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MINI-REVIEW

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From Farm to Fork: Improving Fresh Fruit and Vegetable Transport to Minimize Losses

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Conflict of Interest

The authors assert that the manuscript was developed without any commercial or financial associations that could be interpreted as a potential conflict of interest.

Authors Contribution

All listed authors have contributed significantly, directly, and intellectually to the work and have endorsed it for publication.

Abstract

Fruits and vegetables are essential for human health, providing vital nutrients and phytochemicals. However, significant losses occur during transportation, particularly in countries like India, which is the second-largest producer but faces 25-30% losses due to transport and storage inefficiencies. Globally, about one-third of food products are lost annually, costing $8.3 billion and affecting food security. The Farm to Fork Strategy seeks to improve the sustainability and efficiency of the food supply chain. This article reviews current transportation methods and challenges, highlighting advancements in refrigeration and packaging, and the integration of RFID technology to enhance traceability and reduce post-harvest losses. Effective implementation can improve the quality and shelf life of produce, benefiting both producers and consumers.

KEYWORDS

Cold chain; Fruits; Food security; RFID; Transportation; Vegetables

INTRODUCTION

Fruits and vegetables are vital for life, offering carbohydrates, vitamins, minerals, and phytochemicals essential for health. Ensuring their quality and sustainability requires knowledge of their growth, production, transport, storage, packaging, and marketing (Dias, 2012). India ranks as the second largest producer, yet 25-30% of its produce is lost or damaged due to inadequate transport and distribution, including cold storage and refrigerated trucks. The FAO and NDRC report by the United Nations estimate that about one-third of food products are lost yearly, valued at approximately $8.3 billion (Raut et al., 2019). According to the 2023 Global Hunger Index, India is ranked 111th out of 125 countries (Anonymous, 2023).

The greatest food loss and waste result from a supply-demand mismatch. The Farm to Fork Strategy seeks to create a fair, healthy, and eco-friendly food system by mitigating climate change, reversing biodiversity loss, reducing environmental impacts, and ensuring food security, nutrition, and public health (Arabska, 2021). Over the years, improvements in fruit and vegetable transportation methods have aimed to minimize losses and enhance storage life and quality through various techniques. These include adopting appropriate cultural practices, careful handling, and using suitable packaging materials. Additionally, pre-harvest chemicals and treatments are vital in maintaining the freshness, nutritional value, and appearance of produce during transportation (Amicarelli & Bux, 2020).

This article offers insights into methods and mediums for transporting fruits and vegetables, along with recommended precautions to optimize their condition and minimize losses. Effective implementation of these strategies can enhance overall quality and extend the shelf life of fruits and vegetables, benefiting both producers and consumers.

TRANSPORTATION LOSSES

Reducing post-harvest losses involves implementing effective handling, packaging, transportation, and storage practices. Transportation is especially critical for fresh produce as it introduces a time gap between production and consumption. In developed countries, refrigerated vehicles are typically used to transport perishable foods, but breakdowns, accidents, or delays in loading and unloading can still cause significant losses. Conversely, developing countries face numerous challenges such as inadequate transportation infrastructure, poor road conditions, improper handling, inconsistent temperature control, climate variations, and inefficient logistics management. These factors collectively lead to insufficient preservation of perishable foods during transportation (Elik et al., 2019). Addressing these challenges requires concerted efforts to improve infrastructure, enhance transportation systems, and implement better handling and storage practices. This includes investing in refrigeration technology, training personnel in proper handling techniques, upgrading road networks, and developing more efficient logistics strategies. By mitigating post-harvest losses in transportation, we can ensure more food reaches consumers in optimal condition, contributing to food security and sustainability globally (Sied, 2024).

Moreover, in developing countries, the loading and unloading of agricultural products often involve untrained workers who may handle goods carelessly, resulting in mechanical damage. The absence of proper training and oversight exacerbates these problems. Inadequate packaging and inefficient loading practices, such as carelessly tossing products into transport vehicles, further contribute to losses. Rural areas, where a significant portion of agricultural production occurs, face additional hurdles due to poor road conditions. These conditions increase the risk of food losses during transportation, especially in adverse weather, where vehicles may get stuck in mud or face other obstacles. To effectively address these challenges and reduce fruit and vegetable losses during transportation, several key measures can be implemented:

1. Improved Transportation Infrastructure: Investing in better roads, bridges, and transportation networks can facilitate smoother and more reliable movement of goods.
2. Training and Skill Development: Providing training programs for workers involved in handling perishable goods can improve their understanding of proper handling techniques and reduce the incidence of damage.
3. Enhanced Packaging Standards: Implementing guidelines for appropriate packaging of fruits and vegetables can help protect them from physical damage during transportation.

4. Better Logistics Management: Adopting efficient logistics practices, including scheduling and route planning, can minimize delays and ensure timely delivery of perishable goods.

By addressing these issues comprehensively, significant strides can be made towards reducing post-harvest losses during transportation. This not only supports food security by preserving more food for consumption but also contributes to sustainability goals by reducing resource wastage and environmental impact.

TYPES OF TRANSPORTATION MEDIUM

- Land Transportation

Land transport plays a crucial role in moving fresh fruits and vegetables from rural production areas to urban markets, facilitated primarily through refrigerated vehicles. This mode of transport has become indispensable as global population growth continues and consumer demand for a diverse array of fresh produce year-round intensifies. Refrigerated transport is particularly suited for the long-distance shipment of highly perishable fresh produce between producers/growers and wholesalers. It also serves short-distance deliveries between wholesale markets, retail outlets, and food service facilities, ensuring that produce reaches consumers in optimal condition.

The refrigerated vehicle is equipped with temperature control systems to maintain optimal conditions for the specific types of fruits and vegetables being transported. The infrastructure is essential for preserving freshness, extending shelf life, and meeting consumer expectations for high-quality produce. As the demand for fresh produce continues to grow and distribution networks expand, the role of refrigerated transport remains critical in supporting the global food supply chain and ensuring the availability of fresh fruits and vegetables in markets worldwide.

To maintain the quality and extend the shelf-life of fresh produce during transportation, strict adherence to optimal storage temperatures is essential. This adherence revolves around the maintenance and enhancement of the 'cold chain' a critical process that mitigates both metabolic and microbial deterioration of perishable goods. Given the diverse temperature and atmospheric requirements of each type of fruit and vegetable, and their varying rates of heat emission and sensitivity to gases or odours, transport vehicles must be capable of accommodating these specific needs, particularly in mixed loads where different types of produce are transported together. Addressing these requirements is especially challenging for mixed loads (El-Ramady et al., 2015). Early research into truck transportation of perishable produce underscored several crucial considerations:

1. Airflow Management: Adequate airflow through the load is essential to ensure uniform temperature distribution and prevent hot spots that could accelerate spoilage.
2. Space Utilization: Increased circulation space beneath the load aids in maintaining proper airflow and temperature control.
3. Return-Air Bulkhead: Implementation of a return-air bulkhead helps to optimize airflow patterns and improve overall refrigeration efficiency within the transport vehicle.
4. Loading Patterns: Optimizing loading patterns ensures that each type of produce receives adequate ventilation and remains insulated from temperature fluctuations.
5. Increased Size and Better Insulation: Modern refrigerated trailers are larger and better insulated, which helps to minimize temperature fluctuations and maintain stable internal conditions.
6. Enhanced Return-Air Systems: They provide more return-air space in floor channels and utilize pressure-type return-air bulkheads. This improves airflow management, ensuring that cooled air circulates efficiently throughout the trailer.
7. Structural Integrity and Sealing: Greater structural integrity and tightly sealed doors prevent external heat infiltration and maintain the integrity of the cold chain.
8. Improved Air Delivery Systems: Advanced air delivery chutes ensure even distribution of cooled air to all parts of the trailer, preventing localized temperature variations that can affect product quality.
9. Refined Suspension Systems: Suspension systems have been refined to minimize vibration and mechanical damage during transit, reducing the risk of physical damage to perishable goods.

Advancements in trailer and refrigeration system designs have significantly improved the capabilities of transport vehicles over time. Modern mechanical refrigeration systems now incorporate:

a. Increased Refrigeration Capacity: Enhanced cooling power to effectively maintain desired temperatures even in varying ambient conditions.

b. Precise Monitoring and Control: Advanced sensors and control systems monitor supply and return air temperatures, ensuring tight regulation within ± 1°C of the set point.
c. Refrigerant Modulation: Systems adjust refrigerant flow rates to match cooling demands, optimizing energy efficiency and temperature stability throughout the journey.

Advancements in temperature control and reduction of environmental stresses during transportation play a crucial role in maintaining the quality and extending the shelf life of fresh fruits and vegetables. Innovations in refrigeration technology and trailer design are essential for tackling the complex issues related to the transportation of perishable goods. Continued development in these areas will help address challenges effectively and sustainably. By investing in these technological improvements, transportation companies can ensure that consumers receive fresh produce that adheres to high standards of safety, quality, and freshness (Tassou et al., 2009).

- **Sea Transportation**

Exporters of fresh produce generally select from three transportation options for reaching distant markets: airfreight, refrigerated sea containers, or non-refrigerated sea containers. Airfreight, while fast, may not be economical for large volumes or produce with a longer shelf life. Consequently, many exporters prefer using refrigerated sea containers. These containers are self-contained units that provide better control over produce conditions while offering a more cost-effective solution for transporting large quantities (Tanner & Amos, 2003).

In recent years, the diversity of perishable cargo has grown substantially, along with increasing customer expectations for produce quality. As a result, the global market for refrigerated containers (reefers) was 4,004.7 thousand twenty-foot equivalent units (TEUs) in 2023 and is projected to reach 7,142.8 thousand TEUs by 2030 (Anonymous, 2024). These developments highlight the importance of efficient and reliable transportation methods in fulfilling the needs of the global fresh produce market. The implementation of advanced refrigeration technologies and container systems has allowed exporters to preserve produce quality and extend shelf life across various regions, thereby supporting the ongoing expansion and globalization of the perishable goods trade.

- **Air Transportation**

The rise in global trade of fresh fruits and vegetables has raised concerns about the environmental impact of their transportation. The term "food miles" measures the distance food travels from producer to consumer, suggesting that greater distances lead to higher energy consumption, greenhouse gas emissions, and environmental impact. However, food miles and air miles are simplified metrics that do not fully capture the overall sustainability or environmental impact of food production and transport (James et al., 2006).

Maintaining optimal temperature control during air transport is crucial to reducing post-harvest losses and ensuring the quality and safety of fresh produce. Temperature fluctuations can accelerate physiological processes like respiration and ethylene production, leading to premature ripening, spoilage, and decay. Effective temperature management requires understanding the thermal needs of different produce types and using advanced refrigeration technologies and monitoring systems. Sensors and IoT solutions can provide real-time temperature data, allowing for timely adjustments. Additionally, pre-cooling treatments and insulated containers help mitigate temperature-related stresses. Adhering to these practices preserves the quality, nutritional value, and shelf life of produce, reduces economic losses, and enhances food security. Therefore, a comprehensive approach to temperature management in air transport is essential for maintaining the integrity and marketability of perishable goods.

IMPACT OF VARIOUS MODES OF TRANSPORTATION

Understanding the impact of various transportation methods on fruit and vegetable losses is crucial for optimizing supply chains and minimizing waste. The type of transportation used significantly influences the extent of losses due to factors such as perishability, distance travelled, and transport conditions. The Table 1 provides a comparative overview of potential losses associated with common transportation modes, highlighting key considerations such as cost, temperature control, and risk factors. By examining these elements, stakeholders can better assess the strengths and challenges of each mode and implement effective strategies to enhance the preservation of produce throughout the supply chain.

Table 1: Potential loss factors for different modes of fruit and vegetable transportation

Type of Transportation	Loss Factors
Airfreight	• High-cost limits use to high-value, short-shelf-life produce • Risk of damage during loading/unloading • Requires careful temperature control
Truck Transport	• Versatile for short to medium distances • Risk of mechanical damage and temperature fluctuations • Cost-effective for regional distribution
Sea Transportation (Non- Refrigerated)	• Economical for non-perishable or low-perishability items • Risk of spoilage due to longer transit times and lack of temperature control
Sea Transportation (Refrigerated)	• Effective for large volumes over long distances • Cost-effective for bulk transport of perishable good • Requires reliable refrigeration equipment and monitoring
Refrigerated Containers (By road)	• Suitable for longer distances and larger volumes • Moderate to high costs depending on route and distance • Risk of temperature fluctuations if equipment fails
Train Transport	• Suitable for medium distances • Requires robust loading/unloading processes • Risk of temperature inconsistencies and delays affecting perishable items

OPTIMUM TRANSPORTATION PRACTICES

Effective transportation is crucial in preserving the quality of perishable goods. A key component of maintaining this quality is the implementation of advanced temperature control systems and air circulation mechanisms. Modern practices now integrate sensors, artificial intelligence (AI), and the Internet of Things (IoT) to enhance these systems. Sensors continuously monitor and adjust temperature and humidity levels in real-time, while AI algorithms analyse this data to predict and respond to potential deviations before they impact the produce. The IoT enables seamless communication between these sensors and control systems, ensuring that environmental conditions are maintained precisely throughout the transportation process.

- **Adequate loading practices**

Effective loading practices are vital in maintaining the quality of perishable goods during transportation. The preservation of fresh fruits and vegetables involves managing various physical, chemical, and microbial risks. Each type of produce has specific preservation needs, making it crucial to follow detailed protocols to minimize potential risks. Meticulous loading and unloading practices are fundamental to this process, as they help ensure that products are handled with care and kept in optimal condition throughout their journey. Proper loading practices are designed to minimize transit times and reduce the risk of physical damage. This involves arranging products in a way that prevents shifting and crushing during transit, which can compromise quality and safety. Using appropriate packaging materials that offer protection against environmental factors and physical impact is essential. Additionally, securing products to avoid movement and damage, while ensuring proper ventilation, helps maintain the right environmental conditions and extends shelf life (Elik et al., 2019).

- **Cold chain**

The cold chain is a critical component in the transportation of perishable goods, encompassing thermal and refrigerated packaging methods along with meticulous logistical planning. Its primary objective is to maintain an ideal temperature throughout the transportation process, thereby extending the shelf life of perishable items and safeguarding their quality. Effective temperature management is essential, as even minor deviations can lead to significant changes in shelf life and overall produce quality. Temperature plays a crucial role in controlling biological reactions, which makes it a fundamental environmental factor in preserving the integrity of fresh produce. In addition to temperature control, several other factors influence the quality of produce during transportation. Initial quality of the

produce, environmental humidity, water loss, and atmospheric gas concentrations all play significant roles. Ensuring that these factors are monitored and managed helps to prevent deterioration and spoilage. Mixed loads and physical damage, which can occur due to inadequate handling or packaging, also pose risks that need to be addressed. Furthermore, transport conditions such as road surface quality and the time of day can impact the overall quality of the produce, necessitating careful planning and execution. The cold chain relies on a coordinated approach involving specialized packaging, temperature-controlled vehicles, and real-time monitoring systems. Advanced technologies such as IoT sensors and AI-driven analytics play a pivotal role in maintaining optimal conditions and quickly addressing any deviations. These technologies enable continuous monitoring of temperature and other critical factors, ensuring that corrective actions can be taken promptly to preserve product quality (Mercier et al., 2017).

- **RFID Technology**

Radio Frequency Identification (RFID) is a sophisticated technology used for automatic identification and data capture, composed of three main components: a tag with a chip and antenna, a reader that emits radio signals and reads responses from tags, and middleware that integrates RFID hardware with enterprise applications. RFID technology utilizes radio waves for real-time communication with multiple objects simultaneously, over various distances, without requiring direct line of sight. This capability enhances product traceability and visibility throughout supply chains. RFID helps minimize storage, handling, and distribution costs while boosting sales by reducing stockouts and improving inventory management. Beyond enhancing operational efficiency, RFID technology plays a critical role in restructuring supply chain systems to achieve greater overall efficiency. RFID tags communicate via electromagnetic waves with terminals to monitor various parameters such as temperature, expiration dates, and other critical conditions. This real-time monitoring supports effective management of perishable goods and ensures that products are stored and transported under optimal conditions (Figure 1). Moreover, the integration of RFID with GPS technology offers enhanced tracking capabilities, providing real-time data on the product's condition and location during transit. This combination of RFID and GPS technology enhances visibility and control over the entire supply chain, leading to improved product management and customer satisfaction. By leveraging RFID, companies can achieve greater accuracy in tracking, better manage inventory, and ultimately enhance their overall supply chain performance (Costa et al., 2013).

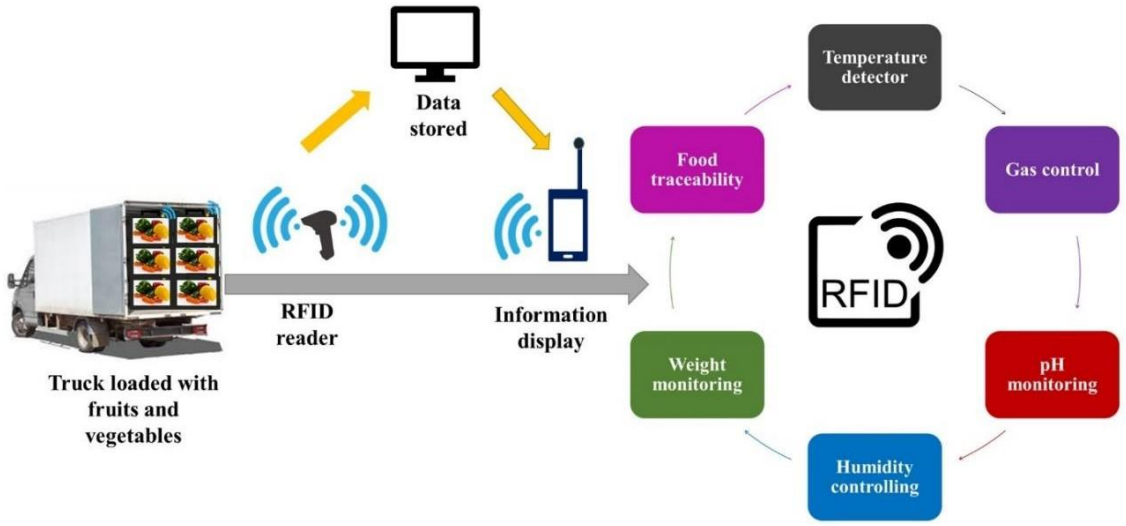

Fig 1: RFID in transportation of fruits and vegetables

CONCLUSION

Addressing the transportation losses of fruits and vegetables is critical for enhancing food security and sustainability. Effective management of transportation practices, including improved infrastructure, advanced refrigeration technologies, and rigorous handling protocols, can significantly reduce post-harvest losses. The integration of RFID technology provides additional benefits by enhancing traceability and monitoring, thus ensuring optimal conditions throughout the supply chain. By adopting these measures, stakeholders can better preserve the quality of perishable goods, reduce

waste, and meet growing consumer demands for fresh produce. Future efforts should focus on continued innovation and investment in transportation technologies and practices to further mitigate losses and support global food security.

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