Heat transfer dynamics during loading in industrial-scale controlled atmosphere storage of apples

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The effective preservation of apples in cold storage relies deeply on understanding the thermal dynamics governing their environment. Inside the storage room, apples are subject to complex thermal interactions, involving both inter-fruit and fruit-environment exchanges that influence the convective and conductive heat transfer processes. In large-scale industrial cold storage facilities, the complexity of process dynamics is further increased by spatial and temporal variations in temperature, humidity, and airflow distribution. Addressing these challenges requires comprehension of heat transfer mechanisms to optimize cold storage design and improve cooling system efficiency. By integrating direct heat flux measurement into advanced real-time monitoring and cooling control systems, an approach for fresh produce shelf-life extension can be achieved. For this reason, the objective of the current research is to obtain real-time cooling data to validate and extend the application of Peltier elements for heat flux detection on apple in an industrial-scale controlled atmosphere storage (1 kPa O2 and 2.5 kPa CO2). Parameters such as temperature, humidity, air speed profile, as well as heat flux and condensation detection on fruit surface emerge as critical data for analysis and decision-making. Spatial temperature distribution, heat flux, condensation, and fruit mass variation were investigated during loading and cooling down phases of a 50t apple CA storage. Heat flux data from the Peltier elements were validated against conventional methods and using a transient heat transfer model to predict fruit temperature. Additionally, the study examined the airflow patterns, where the superimposition of free and forced convection was detected. Condensation on the apple surface was detected during loading, mainly on the fruits located on the outer edges within the bin. The findings improved insights into cooling processes and real-time fruit condition monitoring, thus contributing to more efficient and sustainable postharvest management of apples.