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Cooling Kinetics and Mass Transfer in Postharvest Preservation of Fresh Fruits and Vegetables under Refrigerated Conditions

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Fruits and vegetables are fresh products that are highly perishable and refrigeration is widely applied to extend food shelf-life under postharvest conditions. The main phenomena associated with the refrigeration process are heat and mass transfer, which directly influence food decay. For this reason, the objective of this research is to evaluate the thermal and mass profiles of fresh strawberry and lettuce, under refrigeration. Strawberry and lettuce samples were harvested from a hydroponic system and stored at 5 ± 1 °C for 5 days under low relative humidity conditions (50-60 %). In order to correlate the two main phenomena, the mass transfer and cooling kinetics parameters were quantified. The mass loss results demonstrated a greater reduction for lettuce (21.7 %) than for strawberry (16.7 %) samples, which is related to the larger surface to mass ratio of lettuce. The strawberry transpiration rate presented a stable behavior after the first day of storage (1.31 g kg^{-1} h^{-1}), which provides a linear reduction in the strawberry mass, while lettuce had a higher transpiration rate at the beginning (4.25 g kg^{-1} h^{-1}) and showed a gradual reduction during cold storage until reaching 1.81 g kg^{-1} h^{-1}. Water loss in food occurs through evaporative heat from respiration and a reduction in the water content leads to an increase in the internal food temperature. A gradual increase in the food temperatures was observed for both lettuce and strawberry (by 0.5 °C and 0.1 °C, respectively) during storage due to vegetable physiology. Based on the thermal history, a faster thermal response was observed for lettuce. Also, the cooling rate was higher for lettuce (8.7 °C h^{-1}) than for strawberry (6.9 °C h^{-1}) and the half-cooling times were 0.2 h and 0.3 h for the lettuce and strawberry samples, respectively. These findings aid a better understanding of postharvest food behavior and could lead to novel preservation technologies.

1. Introduction

Water is an important component of fruits and vegetables and represents a large proportion of the mass. This is the driving force for the water dynamics, with transfer from the food to the external environment (Tirawat et al., 2017). The mass transfer is a negative factor for fruit and vegetable preservation because the food becomes dehydrated and this affects the appearance, texture, nutrients and flavor (Agüero et al., 2011). According to Brecht (2003), if the mass loss for fresh foods such as fruits and vegetables reaches between 3-10 %, the product begins to wither and shrink and there is no way to return it to the initial state. In many cases, the product then loses its commercial acceptance (Harker et al., 2019).
It is widely known that food temperature control plays a vital role in maintaining quality because when the food product temperature is reduced, metabolic processes, such as respiration and transpiration, are also reduced, consequently extending the food shelf-life (Chaomuang et al., 2019). The food cooling process involves multiphysical phenomena, such as heat and mass transfer, simultaneously (Defraeye, 2014). Food acts as a hot body inside the refrigerator and the refrigerator function is to reduce the food temperature to enhance the preservation (Mascheroni, 2012). In addition, refrigeration is a food preservation approach that is notable for

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avoiding drastic changes in the organoleptic properties. In this context, this paper reports an evaluation of the thermal and mass profiles for two fresh food products (strawberry and lettuce) under refrigeration conditions.

2. Materials and methods

2.1 Food samples quality and preparation procedure

Strawberries (*Fragaria x ananassa*) and lettuce (*Lactuca sativa*) samples were harvested from a hydroponic system at a local commercial farm in Indaial, Santa Catarina, Brazil. Food samples were selected based on uniformity of size, shape, color and maturity and an appearance which indicated no mechanical damage or disease. Samples were immediately transported to the laboratory and prepared for storage. Strawberry samples were gently brushed to remove casing material or soil and packaged in polyethylene terephthalate (PET) containers with 6 perforations of 1 cm of diameter in the cover, according to Figure 1a. In the case of lettuce the preparation consisted of removing the roots, washing the vegetable in running water and centrifuging in a manual kitchen basket type centrifuge to remove the excess water. Lettuce samples were packaged in open conical packaging with microperforations, as shown in Figure 1b.

2.2 Experimental facility and storage conditions

The experimental facility was designed to reproduce household refrigerator conditions and, as seen in Figure 1c, the experimental facility consists of a control unit (1), responsible for air temperature, humidity and air velocity control, inside the refrigeration system (2). The refrigeration system control parameters were monitored during the tests with a humidity sensor (model 6621, Testo, uncertainty of ± 2.0 % RH), a six-coupled hot wire anemometer (UAS 1000, Degree Controls, uncertainty of ± 3 %) for air velocity measurement and adjustment and four thermocouples (type T, OMEGA, uncertainty of ± 0.2 °C), one on each shelf, to record the air temperature. The food storage was carried out under refrigeration at 5 ± 1 °C for 5 days, with relative air humidity of 50-60 % and air velocity of 0.2 m s^{-1}.

Figure 1: Packaged strawberry (a) and lettuce (b) samples for cold storage. Experimental facility (c) divided into a control unit (1) and the refrigeration system (2).

2.3 Analysis of cooling kinetics

In order to obtain the food temperature profile, four contact thermocouples (type T, OMEGA, uncertainty of ± 0.2 °C) were attached to each food sample and the mean value was used for further analysis. The cooling kinetics of the food products was analyzed using the dimensionless temperature (θ), calculated as

$$\theta(t) = \frac{T_{pf}(t) - T_a(t)}{T_{pi} - T_a(t)} \tag{1}$$

From $\theta(t)$, the half-cooling time ($t_{1/2}$) was calculated. The parameter $t_{1/2}$ represents a θ value of 0.5, which corresponds to the time required to reduce (pull down) the difference between the food temperature and the air temperature by half. In addition, the food cooling rate ($\dot{T}$) was verified, considering the initial (T_{pi}) and final (T_{pf}) food temperatures and the time (t) required for the food temperature to reach the air temperature (T_a). The $\dot{T}$ value was expressed in °C h^{-1} and calculated as

$$\dot{T} = \left(\frac{T_{pi} - T_{pf}}{\Delta t}\right) \tag{2}$$

2.4 Analysis of mass transfer

The food mass loss was determined on an electronic balance (OHAUS, Pioneer series, uncertainty of 0.01 g) with mass data acquisition every 60 s using the software supplied with the equipment. Mass loss (ML) is expressed as a percentage and was calculated as

$$ML = \left(1 - \frac{M_i - M_f}{M_i}\right) 100 \tag{3}$$

where the M_i is the initial mass and M_f the final mass of the food products. The transpiration rate (TR) was calculated per unit of initial mass and time (t) and expressed in g kg^{-1} h^{-1}, according to

$$TR = \left(\frac{M_i - M_f}{M_i \times \Delta t}\right) \tag{4}$$

3. Results and discussion

The dimensionless temperature for strawberry and lettuce during the process of temperature reduction at the beginning of the cold storage is shown in Figure 2a, where it can be observed that lettuce had a faster thermal response then strawberry. The half-cooling times were 0.2 h and 0.3 h for the lettuce and strawberry samples, respectively. Also, the cooling rate was higher for lettuce (8.7 °C h^{-1}) compared with strawberry (6.9 °C h^{-1}). The faster thermal response for lettuce is due to the higher surface-to-mass ratio of the leafy vegetable, which favors heat transfer.

The initial food temperature for lettuce and strawberry was 20.9 °C and 17.8 °C, respectively. The temperature reduction of living fruits and vegetables, such as strawberry and lettuce, reduces the metabolic processes, which increases food shelf-life. However, even in cold storage, gradual increases in both food temperatures were observed (0.5 °C and 0.1 °C for lettuce and strawberry, respectively), due to food metabolism (Figure 2b). This increase in food temperature may also be associated with physiological processes, as energy is released during the respiration process. Also, the correlation between water stress and thermal stress explains the increase in the temperature of the food items during cold storage. As the water content in food decreases the internal food temperature increases (Figure 3a).

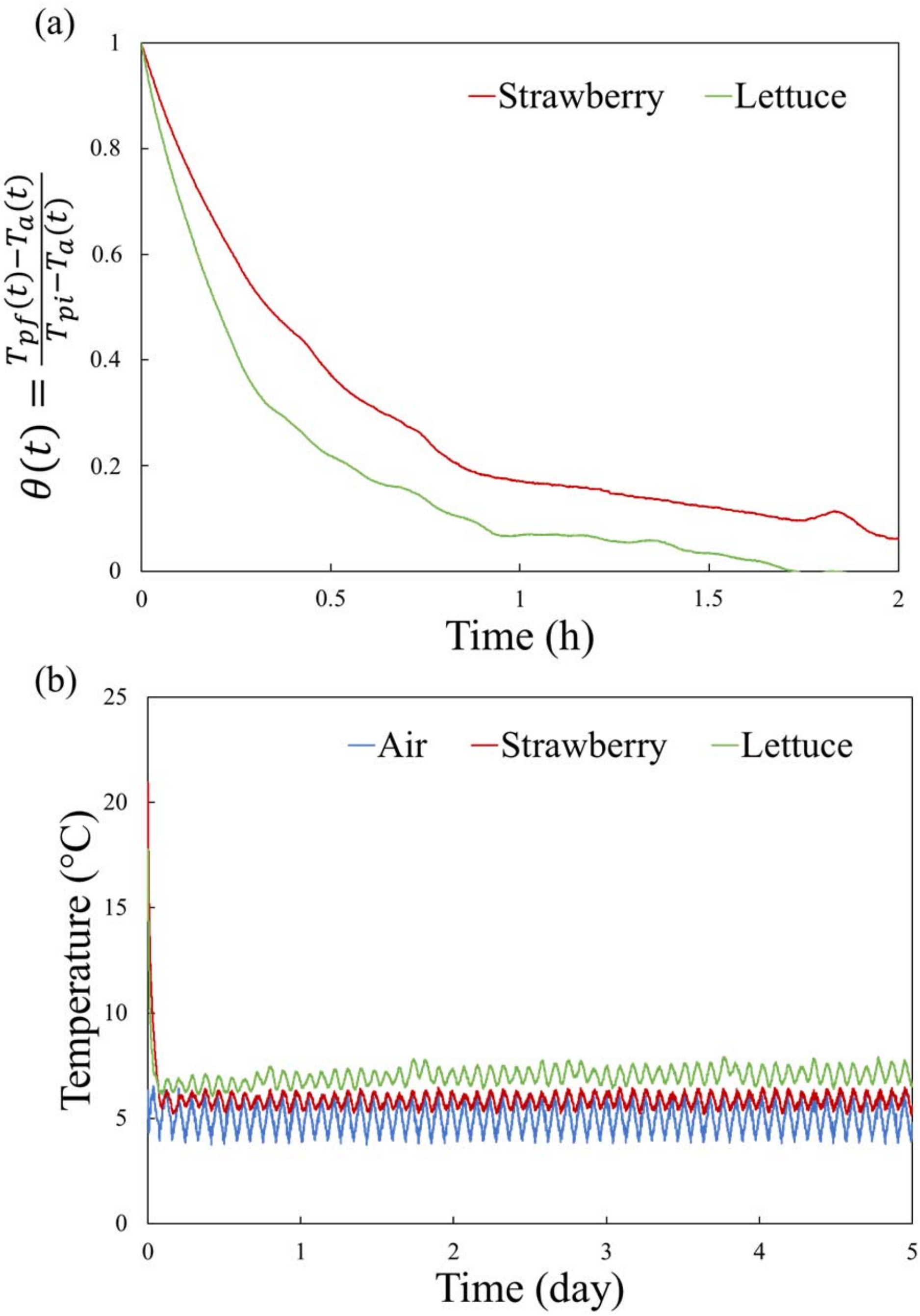

Figure 2: Dimensionless temperatures for strawberry and lettuce (a) and thermal profiles for food and air (b) during 5 days of storage.

The mass loss results demonstrated a more intense reduction for the lettuce (21.7 %) than for the strawberry (16.7 %) samples, as seen in Figure 3a. Lettuce has a large surface area, which is favorable to mass transfer. The transpiration rate oscillates at the beginning of cold storage for both food products. This oscillatory profile may be associated with the evaporation of a layer of moisture present on the food surface after harvest. The strawberry transpiration rate remained stable after the first day of storage (at around 1.31 g kg^{-1} h^{-1}), which led to a linear reduction in the strawberry mass. On the other hand, the lettuce showed a higher transpiration rate at the beginning of cold storage (4.25 g kg^{-1} h^{-1}) followed by a gradual reduction until reaching 1.81 g kg^{-1} h^{-1}, as shown in Figure 3a.

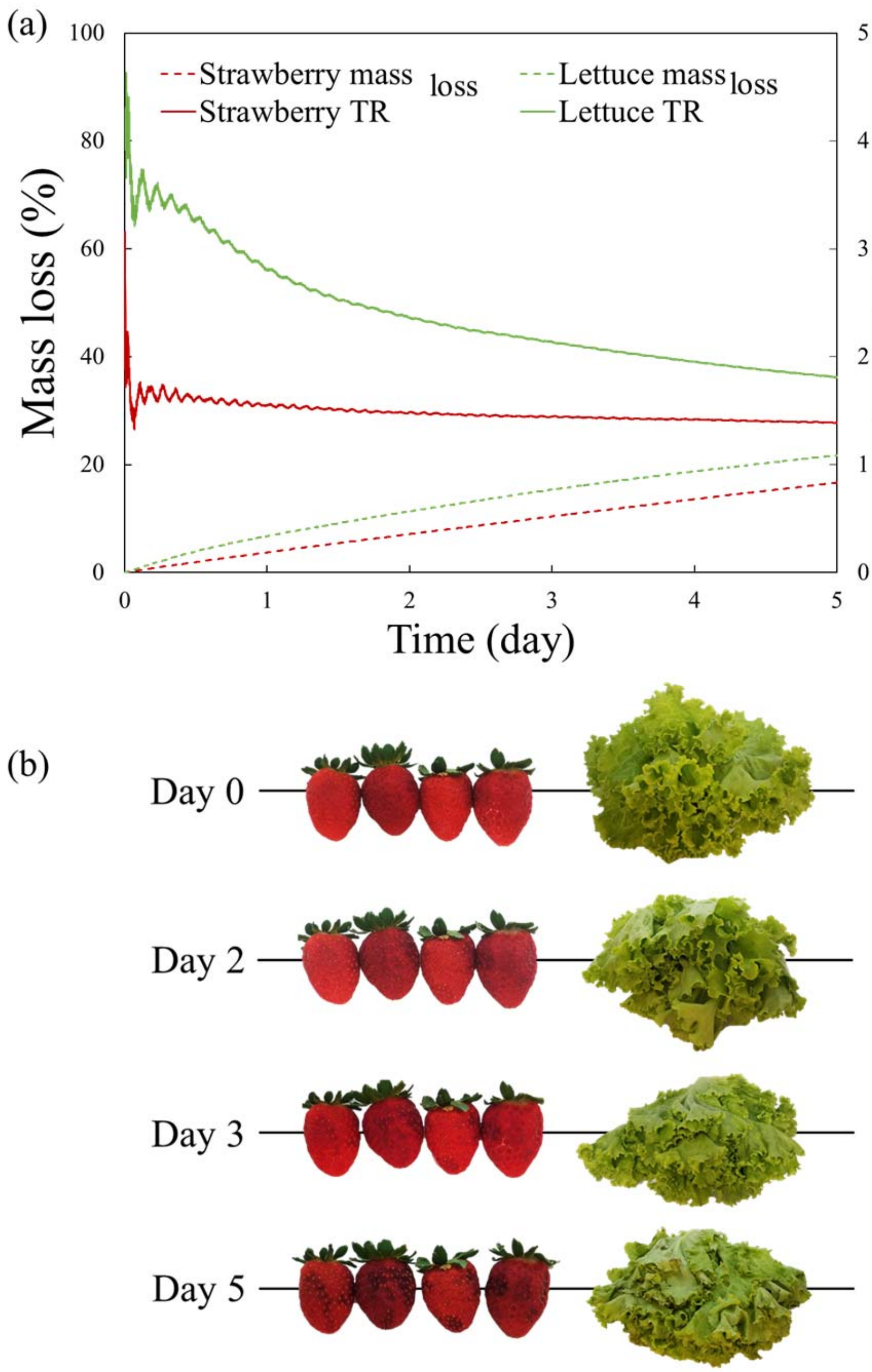

Figure 3: Mass loss and transpiration rate (TR) behavior during 5 days of storage (a) and visual aspect of food products during cold storage (b).

Images of the strawberry and lettuce samples during the 5 days of cold storage are shown in Figure 3b. The visual aspect of the strawberry sample changed from that of fresh fruit to the appearance of intense browning and dehydration. The dehydration was favored by the low relative humidity (50-60 %) inside the refrigeration system, which promoted mass transfer (moisture loss) leading to a juiceless fruit. In addition, drip loss was observed at the bottom of the strawberry package on the last day of storage.

In the case of the lettuce samples, on day 5, the images show a more compact texture and a loss of freshness (weak texture and tensile strength, excess of softness and flaccidity), resulting from a reduction in the cell turgor due to mass loss and fragile vegetable cell structure.

4. Conclusions

The thermal and mass profiles for lettuce and strawberry were determined under refrigeration conditions, during the postharvest stage. The experimental facility, applied to reproduce the operational conditions of household refrigerators, had satisfactory performance and highlighted a correlation between heat and mass transfer. The water reduction of lettuce samples (21.7 %) resulted in a gradual increase in food temperature due to the vegetable metabolism. In comparison to strawberry, lettuce showed a faster thermal response to refrigeration, which is mainly associated with the different surface-to-mass ratios of the two food products. The strawberry samples presented more stable thermal and mass transfer, with linear behavior, and had a lower cooling rate (6.9 °C h^{-1}) and mass loss (16.7 %) than the lettuce. Images collected during storage demonstrate significant changes in both food products. The lettuce sample became more compact and unstructured while the strawberry sample showed an intense browning process and shrinkage.

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References

Agüero M.V., Ponce A.G., Moreira M.R., Roura S.I., 2011, Lettuce quality loss under conditions that favor the wilting phenomenon, Postharvest Biology and Technology, 59, 124-131.

Brecht J. K., 2003, Postharvest Physiology and Pathology of Vegetables, Marcel Dekker Inc, New York, USA.

Chaomuang N., Flick D., Denis A., Laguerre O., 2019, Experimental analysis of heat transfer and airflow in a closed refrigerated display cabinet, Journal of Food Engineering, 244, 101-114.

Defraeye T., 2014, Advanced computational modelling for drying processes – a review, Applied Energy, 131, 323–344.

Harker F.R., Feng J., Johnston J.W., Gamble J., Alavi M., Hall M., Chheang S.L., 2019, Influence of postharvest water loss on apple quality: The use of a sensory panel to verify destructive and non-destructive instrumental measurements of texture, Postharvest Biology and Technology, 148, 32-37.

Mascheroni R.H., 2012, Operations in food refrigeration, CRC Press, Boca Raton, USA.

Tirawat D., Flick D., Mérendet V., Derens E., Laguerre O., 2017, Combination of fogging and refrigeration of white asparagus preservation on vegetable stalls, Postharvest Biology and Technology, 124, 8-17.