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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 micro-organisms. 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^{TM} 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.

the rear of the display case in shelves 1–4 (except the bottom rack) and from the top grille at 0.1 m/s in both cases.

One of the display cases was retrofitted by the manufacturer with French glass doors with a concave wiper design to reduce door-to-door interference, maximize energy savings, and to help keep the glass moisture-free. The doors were designed to be opened, stay open and be closed with little effort.

2.3. Product loading and temperature monitoring

Temperature data loggers with a monitoring frequency set for 10-min intervals (Trix-8, MicroDaQ.com, Ltd., Contoocook, NH) were taped onto the exterior of each baby spinach bag immediately prior to loading the products in the display cases. Over four days, 168,000 temperature-time data points were obtained for the whole set of spinach samples in either display case, or 560 data points per sample. In preliminary studies, we validated that the temperature differences recorded by the data loggers placed inside and outside the product bags were not statistically significant. Each display case has a total capacity of 540 bags (1-gallon per bag) and the baby spinach bags were loaded in the middle 4-foot section of each case, comprising five adjacent columns (8–12) of tray shelves for a total of 150 bags (Fig. 1). The spaces in the display cases not occupied by baby spinach bags were filled with product simulators, constructed using standard 1-gallon Ziploc® bags containing 65 g of shredded sponge material saturated with 266 mL of chlorine solution prepared using a ratio of 7.5 mL/L bleach:water (Kou et al., 2014a).

2.4. Testing conditions

The ambient temperature of the room with the two display cases was 21 °C ± 3 °C during the testing period. Under the same conditions, the relative humidity was 60–70%. For the open display case, product temperatures were mapped at a thermostat setting of 0.6 °C with a 12 h defrost interval of 30 min for a period of four days, as recommended by the manufacturer of the display case. For the display case with doors, product temperatures were mapped at a thermostat setting of 0.6 °C with a 24 h defrost interval of 30 min for a period of four days. The defrost type for the display cases was planned off-cycle. To initiate defrost, a timer stops the compressor, and the evaporator fans continue to circulate air across the evaporator coil, melting any frost build-up. The defrost cycle is terminated by time. Outside of defrost cycles, the compressors turn off when the display cases reach the 0.6 °C set point on the thermostat. Spatial and temporal temperature profiles of the baby spinach products were plotted using MATLAB 8.0 (The Mathworks, Inc., Natlick, MA) (Fig. 2).

2.5. Quality evaluation of baby spinach products

Visual quality and decay evaluation of the baby spinach products were conducted on day zero (product as received) and day 4, the last day of product storage in the open display case and the display case with doors. To ensure sample randomization and objectivity during quality evaluation, all bags were coded with a 3-digit number. The visual evaluation was performed by a trained sensory panel consisting of five members following a modified procedure by Luo et al., (2009). Overall quality was assessed using a 9-point hedonic scale, with 9 = like extremely, 5 = neither like nor dislike, and 1 = dislike extremely (Meilgaard et al., 1991). The overall decay of the samples was defined as the percentage of baby spinach leaves in each bag showing any visible decay (Kou et al., 2009; Valero et al., 2006), as follows,

$$\text{Decay percentage } (\%) = \frac{m_{\text{decay}}}{m_{\text{total}}} \times 100$$

where m_{decay} is the mass of baby spinach leaves estimated by the panel to show signs of decay and m_{total} is the total net weight of baby spinach leaves.

2.6. Electrical energy consumption of the display cases

The electrical energy consumption of the open display case and the case with doors was measured based on the individual consumption of the condensing units, LED lights and evaporator fans in each case. For each condensing unit, advanced pulse output AC power measurement, proportional to kWh consumed, was installed. The metering equipment consisted of a root mean square (RMS) AC watt-hour transducer with pulse output (WattNode, WNB-3Y-208-P, Continental Control Systems LLC, Boulder, CO), three 30 A current transformers for the open case, one 20 A current transformer (Split Core, Continental Control Systems LLC, Boulder, CO) and one 3-phase energy meter/transmitter configuration (M3-FSS12-12VDC, Eltako Electronics, Fellbach, Germany). For the energy consumption of the lights and evaporator fans of both cases, the same metering equipment was installed with two 20 A current transformers. The energy consumption data was captured in kWh and transmitted to a dual radio access point connected to a wireless hot spot, in order to allow for remote access of the data via client software installed in our PCs for analysis of real-time and historical data (Venergy, Magnum Energy Solutions, Hudson, OH).

2.7. Experimental design and statistical analysis

The experiments were run under a completely randomized design with type of case (open or door), case shelf (1–5, top to bottom rack), depth (1–6, front to back) and column (8–12, middle

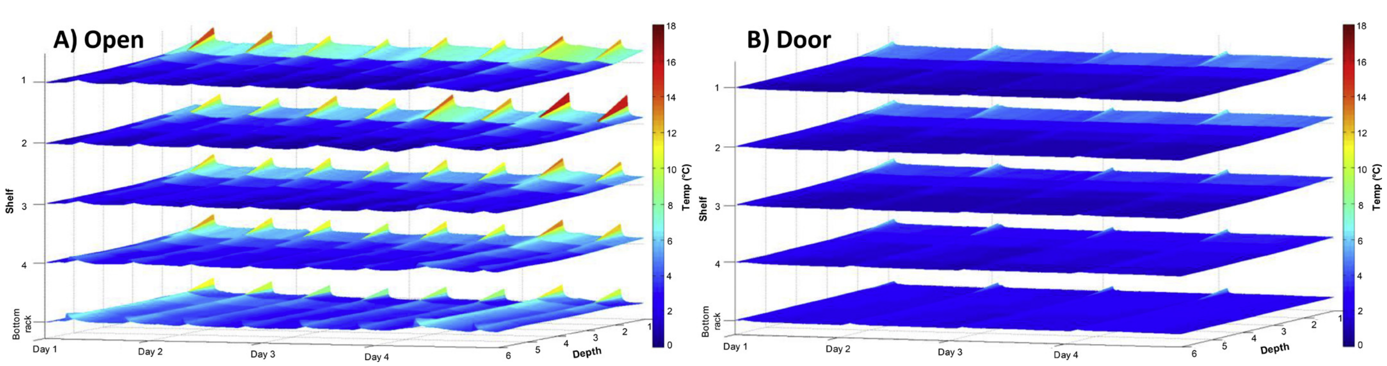

Fig. 2. Full temperature profiles of baby spinach products stored in an open display case (A) and a case with doors (B) for four days. Shelves 1–4 start from the top of the case to the bottom rack. Depths 1–6 go from the front to the rear of the case. Temperature peaks are consistent with the defrost cycles per day set for the cases (two for open and one for doors). Room temperature conditions were constant at 21 °C with relative humidity at 60-70%.

section left to right) as main factors. The dependent variables were temperature, visual quality scores and decay percentage (arcsine transform applied, $\sin^{-1}(x/100)^{1/2}$). Each variable was tested against the main factors using the PROC MIXED procedure in SAS (ver. 9.3, SAS Institute, Cary, NC) to test the null hypothesis at $\alpha = 0.05$. The assumptions of normal distribution, homogeneity of variance and independence of residuals were checked based on the analysis of studentized residuals. Departures from the assumptions were addressed by performing non-parametric analyses using bootstrap re-sampling under the PROC MULTTEST procedure. Pairwise comparisons between treatments among the factors were based on the differences of least square means, and tested for significance using Tukey adjusted p-values, at $\alpha = 0.05$. Correlations between the quality parameters (visual quality and decay) and temperature were analyzed in SAS using the PROC CORR procedure to test the null hypothesis of no correlation at $\alpha = 0.05$ and to determine the Spearman partial correlation coefficient if the correlation was significant.

3. Results and discussion

3.1. Temperature profiles of the baby spinach samples in the open display case

For the refrigerated open display case, we mapped the spatial (shelf and depth) and temporal temperature profiles of baby spinach bags for a period of four days, and found temperature differences among shelves, depths and columns to be statistically significant ($P < 0.001$). Differences in depths were due to the convective heat transfer from the ambient air into the case that caused samples in the front to be warmer than samples in the back of the case.

The spatial and temporal temperature map in Fig. 2A, from day 1 to day 4, shows a total of 8 temperature peaks for the baby spinach bags corresponding to the two defrost cycles per day. The products by the front of the case (depth 1) experienced the highest peaks during the defrost cycles. For instance, on shelf 2 depth 1, temperatures increased from 7.3 °C to a high of 16.3 °C in 30 min. It is relevant to note that on depth 1 in shelves 1–4 (from the top) the average temperatures were above 5 °C, following a decreasing tendency from shelf 1 (8.1 °C on average) to shelf 4 (6.6 °C on average). Lower product temperatures were encountered on the shelves in depths 3–6 as a result of the cold air flow out of the rear of the case on shelves 1–4. The lowest recorded temperature was 0.1 °C on shelf 2 depth 6 (back of the case), just above freezing. The samples on the bottom rack (S5 in Fig. 1) of the display case had the lowest average temperatures in depth 1, at 4.6 °C, because the products sit much closer to the return air grille than products on the shelves. However, products on the bottom rack from depths 2 to 6 experienced higher temperatures than the rest of the shelves, because there is no air flow from the rear of the cabinet in the bottom rack. This temperature discrepancy between the shelves (S1–S4) and the bottom rack (S5) is also a result of the spatial differences.

The concerning fact about the high temperatures on shelves 1–4 by the front of the case and on the bottom rack is the non-compliance with the 5 °C threshold established by the FDA Food Code to prevent microbial pathogen growth in packaged leafy greens. On shelves 1–4, baby spinach products on depth 1 experienced temperatures above 5 °C most of the time during the 4-day trial. The non-compliance with the FDA Food Code on shelf 1 depth 1 was 100% of the time, on shelf 2 depth 1 was 95% of the time, on shelf 3 depth 1 was 74% of the time and on shelf 4 depth 1 was 81% of the time. On depth 2 for shelves 1–4 the temperature non-compliance with the FDA Food Code was reduced considerably to a high of 34% on shelf 4; however, temperatures on

Table 1
Percentage of temperature recordings in compliance with the FDA Food Code temperature threshold of 5 °C or less for baby spinach bags stored in an open display case and a display case with doors over a period of four days.

Percentage of temperature recordings at 5 °C or less							
		OPEN Display Case					
		Depth					
		Front D1	D2	D3	D4	D5	Back D6
Top	Shelf 1	0	71	93	100	100	99
	Shelf 2	5	80	94	98	100	99
	Shelf 3	26	75	94	99	100	98
	Shelf 4	19	66	89	94	94	94
Bottom	Bottom rack	68	48	58	66	69	76

Percentage of temperature recordings at 5 °C or less							
		Display case with DOORS					
		Depth					
		Front D1	D2	D3	D4	D5	Back D6
Top	Shelf 1	75	100	100	100	100	100
	Shelf 2	94	100	100	100	100	100
	Shelf 3	97	100	100	100	100	100
	Shelf 4	98	100	100	100	100	100
Bottom	Bottom rack	99	100	100	100	100	100

depth 2 in the bottom rack fared the worst with 52% of the temperature recordings above 5 °C (Table 1). Overall, for all spatial locations, temperatures in the open case were 24% non-compliant with FDA Food Code. These findings are consistent with a study by Zeng et al. (2014) who reported that 30% of temperatures recorded for fresh-cut romaine mix stored for 3 days in refrigerated retail display, were above 5 °C.

3.2. Temperature profiles of the baby spinach samples in the display case with doors

Preliminary research in our laboratory has shown that retrofitting the open case with doors is the best option to address the temperature excursions observed in the open display case, as it provides a better thermal barrier than the utilization of curtains or product insulators inside the open case (data not shown). The installation of doors can reduce the infiltration load and reduce the entrainment of ambient air into the case (Faramarzi et al., 2002). In our study, as opposed to the open case, the case with doors only required one 30-min defrost cycle for every 24 h of continuous operation, as a result of the significant reduction in heat load after installation of doors to the case.

Fig. 2B shows the temperature profiles among shelves and depths for the baby spinach bags in the display case with doors at a thermostat setting of 0.6 °C over a period of four days. Contrary to the open case scenario, the temperature profiles of the baby spinach bags showed greater uniformity, even though the spatial factors were statistically significant ($P < 0.001$).

The spatial and temporal temperature map in Fig. 2B, from day 1 to day 4, shows a total of 4 temperature peaks for the baby spinach bags corresponding to one 30-min defrost cycle per day. The products by the front of the case (depth 1) experienced the highest peaks during the defrost cycles, with temperatures increasing from 4.9 °C to a high of 10.9 °C in 40 min, on shelf 2, depth 1 at the front of the case; which is exactly the same position of the highest temperature in the open case. Contrary to the open case, average temperatures in the case with doors on depth 1 in shelves 1–4 (from the top) were below 5 °C, following a decreasing tendency from shelf 1 (4.8 °C on average) to shelf 4 (3.2 °C on average). Samples in the bottom rack of the case with doors had the lowest average temperatures on depth 1, at 2.0 °C; much lower than average temperatures observed on depth 1 in the bottom rack of the open case.

In the display case with doors, baby spinach temperatures during the 4-day trial were mostly in compliance with the FDA Food Code temperature threshold of 5 °C. Only depth 1 experienced temperatures above 5 °C, with depth 1 shelf 1 bringing 75% of the product temperatures in compliance with the Food Code. The reason for this average compliance is that contrary to other spatial locations, on depth 1 shelf 1 it could take several hours up to 24 h after the defrost cycle for temperatures to reach 5 °C or below. For the rest of the shelves on depth 1, temperatures decreased much faster after the defrost cycle as compliance increased from 94% on shelf 2 to 98% on shelf 4. For depths 2–6 in all shelves and the bottom rack, all temperatures were 100% in compliance with the FDA Food Code and the lowest temperature recorded was 0.5 °C on depth 6 of shelves 1 and 2, so products were not at risk of experiencing freeze damage (Table 1).

Besides the significant improvements in compliance with Food Code achieved by the case with doors compared to the open case, the temperature differences (ΔT) decreased by almost 6 °C. The ΔT from the warmest to the coldest baby spinach product in the case with doors over four days was 10.4 °C, with the highest temperature (10.9 °C) during the defrost cycle on depth 1 and lowest temperature (0.5 °C) on depth 6. In contrast, for the open display case at the 0.6 °C thermostat setting with two 30 min defrost cycles in 24 h, the ΔT in shelf 1 from depth 1 (16.3 °C) to depth 6 (0.1 °C) was 16.2 °C. Also, for all spatial locations, temperatures in the case with doors were only 1% non-compliant with the FDA Food Code, as opposed to the 24% non-compliance in the open case.

3.3. Visual quality of baby spinach products in the open display case and the case with doors

Based on a 9-point hedonic scale, the mean visual score of the baby spinach samples upon receipt on day zero was 7.9. After storage in the refrigerated display cases for four days, the visual quality of the samples from the case with doors was higher ($P < 0.001$) than the ones from the open case; with mean scores of 7.2 and 6.6, respectively. The higher quality of the samples stored in the case with doors is consistent with the improved temperature uniformity between 1 °C and 4 °C; an optimum storage temperature range that would preserve the quality of commercially packaged baby spinach (Kou et al., 2014b).

During the quality evaluation, the main characteristic that lowered the likeness scored for the panelists was “wet”, which mostly corresponded for samples stored by the front of the open case. The shelf and depth spatial locations of the baby spinach samples had a significant effect ($P < 0.001$) on the visual quality, and the lowest mean score recorded by the panelists was on depth 1 shelf 3 in the open case, at 4.6. On the other hand, the highest score recorded by the panelists was 8.2 on depth 3 shelf 4 of the case with doors. In both display cases, the quality of the samples increased from the front of the case to the back (Fig. 3), with no trend observed in regards to shelves. The bottom rack had the lowest mean quality scores in both cases, shelf 1 had the highest mean score in the open case at 6.7, and shelf 4 had the highest mean score in the case with doors at 7.3.

Pairwise comparisons between the spatial locations of the baby spinach samples and the type of display case, showed that the differences in visual quality between depth 1 (front of the case) and the other depths in the case with doors was significant ($P < 0.001$), but the differences between depth 2 and adjacent depths was not significant ($P < 0.05$). In the open case, the differences in visual quality between depths 1 and 2, and the rest of the depths, was significant ($P < 0.001$). In regards to shelves, there were no significant differences ($P < 0.05$) in visual quality in the case with doors; however, for the open case the differences in visual quality among shelves was significant ($P < 0.001$), except for adjacent shelves.

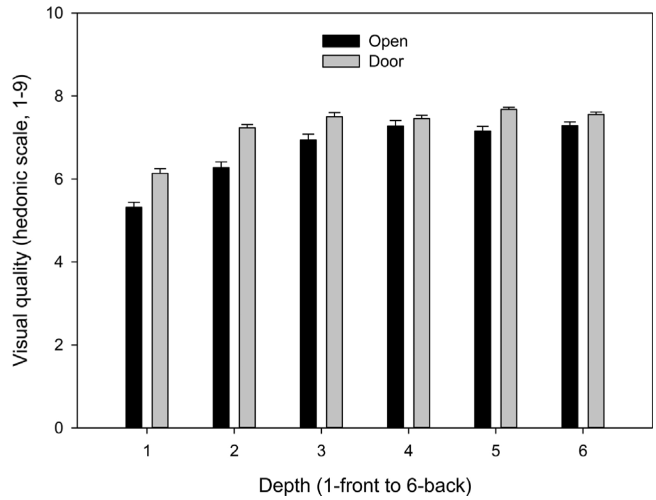

Fig. 3. Visual quality scores (hedonic scale, 1–9) of baby spinach products after storage in an open display case and a display case with doors for four days. Depths 1–6 go from the front to the back of the case. Values shown are mean values ± standard error.

As discussed in Section 3.2, temperature differences in the display cases were significant, and the spatial comparisons confirm the influence of temperature variations and higher temperatures on lower visual quality scores of the baby spinach samples. Fig. 4 shows a good correlation ($P < 0.001$) between visual quality and average temperature for both cases; an inverse relation with a Spearman partial (adjusted) correlation coefficient of −0.69 (−1.0 would indicate a perfect linear relationship). The partial correlation analysis allowed for the adjustment of the variables for the effect of type of display case (door vs. open).

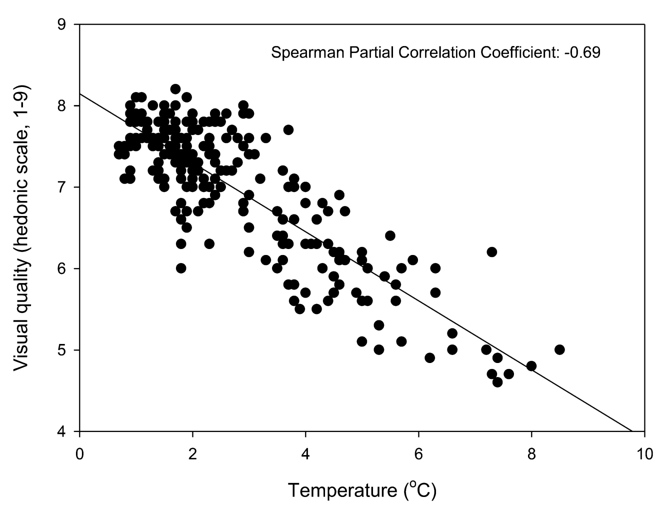

Fig. 4. Correlation between visual quality (hedonic scale, 1–9) and avg. temp. (°C), adjusted by type of refrigerated display case (open vs. doors). The Spearman Partial (adjusted) Correlation Coefficient is −0.69 (−1 would be a perfect linear relationship).

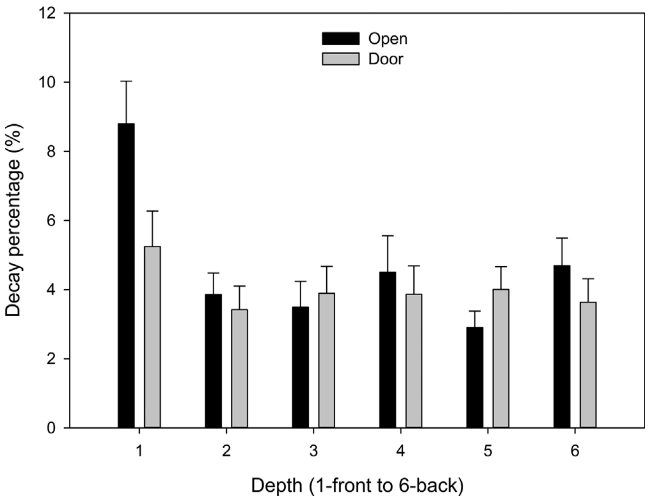

Fig. 5. Decay percentage of baby spinach products after storage in an open display case and a display case with doors for four days. Depths 1–6 go from the front to the back of the case. Values shown are mean values ± standard error.

3.4. Decay percentage of baby spinach products in the open display case and the case with doors

Decay percentage varies significantly among depth ($P < 0.001$), but not among shelves and columns in both open and enclosed cases (Fig. 5). In the open case, the decay percentage was twice as high in the front rows than in the middle and back rows, with some of the bags having a decay percentage as high as 19.5% on depth 1, with an average of 8.8% by the front of the case. In the case with doors, the decay percentage was much lower in the front rows, with an average of 5.5%. These results are consistent with the high temperatures recorded above 5 °C on depth 1 shelf 1 in the open case (Table 1), as well as the low visual quality scores given by the panelists for samples in that spatial location. Previous work by Kou et al. (2014b) reported accelerated decay for commercially packaged ready-to-eat baby spinach for storage temperatures above 8 °C.

As occurred on depth 1 shelf 1, where high decay rates corresponded with higher temperatures, the association between decay percentage and temperature from depths 2 to 6 was also evident. For both cases, the mean decay percentages were lower from depth 2 to depth 6, and no larger than 4.7% (depth 4) for the open case and 4.0% for the case with doors. The lower decay percentages in these locations are consistent with the lower storage temperatures recorded for the baby spinach samples.

Table 2
Comparison in electrical energy consumption and cost between the display case with doors and the open case reported by our study and by Fricke and Becker (2010).

Electrical energy consumption (kWh/day)	USDA		Fricke and Becker	
	Open	Doors	Open	Doors
Condensing unit	54.1	10.8	42.2	11.7
Lights[a]	3.1	4.6	5.2	11.9
Fans	3.7	3.7	5.7	4.8
Anti-sweat heaters	–	none	–	15.5
Total	60.9	19.1	53.1	43.7
Door savings	69%		18%	

[a] The display cases in our study had LED lights. The display cases in the study by Fricke and Becker (2010) did not use LED lights.

3.5. Electrical energy consumption of the open display case and the case with doors

Based on the electrical energy consumption of the condensing units, LED lights and evaporator fans for the open case and the case with doors, the consumption in kWh/day was reduced 69% with the case with doors (Table 2). This significant reduction was primarily due to the low consumption of the condensing unit in the case with doors as a result of the lower refrigeration load. The consumption of the evaporator fans was the same in both cases, and the consumption of lights was higher in the case with doors as a result of the extra LED lights. To evaluate the effect of door openings on energy consumption, we tested two treatments, (1) doors closed all the time and (2) partial door openings 6 times per hour for 12 s. The ASHRAE standard 72-2014, *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). At ambient conditions of 21 °C and 60–70% RH, we found no significant impact of door openings on the energy consumption in the case with doors, and the energy savings compared to the open case was 69% for both treatments.

Our findings are in line with a study by Fricke and Becker (2010) that compared the energy consumption between an open case and a case with doors in actual supermarket settings. The mean door opening frequency reported by the authors was 6 door openings per hour with a mean duration of 12 s, and the most frequent duration was 5 s. These field observations were consistent with the testing procedure outlined in the ASHRAE Standard 72-2014 (ASHRAE, 2014). The authors reported the energy consumption per unit length of an open case to be 1.3 times the consumption of a case with doors, corresponding to an overall 18% reduction. In a different study, Faramarzi et al. (2002) reported that glass door retrofits reduced the total cooling load of the case by 68%, which reduced compressor power demand by 87%.

Table 2 compares side by side the mean electrical energy consumption reported by our study and by Fricke and Becker (2010). The higher energy savings reported in our study for the case with doors (69%) compared to the study by Fricke and Becker (18%) was a result of not using anti-sweat heaters for the doors, the major contributor to the overall energy consumption for the case with doors in the study by Fricke and Becker that accounted for 36% of the energy use. Assuming the use of "no heat" doors in the study by Fricke and Becker, their energy savings would have increased to 47%; and even more if LED lights would have been used. In our study, the use of anti-sweat heaters was not required because our improved case design; with a discharge cold air grille farther back from the glass than what is typical for display cases, which minimized condensation on the glass surfaces. Nonetheless, some condensation in the lower half of the glass doors was observed because the doors were designed to stay moisture free at ambient conditions of 24 °C and 55% of relative humidity. In our study, room temperatures were 21 °C but relative humidity was 60–70%. Our distinct case design and lower relative humidity are factors that guarantee moisture-free doors that would offset the significant energy consumption of the anti-sweat heaters. The effect on retail sales is one concern of retrofitting open cases with doors, despite the demonstrated energy savings in our study and other studies. Fricke and Becker (2010) found no differences in sales of dairy and beers after door retrofits of the open cases. Garry (2010) reported different opinions from retailers and scientists attending the Food Marketing Institute's Energy & Store Development Conference in 2010. While some retailers did not experience an impact in sales after door retrofits, one retailer found a 3–10% decrease in sales, and another retailer expressed additional concerns in regards to keep conveying the fresh concept with open cases. Nevertheless, all the stakeholders referenced in the report by Garry (2010)

Table 3
Time to recoup cost of doors retrofit in our study based on the projected annual energy usage and cost of both types of cases.

Annual energy usage and cost[a] of open and door display cases in our study						
Open case energy use (kWh)	Open case energy cost (US$)	Door case energy use (kWh)	Door case energy cost (US$)	Savings on using doors (US$)	Cost of doors retrofit (US$)	Time to recoup cost of doors retrofit
22,229	$2,445	6,971	$767	$1,678	$3,000	1.8 years

[a] Commercial energy cost in Maryland: $0.11/kWh.

agreed on the important reductions in energy consumption provided by door retrofits. Based on the consumption data in our study, projected to one year, we calculated that the cost of retrofitting an open display case with doors can be recouped in only 1.8 years on energy alone (Table 3). This timeframe may be reduced if other indirect cost reductions are considered, including lower labor costs as a result of the lower product rotation, as well as reduced product spoilage.

4. Conclusions

The temperatures of freshly-packed ready-to-eat baby spinach placed on an open refrigerated display case and a display case with doors were spatially and temporally mapped, and evaluated against the FDA Food Code requirement over a four day storage period. The visual quality and decay rate of the samples were also assessed at the end of the display storage period. Temperature uniformity was much improved in the case with doors, as the spatial temperature differences decreased by $\Delta T = 6\,^{\circ}\mathrm{C}$ compared to the open case, and the temperatures in compliance with the FDA Food Code increased from 76% in the open case to 99% in the case with doors. The lower temperatures and improved temperature uniformity in the case with doors also improved the visual quality and reduced the decay rate. In addition, operational energy costs were 69% less than the open display case.

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References

Alzuwaid, F., Ge, Y.T., Tassou, S.A., Raeisi, A., Gowreesunker, B., 2014. The novel use of phase change materials in a refrigerated display cabinet: an experimental investigation. 3rd IIR International Conference on Sustainability and the Cold Chain, ICCC, Int. Inst. Refrig., pp. 235–242.

ANSI/ASHRAE Standard 72-2014, 2014. Method of testing open and closed commercial refrigerators and freezers. Am. Soc. Heat. Refrig. Air-Cond. Engineers, 20 p.

Australia New Zealand Food Standards Code (ANZFSC), 2014. Food safety standards—Temperature control requirements—Chapter 3 (Australia only). http://www.foodstandards.gov.au/consumer/safety/faqsafety/pages/foodsafetyfactsheets/foodsafetystandardst85.aspx (accessed 18.03.15.).

Canadian Food Inspection Agency (CFIA), 2014. Code of practice for minimally processed ready-to-eat fruit and vegetables. http://www.inspection.gc.ca, accessed (18.03.15.).

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. Int. J. Refrig. 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 Trans. 108 (Part 1), 673–679.

Fricke, B.A., Becker, B.R., 2010. Doored display cases: they save energy, don't lose sales. ASHRAE J. 52, 18–26.

Garry, M., 2010. New tests support doors on cases. http://supermarketnews.com/technology/new-tests-support-doors-cases, (accessed 18.03.15.).

Jacxsens, L., Devlieghere, F., Debevere, J., 2002. Temperature dependence of shelf-life as affected by microbial proliferation and sensory quality of equilibrium modified atmosphere packaged fresh produce. Postharvest Biol. Technol. 26, 59–73.

Kou, L., Luo, Y., Ding, W., Liu, X., Conway, W., 2009. Hot water treatment in combination with rachis removal and modified atmosphere packaging maintains quality of table grapes. HortScience 44, 1947–1952.

Kou, L., Luo, Y., Park, E., Turner, E.R., Barczak, A., Jurick, W.M., 2014a. 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 Biol Technol. 91, 96–103.

Kou, L., Luo, Y., Ingram, D.T., Yan, S., Jurick, W.M., 2014b. Open-refrigerated retail display case temperature profile and its impact on product quality and microbiota of stored baby spinach. Food Control 47, 686–692.

Lu, Y.L., Zhang, W.H., Yuan, P., Xue, M.D., Qu, Z.G., Tao, W.Q., 2010. Experimental study of heat transfer intensification by using a novel combined shelf in food refrigerated display cabinets. Appl. Therm. Eng. 30, 85–91.

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. J. Food Prot. 72, 2038–2045.

Meilgaard, M.C., Civille, G.V., Carr, B.T., 1991. Sensory Evaluation Techniques, 2nd ed. CRC Press Inc., Boca Raton, FL.

Nunes, M.C.N., Emond, J.P., Rauth, M., Dea, S., Chau, K.V., 2009. Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste. Postharvest Biol. Technol. 51, 232–241.

U.K. Food Standards Agency (FSA), 2007. Guidance on temperature control legislation in the United Kingdom. http://www.food.gov.uk/sites/default/files/multimedia/pdfs/tempcontrolguiduk.pdf (accessed 18.03.15.).

U.S. Food and Drug Administration (FDA), 2013. Food Code. http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/default.htm (accessed 18.03.15.).

Valero, D., Valverde, J.M., Martínez-Romero, D., Guillén, F., Castillo, S., Serrano, M., 2006. The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safety and functional properties of table grapes. Postharvest Biol. Technol. 41, 317–327.

Wells, J.H., Singh, R., 1989. A quality-based inventory issue policy for perishable foods. J. Food Process. Preserv. 12, 271–292.

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. Int. J. Refrig. 17, 436–444.

Yu, K.-Z., Ding, G.-L., Chen, T.-J., 2009. Experimental investigation on a vertical display cabinet with central air supply. Energy Convers. Manage. 50, 2257–2265.

Zeng, W., Vorst, K., Brown, W., Marks, B.P., Jeong, S., Pérez-Rodríguez, F., Ryser, E.T., 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. J. Food Prot. 77, 197–206.