Supply Chain Optimization for Fresh Fruits and Vegetables: Barriers and Solutions

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Posted Date: 10 April 2025

doi: 10.20944/preprints202504.0877.v1

Keywords: Supply chain; Post harvest losses; Fruits and vegetables; Cold chain logistics

 doi:10.20944/preprints202504.0877.v1

Article

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Abstract: The fruits and vegetables (F&V) supply chain is beset by enormous challenges, especially in India, with post-harvest losses ranging from 30–40% and cold chain infrastructure inefficiencies, fragmented networks, and technology gaps that limit export opportunities and domestic food security. This research highlights major issues like lack of proper storage, transportation bottlenecks, farmer unawareness, and irregular quality standards as major contributors to wastage and economic loss. In response to these challenges, optimization practices such as cold chain logistics, Just-in-Time (JIT) inventory systems, IoT-based monitoring, and circular economy strategies are suggested. Also, cooperative supply chain structures, R&D investments, and consumer education are prioritized to make the system more transparent, sustainable, and resilient. Through the incorporation of demand forecasting, sophisticated inventory management, and public-private partnerships, this study emphasizes implementable solutions in mitigating PHL, enhancing supply chain effectiveness, and aligning India's F&V sector with international standards of quality.

Keywords: supply chain; post harvest losses; fruits and vegetables; cold chain logistics

1. Introduction

Consumer perception and the physicochemical characteristics of horticultural commodities combine to form the quality of fruits and vegetables. The difficulties in establishing a common definition of quality for horticultural products are partly caused by the numerous parties involved in the supply chain, each of whom functions essentially as a consumer with respect to the previous chain link [1]. According to a general definition, fruits are "the portions of plants which bear seeds." Such a definition encompasses compound fruits like berries, false fruits like apples and pears, and true fruits like citrus [2]. Vegetables are the fresh plant parts that, when consumed raw, cooked, canned, or in another form, offer adequate nutrition for humans [3]. In other words, "A vegetable is "an edible, typically succulent plant or part of it consumed with staples as main meal or supplementary food in cooked or raw state" [4]. By optimizing the current inventory, supply chain management aims to guarantee that the product is delivered at the appropriate time and location. The Supply Chain Operations Reference (SCOR), which emphasizes internal, customer, and shareholder values, contains components that can be used to gauge supply chain performance. The SCOR model provides a total view of supply chain drivers, but it is possible to modify it to suit the object in question under review [5]. To make a balanced diet, there is more demand for such products because the world is developing and becoming increasingly concerned about health and nutrition [6]. India's export market share in the fruit and vegetable sector, however, is not encouraging. The inability to achieve

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quality and safety requirements and excessive post-harvest losses (PHL) are the main reasons for such a low export market share. Much of the produce is lost due to excessive postharvest losses, so little or no quantity remains to be exported [7]. In India, the wastage occurring in the inefficient post-harvest stages of the supply chain annually accounts for roughly 33.1% of the total production. Among the fruits and vegetables, the percentage of production losses was 15.88% for guava, 12.44% for tomatoes, 10.39% for apples, 9.69% for citrus, 9.56% for cauliflower, 9.37% for cabbage, and so on [7]. Additionally, most countries around the world do not meet their quality and safety standards. This study examines supply chains (SCs) that handle perishable goods with a short shelf life from production to delivery; these are known as agri-fresh food supply chains (AFSCs). Because of this, an AFSC begins with farmers producing crops and concludes with delivery to customers via various distribution companies. When it comes to things like product bulkiness and perishability, seasonal and dispersed production, high quality and quantity variability, and particular logistics service requirements, AFSCs are different from other SCs [7]. These characters result in difficult SC management issues. The following are the aims of study;

- Examine inefficiencies in supply chains, such as losses, infrastructure deficits, and coordination issues.
- Evaluate technological and logistical interventions to enhance resilience and mitigate waste.
- Build models for partnership, investment, and adoption of circular economy.
- Establish policies regarding standards of quality, logistics, and empowerment of farmers.

2. Current Issues with Fresh Produce Supply Chains in India

The main problems influencing India's fresh produce supply chains are examined in detail below [8]:

- Damages sustained during storage and transit
- The absence of suitable technologies, sophisticated methods, funds, and expertise among collaborators
- Insufficient knowledge regarding the movement of goods and markets
- Insufficient supply chain transparency
- Monitoring and traceability
- Less oversight of product quality and safety throughout the supply chain
- Partners in the chain share significant risks and investments.
- Products with a short shelf life
- Farmers' ignorance and lack of awareness
- Absence of post-harvest facilities, such as storage

3. Strategies for Supply Chain Optimization

3.1. Supply Chain Optimization Introduction

The methodical process of improving different supply chain components in order to increase value, lower costs, and improve efficiency is known as supply chain optimization. Optimizing supply chains is essential for reducing losses at every stage of the food waste process, from production to consumption. Organizations can successfully address inefficiencies that lead to food waste by optimizing procedures, enhancing stakeholder coordination, and putting best practices into place. Supply chain optimization is important because it can improve sustainability and resource use. In addition to cutting waste, effective supply chains also save operating expenses, which boosts company profitability [9]. Moreover, food items can be transported on schedule, with minimal wastage and freshness assured, by optimizing logistics and stock management.

3.2. Demand Prediction

 doi:10.20944/preprints202504.0877.v1

One of the most important components of supply chain optimization is calling for forecasting, through which companies can exactly forecast customer demand and adjust production as well as stock levels accordingly. Food wastage can be minimized by effectively predicting demand, which ensures that the supply tightly reflects actual market needs. Many methods and technologies are employed to make demand forecasting more accurate. Patterns in historical sales records are frequently determined through the use of classical statistical techniques like time series analysis and moving averages. These techniques give a simple insight into patterns of demand over time. They might not, however, adequately record abrupt changes within the market or shifts in consumer behavior.

Implementation of advanced technologies, including machine learning (ML) and artificial intelligence (AI), is enhancing demand forecasting. The technologies scan more data from different sources, such as social media trends, weather, and sales transactions, to reveal complex demand patterns and make more accurate predictions [10]. In addition, cloud-based platforms allow for instant integration of data and stakeholder participation, through which a more responsive reaction is made to demand variations. Companies can reduce overproduction, optimize stock levels, and eventually reduce food waste throughout the supply chain by applying these methods and technologies.

3.3. Inventory Management

In food supply chains, food waste can be limited only with good inventory control. Companies can reduce losses by making sure perishable items are consumed before they rot by having the right amount of stock. In an effort to enhance overall effectiveness and inventory control, several techniques can be applied. One of the approaches is just-in-time (JIT) inventory systems. Another effective strategy is the implementation of advanced inventory tracking technologies such as barcode and RFID (Radio Frequency Identification) systems. With the help of these technologies, reordering is possible at the earliest while overstocking can also be prevented due to their real-time tracking of product status and inventory levels [11]. Inventory management software can also make operations streamlined by automating operations such as order processing, demand planning, and inventory replenishment. These software applications can assist businesses in making sound decisions by providing meaningful data about the performance of the inventory. Through the adoption of these inventory management methods, companies can enhance productivity, reduce waste, and contribute to creating a sustainable food supply chain.

3.4. Cold Chain Logistics

These cold chain logistics are required in order to preserve perishable food products' safety and quality throughout the supply chain. To reduce food wastage, prevent food from deteriorating, and maintain consumer safety, a uniform temperature is critical. Cold chain logistics efficiency and losses can be significantly enhanced through the application of best practices. One of the standard practices is employing temperature-controlled transport vehicles, which are equipped with refrigeration systems to ensure that every product is transported at the correct temperature. The tracking of such temperature conditions on a routine basis using IoT (Internet of Things) tools allows real-time tracking and alerting in case temperature variations are observed [12].

3.5. Just-in-Time (JIT) Inventory Systems

Nothing is wasted with Just-in-Time (JIT) inventory systems, as the inventory levels are closely matched to actual demand. This system has a number of advantages, especially in food waste reduction and improving operational efficiency. One of the main advantages of JIT is that it eliminates a major component of holding costs, i.e., inventory storage. By receiving goods only when they are required in the production process, companies can reduce storage costs and reduce spoilage,

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particularly for perishable products [13]. Moreover, JIT systems enhance cash flow, as money is not invested in unnecessary inventory, providing room for reinvestment in other business sectors.

3.6. Approaches for Circular Economy

Compared to the traditional linear trend of "take, make, dispose," the circular economy principles focus on waste reduction and stimulating continuous use of resources. These concepts can be effectively implemented in agriculture to reduce food waste, enhance sustainability, and ensure optimum use of resources. One of the vital elements of the practice of circular economy in farming is closing the loop in food production. It entails reducing the amount of total waste by reclaiming waste products and by-products as inputs into another process. For example, waste from processing organic food may be used in producing a soil amendment that is nutrient-rich, ensuring healthier plants and reducing dependence on chemical fertilizers [14].

3.7. Optimization Strategies Summary

Optimization techniques are important in preventing food waste in the agricultural supply chain by eliminating inefficiencies and maximizing resource use. Overall, these techniques promote a more sustainable and efficient system that minimizes losses from consumption to production. Demand forecasting methodologies allow producers to match production with real-world market demand, minimizing overproduction and waste as a consequence to a great degree. Proper management of stocks, especially under Just-in-Time (JIT) systems, means that products that perish before sale are dispatched before they perish, reducing losses entailed by dead stock.

4. Fruit and Vegetable Supply Chain Issues and Challenges in India

A number of factors will obstruct the fruit and vegetable industry's effective supply chain in India. While determining the dimensions of various factors, the authors have attempted to compile and classify these factors. Cold chain problems, supply chain fragmentation problems, linkage and integration problems, infrastructure problems, packaging problems, technological problems, problems with farmers' knowledge and awareness, problems with quality and safety, problems with processing, problems with supply chain efficiency, financial problems, problems with post-harvest losses, problems with transportation, and problems with information. Chronic variables have been identified in various states. In order to develop mitigation strategies, some of these factors must be evaluated in various states based on their markets and demographics.

Table 1. The main problems with India's fruit and vegetables (F&V) supply chain and the respective solutions.

Category	Key Issues	Mitigation Strategies
Cold Chain [15]	Lack of cold and warehousing facilities, Inadequate capacity, fragmented network.	Increase cold chain networks, make investments in cold storage infrastructure, and form public-private partnerships.
Fragmented Supply Chain [16]	Farmers' income is being reduced by too many intermediaries, as well as the prevalence of commission and local agents.	Promotes direct farmer-market linkages; establish farmer cooperative, The state

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		government could act as a village-level aggregator at the producer level.
Integration [16]	Insufficient forward and backward integration among interested parties Due to farmers' small landing sizes, the marketing channel has poor linkage from the farm gate to the mandi.	Promote contract farming and cultivate alliances among farmers, retailers, and processors.
Infrastructure [17]	In rural and hilly areas, poor connectivity, inadequate loading and unloading facilities, and poor packaging.	Improve storage facilities and roadways; create hubs for rural infrastructure.
Packaging [17]	High packaging costs; improve handling leading to spoilage.	Subsidize affordable packaging materials; train farmers on standardized packaging.
Technology [18]	Outdated machinery/techniques; low tech adoption.	Modernize equipment (e.g., IoT sensors); provide subsidies for technology adoption.
Farmer Knowledge [17]	Low awareness of post-harvest practices, quality seeds and technology.	Conduct training programs; disseminate knowledge via extension services.
Quality & Safety [18]	Poor hygiene, inconsistent standards, and quality degradation.	Enforce quality certifications (e.g., FSSAI); implement safety audits.
Processing & Addition [18]	Low processing rates (1-2%); limited proximity to processing units.	Establish localized processing units; incentivize value-added product development.

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Financial [19]	Low farmer income; pricing opacity in mandis.	Implement transparent pricing systems (e.g., e-NAM); improve access to credit and insurance.
Post Harvest-Losses [20]	30-40% losses due to poor storage/transport.	Expand cold chain access; adopt pre-cooling techniques and better inventory management.
Transportation [21]	Lack of refrigerated vehicles; high transport costs.	Invest in refrigerated transport fleets; optimize logistics routes.
Market Demand & Information [21]	Farmers lack real-time price/demand information.	Develop digital platforms (e.g., mobile app) for market data sharing.

5. The Supply Chain's Future for Fresh Produce

With the fresh produce sector ongoing evolution, the role of a flexible and robust supply chain cannot be emphasized enough. The issues raised in this article highlight the imperative for ongoing innovation, cooperation, and investment in new technologies and green practices.

5.1. Cooperative Supply Chain Frameworks

Impact: Stakeholder collaboration across supply chains, involving farmers, distributors, retailers, and technology providers, is key to breaking through challenges and streamlining efficiency. Cooperative models, such as collaborative distribution networks and joint ventures, lower costs and supply chain resilience.

Application: Businesses may pursue collaborations with logistics companies and technology businesses to create integrated supply chain solutions. Such collaborations can exploit common facilities, including transportation and storage facilities, in order to streamline operations and minimize expenses.

5.2. Investment in Research and Development

Impact: To drive innovation in the supply chain for fresh produce, ongoing investment in research and development (R&D) is needed. To enhance the quality and sustainability of fresh produce, R&D can focus on creating new varieties of crops, innovative processing technologies, and advanced packaging technologies.

Application: Projects for supply chain management improvement, post-harvest care, and farm operations could be funded. Innovation and the use of new technology can be encouraged by collaboration with academic centers and research institutions.

5.3. Consumer Engagement and Education

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Effect: Demand for sustainably produced products is heightened when consumers are educated on the importance of sustainable practices in the supply chain of fresh produce. Higher-educated customers are more likely to patronize companies that are concerned about the environment and social responsibility.

Application: Companies may initiate consumer outreach programs focusing on their support for sustainability and environment. Higher levels of transparency due to third-party certification and traceability networks will also generate more customer trust and loyalty.

6. Conclusion

Implementation of new measures will take care of post-harvest waste, integrated infrastructure, and below-par cold chain logistics and streamline the entire value chain, giving the consumer fresh, affordable produce at fair prices. A number of key strategies, such as AI/ML-powered demand planning, Just-in-Time inventory planning, and refrigeration technology investment, can reduce spoilage and increase productivity. Enhancing transparency and streamlining operations call for the creation of strong collaborative frameworks among stakeholders, such as farmers, legislators, and private sector actors. Farmers also need to be trained in post-harvest practices, technology utilization, and circular economy principles that transform agricultural waste into value-added resources. India's own internal issues, like inadequate transportation and meagre finance, necessitate focus on digital traceability, eco-friendly practices, and in-built processing centers. Thus, India can turn its agri-fresh supply chain into a robust, future-ready network that will enhance export competitiveness, minimize wastage, and offer consumers fresher, safer produce.

References

1. Kyriacou, M. C., & Rouphael, Y. (2018). Towards a new definition of quality for fresh fruits and vegetables. *Scientia Horticulturae*, *234*, 463-469.
2. Roberts, T. A., Cordier, J. L., Gram, L., Tompkin, R. B., Pitt, J. I., Gorris, L. G. M., & Swanson, K. M. J. (2005). Fruits and fruit products. In *Micro-Organisms in Foods 6: Microbial Ecology of Food Commodities* (pp. 326-359). Boston, MA: Springer US.
3. Belitz, H. D., Grosch, W., Schieberle, P., Belitz, H. D., Grosch, W., & Schieberle, P. (2004). Vegetables and vegetable products. *Food chemistry*, 772-805.
4. Tsao, S. J. J., & Lo, H. F. (2003). I. DEFINITION OF A VEGETABLE. *Handbook of Vegetable Preservation and Processing*, 1.
5. Guritno, A. D., Fujianti, R., & Kusumasari, D. (2015). Assessment of the supply chain factors and classification of inventory management in suppliers' level of fresh vegetables. *Agriculture and Agricultural Science Procedia*, *3*, 51-55.
6. Vasant P. Gandhi, Zhangyue Zhou, (2014), Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China, *Food Research International*, Volume 63, Part A, Pages 108-124, https://doi.org/10.1016/j.foodres.2014.03.015.
7. Kumar, A., & Agrawal, S. (2023). Challenges and opportunities for agri-fresh food supply chain management in India. *Computers and Electronics in Agriculture*, *212*, 108161.
8. Singh, S. P., Sikka, B. K., & Singh, A. (2009, June). Supply chain management and Indian fresh produce supply chain: opportunities and challenges. In *19th Annual World Symposium of the International Food & Agribusiness Management Association*.
9. Cuthbertson, R., & Piotrowicz, W. (2011). Performance measurement in supply chain management: A review. International Journal of Logistics Management, 22(3), 293-303.
10. Chong, A. Y.-L., Lo, C. K. Y., & Weng, X. (2017). The role of big data analytics in supply chain management: A review. International Journal of Production Economics, 193, 130-143.
11. Akkerman, R., Farahani, R. Z., & Grunow, M. (2010). Fulfilling consumers' demand while reducing food waste: A review of food supply chain management. Waste Management, 30(2), 100-114.

 doi:10.20944/preprints202504.0877.v1

12. Kumar, S., Singh, P., & Kumar, A. (2017). A comprehensive review of cold chain logistics: A case of perishable food products. Journal of Food Science and Technology, 54(3), 522-534.
13. Cohen, L., & Roussel, J. (2013). Strategic Supply Chain Management: The Five Core Disciplines for Top Performance. McGraw-Hill.
14. Ellen MacArthur Foundation. (2019). Completing the Picture: How the Circular Economy Tackles Climate Change. Retrieved from Ellen MacArthur Foundation.
15. Jain, N. (2007). International Conference on Agribusiness and Food Industry in Developing Countries: Opportunities and Challenges, from IIM lucknow: http://www.iiml.ac.in/events/P1_02_Neeraj_Jain.pdf
16. atyanarayana, A., Math, R. G., Jyothirmayi, T., & Rao, D. G. (2007). International Conference on Agribusiness and Food Industry in Developing Countries: Opportunities and Challenges. Retrieved January 22, 2014, from IIM Lucknow website: http://www.iiml.ac.in/events/C5_03_A_Satyanarayana.pdf
17. Sharma, G., & Singh, S. (2011). Economic Analysis of Post-harvest Losses in Marketing of Vegetables in Uttarakhand. Agricultural Economics Research Review, 24, 309-315.
18. Kapoor, P. (2009, July 28). Doctoc-International Summit on Food Processing and Agribusiness: http://www.docstoc.com/docs/127265667/ENTREPRENEURIAL-OPPORTUNITIES-IN-THE-AGRI-BUSINESS
19. Ramesh, S. (2009, July 28). Food Processing Sector in India-Challenges and Oppurtunities-KPMG. http://www.scribd.com/doc/39050239/Food-Process-Sing-Opportunities-in-India-Ppt
20. Veena, Babu, K. N., & Venkatesha, H. R. (2011). Supply Chain: A Differentiator in Marketing Fresh Produce. The IUP Journal of Supply Chain Management, VIII (I), 23-36.
21. Narula, S. A. (2011). Reinventing cold chain industry in India: need of the hour.Interview with Mr Sanjay Aggarwal. Journal of Agribusiness in Developing and Emerging Economies, 1 (2)