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Minimizing pathogen growth and quality deterioration of packaged leafy greens by maintaining optimum temperature in refrigerated display cases with doors

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ABSTRACT

Retail display of packaged fresh-cut leafy greens is a critical stage of cold chain management and is prone to temperature fluctuations when produce is displayed in open cases, due to infiltration of ambient air into the case. Previous studies demonstrated that retrofitting open display cases with doors is the most effective solution to bring produce temperatures into compliance with FDA Food Code ($< 5\,^{\circ}C$), retain product quality longer, and reduce operational energy costs. In this study, we evaluated changes in quality attributes and populations of inoculated bacterial pathogens (*Escherichia coli* O157:H7, *Salmonella enterica*, and *Listeria monocytogenes*) in packaged baby spinach, chopped romaine, and lettuce mix displayed in a refrigerated case retrofitted with doors. All products displayed in the case with doors maintained high freshness and attractiveness after 3-day display, and the quality was comparable to that of products stored at a constant temperature in a 4 °C cold room. No substantial changes in pathogen populations were observed during the display period. These results demonstrate that retrofitting display cases with doors is a practical means of reducing temperature fluctuations and damage for fresh-cut products.

1. Introduction

Consumer demand for fresh-cut produce, especially leafy greens, continues to grow owing to the high nutritional value and convenience. However, fresh-cut produce has also recently emerged as one of the leading vehicles of foodborne outbreaks of gastrointestinal illness involving various bacterial pathogens, including enterohemorrhagic *Escherichia coli* (EHEC), *Salmonella enterica*, and *Listeria monocytogenes* (CDC, 2007; CDC, 2012; Lynch, Tauxe, & Hedberg, 2009; Painter et al., 2013; Slott, 2015). The recently enacted Food Safety Modernization Act (FSMA) requires fresh-cut produce processors to take effective measures to identify, prevent, and mitigate food safety hazards including pathogen contamination of food at all stages of food production and distribution (FDA, 2015). One of the critical factors outlined by FSMA for maintaining food safety is cold chain management.

For fresh-cut leafy greens, a cold chain failure can result in rapid product quality deterioration, growth of spoilage organisms and, if present, foodborne pathogens (Gorny, 2006; Luo, He, & McEvoy, 2010; Lynch et al., 2009; Roberts, Pitt, Farkas, & Grau, 1998). A more troubling aspect is that, at higher temperatures, the growth of some bacterial pathogens such as *E. coli* O157:H7 can outpace that of the spoilage bacteria, resulting in unsafe products without visual deterrent or detection (Luo, He, McEvoy, & Conway, 2009, 2010). Current FDA food safety guidelines for time/temperature controlled foods recommend refrigeration at temperatures not exceeding 5 °C in the supply chain, including food production, transportation and retailing (FDA, 2013, 2015).

Most retail establishments display produce in open-case refrigerated cases to enhance the customer experience. However, open cases for fresh-cut produce display have inherent issues with temperature uniformity and higher temperatures. In actual retail settings, temperature differences greater than 5 °C have been reported for fresh-cut products on shelves (Willocx, Hendrick, & Tobback, 1994) and higher temperatures are typically encountered at the front of the case (Evans, Scarcelli,

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Fig. 1. Schematic of the refrigerated retail display case with glass doors. Numbers 3, 9 and 15 represent the columns of shelves where the bagged produce was loaded for quality evaluation. F → B (front-to-back) refer to depths (front-D1, middle-D3 and back-D5). Columns 2, 8 and 14 were loaded with bagged produce for safety evaluation. The rest of the case was filled with product simulators.

& Swain, 2007).

The infiltration of ambient air into the open case, despite the presence of an aerothermodynamic barrier set by its cool air curtain, inevitably results in temperature elevation and temperature fluctuations for products displayed in the front rows. In fact, 70–80% of the cooling load of the cases consists of ambient air infiltration across the air curtain (Faramarzi, 2002). At the front of the open case, products are often subjected to temperatures above the FDA Food Code requirement of 5 °C for packaged leafy greens (Kou, Luo, Ingram, Yan, & Jurick, 2015). Under these conditions, bacterial pathogens are capable of significant proliferation. The elevated temperatures also accelerate product quality deterioration and shorten product shelf life (Kou et al., 2014).

In previous work, Zeng et al. (2014) reported that 30% of temperatures recorded in an open case at the retail level, for fresh-cut romaine mix, were above 5 °C after 3-day storage. In line with these findings, de Frias, Luo, Kou, Zhou, and Wang (2015) demonstrated that for all spatial locations in the open case, 24% of product temperatures were non-compliant with FDA Food Code.

To address these temperature issues with open display cases, previous work by Kou et al. (2015) evaluated several modifications to lower product temperatures and to improve temperature uniformity. For instance, the use of insulated foam blocks in the front and back of the case, reduced product temperatures in the front by blocking the infiltration of ambient air, and increased product temperatures above freezing for products in the back. Although effective, these foams may not be practical at the retail level. Another modification evaluated was the use of night curtains, which improved temperature control but was impractical for the stores to use during the day.

De Frias et al. (2015) found that retrofitting open display cases with glass doors was the most effective modification to the open case for reducing ΔT of bagged baby spinach and for keeping products below 5 °C. Furthermore, product compliance with FDA Food Code increased from 76% in the open case to 99% in the case with doors. These lower temperatures resulted in improved baby spinach quality and reduced operational energy costs by up to 69% compared to open cases (de Frias et al., 2015).

The purpose of the present study is to assess the food safety and quality of the most common bagged fresh-cut leafy greens, including baby spinach, chopped romaine lettuce, and lettuce mix after storage in a refrigerated display case retrofitted with doors under conditions simulating commercial retail display.

2. Materials and methods

2.1. Fresh-cut produce

Packaged baby spinach, chopped romaine lettuce, and lettuce mix (romaine, iceberg, and green leaf lettuce combination) were provided in-kind from a leading US fresh-cut processor. The packaged fresh-cut products came in 30 cm × 23 cm retail bags with a net weight of 170 g. The products were shipped on the day of processing in commercial refrigerated truck (2–4 °C) to the Beltsville Agricultural Research Center (BARC) at the U.S. Department of Agriculture-Agricultural Research Service (Beltsville, MD, USA), and transferred immediately to a 4 °C cold room upon arrival.

2.2. Setup of the refrigerated display case with doors

Experiments were conducted in one 12-foot long (3.66 m) retail display case retrofitted with French-style glass doors installed in a dedicated room (3.8 m (L) x 3.6 (W) x 2.4 m (H)) with biosafety level 2 (BSL-2) capability at the USDA-ARS Beltsville Agricultural Research Center. This vertical display case has three 4-foot (1.22 m) sections, with four shelves per section. Six columns of Trion Wonderbar™ spring-loaded push-shelves (Trion Industries, Inc. Wilkes-Barre, PA, USA) were installed in each section for a total of 18 columns in the case. Each column is equipped with four push-shelves to accommodate 6 bags of product on each shelf. The original analog thermostat was replaced with a digital one for improved temperature control accuracy and precision.

Under a thermostat setting of 0.6 °C, the separate compressor provided refrigerated air discharged from the top of the case into the return grille at 0.1 m/s via three fans that conduct the air upwards through the evaporator coils (one set per 1.29 m section) and discharged from the rear in shelves 1–4 and from the top grille at 0.1 m/s (de Frias et al., 2015). The planned-off cycle defrost was programmed for 30 min with an interval of 24 h.

2.3. Product load and temperature monitoring in the display case for the quality and pathogen studies

For the sensory study, each shelf in columns 3, 9 and 15 of the display case were loaded with three bags (front, middle and back) of ready-to-eat baby spinach, chopped romaine lettuce or lettuce mix, for a total of 45 bags of product (Fig. 1). Temperature data loggers (Trix-8, MicroDaQ.com, Ltd., Contoocook, NH, USA) were taped onto the exterior of each product and monitoring frequency was set for a 2-min interval for four days.

The surface temperature of all the displayed bags of fresh-cut produce was monitored for the whole storage period, and nearly 3000 readings were recorded for each bag over four days. Data loggers were placed outside the bags, as previous studies demonstrated no differences between data loggers placed inside versus on the product bags, once the temperature reached equilibrium (de Frias et al., 2015).

For the pathogen study done concurrently, each shelf in columns 2, 8 and 14 of the display case were loaded with three bags of ready-to-eat baby spinach or chopped romaine lettuce inoculated with a three-strain cocktail of *E. coli* O157:H7, *S. enterica,* and *L. monocytogenes*, for a total of 45 bags. The rest of the display case was loaded with product simulators consisting of 3.78 L (1 gal) Ziploc bags filled with 65 g of shredded sponge saturated with 266 ml of chlorine solution (7.5 ml bleach/1L water) (Kou et al., 2014). On day 0, samples were placed in the display case. Six bags of inoculated leafy greens were randomly selected for microbial analysis, and three bags of uninoculated leafy greens were selected for sensory evaluation to obtain pre-display data. After three days, all the samples were removed from the display case for sensory evaluation and microbiological analyses.

2.4. Testing conditions

Ambient conditions during testing, temperature at 17.7 °C - 18.5 °C and relative humidity of 60–70% were selected to simulate the real conditions in retail supermarkets and for the display cases when holding fresh vegetables, which require higher RH values to prevent dehydration. The display case was programmed with a thermostat setting of 0.6 °C and a daily 30 min defrost cycle (planned off-cycle) for three days. The compressor stopped during the programmed defrosting, allowing the evaporator fans to continue circulating air across the evaporator coil to melt any frost build-up (de Frias et al., 2015).

The test duration of three days for both the quality and safety assessments was selected to provide a worst-case scenario. Similar conditions were selected by Zeng et al. (2014) in their food safety studies involving retail stores.

2.5. Sensory evaluation

Visual quality and freshness of bagged baby spinach, chopped romaine, and lettuce mix were assessed prior to display (day 0), immediately after 3-day display, and in the 4 °C cold room. Sensory evaluations were conducted by a three-member trained panel following a modified procedure by Luo et al. (2009). Sample bags were labeled with random 3-digit codes to ensure testing objectivity. Visual 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, 2016). Freshness attributes (i.e., wetness, dehydration, discoloration and yellowing) were evaluated with a 100-point scale, where 0 = decomposed and 100 = fresh (pristine), similar to the unstructured line scale that was used in other sensory studies for fresh produce (Park et al., 2018; Xiao et al., 2015).

2.6. Inoculum preparation and inoculation

Three-strain cocktails for each species of pathogen including *E. coli* O157:H7 with nalidixic acid resistance (RM1918, RM4406, RM5279), *S. enterica* transformed with plasmid pGT-KAN (Newport FDA 2757, Thompson RM 1987; Typhimurium SL1344), and *L. monocytogenes* (NRRL B59186, Scott A 45A54, Scott A 45A65) were used in this study. A single colony for each strain was transferred to tryptic soy broth (TSB, Neogen, Lansing, MI, USA) with 50 mg/L nalidixic acid (*E. coli*), or 50 mg/L kanamycin (*S. enterica*), or without antibiotics (*L. monocytogenes*) and incubated for 20 h at 37 °C with shaking. Cells were harvested by centrifugation at 4300 g for 5 min, washed once in sterile phosphate-buffered saline (PBS), and re-suspended in PBS. Equal volumes of cell suspensions from each strain were mixed and diluted in PBS to achieve a cocktail of inocula with approximately 10^6 CFU/mL for each of the three species. Bagged leafy greens were inoculated per the modified method of Zeng et al. (2014). The surface of each bag of produce samples was sterilized using 70% ethanol prior to inoculation. Then, each bag of unopened produce was inoculated by injecting 2 ml of the cocktail inoculum through a pre-sealed septum (Dansensor, Ringsted, Denmark) into the bag using a Precision Glide general use syringe (Becton Dickinson, Sparks, MD, USA). The bag incision was immediately sealed with a second septum to avoid change in package atmosphere, and the bag was then vigorously shaken for 1 min inside a BSL-2 hood to allow even distribution of the inoculum. Forty-five bags of inoculated products were loaded on shelves in the columns adjacent to those for produce quality analysis. Six additional bags of inoculated products were randomly selected on day 0 for microbial analysis.

2.7. Microbial analysis

Product samples (25 g) were randomly taken from each package and macerated with 225 mL PBS in a stomacher (Biomaster 400, Seward, Ltd., London, UK) at 230 rpm for 2 min. The filtrate, or its appropriate dilution in sterile PBS, was spiral plated (Microbiology International, Frederick, MD, USA) for enumeration of surviving pathogens using selective agar media as follows: *E. coli* O157:H7 on MacConkey's Agar supplemented with 50 mg/L nalidixic acid (Difco Lab, Sparks, MD., USA.) and incubated at 37 °C for 24 h; *S. enterica* on tryptic soy agar supplemented with 50 mg/L kanamycin (Difco Lab.) and incubated at 37 °C for 24 h; *L. monocytogenes* on Brilliance Listeria Agar (Thermal Scientific, Odessa, TX) and incubated at 37 °C for 48 h. Microbial colonies were counted using an automated colony counter (ProtoCOL SR; Synoptics, Cambridge, UK) and reported as log CFU/g of fresh tissue.

2.8. Statistical analysis

The design of experiments was completely randomized, with depth (1, 3, 5, front to back), shelf (1–5, top to bottom rack) and column (2 or 3, 8 or 9, 14 or 15, left to right) as independent variables. Product quality and pathogen growth were the dependent variables. The temperature and quality evaluations and microbial data were analyzed using the PROC MIXED procedure in SAS (ver. 9.3, SAS Institute, Cary, NC) to test the null hypothesis at $\alpha = 0.05$. Microbial data were log transformed and analyzed using a two-factor (organism and storage duration) linear model. An analysis of studentized residuals was performed to test the assumptions of normal distribution, homogeneity of variance and independence of studentized residuals. Departures from the assumptions were addressed with bootstrap re-sampling (PROC MULTTEST) non-parametric analyses. The variance grouping technique was used to correct for variance heterogeneity. Pairwise comparisons between treatments among the factors were based on the differences of least square means, and tested for significance using Tukey (or Sidak for microbial data) adjusted p-values to maintain experiment-wise error ≤ 0.05.

3. Results and discussion

3.1. Product temperature profiles in the display case with doors

The temperature profiles were plotted as box and whisker diagrams to capture the variations (Fig. 2A, B, C). The y-axis represents temperature and the x-axis the depth within the display case (1-front to 5-back), for each of the three sections of the case (L-left, M-middle, and R-right). For the three trials with different types of fresh-cut produce, the product temperature profiles were comparable. During regular refrigeration cycles (not defrost), even though the spatial factors (column and depth) were statistically significant ($p < 0.001$), all temperatures were below the 5 °C limit established by the FDA Food Code to prevent pathogen growth in leafy greens. Increased product temperatures at depth 1 (< 3.6 °C on average) are associated with the proximity to the glass doors which are in contact with ambient air. Relatively lower product temperatures at depths 3 (< 1.7 °C on average) and 5 (< 1.32 °C on average) were expected as they are farther away from the door, in addition to the cold air flow out of the rear of the case on shelves 1–4.

Outliers above the upper whiskers in Fig. 2 represent temperature data during defrost cycles. Products at the front of the case (depth 1) experienced the highest temperatures at defrost (one 30-min defrost cycle per day), reaching 5.2 °C at depth 1 in the middle column (just above the FDA Food Code threshold). Among columns, product temperatures in the middle (1.5 °C on average) were lower than on the side columns (1.9 °C on the left, 2.2 °C on the right), as products on the two sides of the display case are more exposed to any conductive heat from the side walls of the display case. Overall, the lowest product temperature recorded was 0.5 °C, at depth 5 in the middle column, above the freezing point of water. The largest temperature difference (between whiskers in Fig. 2) was 3.5 °C.

The effectiveness of glass doors as a barrier to the infiltration of ambient air into the display case is evident by the very limited variation in product temperatures at different ambient temperatures. In agreement with previous work, we reported that temperatures of bagged baby spinach in compliance with the FDA Food Code, increased from 76% in the open case to 99% in the case with doors at an ambient temperature of 21 °C and a thermostat setting of 0.6 °C for both types of cases (de Frias et al., 2015). The non-compliance temperatures in the open case corresponded mainly to products located in the front of the case, at depths 1 and 2. The lower product temperatures in the case with doors retained visual quality and reduced decay rates in the salads.

The present study, validates the earlier study, as product temperatures in three types of bagged salads were 100% compliant with Food Code (except for one defrost cycle outlier of 5.2 °C) at an ambient temperature of 18.5 °C. Also, these lower temperatures improved food quality and safety as discussed in the next sections.

3.2. Quality evaluation of packaged leafy greens in the display case with doors

Product sensory attributes, including visual quality and freshness, for each of the tested fresh-cut products was evaluated upon receipt of the samples on day zero, after 3-day display in the case retrofitted with doors, and after 3-day storage at constant temperature in a 4 °C cold room. All the products received near top scores at the time of receipt, and all the displayed products maintained high quality after 3-day storage, comparable to those stored in the 4 °C cold room.

Product freshness was scored on a 100-point scale (Table 1), where 0 = decomposed and 100 = fresh (pristine). The freshness attributes evaluated consisted of surface wetness, dehydration, discoloration and

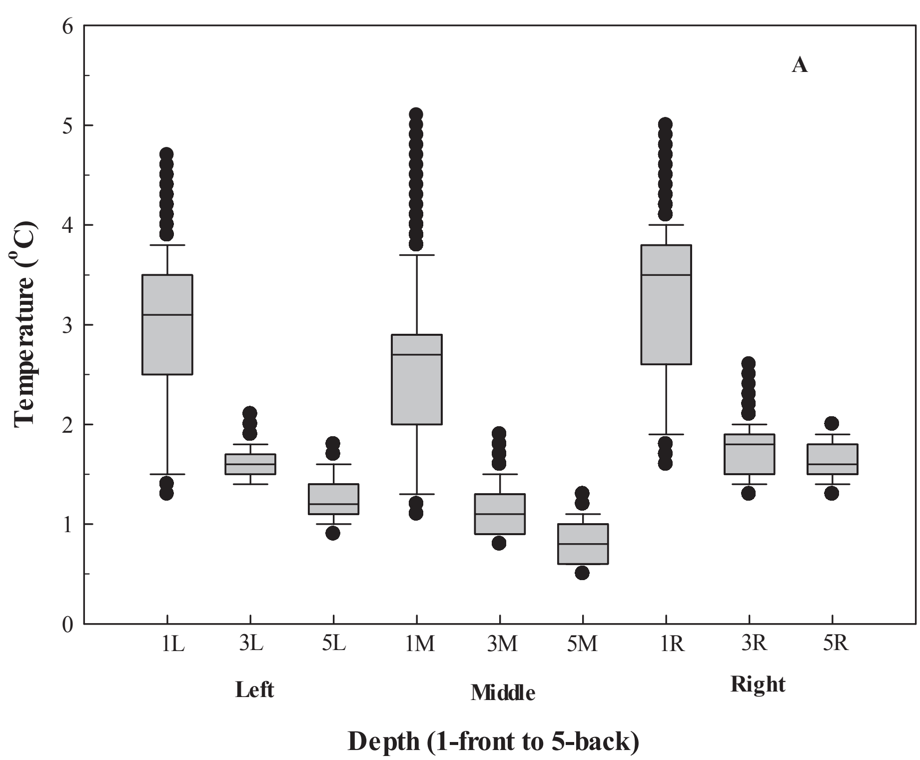

Fig. 2. Temperatures recorded in bagged baby spinach products displayed in a case with glass doors for three days. Depths 1, 3, 5 are positioned from front to back of the case, and L (left), M (middle), R (right) represent columns 3, 9 and 15, respectively. Outliers are consistent with temperature spikes associated with the single 30-min defrost cycle per day. Room temperature conditions were constant at 18.5 °C ± 1.2 °C. A. Baby spinach; B. Cut Romaine lettuce; and C. Lettuce mix.

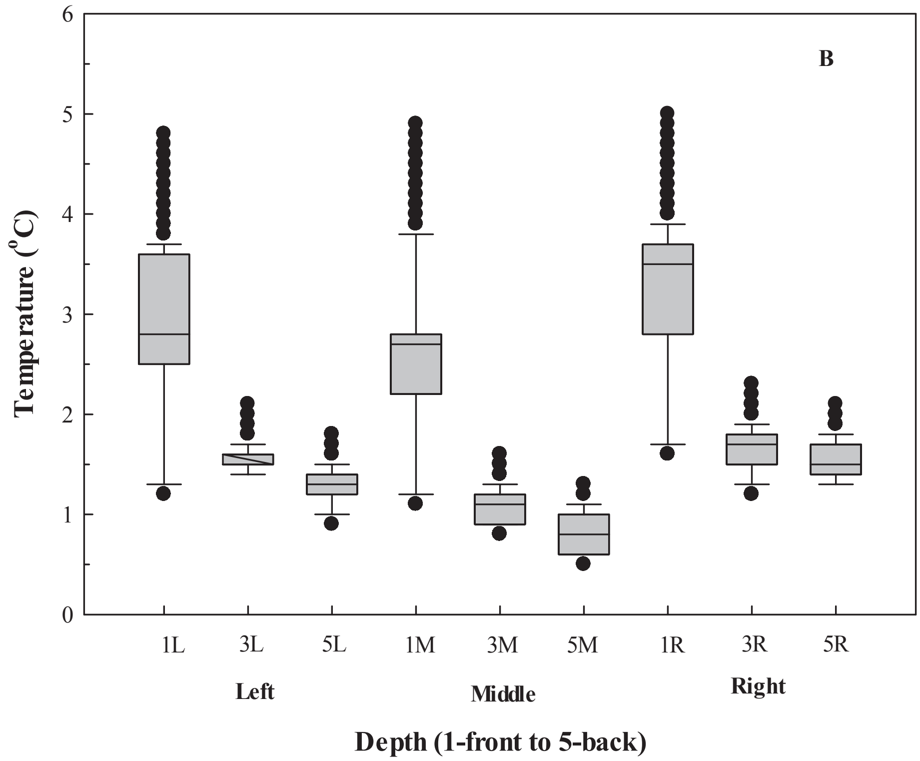

Fig. 2. (*continued*)

yellowing. After 3-day display in the case with doors, the freshness scores for baby spinach, chopped romaine, and lettuce mix decreased from 95, 95, and 90 on day zero to 88, 84, and 87, respectively. Similar decreases in the freshness scores were obtained for those stored at 4 °C in cold room (86, 84, and 89, respectively). The decline in freshness scores, although statistically significant ($p < 0.001$), would still reflect products that would be considered fresh by consumers.

For baby spinach and chopped romaine on display, the evaluation of freshness among the spatial locations showed no significant differences ($p > 0.05$) after 3-day storage in the case with doors. For lettuce mix, differences in freshness were statistically significant ($p < 0.001$) for the spatial locations "shelf" and "depth". Pairwise comparisons between the spatial locations of the lettuce mix samples, showed that differences in product freshness between depth 1 (front of the case), and depths 3 or 5, were significant ($p < 0.001$). However, differences between depths 3 and 5 were not significant ($p > 0.05$).

Product visual quality was scored based on a 9-point hedonic scale (Table 2), where 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely. The quality scores for baby spinach, chopped romaine and lettuce mix decreased from 8.3, 8.5, and 8.0, on day 0–7.8, 7.2, and 7.8, respectively, after the 3-day display. The quality scores for the products in the display case were comparable to those stored at 4 °C in cold room (7.6, 7.6, and 8.2, respectively). Similar to freshness evaluations, the effect of spatial locations in the display case on product visual quality was not statistically significant ($p > 0.05$) for baby spinach and chopped romaine. The effect of spatial location on the visual quality and freshness scores of mixed lettuce salads was significant ($p < 0.001$). Overall, bagged produce placed in the front row (depth 1), where elevated temperature occurred, had the lowest freshness and visual quality scores for each type of produce. Panelists reported unappealing attributes for samples that corresponded mainly to products at depth 1. For baby spinach, the most common description was "wet", whereas for chopped romaine lettuce and lettuce mix, most samples at depth 1 were described as showing "browning".

3.3. Survival and growth of inoculated pathogens under storage conditions

We compared the populations of three major foodborne bacterial pathogens (*E. coli* O157:H7, *S. enterica*, and *L. monocytogenes*) on the three packaged leafy green products before and after display in the case retrofitted with doors. Populations of the recovered pathogens are shown as dot plots (Fig. 3) without identifying the bag locations. In general, after 3 days in the display case, the bacterial populations in the bagged products were maintained at levels comparable to those on the day of inoculation. No significant growth was observed on baby spinach or mixed leaf salads for any of the pathogens, and *E. coli* O157:H7 declined slightly, but significantly on the mixed salad ($P = 0.0296$). Significant, although minimal growth of about 0.2 log was observed on chopped romaine lettuce for all three pathogens ($P < 0.001$). However, statistical analyses did not show any specific trend regarding spatial locations of the bagged products (data not shown).

3.4. Retail response to displaying produce behind doors

3.4.1. Consumer acceptance

Even though some major retail chains have started to implement display cases with doors for high value fresh-cut products, traditional open cases remain the most commonly used equipment to display fresh-cut products. Increasing evidence point to consumers being open to purchasing bagged salads displayed behind doors, and understanding the benefits of higher quality and reduced safety risks (Fricke & Becker, 2010; Slott, 2014, 2015). At the Food Marketing Institute's Energy & Store Development Conference in 2010, major retailers reported their experiences with door retrofits on their open cases (Garry, 2010). In

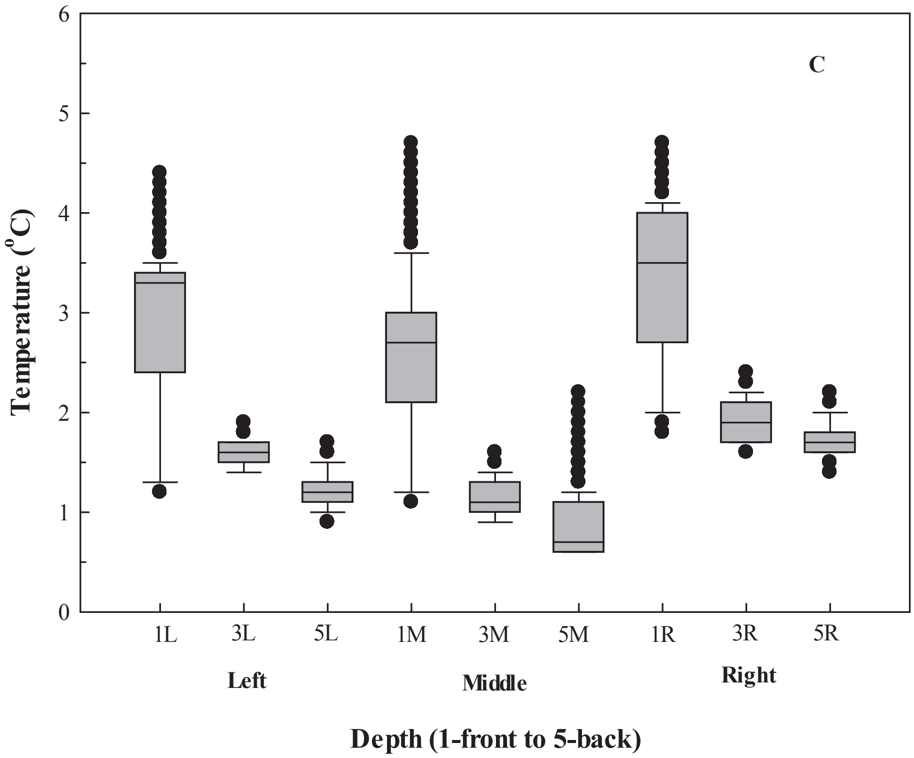

Fig. 2. (*continued*)

Table 1
Overall freshness score of fresh cut produce on days 0 and 3 after cold room storage at 4 °C, and day 3 after display in a case with doors.[a]

	Day 0		Day 3 Cold Room	
Spinach	95.0		86.0	
Cut Romaine	95.0		84.0	
Lettuce Mix	90.0		89.0	
	Day 3, in display case			
	Depth 1	Depth 3	Depth 5	Average
Baby Spinach				
Shelf 1	84.9 ± 4.5	87.8 ± 2.9	89.0 ± 3.8	87.2
Shelf 2	87.3 ± 0.9	87.9 ± 1.7	88.2 ± 4.2	87.8
Shelf 3	88.6 ± 1.3	88.3 ± 1.7	91.2 ± 1.7	89.4
Shelf 4	85.9 ± 4.2	90.6 ± 4.6	87.1 ± 4.2	87.9
Shelf 5	88.1 ± 2.7	87.3 ± 0.3	87.4 ± 2.2	87.6
Average	87.0	88.4	88.6	88.0
Cut Romaine				
Shelf 1	82.1 ± 3.3	83.1 ± 7.8	84.0 ± 6.4	83.1
Shelf 2	83.1 ± 6.8	89.2 ± 3.6	83.0 ± 7.1	85.1
Shelf 3	81.6 ± 4.2	85.3 ± 4.9	83.7 ± 2.3	83.5
Shelf 4	79.1 ± 3.4	88.9 ± 3.7	83.4 ± 6.2	83.8
Shelf 5	83.9 ± 5.2	84.6 ± 2.8	89.4 ± 3.6	86.0
Average	82.0	86.2	84.7	84.3
Lettuce Mix				
Shelf 1	79.4 ± 6.3	87.9 ± 5.6	92.0 ± 1.2	86.4
Shelf 2	85.3 ± 8.0	88.8 ± 2.0	90.6 ± 5.1	88.2
Shelf 3	82.9 ± 1.3	93.0 ± 3.5	90.6 ± 4.2	88.8
Shelf 4	90.1 ± 6.8	91.9 ± 2.0	86.6 ± 1.8	89.5
Shelf 5	80.6 ± 5.1	78.6 ± 8.1	88.0 ± 2.5	82.4
Average	83.7	88.0	89.6	87.1

[a] The freshness was scored on a 100-point scale, where 0 = decomposed and 100 = fresh (pristine). Each value is the average of the three columns as scored by three trained panelists.

Table 2
Overall quality of fresh cut produce on day 0, day 3 after cold room storage at 4 °C in a cold room (CR), and day 3 after storage in a display case with doors.[a]

	Day 0		Day 3 Cold Room	
Baby Spinach	8.3		7.6	
Cut Romaine	8.5		7.6	
Lettuce Mix	8.0		8.2	
	Day 3, in display case			
	Depth 1	Depth 3	Depth 5	Average
Baby Spinach				
Shelf 1	7.3 ± 0.3	7.8 ± 0.5	8.0 ± 0.3	7.7
Shelf 2	7.6 ± 0.2	7.8 ± 0.5	7.8 ± 0.4	7.7
Shelf 3	7.9 ± 0.3	7.8 ± 0.5	8.3 ± 0.3	8.0
Shelf 4	7.6 ± 0.4	8.2 ± 0.7	7.8 ± 0.7	7.9
Shelf 5	7.9 ± 0.3	7.7 ± 0.4	7.7 ± 0.6	7.8
Average	7.7	7.9	7.9	7.8
Cut Romaine				
Shelf 1	7.2 ± 0.5	7.3 ± 0.5	6.7 ± 0.4	7.1
Shelf 2	7.2 ± 0.5	7.7 ± 0.3	7.3 ± 0.9	7.4
Shelf 3	7.2 ± 0.6	7.2 ± 0.5	7.0 ± 0.4	7.1
Shelf 4	6.6 ± 0.5	7.7 ± 0.6	7.2 ± 0.5	7.2
Shelf 5	7.2 ± 0.5	7.2 ± 0.4	7.7 ± 0.6	7.4
Average	7.1	7.4	7.2	7.2
Lettuce Mix				
Shelf 1	6.9 ± 1.0	8.0 ± 0.8	8.3 ± 0.3	7.7
Shelf 2	7.6 ± 1.0	8.0 ± 0.3	8.2 ± 0.6	7.9
Shelf 3	7.2 ± 0.0	8.4 ± 0.5	8.3 ± 0.3	8.0
Shelf 4	8.2 ± 0.9	8.6 ± 0.2	7.7 ± 0.3	8.2
Shelf 5	6.8 ± 0.4	6.8 ± 0.7	8.2 ± 0.4	7.3
Average	7.3	8.0	8.1	7.8

[a] Overall quality is scored on a 9-point hedonic scale, where 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely. Each value represents the average of the three columns as scored by three trained panelists.

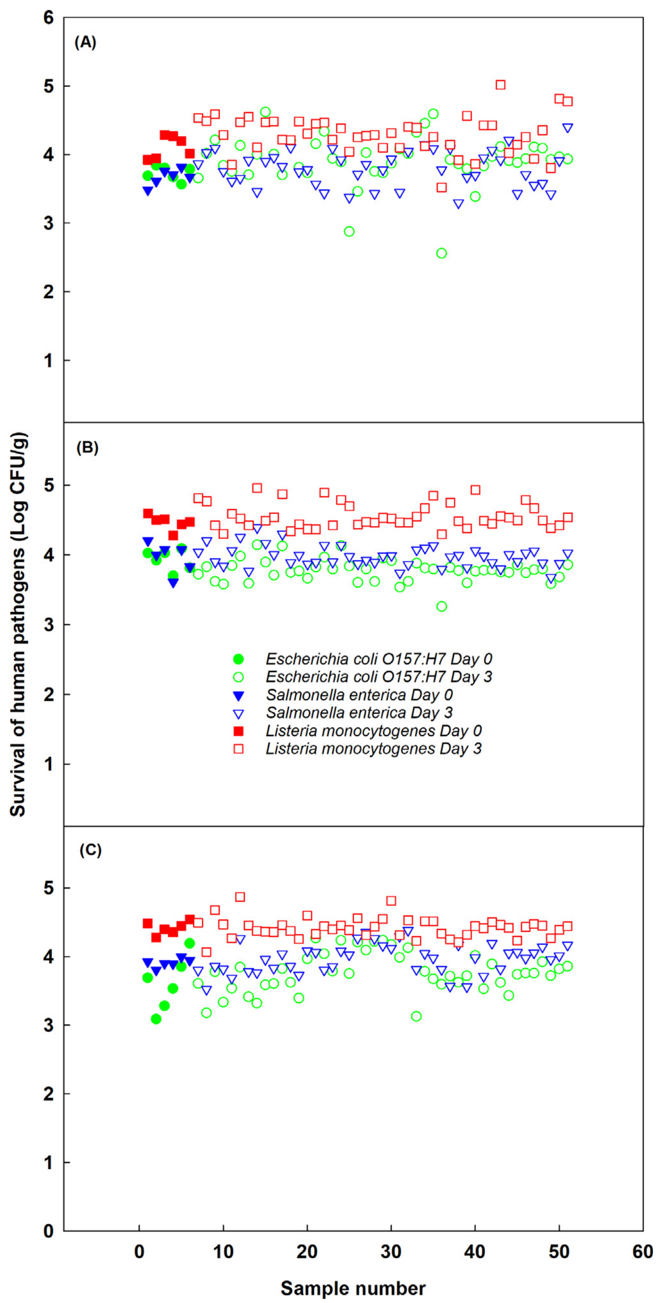

Fig. 3. Populations of *E. coli* O157:H7, *S. enterica*, and *L. monocytogenes* on bagged fresh-cut produce on day 0 after inoculation and on day 3 after display in the case with doors (inclusive of all locations within the case). Forty-five bags of inoculated products were loaded on shelves in the columns adjacent to those for produce quality analysis. Six additional bags of inoculated products were randomly selected on day 0 for microbial analysis. A. Baby spinach; B. Cut Romaine lettuce; and C. Lettuce mix.

general retailers reported improved product quality and shelf life and favorable consumer response to displaying produce behind glass doors (Garry, 2010; Slott, 2014, 2015).

3.4.2. Energy savings

All the retailers referenced in the report by Garry (2010) agreed on the important energy savings provided by retrofitting open cases with doors. Retailers need to be aware that the energy savings associated with installing doors, result primarily from the ability to reduce defrost cycle duration and frequency and increase thermostat settings. Once doors are retrofitted, too low temperatures can result in ice build-up and product loss to freezing if such adjustments are not made.

For the investment of retrofitting open display cases with doors for bagged salads, the retailer is expecting a payback within 2.8–4 years (Slott, 2015). This estimate is comparable to findings by de Frias et al. (2015). In this study, the time to recuperate costs of door retrofits was 1.8 years on energy savings alone, using doors without anti-sweat heaters. The energy cost of anti-sweat heaters would push back the payback period, approaching the retailer's estimate in the Slott (2014, p. 30) report by Produce Business Magazine.

Regarding the electrical energy consumption, previous studies have analyzed and compared the performance of the open display case versus the display case with doors (Faramarzi, 2002; Fricke & Becker, 2011; de Frias et al., 2015). The most significant energy savings of using display cases with doors are achieved in the electrical energy consumption of the condensing units. Faramarzi, Coburn, and Sarhadian (2002) reported that glass door retrofits reduced the total cooling load by 68%, reducing compressor power demand by 87%. Fricke and Becker (2010) found that energy consumption of the condensing units decreased 72%, from 42.2 kWh/day to 11.7 kWh/day. de Frias et al. (2015) determined that consumption of the condensing units decreased 80%, from 54.1 kWh/day to 10.8 kWh/day.

Furthermore, the same study found no significant impact of door openings on temperature profiles or energy consumption in the case with doors, when two treatments were tested, (1) doors closed all the time and (2) partial door openings 6 times per hour for 12 s. For these door opening tests, the ASHRAE standard 72–2014 was used. This *Method of testing open and closed commercial refrigerators and freezers*, states that each door be sequentially and fully opened 6 times per hour for 6 s for a period of 8 h (ASHRAE, 2014).

4. Conclusion

In the present study, we demonstrated that fresh-cut leafy green products displayed in a case retrofitted with glass doors, over a typical retail display period of 3 days, maintained uniform quality attributes comparable to those stored under a constant temperature of 4 °C. Aside from one exception in which a bag measured an outlying temperature of 5.2 °C during the defrost cycle, 100% of samples maintained compliance with the FDA Food Code requirement of 5.0 °C or less, while no product exhibited freezing damage or other visual quality deterioration. As expected, because of the lower temperatures, the growth of inoculated foodborne bacterial pathogens was controlled. All these observations indicate that using display cases with doors or retrofitting open cases with doors, can better maintain the quality and safety of fresh-cut produce for retail display.

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References

ANSI/ASHRAE (2014). Method of testing open and closed commercial refrigerators and freezers. Atlanta, (GA). *Am. Soc. Heat. Refrig. Air-Cond. Engineers,* 2–20 Standard 72-72-2014.

Centers for Disease Control and Prevention (CDC) (2007). *Investigation of an Escherichia coli O157:H7 outbreak associated with Dole pre-packaged spinach.* https://www.cdc.gov/nceh/ehs/docs/investigation_of_an_e_coli_outbreak_associated_with_dole_pre-packaged_spinach.pdf, Accessed date: 5 October 2017.

Centers for Disease Control and Prevention (CDC) (2012). *Multistate outbreak of shiga toxin-producing Escherichia coli O157:H7 infections linked to organic spinach and spring mix blend (Final Update).* https://www.cdc.gov/ecoli/2012/o157h7-11-12/index.html, Accessed date: 5 October 2017.

Evans, J. A., Scarcelli, S., & Swain, M. V. L. (2007). Temperature and energy performance of refrigerated retail display and commercial catering cabinets under test conditions. *International Journal of Refrigeration, 30*, 398–408.

Faramarzi, R. T., Coburn, B. A., & Sarhadian, R. (2002). Performance and energy impact of installing glass doors on an open vertical deli/dairy display case. *ASHRAE Transactions, 108*, 673–680.

de Frias, J. A., Luo, Y. G., Kou, L. P., Zhou, B., & Wang, Q. (2015). Improving spinach quality and reducing energy costs by retrofitting retail open refrigerated cases with doors. *Postharvest Biology and Technology, 110*, 114–120. http://dx.doi.org/10.1016/j.postharvbio.2015.06.016.

Fricke, B. A., & Becker, B. R. (2010). Doored display cases they save energy, Don't lose sales. *ASHRAE Journal, 52*(9), 18–25. http://www.freepatentsonline.com/article/ASHRAE-Journal/257352855.html, Accessed date: 5 October 2017.

Fricke, B. A., & Becker, B. R. (2011). Comparison of vertical display cases: Energy and productivity impacts of glass doors versus open vertical display cases. *ASHRAE Transactions, 117*, 847–858. https://www.thefreelibrary.com/Comparison+of+vertical+display+cases%3A+energy+and+productivity+impacts...-a0257557870, Accessed date: 5 October 2017.

Garry, M. (2010). New tests support doors on cases. http://www.supermarketnews.com/technology/new-tests-support-doors-cases, Accessed date: 18 May 2017.

Gorny, J. R. (2006). Commodity specific food safety guidelines for the lettuce and leafy greens supply chain: International Fresh-cut Produce Association. https://www.fda.gov/downloads/Food/FoodSafety/ProductSpecificInformation/Fruits-VegetablesJuices/GuidanceComplianceRegulatoryInformation/UCM169008.pdf, Accessed date: 5 October 2017.

Kou, L. P., Luo, Y. G., Ingram, D. T., Yan, S. L., & Jurick, W. M. (2015). Open-refrigerated retail display case temperature profile and its impact on product quality and microbiota of stored baby spinach. *Food Control, 47*, 686–692.

Kou, L. P., Luo, Y. G., Park, E., Turner, E. R., Barczak, A., & Jurick, W. M. (2014). Temperature abuse timing affects the rate of quality deterioration of commercially packaged ready-to-eat baby spinach. Part I: Sensory analysis and selected quality attributes. *Postharvest Biology and Technology, 91*, 96–103. http://dx.doi.org/10.1016/j.postharvbio.2013.12.025.

Luo, Y., He, Q., & McEvoy, J. L. (2010). Effect of storage temperature and duration on the behavior of *Escherichia coli* O157:H7 on packaged fresh-cut salad containing romaine and iceberg lettuce. *Journal of Food Science, 75*(7), M390–M397. http://dx.doi.org/10.1111/j.1750-3841.2010.01722.x.

Luo, Y., He, Q., McEvoy, J. L., & Conway, W. S. (2009). Fate of Escherichia coli O157:H7 in the presence of indigenous microorganisms on commercially packaged baby spinach, as impacted by storage temperature and time. *Journal of Food Protection, 72*, 2038–2045.

Lynch, M. F., Tauxe, R. V., & Hedberg, C. W. (2009). The growing burden of foodborne outbreaks due to contaminated fresh produce: Risks and opportunities. *Epidemiology and Infection, 137*(3), 307–315. http://dx.doi.org/10.1017/s0950268808001969.

Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2016). *Sensory evaluation techniques* (5th ed.). Boca Raton, FL: CRC Press.

Painter, J. A., Hoekstra, R. M., Ayers, T., Tauxe, R. V., Braden, C. R., Angulo, F. J., et al. (2013). Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998-2008. *Emerging Infectious Diseases, 19*(3), 407–415. http://dx.doi.org/10.3201/eid1903.111866.

Park, E., Luo, Y., Marine, S. C., Everts, K. L., Micallef, S. A., Bolten, S., et al. (2018). Consumer preference and physicochemical evaluation of organically grown melons. *Postharvest Biology and Technology, 141*, 77–85 2018.

Roberts, T. A., Pitt, J. I., Farkas, J., & Grau, F. H. (1998). Microbial ecology of food commodities. *Microorganisms in Foods, 6*, 379–389 Blackie Academic & Professional, 6.

Slott, M. (2014). *Wakefern/shoprite supermarkets: Co-opting green the rite way. Produce business magazine*.

Slott, M. (2015). Weis Markets: Closing the loop on sustainability. *Produce Business Magazine,* 31.

U.S. Food and Drug Administration (FDA) (2015). Standards for the growing, harvesting, packing, and holding of produce for human consumption. https://www.fda.gov/Food/GuidanceRegulation/FSMA/ucm334114.htm, Accessed date: 4 October 2017.

U.S. Food and Drug Administration (FDA) Food Code (2013). *Recommendations of the United States public health Service and food and drug administration.* College Park, MD. U. S. Department of Health and Human Services https://www.fda.gov/downloads/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/UCM374510.pdf, Accessed date: 4 October 2017.

Willocx, F., Hendrick, M., & Tobback, P. (1994). A preliminary survey into the temperature conditions and residence time distribution of minimally processed MAP vegetables in Belgian retail display cabinets. *International Journal of Refrigeration, 17*(7), 436–444.

Xiao, Z., Lester, G. E., Park, E., Saftner, R. A., Luo, Y., & Wang, Q. (2015). Evaluation and correlation of sensory attributes and chemical compositions of emerging fresh produce: Microgreens. *Postharvest Biology and Technology, 110*(2015), 140–148.

Zeng, W. T., Vorst, K., Brown, W., Marks, B. P., Jeong, S., Perez-Rodriguez, F., et al. (2014). Growth of *Escherichia coli* O157:H7 and *Listeria monocytogenes* in packaged fresh-cut romaine mix at fluctuating temperatures during commercial transport, retail storage, and display. *Journal of Food Protection, 77*(2), 197–206. http://dx.doi.org/10.4315/0362-028x.jfp-13-117.