Reducing Environmental Impact through Minimizing Fresh Produce Supply Chain Losses: Toward a Sustainable Food System

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Background

Reducing environmental impacts and minimizing postharvest losses in the food supply are critical challenges for building sustainable food systems. In Japan, fresh produce accounts for more than 70% of the food loss[1)], making the development of loss reduction technologies highly beneficial. However, it is commonly believed that introducing technologies such as cold chain management and packaging materials increases the environmental impact due to additional energy consumption and plastic use. This perception overlooks the environmental benefits that can be achieved by reducing losses through technology, which can lead to lower production mass. In reality, the production stage has the largest environmental impact within the food life cycle. By optimizing the distribution stage, it is possible to reduce the overall environmental impact. The objective of this study was to quantitatively clarify the impact of technologies for reducing postharvest losses of fresh produce on the overall environmental impact of the supply chain. Specifically, the study aimed to evaluate the extent to which loss rates during transportation affect the overall environmental impact and present guidelines for building a sustainable distribution system.

Materials and Methods

Strawberries and peaches, for which damage during transport is a key issue, were selected as the target products. For strawberries, assuming international transport, multiple scenarios were established. The impact of differences in transport modes (air freight/sea freight) and packaging materials on environmental load was calculated using life cycle assessment (LCA)[2)].

As an additional experiment, transportation vibration tests using different cushioning materials were conducted on fragile produce to evaluate the loss reduction effects of various materials. Furthermore, LCA was performed on commonly used packaging containers (three types for strawberries[3)] and five types for peaches[4)]). To evaluate loss reduction effects appropriately, the functional unit was defined as “the delivery of 1 kg of undamaged produce to a retail store.” Based on these analyses, the trade-offs between loss reduction and introduction of additional technologies (in this study, cushioning packaging materials) were examined.

Results and Discussion

The results of the LCA targeting international distribution confirmed that the mode of transport has the greatest impact on environmental impact. Replacing air freight with sea freight was found to reduce the overall environmental impact by approximately 30–40%. This demonstrates that sea freight is effective from the perspective of reducing environmental impact. Furthermore, even when standard containers were replaced with high-cushioning containers, the increase in environmental impact from the containers was smaller than the change from the difference in transport mode.

Vibration tests were conducted on strawberries, assuming transport distances of 50 to 2000 km (by truck transport). Loss rates were obtained for each transport distance for cardboard boxes alone and cardboard boxes used in combination with three types of packaging technologies. The LCA results showed that the strawberry production process accounted for 77.2 to 90.1% of the total effect and that packaging material manufacturing accounted for 8.9 to 12.9%. These together constituted the majority of the effect.

The loss rates from the vibration tests were as follows:

Cardboard box only: 5.51–52.33%

Cardboard box + Packaging A: 0.73–8.43%

Cardboard box + Packaging B: 0.86–8.99%

Cardboard box + Packaging C: 3.61–27.56%

In this LCA, an evaluation per unit arrival at a retail store showed that Packaging A, B, and C reduced the environmental impact by 48.8%, 50.4%, and 33.1%, respectively, under conditions equivalent to 2000 km of transport in comparison to using only the cardboard box. This difference was primarily attributable to the greater effect of the lower production required to deliver a fixed quantity of product to stores obtained through loss reduction, which outweighed the increase in impact derived from manufacturing the packaging material.

Conversely, under conditions equivalent to 50 km transport, the environmental impact of Packaging materials A and C exceeded that of the control group. This suggests that these forms of packaging may be excessive for short-distance transport. In other words, it became clear that minimizing loss and minimizing environmental impact do not necessarily coincide.

For peaches, the results also showed reduced loss attributable to the packaging containers. However, for peaches, the tendency was that minimizing loss directly led to minimizing environmental impact (details omitted).

Based on the aforementioned results, to reduce the environmental impact within the distribution process, measures at the distribution stage must include not only appropriate selection of transportation method but also packaging design and use that considers the relationship between postharvest losses and environmental impact.

Future Prospects

This study is significant because it quantitatively demonstrates how food loss reduction technologies contribute to reducing environmental impact. Future applications are anticipated for other fresh produce and processed foods, expansion into international logistics systems, and utilization in policy recommendations and corporate sustainability strategies. Furthermore, it is important to explore comprehensive loss reduction measures in combination with digital management of transport environments using IoT sensors and data integration.

1) Food Balance Sheet, Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan (2024)
2) T. Watanabe, et al. Investigating the development of pre and postharvest technology for strawberry exports based on carbon-dioxide emissions, Journal of the Japanese Society of Agricultural Machinery and Food Engineers, 86(6), 412–419 (2024, in Japanese)
3) Y. Sasaki, et al. Optimal packaging for strawberry transportation: Evaluation and modeling of the relationship between food loss reduction and environmental impact, J. Food Eng., 314, 110767, (2022)
4) Y. Sasaki, et al. Determination of the most environmentally friendly packaging for peach during transportation by modeling the relationship between food loss reduction and environmental impact, J. Food Eng., 331, 111120, (2022)