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Postharvest Biology and Technology 40 (2006) 308–313
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Maximum slat width for cooling efficiency of horticultural produce in wooden crates

Clément Vigneault [a,b,*], Bernard Goyette [a], Larissa R. de Castro [a,b]

[a] Horticultural Research and Development Centre, Agriculture and Agri-Food Canada, Saint-Jean-sur-Richelieu, Que., Canada J3B 3E6
[b] College of Food Engineering, State University of Campinas, Cidade Universitária Zeferino Vaz CP 6121, Campinas, SP 13083-862, Brazil

Received 25 May 2005; accepted 16 January 2006

Abstract

The influence of wood package design on airflow distribution was investigated for forced-air cooling using horticultural produce simulators. The position of grooves on the container walls was tested using slat width of 100–200 mm and airflow rates ranging from 0.0005 to 0.003 $m^3 kg^{-1} s^{-1}$. The package opening configurations were compared based on their impact on the energy added to the system using a methodology previously developed. For this purpose, apples and sweet corns were taken as examples of produce from two different extremes in the respiration activity range. For airflow rates as low as 0.0005 $m^3 kg^{-1} s^{-1}$one groove at the bottom of the container produced a cooling process more uniform than the other one-groove configurations and even two grooves because of natural convection effect. If packing low respiration rate produce, increasing airflow rate could compromise the process energy efficiency because of air circulation obstruction for less vented containers. For high respiration rate produce enlarging open area above 2.4% would be recommended rather than increasing airflow rate to enhance cooling energy efficiency.

Keywords: Wooden crates; Package design; Forced-air cooling; Air velocity; Air distribution

1. Introduction

Horticultural produce losses reach up to 50% because of inefficient postharvest procedures (Camargo and Perdas, 2002). About half of these are due to physical injuries and poor conservation during handling, storage, and distribution of produce in inadequate packages (Cortez et al., 2002).

There are different materials used for packing fruit and vegetables, such as wood, corrugated cardboard, and plastic. The most suitable package for any horticultural crop depends on the region, length, and nature of the market chain (Cortez et al., 2002); the methods of handling and transport (LeBlanc and Hui, 2005); the environmental conditions; the availability and costs of material; and the postharvest procedures required for each produce (Kader, 2002; Cortez et al., 2002).

Wood containers have been extensively used for most of the fruit and vegetables in South America and for a few horticultural produce, such as apple, grape, stone fruit, snap bean, tomato, and sweet corn in North America. Whether it moulds wooden crates, baskets or a simple tray with raised corners, this material has been basically preferred because of its mechanical resistance attributes (Mcgregor, 1987). For instance, wire-bound crates are often used for those crops that require hydrocooling because their stacking strength is preserved in water contact. Moreover, this type of container can be dissembled to reduce shipping and disposal costs (Boyette et al., 2000). However, the restrictions imposed by the current international agricultural standards have limited the reuse of wood containers. This has forced the markets to search for new designs that allow sanitization and avoid cross contamination (Pitchler, 2004).

Regardless of the material, the design of horticulture produce packages must ensure not only hygienic maintenance, secure and easy handling, but also enough venting for ade-

* Corresponding author. Tel.: +1 450 346 4494x170; fax: +1 450 346 7740.
E-mail address: vigneaultc@agr.gc.ca (C. Vigneault).

0925-5214/$ – see front matter.
doi:10.1016/j.postharvbio.2006.01.005

quate produce quality conservation. For fruit and vegetables submitted to forced-air cooling, package opening area must be large and well distributed to provide fast and uniform cooling (Castro et al., 2005; Vigneault and Goyette, 2002). Fast cooling would be also attained by increasing the airflow rate but it could overprice the energy required for the process, especially for less vented packages (Émond et al., 1996; Boyette, 1996; Castro et al., 2005). Thus, package opening area must be optimized to guarantee produce integrity and quality conservation, and compensate for any costs derived from additional material required for structural support.

Much research has been done on the effect of the slats rough surface, splinters, and raised staples of wooden crates on the incidence and increase of mechanical injuries to horticultural produce (Ferreira et al., 2003; Neibauer and Maynard, 2003; Moretti et al., 2002; Castro et al., 2001; Costa and Caixeta Filho, 1996; Soares et al., 1993). There are also some scientific references regarding conservation of fruit in wood boxes and submitted to room cooling (Sanches et al., 2003). However, the role of wood package design on airflow distribution effectiveness during forced-air cooling has not been sufficiently explored yet.

The aims of this research were: (a) to evaluate the effect of the slat width or the groove distribution and the airflow rate on the cooling efficiency of forced air precooling system; (b) to investigate the possibility of increasing airflow rate to compensate for any negative effect of vented area size; (c) to determine the airflow rate impact on the energy added to the system to perform the same precooling process when using different opening configurations.

2. Material and methods

2.1. Produce simulator

The produce simulator described in detail by Vigneault and Castro (2005) consists of solid polymer balls 52.36 mm in diameter and weighing 125.55 g. One hundred and twenty eight balls were instrumented with a 30-gage insulated copper-constantan thermocouple wire placed in their center with a precision of $\pm$0.025 mm and their thermal properties were measured (Vigneault and Castro, 2005). Sixty-four out of these balls were selected for their relatively high uniformity in terms of cooling rate index ($-0.1414 \pm 0.0081\,\mathrm{min}^{-1}$), thermal conductivity ($683.9\,\mathrm{W\,mm}^{-1}\,\mathrm{K}^{-1}$), and heat capacity ($1.125 \pm 0.066\,\mathrm{kJ\,kg}^{-1}\,{}^{\circ}\mathrm{C}^{-1}$) (Castro et al., 2005).

2.2. Experimental set-up

The 64 instrumented balls were uniformly distributed along with other 448 balls on a columnar pattern to form a cubic matrix of 8-ball-side dimension. This arrangement resulted in 47.64% of porosity and was inserted in a forced-air cooling tunnel (Fig. 1). A forced-air cooling set up was simulated by assembling four acrylic plates to form a tunnel of 420 mm inside square cross-section and 1250 mm long. The ball matrix was positioned at 220 mm from the edge of the air-inlet tunnel. The portion of the tunnel containing the balls was insulated with a 25 mm-thick polystyrene foam to reduce heat conduction through the wall of the tunnel. The end of the air-inlet tunnel was attached to a 520 mm × 840 mm × 1100 mm aluminum static heat-exchanger to reduce the temperature

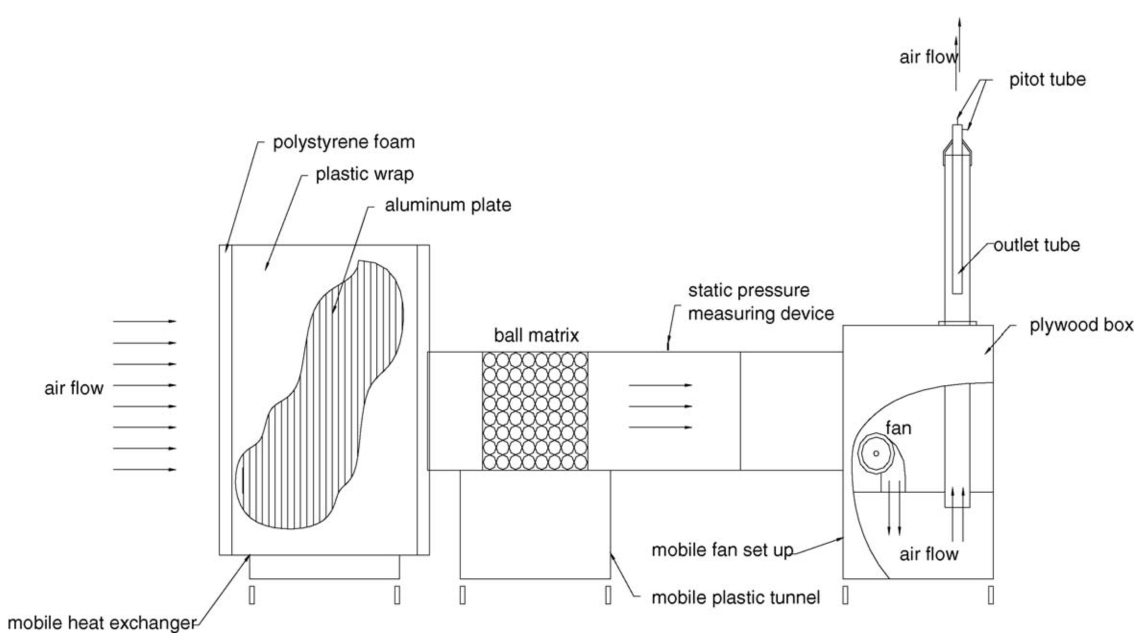

Fig. 1. Experimental set up showing forced air tunnel, balls matrix, fan, and air pressure drop and flow rate measuring devices.