Journal of Food Engineering 96 (2010) 279–286

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Design of a forced-air-twin-chamber for investigating the effects of controlled levels of non-uniformity in heat treatment of tomatoes on product quality

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ARTICLE INFO

Article history:
Received 15 February 2009
Received in revised form 24 July 2009
Accepted 30 July 2009
Available online 7 August 2009

Keywords:
Non-uniform heat treatment
Temperature
Air velocity
Tomato

ABSTRACT

A twin-chambered forced-air apparatus was built to simultaneously apply different environments to each hemisphere of tomato (*Lycopersicon esculentum* Merr.) fruit. This setup enabled one hemisphere of each fruit to be exposed to an air temperature–velocity combination of 39 °C/0.24 m s^{-1}; while the other hemisphere was simultaneously exposed to a combination of 36 °C/0.24 m s^{-1}, 37 °C/0.24 m s^{-1}, or 36 °C/0.12 m s^{-1}. Tomato fruits were divided into four lots: one left untreated; two lots were uniformly heat treated by maintaining the same environment in each chamber; and the remaining were subjected to twin chamber heat treatment. The fruits were then transferred to storage conditions at 14 °C, and allowed to ripen at 20 °C or subjected to chilling injury at 2 °C. The temperature difference between the two chambers significantly influenced the uniformity of color, whereas the firmness, titratable acidity and sugar to acid ratio were only marginally affected. Decreasing the temperature difference between the two chambers or increasing air velocity in heated chamber significantly improved the uniformity of quality.

1. Introduction

Heat treatment is used for disinfestation and disinfection of an increasing variety of crops (Lurie, 1998). Due to consumer requirements, environmental concerns and regulatory issues (Mulas and Schirra, 2007), a potentially non-damaging physical treatment is needed to replace chemical methods currently in use (Lurie, 1998). Heat treatment appears to be one of the most promising means for postharvest quarantine and control of decay (Fallik, 2004). Heat treatments can also be used to inhibit ripening, induce resistance to chilling injury (CI), and reduce external skin damage during storage, thus extending storability and marketability (Lurie, 1998).

However, the difficulty of producing a uniform heat treatment within a storage volume is one of the main obstacles in the industrialization of this process. Under bulk processing conditions, the heating field to which each commodity is exposed is rarely the same. This leads to heat treatment differences developing not only between commodities stored in a given space but also within a single commodity or even a unit such as a single fruit. Some researchers have studied bulk heating issues in the context of scaling-up radio frequency (Birla et al., 2004; Wang et al., 2006) or hot water treatments (Bollen and Dela Rue, 1999; Birla et al., 2004; Fallik, 2004; Wang et al., 2006). When a conventional medium such as air is employed, the low specific heat capacity and poor heat transfer ability can cause problems, making it difficult to obtain uniform heating within each individual unit. For instance, it has been found that the part of apples within cavities created by two fruits butted together and effectively sealed off from the heating medium, would delay by 25 min the apple tissue reaching within 1 °C of the target temperature when exposed to a hot water drench. This delay could be as high as 70 min when a forced-air heating system is employed (Bollen and Dela Rue, 1999). Heterogeneity exists not only within each single fruit but also between fruits exposed to air treatment. Vigneault and de Castro (2005) discussed the possibility of using an indirect measurement method of air velocity pattern inside a container during precooling to aid the container openings design. Their results demonstrated that the variance in temperature distribution increased as the open area of the container dropped below 25%, and that the airflow rate had a significant effect on the half-cooling time variance when the opening area was reduced or the openings are non-uniformly distributed non-uniformly (Vigneault and de Castro, 2005).

In the present study we sought to design a device to investigate the effect of known levels of non-uniform heating of individual tomato fruits. The results of this study could then inform the scaling-up of heat treatment applications by highlighting the links between engineering parameters and heat treatment effects. Quality, disease control, and chilling injury control differences attributable

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doi:10.1016/j.jfoodeng.2009.07.024

to heat transfer differences among individual commodities items (tomato fruit) were studied by exposing them to a range effective temperature. The non-uniformity effect of heat treatment within an individual commodity was analysed by using the custom designed device.

2. Materials and methods

2.1. Experimental setup

The experimental setup (Fig. 1), consisting of an insulated forced-air-twin-chamber, was built to generate a non-uniform heat treatment for individual tomato fruit. This setup insured that the hemisphere of the tomato located in one chamber was exposed to warm air at a controlled temperature of 39 °C and uniform air velocity of 0.24 m s^{-1}; whereas the hemisphere located in the second chamber was exposed to heating at lower temperatures (36 °C or 37 °C), under similar or lower (0.12 m s^{-1}) air velocities or under slower air circulation conditions (0.12 m s^{-1}; 36 °C).

2.1.1. Structure

Two 1185 × 700 × 140 mm chambers (Fig. 1) were superimposed to generate an upper and lower chamber. The upper chamber was always received the standard 39 °C/0.24 m s^{-1} heat-air velocity treatment combination, while the lower chamber was heated to a lower temperature and was subjected to an equal or lower air flow. Each of the twin chambers was further divided into nine parallel tunnels (130 mm in width; Fig. 1) in order to expose all tomato fruits to a relatively uniform airflow. The 700 mm length of the tunnels kept the tomato fruits from being subjected to too great an airflow gradient along the flow direction. Structural supports were constructed of a combination of steel and plastics to provide adequate strength and thermal insulation.

The external shell of the chamber was a single fabricated steel structure (Fig. 1), supporting the inner components. Some parts such as the inlet and outlet side walls, and the supporting plate were made of Acrylic Sheet (Professional Plastics Inc., Fullerton, CA, USA), taking advantage of its electrical insulating ability, moisture and chemical resistance, low thermal conductivity (0.186 W m^{-1} K^{-1}), transparency, and relatively low cost.

2.1.2. Heat exchanger

As the air in upper chamber was to be controlled at temperatures higher than ambient, an electric heater, consisting of eight 100 W incandescent bulbs, was used for heating. As the air temperature in the lower chamber was to be controlled across a wider range (23–39 °C), temperature control was achieved by means of a heat exchanger which could function as either a heater or cooler. A radiator-like heater core and VWR Signature™ Heated/Refrigerated Circulator (VWR International, West Chester, PA, USA) were employed for this purpose. Hot or cold water controlled at the desired temperature passed from the circulator through a winding tube of the core, where heat exchange occurred between water and the air forced through. Fins attached to the core tubes served to increase the surface for heat transfer to the air forced past them by a fan, thereby heating or cooling the produce. Circulating water temperature was set 2 °C higher or lower than the targeted air temperature in order to heat or cool air through the heater core. A large capacity reservoir (28 L) helped compensate for unexpected heat load changes.

2.1.3. Thermal insulation

Chambers were separated from each other by a 12 mm-thick insulation material (Microcell™; Foam N′ More, Inc., Michigan) supported by an 8 mm-thick plastic plate (Fig. 1, point 3). Microcell™, a "Skin-Soft" esthetically pleasing material that exhibits a smooth surface and extremely uniform cell structure, offers excellent flexibility, strength and resilience for thermal insulation applications. The Microcell™ is closed cell crosslinked polyethylene foam which is resistant to mildew mold, rot and bacteria. It also has a superior chemical resistance. Acrylic sheet (Fig. 1, point 4) is a self-supporting thermal insulation material and was used to support the

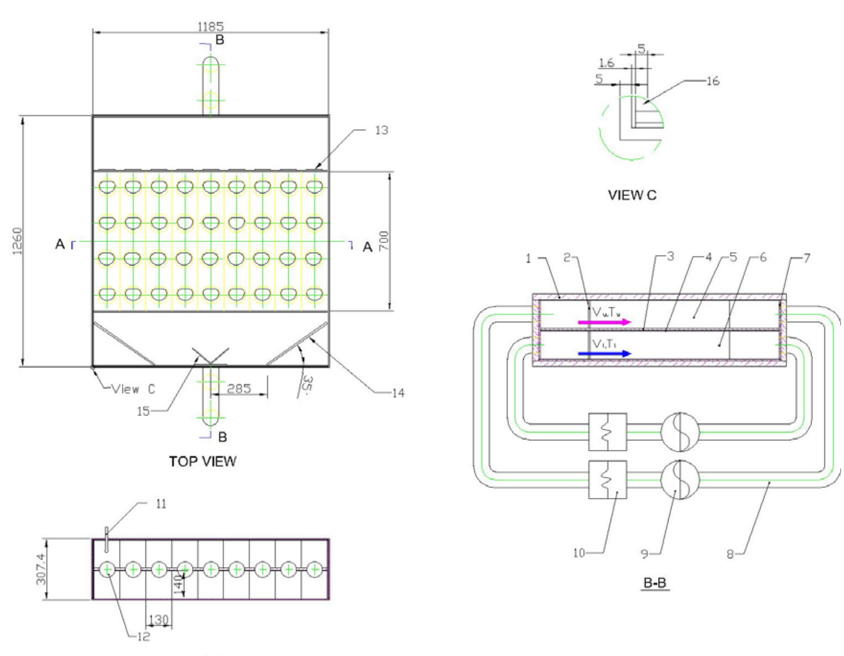

Fig. 1. Experimental setup consisting of a forced-air twin-tunnel allowing a produce matrix to be exposed to non-uniform environmental conditions as follows: (1) thermal insulation blanket; (2) aluminum mesh plate coated with porous adhesive-bonded fabric; (3) Microcell™; (4) plastic support; (5) upper tunnel; (6) lower tunnel; (7) plastic outlet wall; (8) air flow pipe; (9) fans; (10) heat exchangers; (11) thermocouples; (12) produce; (13) adjustable tunnel outlet opening; (14) baffle; (15) V-shape flow deflector; (16) cellular polystyrene thermal insulation board.