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Improving spinach quality and reducing energy costs by retrofitting retail open refrigerated cases with doors

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ABSTRACT

The prevalence of open-refrigerated display cases is ubiquitous in retail supermarkets, even in the face of the non-uniform temperature conditions present in these cases. In this paper, the temperature variations (ΔT) of packaged ready-to-eat baby spinach were evaluated for an open display case and a display case with glass doors, in order to assess the advantages of this physical barrier in minimizing ΔT and decay rate, and improving the visual quality of the samples after four days of storage. The two 3.66 m display cases were installed in the same room and conditions were constant at 21 °C and 60–70% of relative humidity, with a thermostat setting for both cases set at 0.6 °C. Results showed that the display case with doors significantly improved temperature uniformity and compliance with the U.S. Food and Drug Administration (FDA) Food Code recommendation of 5 °C or less to prevent microbial pathogen growth in packaged leafy greens. Only 1% of the temperature readings over four days in the case with doors were non-compliant with the FDA Food Code, while 24% of the readings in the open case were non-compliant; mostly recorded by the front positions of the case. The lower temperatures and ΔT of the case with doors were consistent with the higher visual quality scores ($P < 0.001$) for the baby spinach samples recorded by trained panelists, based on a 9-point hedonic scale, at 7.2 and 6.6 for the case with doors and the open case, respectively. Differences in decay rate were significant ($P < 0.001$) by the front of the case, with mean values of 8.8% for the open case and 5.5% for the case with doors. Furthermore, operational energy costs were 69% less than the open display case and the cost of door retrofits can be recouped in less than two years by energy savings alone.

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1. Introduction

Storage temperature is a critical factor for maintaining food quality and safety in packaged ready-to-eat fruits and vegetables (Kou et al., 2014a). Jacxsens et al. (2002) reported that temperatures at or below 4 °C can maintain the quality of fresh-cut produce and significantly reduce the growth of spoilage microorganisms. Kou et al. (2014b) also reported that temperatures at 1–4 °C can maintain the quality of baby spinach for up to 18 days post-processing. However, maintaining these temperature conditions during transportation and storage at the retail terminus has been a challenge due to the heterogeneous logistics across the chain. Zeng et al. (2014) observed that non-uniform temperatures during commercial transport, retail storage and display promote the growth of *Escherichia coli* O157:H7 and *Listeria monocytogenes* in packaged fresh-cut romaine mix, with populations increasing to a maximum of ~3 logs CFU/g at retail storage, consistent with temperature abuse between 8 °C and 16 °C. Across the cold chain, no pathogen growth occurred when temperatures remained at 4 °C or below (Zeng et al., 2014).

The U.S. Food and Drug Administration (FDA) updated its Food Code in 2009 to include packaged ready-to-eat leafy greens requiring time/temperature control for safety food at 5 °C or less to minimize pathogen proliferation in the supply chain (FDA, 2013). Other agencies around the world have also set temperature storage requirements for these vegetables. The Canadian Food Inspection Agency (CFIA) code of practice for minimally processed ready-to-eat vegetables established a 4 °C threshold during transportation and storage of produce (CFIA, 2014). The Australia New Zealand Food Standards Council defines specific temperature requirements

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for the transport, storage and display of “potentially hazardous food” at 5 °C or less (ANZFSC, 2014). The United Kingdom requires foods that are prone to the growth of pathogens, like ready-to-eat vegetables, to be held at or below 8 °C (FSA, 2007). Unfortunately, the implementation of these science-based food safety regulations is hindered by insufficient engineering efforts to ensure proper temperature control, in particular during refrigerated product display.

Retail stores usually keep packaged leafy greens in open refrigerated display cases, due to the unobstructed accessibility to products and appealing display. Despite the aerothermodynamic barrier established by an air curtain between the refrigerated space and the surroundings, 70–80% of the cooling load consists of ambient air infiltration across the air curtain (Faramarzi et al., 2002). Consequently, in commercial conditions, ΔT has been reported to be greater than 5 °C for products on the shelves (Willocx et al., 1994), and most of the high temperature abuse is encountered by the front of the display cases (Evans et al., 2007). These temperature issues translate into quality loss for products stored in open display cases (Kou et al., 2014a).

Fruits and vegetables in produce departments may be exposed to high temperatures during retail display. Nunes et al. (2009) recorded large temperature variations in open refrigerated displays, ranging from −1.2 °C to 19.2 °C; conditions that triggered a reduction in the quality and shelf life of produce, and accounted for 55% of the produce waste. In a different study, Kou et al. (2014b) reported that storage temperatures greater than 8 °C resulted in a significant reduction in the shelf life of packaged ready-to-eat baby spinach; confirmed by an accelerated tissue electrolyte leakage, product yellowing, decay and off-odor development. In an earlier study, Wells and Singh (1989) reported that perishable foods stored under varying temperature conditions will have deterioration functions different from products stored at constant temperatures.

Recent literature have explored different options to address the temperature differences affecting products stored in open display cases. Yu et al. (2009) reported a design for a vertical display cabinet with central air supply, Lu et al. (2010) explored the use of heat pipes, and Alzuwaid et al. (2014) investigated the use of phase change materials to reduce temperatures in open cases and for more stabilization of the product temperatures during defrost cycles. However, the infiltration of convective heat from the ambient air into the case that causes temperature increases for products in the front of the case, still needs to be addressed.

Preliminary work in our laboratory has shown that use of clear glass doors is the most effective modification to the open case for reducing ΔT of packaged leafy-greens, and for keeping products in compliance with the FDA Food Code temperature requirement of 5 °C or less. In addition, display cases with doors reduce operational energy costs, compared to open cases (Fricke and Becker, 2010).

Notwithstanding the ΔT and energy advantages of the cases with doors, the potential benefits in improving the quality and shelf life of produce has not being readily explored in the relevant literature. Following a thorough mapping of spatial and temporal product temperatures in the cases, this study assessed the visual quality and decay of packaged ready-to-eat baby spinach products after four days of storage in a display case with doors and an open display case. The energy consumption between the cases was also compared.

2. Materials and methods

2.1. Materials

Freshly-packed baby spinach leaves (170 g in each 30 cm × 23 cm bag) were kindly donated by Dole Fresh Vegetables, Inc. (Bessemer, NC). The products were shipped in a commercial refrigerated truck (2–4 °C) to the Beltsville Agricultural Research Center (BARC) at the US Department of Agriculture-Agricultural Research Service (USDA-ARS) (Beltsville, MD, USA), and immediately transferred to a 1 °C cold room upon arrival.

2.2. Equipment setup

Two retail display cases, 12-foot long (3.66 m), were installed in a room at BARC-USDA-ARS prepared solely for the cases. The room dimensions were 3.8 m (L) × 3.6 m (W) × 2.4 m (H). The cases included standard LED light, air curtains, and the display case duty operations were regulated by a digital thermostat set at 0.6 °C. This thermostat setting was chosen because lower settings cause product temperatures in the rear of the cases to fall below freezing.

Each display case contained three, 4-foot (1.22 m) sections with four shelves per section (from 1-top to 4-bottom) and a bottom rack, as shown in Fig. 1. Each 4-foot (1.22 m) shelf section was installed with 6 columns of TRION Wonderbar™ tray shelves (Trion Industries, Inc., Wilkes-Barre, PA, USA), for a total of 18 columns, which had spring-loaded ‘push-shelving’ to accommodate 6 bags of product (30 × 23 cm dimension) (Fig. 1). Three sets of evaporator coils (one set per 4-foot section) are enclosed in the back of the display cases. The air flow pattern is from the discharge grille on the top, moving downwards into the return grille via the three sets of fans that conduct the air through the evaporator coils. As cold air moves upwards, it is discharged from

Fig. 1. Schematic of the open-refrigerated retail display case. S1–S4 represent different shelves, and D1–D6 refer to depths. S5 represents the bottom rack. The baby spinach samples were loaded in columns 8–12, and the rest of the case was filled with product simulators.