Summary of Doctoral Thesis

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Title	Influence of postharvest technology application to transportation and processing for fruits and vegetables on reduction of environmental impact

Among the Sustainable Development Goals (SDGs), Goal 12 includes the target that by 2030, the per capita global food waste should be halved at the retail and consumer levels, and food losses along production and supply chains should be reduced, including postharvest losses. According to an FAO report, the large amounts of resources required to produce food that is eventually wasted are consumed in vain, resulting in greenhouse gas emissions with no additional benefit, which impedes achievement of Goal 13 among the SDGs, i.e., climate action. Food waste has been estimated to emit 4.4 Gt-CO_2eq per year. Thus, loss reduction can achieve both these goals.

To decrease the food loss and waste (FLW), some postharvest technologies have been developed such as drying and freezing. Drying gets rid of moisture from the products and can inhibit their deterioration, prolonging their shelf life. Additionally, non-standard products are acceptably used for drying (processing), and thus efficient use of such products can decrease the FLW. As another way, packaging could solve the loss and waste problem. Packaging is one of the postharvest techniques to increase the shelf life of packaged products. Fruit and vegetable packaging provides certain useful functions, e.g., protection of packaged products from undesired, physical (vibrations and shocks during transportation), chemical, and biological changes, prevention of product loss and pollution, and display of valuable information (e.g., ingredient and allergen labeling). To decrease food losses, many researchers have studied packaging conditions, e.g., active packaging and modified atmosphere packaging (MAP), while other researchers have focused on maintaining the commercial quality of packaged fruits during transportation.

These postharvest technologies can decrease food loss but increase the environmental load due to electricity and material consumption for drying and packaging production. Thus, it is important for sustainability maintenance to assess the increase-decrease balance from an environmental perspective. One of the suitable methods for balance evaluation is life cycle assessment (LCA). This method targets all the processes required for a product (from raw material and energy production through transport, processing, distribution, use, waste, and recycling) to assess the environmental impacts, e.g., climate change, acidification, and land use. LCA studies have evaluated postharvest techniques from an environmental perspective. Additionally, many LCA reports consider the environmental loads of package production throughout the life cycle of foods. However, these LCA studies neglected the influence of food loss reduction attributed to packaging on the environmental impacts (i.e., the indirect impact of packaging). Articles have further demonstrated that many packaging-related LCA studies have focused only on the environmental impact associated with package production (direct impact) while excluding the impact of packaged products along the supply chain. According to a review article of food LCA studies, even though several studies have determined the environmental benefit associated with the indirect impact of extending the shelf life of packaged products, this topic has been given little attention, and the indirect environmental impact of packaging has been inadequately considered in recent food LCA practices. It has been concluded that for certain foods, the indirect impact (food loss reduction) decreases the environmental impact associated with the life cycle, even though package production and waste increase the aforementioned impact. Thus, it is essential for environmental sustainability maintenance to assess not only the direct impact but also the indirect impact of the postharvest technologies throughout the life cycle of the food supply chain.

This thesis assesses the trade-offs regarding postharvest technologies (packaging and drying) and environmental impact by LCA to evaluate a reduction potential of environmental loads in the life cycle of fruits and vegetables through introducing the technologies and to environmentally optimize the food supply chain. Chapter I describes a general introduction of fruits and vegetables and established postharvest technologies.

Chapter II discusses the relationship between reduction of food losses caused during transportation by packaging for strawberries and environmental loads through comparing packaging and nonpackaging conditions. The hot spot analysis was conducted in the life cycle of strawberry to determine the most relevant impact categories and analyze them in detail. The climate change (CC), resource consumption (RC), and urban air pollution (UAP) impacts were environmentally significant among the assessed 14 impact categories and accounted for over 80% of the total environmental loads. Comparing packaging and nonpackaging, it showed that packaging can reduce the environmental loads for the three impact categories by up to 47.3% through food loss reduction although packaging itself increases the loads attributed to the production and waste; the reduction of the environmental impact by packaging for strawberries was clarified.

Chapter III evaluates three types of packaging for strawberries were evaluated to obtain the findings about an ideal and suitable packaging condition which causes lower food loss and environmental load. Relationship between the damage area ratio and environmental load for the CC and UAP impacts were accurately modeled by an empirical non-linear model (exponential and linear combination model): this model showed that the minimum point of environmental impacts and the point of the damage area ratios were different. From the modeling, the damage area ratio, which can minimize the environmental loads on the CC and UAP impact, was obtained. It concluded that minimizing food loss does not always minimize the environmental impact, and conversely, excessive reduction of the loss by packaging may increase the impact in the strawberry life cycle. The obtained result recommends a packaging which might cause some injuries on strawberry surface but minimizes the environmental loads.

Chapter IV focuses on the packaging for peaches and compares packaging and nonpackaging conditions to quantify the reduction potential of environmental loads through food loss reduction by packaging and to find the environmental hot spot. Additionally, peach cultivation and packaging production processes are assessed in detail. This study conducts LCA based on 15 impact categories and considers the environmental trade-offs between each category. The CC, RC, and UAP impacts were reduced by up to 92.2%, 87.7%, and 94.1%, respectively, through food loss reduction by packaging. This result showed that packaging can decrease the environmental loads in the entire life cycle. Through the analyses, this study suggests that the trade-offs should be considered when developing packaging for peaches to decrease both food loss and environmental impact.

Chapter V assesses five types of packaging for peaches to obtain a finding for producing an environmentally friendly packaging condition and models the relationship between food loss ratio and environmental load. This study discusses a factor that determines whether the relationship is linear or nonlinear. The evaluation result revealed that the amount of packaging (plastic) required to transport 1 kg of not injured peaches can determine whether the relationship is linear or nonlinear; a packaging, which can hold more peaches, decreases more environmental loads associated with packaging production and makes the relationship linear. Moreover, a reusable plastic box was not effective to reduce environmental loads of the life cycle compared to a single-use cardboard box; the reusable box caused more food losses and related environmental loads, and thus the loads between the two boxes were almost the same. These results can be applied in food-packaging system to modify the development, production, and use of packaging from environmental perspective.

Chapter VI models the relationship between food loss reduction via packaging for ripened peaches and the environmental load in their life cycle, advising on how the packaging of ripened peaches can be designed based on transportation distance, for least load on the environment. The current study has assessed ripened peaches with the different analysis approach compared to the studies in other chapters to find an environmentally ideal packaging condition with considering the distances (a packaging suitable for each distance) by modeling the food-packaging system. The CC and UAP impacts were monotonically decreased by food loss reduction. The slope of a straight line approximating the relationship increased with transportation distance. Additionally, the relationship between the slope and transportation distance indicated that under 100 km transportation, a packaging that has lower environmental load for its production is sufficient to lower the environmental load of the whole life cycle while above 300 km, packaging that has a high ability of protection for packaged peaches is suitable for environment. Therefore, packaging should be developed and proposed on a transportation distance basis to minimize the environmental loads in the life cycle of ripened peach.

Chapter VII discusses the influence of the protection for spinaches by MAP on the life cycle environmental loads. Additionally, this study proposes a model to estimate the environmental loads of the spinach life cycle. The model could be applied not only to spinach but also to other fruits and vegetables packaged with various packaging conditions (e.g., film, tray, or box). Thus, using this model can promptly calculate the environmental loads in any fruits and vegetables without time-consuming LCA process and can promote the environmentally sustainable development of packaging production.

Chapter VIII targets food processing sector, which is regarded as an environmental hot spot, in the life cycle of dried cabbage to decrease the environmental impact in this sector and the entire life cycle by a postharvest technique, blanching before drying. Blanching pretreatment reduced the environmental load by 53.3%–70.2% through shortening the drying time. The environmental efficiency based on soluble solid content or L-ascorbic acid content for blanching condition was higher than that for control condition; this indicates that blanching is a preferable pretreatment for environment in dried cabbage production process. Through the results, it claims that both environmental impact and nutritious ingredient should be considered when conducing LCA on a processed food with any postharvest technologies that may influence on the nutrition.

Chapter IX summarizes the general conclusion based on the obtained results and discussion from Chapter II to VIII. The limitations and future works of these studies have been described in this chapter. The novel assessment can optimize the development and use of these postharvest technologies and improve the environmental sustainability in food supply chain.

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