CHALLENGES AND LOGISTICAL SOLUTIONS FOR FRUIT TRANSPORTATION IN BRAZIL

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INTRODUCTION

Brazil holds a prominent position in global fruit production, ranking as the third largest producer worldwide, with strong representation in crops such as orange, banana, pineapple, açaí, and Brazil nut. Additionally, it is among the top five global producers of papaya, coconut, and lime, establishing itself as a major supplier for both domestic and international markets. The country also ranks among the top ten global producers of crops such as cocoa, cashew, avocado, persimmon, mango, guava, and tangerine, highlighting the diversity of its fruit production.

Despite this relevance in the agricultural landscape, logistical efficiency in fruit transportation remains a significant challenge for the sector. Given the highly perishable nature of these products, the adoption of strategies that minimize losses and ensure the maintenance of quality from harvest to the final consumer is essential. Factors such as deficient infrastructure, inadequate transport and storage conditions, and long distances between production centers and consumer markets directly impact the competitiveness of Brazilian fruit farming.

In this context, it is crucial to understand the main logistical challenges faced by the sector and the solutions that can contribute to a more efficient flow of production. The implementation of advanced technologies, the improvement

of best practices in pre- and post-harvest handling, and investments in infrastructure are among the necessary measures to reduce waste and ensure that fruits reach the market with superior quality.

MAIN LOGISTICAL CHALLENGES IN FRUIT TRANSPORTATION IN BRAZIL

Fruit transportation in Brazil faces significant challenges, primarily due to the poor condition of road infrastructure, the lack of investment in storage facilities, and the vast distances between production regions and distribution or consumer centers (Oliveira; Pereira, 2019; Ferreira, 2024). The inadequate quality of highways, often poorly maintained, contributes to longer transit times and increases the risk of losses due to impact damage during transport (Moreira et al., 2018; Stein, 2023). Furthermore, the extensive distance between production zones and major consumer markets or ports makes efficient transportation essential to prevent product deterioration (Pereira, 2014; Carpo Logistics, 2024).

Another critical factor is the shortage of suitable refrigerated transport, as not all logistics companies have vehicles equipped with temperature control systems, which are vital for preserving fruit quality (Aliotte et al., 2022). The absence of this technology can accelerate ripening and deterioration processes, leading to significant losses along the supply chain. In the context of exports, the challenges are compounded by customs bureaucracy, difficulties in port handling, and prolonged transit times—factors that can compromise product integrity and hinder commercialization in international markets.

TECHNOLOGIES AND BEST PRACTICES TO MINIMIZE LOSSES IN FRUIT TRANSPORTATION AND STORAGE

The adoption of technologies and best practices is essential to minimize losses and ensure fruit quality throughout transportation and storage until commercialization. The use of refrigerated transport, such as trucks and containers with temperature control systems, is fundamental for maintaining fruit freshness and preventing premature deterioration. In addition, real-time monitoring through temperature and humidity sensors installed in vehicles allows for immediate adjustment of environmental conditions, ensuring more efficient transport (Spagnol et al., 2018).

Palletization and proper handling also play a crucial role, as avoiding excessive stacking and using appropriate pallets reduces mechanical impacts that can compromise fruit integrity. Finally, controlled storage in distribution centers equipped with cold chambers provides an adequate environment to preserve fruit quality before delivery to the final consumer.

IMPORTANCE OF HANDLING DURING HARVEST AND PACKAGING SELECTION

The procedures adopted during fruit harvesting and packaging exert a direct influence on postharvest longevity and resistance to mechanical and physiological damage during transportation. To maintain product quality, the use of ventilated and structurally robust packaging—such as plastic crates or reinforced cardboard boxes—is recommended, as these mitigate physical injuries and facilitate adequate airflow (Santos Filho et al., 2014). Furthermore, segregation based on ripening stage is critical, as fruits at different physiological maturity levels must be stored separately to prevent excessive ethylene release—a phytohormone that accelerates ripening and may compromise postharvest conservation. Another relevant strategy is the individual protection of highly perishable fruits, such as mangoes and apples, which can be wrapped in paper or protective meshes to reduce friction and minimize mechanical damage during handling and transport (Lima et al., 2014).

In addition, the rigorous control of temperature and relative humidity during transportation plays a pivotal role in maintaining fruit quality. Lower temperatures reduce metabolic activity, particularly respiration rate, thereby delaying senescence and ripening processes (Steffens et al., 2007). Avoiding excessive humidity is equally important, as it limits microbial proliferation—especially fungal and bacterial pathogens—responsible for accelerating deterioration. Therefore, the adoption of optimal transport conditions contributes significantly to extending postharvest shelf life and ensuring that fruits reach their final destination in a commercially acceptable state, while minimizing quantitative and qualitative losses throughout the supply chain.

TECHNOLOGICAL INNOVATIONS IN FRUIT PRESERVATION

In recent years, novel technologies have been developed to extend the shelf life of fruits and reduce losses throughout the supply chain. Among these innovations, edible natural coatings stand out—films formulated from algae, proteins, and natural waxes (Barboza et al., 2022). These coatings function as physical barriers, reducing water loss and protecting fruits against microbial attacks, thereby prolonging their preservation. Another innovative solution involves smart packaging, designed to absorb ethylene released by fruits during ripening, thus helping to delay this process and extend product shelf life (Martinazzo et al., 2020). In addition, the use of quality-monitoring sensors has become an efficient strategy, as these devices are capable of detecting variations in fruit condition, allowing for rapid adjustments during both storage and transport, and ensuring that fruits reach consumers in optimal condition (Ruiz-Garcia et al., 2007).

Beyond technologies for storage and transport, pre- and postharvest treatments play an essential role in maintaining quality and extending fruit longevity. Table grapes, for instance, exhibit highly appreciated sensory attributes, including vitamins and bioactive compounds that may undergo concentration changes during ripening. Their berries are rich in polyphenols, which can be divided into flavonoids and non-flavonoid compounds. These phenolic compounds are closely associated with fruit perishability, which has driven significant research aimed at developing strategies to preserve quality during postharvest storage and transport. However, during postharvest handling, moisture loss may occur, leading to reduced firmness, dehydration, cracking, shriveling, and increased susceptibility to pathogens—factors that contribute to significant fruit wastage.

In this context, numerous studies have explored the exogenous application of salicylic acid (SA) and melatonin during both preharvest and postharvest phases to enhance the organoleptic and nutritional attributes of grapes. Moreover, these compounds have demonstrated significant potential in mitigating oxidative stress, contributing to the preservation of bioactive compounds. These phytohormones have emerged as promising, cost-effective, and accessible tools for producers, reducing postharvest losses and, in preharvest applications, promoting the regulation of ripening and enhancing resistance to environmental stress—key elements for maintaining fruit quality and reducing food waste.

In the case of table grapes, the exogenous application of melatonin, either alone or in combination with SA, has been shown to improve the physical characteristics of berries, bunches, and rachises, while also controlling decay and reducing postharvest berry drop. This approach delayed losses during the storage of seedless 'BRS Vitória' grapes and preserved postharvest quality by enhancing antioxidant capacity and key quality attributes, such as soluble solids, phenolic acids, and resveratrol—compounds with recognized antifungal activity.

The application of salicylic acid has also demonstrated positive effects on extending the postharvest quality of 'Niagara Rosada' grapes. According to Domingues Neto et al. (2024), the concentration of 0.28 g L^{-1} delayed berry deterioration and preserved sensory and nutritional characteristics during storage. This dosage effectively induced the synthesis of phenolic compounds, thereby increasing the antioxidant capacity of the fruit. In contrast, higher SA concentrations (0.83 and 1.10 g L^{-1}) resulted in greater anthocyanin content and intensified enzymatic activities—such as peroxidase and superoxide dismutase—in rachises. These effects contributed to improved preservation of 'Niagara Rosada' grapes, reducing decay and degradation during storage while maintaining the fruit's sensory and nutritional quality.

Other fruits have also benefited from these approaches as part of a more sustainable agricultural model based on natural coatings (Sharma et al., 2024). In strawberries, SA has been applied as a defense inducer, reducing pathogen incidence and delaying enzymatic browning, thereby improving both yield and fruit quality (Mohamed et al., 2018; Favaro et

al., 2019; Feng et al., 2020). In mangoes, natural coatings based on chitosan have emerged as effective postharvest tools, minimizing moisture loss and delaying ripening (Bambalele et al., 2021; Khalil et al., 2022; Parvin et al., 2023). For citrus fruits, heat treatments combined with growth regulators have shown efficacy in maintaining peel firmness and reducing postharvest degradation (Adhikary et al., 2022; Ejaz et al., 2022; Strano et al., 2022).

Thus, the integration of emerging technologies, innovative packaging solutions, and specific physiological treatments represents a significant advancement in the fruit production chain, enabling greater logistical efficiency, reduced waste, and the delivery of high-quality products to the consumer market.

THE IMPACT OF LOGISTICAL INFRASTRUCTURE ON FRUIT DISTRIBUTION

The precarious state of Brazil's logistical infrastructure directly affects the competitiveness of the fruit sector, hindering the distribution of production and increasing operational costs. Poor road maintenance, the scarcity of strategically located distribution centers, and inefficiencies in port operations not only raise transportation expenses but also contribute to increased postharvest losses along the supply chain. To mitigate these issues, several measures have been identified as essential. Among them, investment in alternative transportation modes—such as railways and inland waterways—stands out, as these could be more extensively utilized to reduce logistical costs and shorten transport times.

Furthermore, the expansion of regionally distributed centers equipped with climate-controlled storage facilities near production areas would help minimize losses prior to market dispatch. Another key measure involves reducing bureaucratic obstacles in the export process through the digitalization of documentation and improvements to port infrastructure. These advancements would facilitate faster loading operations and, consequently, enhance the international competitiveness of Brazilian fruit products.

STRATEGIES FOR FRUIT GROWERS TO IMPROVE LOGISTICAL EFFICIENCY

Ensuring that fruits reach the market with high quality requires careful logistical planning. To achieve this, growers can adopt simple yet effective strategies. Harvest scheduling is one of the most important approaches to avoid losses and waste, as it allows for a more evenly distributed harvest over time, reducing the concentration of fruit supply in a single period and facilitating its distribution. Additionally, considering the distance to major consumer markets during production and transport planning is essential—more robust cultivars should be prioritized for long-distance transportation, while more delicate fruits should be directed toward nearby markets.

Establishing partnerships with specialized logistics companies can also make a significant difference, as firms equipped with refrigerated vehicles ensure better preservation of fruit quality during transport. Another efficient solution involves the use of tracking technologies, which enable real-time monitoring of shipments and the prompt resolution of any issues that may arise during transit. By adopting these practices, growers can reduce postharvest losses, optimize logistical costs, and enhance their competitiveness in the marketplace.

DIFFERENCES BETWEEN LOGISTICS FOR THE DOMESTIC MARKET AND FOR EXPORT

Fruit transportation presents distinct challenges depending on the destination—whether for the domestic market or for export. In the domestic market, the primary requirement is prompt delivery, as fruits typically reach consumers within a few days. Road transportation is the most commonly used mode, and refrigeration is not always necessary, depending on the fruit species and the distance traveled.

In contrast, export logistics are more complex, as they must comply with strict quality control standards, certifications, and phytosanitary inspections. Moreover, fruits intended for international markets are generally transported in refrigerated containers to ensure their preservation throughout extended transit periods. Thus, each transportation modality requires specific planning to maintain product quality and ensure market competitiveness.

CONCLUSION

Fruit logistics in Brazil still faces structural challenges that affect the competitiveness of the sector. However, recent advances—such as refrigerated transport, smart packaging, and real-time monitoring—have contributed to reducing postharvest losses and optimizing distribution. Strategic investments in infrastructure, thermal control, and innovative technologies are essential to ensure fruit quality and to strengthen the fruit production sector in both domestic and international markets.

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