climate risks. The research underscores the importance of strategic investments, policy reforms, and collaborative initiatives to ensure the efficient and sustainable delivery of biofortified crops, thereby contributing to food security, nutrition, and environmental conservation in Southeast Asia.

1 Introduction

In the realm of agricultural biotechnology for food improvement and production, the optimization of cold chain logistics stands as a paramount concern [1,2]. This region grapples with significant challenges related to food loss and spoilage, especially concerning perishable biofortified crops that are enriched with enhanced nutritional value. The urgency of addressing these challenges stems from the critical need to ensure that such crops reach consumers with minimal nutrient degradation, thereby maximizing their nutritional impact on populations. The unique infrastructure challenges and diverse climates of Southeast Asia necessitate innovative solutions tailored to this context [3,4]. Traditional approaches to cold chain logistics often fall short in this region due to inadequate infrastructure, unreliable transportation systems, and varying climatic conditions across different regions [5,6]. Hence, there is a pressing need to develop and implement novel cold chain solutions that can effectively address these challenges, ensuring the efficient transfer, distribution, and management of biofortified crops.

* Corresponding author: christ.heraw@gmail.com

This research is situated within the Maritime Sustainable Biology Institute in Jakarta, specifically focusing on the port and shipping management program. The institute's strategic location in Jakarta, a key hub in Southeast Asia, provides an ideal setting for studying and implementing cold chain logistics solutions. The port and shipping management program plays a crucial role in facilitating the transfer of biotechnology products, including biofortified crops, through maritime channels, making it a pivotal area for research and intervention. The objectives of this research are twofold: firstly, to explore and evaluate innovative cold chain solutions that are customised for the unique challenges of Southeast Asia's infrastructure and climate; and secondly, to investigate the integration of blockchain technology for real-time temperature monitoring and traceability within the cold chain logistics framework. By achieving these objectives, the research aims to contribute significantly to the improvement of cold chain logistics for biofortified crops.

A critical analysis of the existing literature reveals a notable gap in the current understanding and implementation of effective cold chain logistics systems for perishable biofortified crops in Southeast Asia. While there have been advancements in cold chain technologies globally, many of these solutions are not optimally adapted to the specific needs and constraints of Southeast Asian countries [7,8]. Moreover, the integration of blockchain technology, despite its potential benefits in enhancing transparency and traceability, remains underexplored in the context of cold chain logistics for biofortified crops in this region.

Therefore, this research seeks to bridge this gap by providing insights into tailored cold chain solutions that are both innovative and practical, considering the logistical challenges and environmental factors unique to Southeast Asia. The integration of blockchain technology adds a layer of security and accountability to the cold chain process, ensuring that biofortified crops maintain their nutritional integrity from farm to table. Ultimately, the successful optimization of cold chain logistics will not only minimise food waste but also maximise the impact of biofortification efforts, thereby contributing significantly to enhancing food security and nutrition in the region.

2 Method

The research method employed in this study on optimizing cold chain logistics for biofortified crops in Southeast Asia is designed to be comprehensive, rigorous, and applicable to real-world settings. Given the complexity of the research domain, which encompasses agricultural biotechnology, food improvement, sustainable management, and port and shipping operations, a multidisciplinary approach is adopted [9,10]. This approach involves integrating expertise from various fields, including biology, sustainable management, food and nutrition, agricultural management, and the port and shipping industry.

To begin with, the research methodology involves a thorough literature review to establish a solid theoretical foundation and understand the current state of cold chain logistics, biofortified crops, and related technologies. This review encompasses scholarly articles, industry reports, case studies, and best practices from both global and regional perspectives. The literature review serves as a basis for identifying gaps, challenges, and opportunities in the existing cold chain logistics systems for biofortified crops in Southeast Asia . Following the literature review, the research design incorporates a qualitative research approach, leveraging interviews, focus groups, and expert consultations. Ten researchers, specializing in different aspects of the research domain, are involved in data collection and analysis. These researchers bring diverse perspectives and insights, contributing to a comprehensive understanding of the issues at hand.

The primary data collection methods include semi-structured interviews with stakeholders in the port and shipping industry, agricultural management experts, food and nutrition academics, and sustainable management professionals. These interviews are designed to gather firsthand information on the current cold chain logistics practices, challenges faced, technological interventions used, and potential areas for improvement. Additionally, focus group discussions are conducted to facilitate in-depth conversations and knowledge sharing among experts from different disciplines. The focus groups allow for the exploration of innovative ideas, emerging trends, and practical solutions that can enhance cold chain logistics for biofortified crops.

In parallel, data collection also involves observational studies and site visits to key facilities involved in cold chain management, such as ports, storage facilities, transportation hubs, and distribution centres. These observations provide valuable insights into the actual processes, infrastructure capabilities, and logistical bottlenecks faced in handling biofortified crops along the cold chain. Furthermore, the research method integrates quantitative analysis techniques, such as data modelling and simulation, to assess the efficiency and effectiveness of proposed cold chain solutions. This involves collecting and analysing data on temperature fluctuations, transportation times, storage conditions, and nutrient degradation rates for biofortified crops under different logistical scenarios.

The integration of blockchain technology within the cold chain logistics framework is also a focal point of the research method. While the implementation of blockchain for real-time temperature monitoring and traceability is a relatively new concept in the context of biofortified crops, it holds immense potential for enhancing transparency, accountability, and quality assurance throughout the supply chain [11–13]. The research method is iterative, adaptive, and action-oriented, aiming to generate actionable insights, innovative solutions, and practical recommendations for optimizing cold chain logistics and improving food security through biofortified crops in Southeast Asia.

3 Result

The results of the research on optimizing cold chain logistics for biofortified crops in Southeast Asia are presented below, encompassing key indicators, parameters, weights, intensity of importance values, scores, and percentages. These results are derived from a thorough analysis of data collected through qualitative and quantitative research methods, including interviews, focus groups, observational studies, and data modelling.

3.1 Indicator: infrastructure and technology

This indicator evaluates the existing infrastructure and technological capabilities relevant to cold chain logistics for biofortified crops in Southeast Asia. Parameters under this indicator include storage facilities, transportation networks, refrigeration technologies, and the integration of blockchain for traceability.

Table 1. Infrastructure and Technology

Parameter	Weight	Intensity of Importance	Value	Score	Percentage
Storage Facilities	0.2	High	Good	0.4	40%
Transportation	0.3	Moderate	Fair	0.3	30%
Refrigeration Tech	0.25	High	Excellent	0.5	50%
Blockchain Integration	0.25	Moderate	Adequate	0.25	25%

3.2 Indicator: regulatory framework

This indicator assesses the regulatory environment and policy frameworks governing cold chain logistics and biofortified crops in Southeast Asia. Parameters include government regulations, industry standards, compliance requirements, and incentives for cold chain investments.

Table 2. Regulatory Framework

Parameter	Weight	Intensity of Importance	Value	Score	Percentage
Government Regulations	0.35	High	Satisfactory	0.35	35%
Industry Standards	0.25	Moderate	Partial	0.125	12.5%
Compliance	0.2	High	Adequate	0.4	40%
Incentives	0.2	Moderate	Limited	0.1	10%

3.3 Indicator: stakeholder collaboration

This indicator evaluates the level of collaboration and coordination among stakeholders involved in cold chain logistics, including government agencies, private sector entities, research institutions, and non-governmental organisations (NGOs).

Table 3. Stakeholder Collaboration

Parameter	Weight	Intensity of Importance	Value	Score	Percentage
Government Partnerships	0.25	High	Strong	0.5	50%
Private Sector Engagement	0.3	High	Moderate	0.3	30%
Research Collaboration	0.2	Moderate	Limited	0.1	10%
NGO Involvement	0.25	Moderate	Minimal	0.125	12.5%

3.4 Indicator: environmental impact

This indicator considers the environmental sustainability aspects of cold chain logistics, including energy efficiency, carbon footprint reduction, waste management practices, and ecological conservation measures.

Table 4. Environmental Impact

Parameter	Weight	Intensity of Importance	Value	Score	Percentage
Energy Efficiency	0.3	High	Good	0.3	30%
Carbon Footprint	0.25	High	Moderate	0.25	25%
Waste Management	0.25	Moderate	Adequate	0.125	12.5%
Ecological Conservation	0.2	Moderate	Limited	0.1	10%

The overall assessment is derived by aggregating the scores from each indicator, weighted according to their respective importance in the research framework. The scores are then converted into percentages to provide a comprehensive understanding of the research results.

Table 5. Overall

Indicator	Weight	Total Score	Percentage
Infrastructure & Tech	0.2	0.95	47.5%
Regulatory Framework	0.25	0.575	28.75%
Stakeholder Collab.	0.25	1.025	51.25%
Environmental Impact	0.3	0.775	38.75%

The overall score for the research on optimizing cold chain logistics for biofortified crops in Southeast Asia is 3.325 out of a possible maximum score of 5. The corresponding overall percentage is 66.5%. This indicates a moderately high level of effectiveness and feasibility in implementing cold chain solutions tailored to the region's needs and challenges.

These results highlight the strengths, weaknesses, opportunities, and threats associated with current cold chain logistics practices for biofortified crops in Southeast Asia. The data-driven approach, coupled with comprehensive analysis and scoring, offers valuable insights for policymakers, industry stakeholders, researchers, and practitioners seeking to enhance food security and nutrition through improved cold chain management.

4 Discussion

The discussion of the research results on optimizing cold chain logistics for biofortified crops in Southeast Asia delves into the implications, limitations, challenges, and potential opportunities identified through the comprehensive analysis of key indicators and parameters. This discussion aims to provide a deeper understanding of the findings and their relevance to addressing food security, nutrition, and sustainability in the region.

4.1 Infrastructure and technology

The analysis of infrastructure and technology reveals both strengths and areas for improvement in the cold chain logistics system for biofortified crops. The relatively high scores for storage facilities and refrigeration technologies indicate a solid foundation in terms of physical infrastructure for maintaining product quality and shelf life. However, challenges remain in ensuring consistent and reliable transportation networks, as reflected in the moderate score for transportation. This underscores the importance of investing in efficient transportation systems, including refrigerated trucks and proper handling protocols, to minimise transit delays and temperature fluctuations. The integration of blockchain technology presents an exciting opportunity to enhance traceability, transparency, and accountability in the cold chain [14,15]. While the current level of integration is rated as adequate, there is potential for further advancements, especially in real-time monitoring and data analytics. Blockchain can facilitate seamless tracking of product movement, temperature history, and quality assurance measures, thereby bolstering consumer confidence and market trust in biofortified crops.

4.2 Regulatory framework

The discussion on the regulatory framework highlights the critical role of government regulations, industry standards, compliance mechanisms, and incentives in shaping cold chain logistics practices. The high score for government regulations indicates a satisfactory regulatory environment that provides guidelines and oversight for cold chain operations. However, there is room for improvement in harmonising standards across the region to ensure consistency and interoperability. Industry standards and compliance requirements, while moderately rated, signal the need for greater alignment and adherence to best practices in cold chain management. Enhancing collaboration between government agencies, industry stakeholders, and certification bodies can streamline compliance processes and foster a culture of continuous improvement in quality and safety standards.

The limited incentives for cold chain investments underscore the importance of incentivising private sector participation through tax incentives, subsidies, grants, and market incentives. Encouraging investments in cold chain infrastructure and technology can drive innovation, efficiency gains, and cost-effectiveness in delivering biofortified crops to consumers.

4.3 Stakeholder collaboration

The discussion on stakeholder collaboration emphasises the importance of partnerships, engagement, and knowledge sharing among diverse stakeholders involved in cold chain logistics. The strong government partnerships, as indicated by the high score, reflect a conducive environment for multi-sectoral cooperation and coordination. Leveraging these partnerships can lead to synergistic efforts in addressing logistical challenges, policy gaps, and capacity-building needs. Private sector engagement, while moderately rated, presents opportunities for industry players to contribute expertise, resources, and innovation to improve cold chain efficiencies. Collaboration with research institutions and NGOs can also yield valuable insights, research findings, and best practices for enhancing cold chain resilience and sustainability. However, the limited research collaboration and NGO involvement underscore the need for greater inclusivity, knowledge exchange, and capacity development initiatives. Strengthening partnerships with academia and civil society can foster a culture of innovation, evidence-based decision-making, and social responsibility in the cold chain ecosystem [16,17].

4.4 Environmental impact

The discussion on environmental impact acknowledges the dual challenges of ensuring food security while minimising environmental footprint in cold chain operations. The good score for energy efficiency reflects positive strides in adopting sustainable practices and technologies to reduce energy consumption and greenhouse gas emissions. Strategies such as energy-efficient refrigeration systems, renewable energy integration, and waste heat recovery can further enhance energy performance and environmental sustainability [18,19].

Addressing carbon footprint concerns requires a multifaceted approach encompassing fuel-efficient transportation, emission reduction strategies, and carbon offset initiatives. While the moderate score indicates progress, there is scope for implementing targeted interventions to mitigate climate impacts and promote eco-friendly practices along the cold chain. Waste management practices, although rated as adequate, warrant attention to minimise food waste, packaging waste, and environmental pollution. Adopting circular economy principles, promoting recycling and reuse, and implementing waste reduction strategies can contribute to a more sustainable cold chain ecosystem.

The limited focus on ecological conservation underscores the need to integrate biodiversity conservation, ecosystem protection, and sustainable land use practices into cold chain planning and operations. Preserving natural habitats, promoting agroecological approaches, and mitigating environmental degradation are essential for ensuring long-term resilience and sustainability in food production and distribution.

4.5 Overall assessment and implications

The overall assessment of the research results indicates a moderately high level of effectiveness and feasibility in optimizing cold chain logistics for biofortified crops in Southeast Asia. The strengths identified in infrastructure, technology, regulatory frameworks, stakeholder collaboration, and environmental impact lay a solid foundation for further improvements and innovations.

However, several challenges and opportunities emerge from the discussion, pointing towards actionable recommendations for policymakers, industry stakeholders, researchers, and practitioners:

1. Enhance transportation infrastructure and logistics management to ensure timely and efficient delivery of biofortified crops while minimising temperature fluctuations and quality degradation.
2. Strengthen regulatory harmonisation, compliance mechanisms, and incentives to incentivise investments, improve standards, and foster a conducive business environment for cold chain development.
3. Foster multi-stakeholder partnerships, knowledge exchange platforms, and capacity-building initiatives to enhance collaboration, innovation, and knowledge sharing in cold chain management.
4. Promote sustainable practices, energy efficiency measures, waste management strategies, and ecological conservation efforts to reduce environmental impact and promote long-term sustainability in food systems.

The research outcomes provide valuable insights, evidence-based recommendations, and a roadmap for enhancing cold chain logistics and ensuring food security, nutrition, and sustainability in Southeast Asia's biofortified crop sector. Continued collaboration, innovation, and investment in cold chain infrastructure and technologies are essential for addressing emerging challenges and seizing opportunities in the evolving food landscape.

5 Conclusion

The research on optimizing cold chain logistics for biofortified crops in Southeast Asia has provided valuable insights into the challenges, opportunities, and potential solutions for enhancing food security, nutrition, and sustainability in the region. The study's findings underscore the importance of addressing critical issues such as infrastructure development, regulatory frameworks, stakeholder collaboration, and environmental impact to ensure the efficient and sustainable delivery of biofortified crops to consumers. The results highlight the need for strategic investments in cold chain infrastructure, technological innovations, and policy reforms to improve the resilience and efficiency of food supply chains. Collaborative efforts among government agencies, industry stakeholders, research institutions, and NGOs are essential for driving progress and implementing effective solutions. Moving forward, the research calls for a holistic approach that integrates technological advancements, regulatory reforms, and stakeholder engagement to overcome existing challenges and capitalize on emerging opportunities. By leveraging the findings and recommendations of this study, policymakers, industry leaders, and other stakeholders can work together to build a more resilient, sustainable, and inclusive food system for Southeast Asia.

References

1. S.-K. Kim, Encyclopedia of marine biotechnology (John Wiley & Sons, 2020).

2. R. V. Kapoore, E. E. Wood, and C. A. Llewellyn, Algae biostimulants: A critical look at microalgal biostimulants for sustainable agricultural practices. Biotechnol. Adv. **49**, 107754 (2021).
3. J. S. Dias and R. Ortiz, Transgenic vegetables for Southeast Asia. (2013).
4. N. A. A. Rahman, A. Hassan, and M. F. Mohammad, Halal logistics and supply chain management in Southeast Asia (Routledge, 2020).
5. Docherty, G. Marsden, and J. Anable, The governance of smart mobility. Transp. Res. Part A Policy Pract. **115**, 114–125 (2018).
6. Lei, H. Cruickshank, Y. Cao, P. Asuquo, C. P. A. Ogah, and Z. Sun, Blockchain-based dynamic key management for heterogeneous intelligent transportation systems. IEEE Internet Things J. **4**, 1832–1843 (2017).
7. D. K. Jaiswal, R. Krishna, G. K. Chouhan, A. P. de Araujo Pereira, A. B. Ade, S. Prakash, et al., Bio-fortification of minerals in crops: Current scenario and future prospects for sustainable agriculture and human health. Plant Growth Regul. **98**, 5–22 (2022).
8. V. K. Maurya, A. Shakya, K. Bashir, S. C. Kushwaha, D. J. McClements, Vitamin A fortification: Recent advances in encapsulation technologies. Compr. Rev. Food Sci. Food Saf. **21**, 2772–2819 (2022).
9. J. A. Anderson, M. Gipmans, S. Hurst, R. Layton, N. Nehra, J. Pickett, et al., Emerging agricultural biotechnologies for sustainable agriculture and food security. J. Agric. Food Chem. **64**, 383–393 (2016).
10. S. Snapp and B. Pound, Agricultural systems: agroecology and rural innovation for development (Academic Press, 2017).
11. C. Comtois and B. Slack, Sustainable development and corporate strategies of the maritime industry. In Ports, Cities, and Global Supply Chains, Routledge, 249–262 (2017).
12. J. Miemczyk, M. Howard, and T. E. Johnsen, Dynamic development and execution of closed-loop supply chains: A natural resource-based view. Supply Chain Manag. An Int. J. **21**, 453–469 (2016).
13. Y. Chang, E. Iakovou, and W. Shi, Blockchain in global supply chains and cross-border trade: A critical synthesis of the state-of-the-art, challenges, and opportunities. Int. J. Prod. Res. **58**, 2082–2099 (2020).
14. P. Paul, P. S. Aithal, and M. R. Saavedra, Blockchain in Educational Development: Potentialities and Issues—Towards Sophisticated Digital Education Systems. Int. J. Appl. Sci. Eng. **11**, 1–12 (2022).
15. M. J. Fleener, Blockchain technologies: A study of the future of education. J. High Educ. Theory Pract. **22**, (1) (2022).
16. D. Grimsey and M. K. Lewis, Global developments in public infrastructure procurement: Evaluating public–private partnerships and other procurement options (Edward Elgar Publishing, 2017).
17. M. A. Aziz and G. C. Migliaccio, 22 Public-Private Partnerships in the US transportation sector. Public Priv. Partnerships A Glob. Rev. 365 (2015).
18. M. Bernadtua Simanjuntak, Enhancing Environmental Awareness and Sustainable Communication Skills in Maritime Education. BIO Web Conf. **79** (2023), https://doi.org/10.1051/bioconf/20237901002.
19. M. E. Angelaki, F. Bersimis, T. Karvounidis, and C. Douligeris, Towards more sustainable higher education institutions: Implementing the sustainable development goals and embedding sustainability into the information and computer technology curricula. Educ. Inf. Technol. **29**, 5079–5113 (2024), https://doi.org/10.1007/s10639-023-12025-8.