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Open-refrigerated retail display case temperature profile and its impact on product quality and microbiota of stored baby spinach

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ABSTRACT

Maintaining proper storage temperature is critical for ensuring the quality and safety of fresh-cut products. The US Food and Drug Administration Food Code recommend that packaged fresh-cut leafy green vegetables be kept no warmer than 5 °C at all times to ensure food safety. Substantial temperature variations, however, within the widely used open refrigerated display cases used in retail stores are known to present the technical challenge of complying with this federal guidance for industry. This study determined the extent of the spatial and temporal temperature variations within two commercial open-refrigerated display cases under different operating conditions, and their impact on the quality and microbial growth of packaged baby spinach products. The packaged products were received within 2 d of commercial processing and temperature data loggers were placed inside-and-outside of each bag. All bags were immediately loaded in the display cases and the overall visual quality, tissue electrolyte leakage, total aerobic mesophilic bacteria and psychrotrophic bacteria were evaluated for each bag. Results from this study showed that the temperature variation in the cases was dependent on spatial location, thermostat setting, and defrost cycle interval and duration of defrost. The largest temperature differentials were found for samples located in the front and back rows of the display cases. Samples located in the front rows had the highest temperature due to heat penetration from the surrounding ambient environment, while those in the back were damaged as temperatures fell below freezing. These products received low quality scores and had higher tissue electrolyte leakage. In order to reduce the large temperature variations in the display cases, insulating foam boards were installed which significantly ($P < 0.05$) decreased the temperature variation by 3.5 °C and enabled samples in the front rows of the cases to remain less than 5 °C as recommended by the FDA. These results suggest that the quality and safety of packaged ready-to-eat spinach at retail will benefit from improvements in open refrigerated case design or the utilization of insulation, doors or curtains.

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1. Introduction

Packaged fresh-cut vegetables are popular food products as they are convenient, healthy, and ready-to-eat. Due to increased consumer demand, the fresh-cut produce industry has been rapidly expanding. However, fresh-cut produce has limited shelf stability due to rapid product quality deterioration. Advancements in fresh-cut packaging technologies have enabled the industry to maintain quality for longer periods of time (approximately 14 d) (Chua, Goh, Saftner, & Bhagwat, 2008; Kim, Luo, Saftner, & Gross, 2005). The ability to maintain recommended storage temperatures of these fresh-cut products is vital to ensure optimal food quality, and extended product shelf life (Evans, Scarcelli, & Swain, 2007).

Storage temperature is an important factor affecting the growth of spoilage and pathogenic bacteria. Studies from Luo, He, McEvoy, and Conway (2009) and Luo, He, and McEvoy (2010) showed that *Escherichia coli* O157:H7 grows rapidly in temperature-dependent manner on bagged fresh-cut leafy green products. The US Food and Drug Administration (FDA, 2009) revised the Food Code to include packaged fresh-cut leafy greens in the “temperature control

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for safety" (TCS) food category, and recommended that these products be maintained at 5 °C or below in transport, storage and retail display. This has also been adopted in the 2013 version of the Food Code (FDA, 2013).

Open-refrigerated display cases are widely used in supermarkets and grocery stores as a primary means to provide the cold temperature necessary for the proper storage of fresh and fresh-cut produce. Although these cases have the visual benefit of being aesthetically pleasing with concomitant easy access by consumers, they are not energy efficient and often fail to provide the temperature necessary for proper storage of the packaged fresh-cut fruits and vegetables. Surveys conducted by Willocx, Hendrick, and Tobback (1994) showed that 30% of products presented in Belgian refrigerated display cases were subjected to temperature variations and abuse in commercial settings. Evans et al. (2007) further reported that the majority of high temperature abuse (97%) was located at the front rows of the open-refrigerated display cases and that refrigeration systems and designs of retail displays were not sufficient to keep temperature or humidity within recommended ranges. Furthermore, temperature profiles in commercial retail displays showed large variations depending on the location of the produce in the displays (Nunes, Emond, Rauth, Dea, & Chau, 2009). These surveys reinforce the fact that retail display cases represent a weak link in the maintenance of a proper cold chain management (Wells & Singh, 1989).

The highly variable temperature conditions associated with the storage of fresh-cut products in commercial open-refrigerated display cases dramatically affect the quality and safety of produce (Allende, Luo, McEvoy, Artés, & Wang, 2004; Jacxsens, Devlieghere, & Debevere, 2002; Nunes et al., 2009; Paull, 1999). Danyluk and Schaffner (2011) suggest that research-based time range estimates for retail storage and accurate correlations between time and temperature during retail storage are needed, and the importance of this lag time in modeling *E. coli O157:H7* growth in leafy greens is currently unknown. Recently, Zeng, et al. (2014) reported that the profiles of long-term temperature abuse and high average temperature over time rather than transient temperature abuse, such as the defrost cycles of refrigeration units, lead to more accurate growth and an increased probability distributions of *E. Coli* O157:H7 and *Listeria monocytogenes* growth during commercially-bagged salad greens transportation, retail storage and display. Despite these prior research efforts, important data gaps exist in the areas of temperature profile mapping of retail refrigerated display cases as impacted by case operating conditions, and their correlations with microbial growth and product quality; along with practical approaches that could generate real world management options. The aim of this study was to determine the spatial and temporal temperature profiles of the display cases under different operating conditions, and their association with the quality and microbiota of stored packaged baby spinach.

2. Materials and methods

2.1. Equipment and experimental operating conditions

Two 12-foot long retail display cases were installed in a room prepared exclusively for the cases with an HVAC system and ambient temperature control at 22 °C. The dimensions of the room are 3.8 m (L) × 3.6 m (W) × 2.4 m (H). Each case consisted of three 4-foot sections (from side to side) and five modular shelves (from top to bottom) that are with flexible placement. Each 4-foot section was installed with 6 columns of TRION Wonderbar™ tray shelves (Trion Industries, Inc. Wilkes-Barre, PA, USA). The TRION Wonderbar shelves had proprietary spring-loaded 'push-shelving' to accommodate the bagged products and each column held up to 6 (30 cm × 23 cm) bags. External stand-alone condensing units provided customizable duty schedules for defrost time. Commercially packaged baby spinach leaves (170 g per bag; 30 cm × 23 cm bag) within 2 d of processing were donated by Dole Fresh Vegetables, Inc. (Bessemer City, NC, USA). The products were shipped overnight via commercial refrigerated truck (2–4 °C) to the Beltsville Agricultural Research Center at the US Department of Agriculture-Agricultural Research Services (Beltsville, MD, USA). All products tested in each trial were obtained from the same production line and shift in order to minimize the biological variation of the samples. Upon receiving, the samples were immediately transferred to a 1 °C cold-room where Model Trix-8 Log Tag temperature data loggers were installed (MicroDAQ, Contoocook, NH) inside and outside each bag (2 loggers per bag) The monitoring frequency was set at 2-min intervals and the samples were then loaded onto the display cases. All un-occupied spaces in the case were loaded with package simulators constructed using standard 1-gallon Ziploc® bags containing 65 g of shredded sponge material saturated with 266 mL of chlorine solution prepared at a ratio of bleach: water solution (7.5 g/L). In a preliminary study, we validated the response of these simulators to temperature changes compared to packaged baby spinach samples and found no significant differences ($P > 0.05$).

2.2. Evaluation of temperature profiles, product quality and microbiota

Two duty schedules (thermostat, defrost time and duration) were tested. The first set of experiment had the thermostat set at 28 °F (−2.2 °C), with a 12 h defrost interval, each at 30 min duration, and the second experiment had the thermostat setting increased to 31 °F (−0.5 °C), while the defrost cycle remained the same (30 min, 12 h interval). In both set of experiments, commercially packaged baby spinach bags were loaded onto three adjacent columns and four shelves. Each column in each of the four shelves were filled with 6 spinach packages each, with a total of 72 (3 columns × 4 shelves × 6 bags) bags (Fig. 1). In both sets at time zero (product as received) and after three days of display storage, packages were opened and product was evaluated for tissue electrolyte leakage, overall quality, total aerobic mesophilic bacteria and psychrotrophic bacterial populations.

Sensory attributes of overall visual quality were evaluated immediately after opening the bags by a three-member trained panel following a modified procedure from (Luo, McEvoy, Wachtel, Kim, & Huang, 2004). Overall quality was evaluated with a 9-point hedonic scale, where 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely (Meilgaard, Civille, & Carr, 1991).

Tissue electrolyte leakage was measured following a modified procedure from Luo et al. (2009). The samples (25 g) were submerged in 500 mL aliquots of distilled water at 5 °C for 30 min. The electrical conductivity of the solution was measured using a conductivity meter (model 135A; Orion Research Inc., Beverly City, Mass. USA). Total sample conductivity was determined for the same treatments after freezing at −20 °C for 24 h and subsequent thawing. Tissue electrolyte leakage was expressed as a percentage of the total conductivity.

Samples (25 g) of spinach leaves were randomly taken from each package, and macerated with 225 mL phosphate buffered saline in filtration stomacher using a Lab Stomacher (Biomaster 400, Seward, Ltd., London, UK) at 230 rpm for 2 min. A 50 μL sample of each filtrate or its appropriate dilution was spread on agar plates with an automatic spiral plater (Wasp II, Don Whitley Scientific Ltd., West Yorkshire, U.K.). Enumeration of the total aerobic mesophilic bacteria and psychrotrophic bacteria were completed after plating