Spatial Variation of Fruit Cooling Rate and Relative Humidity inside 'Super-vent' Packaging for Citrus during Static Cooling

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Abstract

Inadequate cold chain maintenance contributes to high incidence of postharvest losses and wastage of horticultural fresh produce. Packaging plays a critical role in fresh produce handling and contributes to maintaining the cold chain and reduction of handling damage. A wide range of packaging designs and vent characteristics (size/shape of opening and position on package) are used in the fruit industry. The use of inappropriate ventilated packaging can result in cooling heterogeneity and incidence of physiological disorders during cold storage. The objective of this study was to investigate the effects of package position inside the cold store and vent position on package on fruit cooling rate. Results of studies on 'Valencia' orange packed inside 'Super-vent' cartons showed that the position of packaging inside a cold store affected heat transfer and cooling rate of fruit. The regions that were exposed to cooling air showed a significantly higher cooling rate of the fruit than the center positions. The effects of conductive heat transfer between the floor and the package was significant in promoting rapid fruit cooling. Results obtained also showed that fruit near the vent area cooled significantly faster than fruit in other locations inside the carton. These findings highlight the need to adopt cost-effective and resource-efficient approaches to the design of vents on horticultural packaging.

INTRODUCTION

The design and use of packaging significantly affects the quality and shelf life of the packaged produce. Poor environmental conditions inside and outside the package can accentuate already present disorders, resulting in poor quality produce at the end of the cold chain (Thompson, 2003). These factors accumulate and influence the quality of the produce. Produce can spend up to 10 weeks inside a carton and must withstand a variety of storage conditions. This period is critical as improper conditions can stress negative influences, resulting in a higher incidence in disorders, quality loss and consequently revenue loss (Dincer, 1994). Cartons are therefore one of the tools at the producer's disposal. Packaging protects the fresh produce from physical damage while modifying the environmental condition inside the package. The type of packaging material and ventilation influences the relative humidity (% RH), airflow pattern, physiological development, and can directly affect produce cooling rate (de Castro et al., 2005b).

Traditional designs of citrus cartons commonly make use of a hole/s in the middle of the cartons walls. The design focuses primarily on horizontal air movement during forced air cooling. These cartons may "short-circuit" the flow of air due to blockages owing to incorrect placement of telescopic lids, package labels, as well as by fruit which unintentionally move into positions that block the ventilation holes.

A newer carton design, called Super-vent, has been introduced into the citrus fruit industry (Fig 1a) which places the ventilation holes at the top and bottom edges of the carton. Consequently, the flow of air travels both horizontally and vertically through a stack. There is concern among industry on the potential for micro-climatic conditions ('hot and cold spots') to develop inside the package along the cold chain.

The aim of this study was to investigate the spatial variation of the fruit cooling rate and quality inside super-vent cartons under static cold room conditions.

MATERIALS AND METHODS

Materials

'Valencia' oranges were bought pre-packaged from a local South Africa farm in the Western Cape. Fruit were harvested two weeks before arriving at the laboratory, and were stored at 7°C for several weeks. By the end of the experiment the fruit were near the end of their storage life time. Blemish-free fruit were randomly selected and warmed for 30 hours in the laboratory at 26°C, at which point they were randomly repackaged, with a density of 72 fruit per carton. The experiment made use of four Super-vent cartons as shown in Fig. 1. The cold room was set at 7.3°C, 88 %RH, and the temperature of the concrete floor was 8.4°C. The carton design specifications are listed in Tables 1(a) and (b) The cartons were placed directly on the concrete floor, with 20cm of clearance between each other and 40cm away from the nearest obstacle in the room (Fig. 2*)*. One replication was performed per carton, due to each carton experiencing a unique environment while inside of the cold storage room. Data collected included air temperature and relative humidity, and fruit pulp temperature, which were recorded continuously during the storage period using Tinytag loggers (View 2, Tinytag, Gemini Data Loggers UK, West Sussex/UK) and eTemperature button Loggers (TCZ, Thermochrone, Baulkham Hills/Australia). Loggers were programmed to measure every 30 minutes for a period of three weeks, and the readings were used to calculate the momentary cooling rate (R) as follows (Dincer, 1994; Thompson et al, 1998):

(1)

(2)

(3)

(4)

(5)

Where:

C = cooling coefficients (s^{-1}), J = lag factor, S = seven-eighths cooling time (s), T_a = cooling medium temperature (°C), T = product temperature at time t (°C), T_i = initial product temperature (°C), θ = dimensionless temperature, S = $\frac{7}{8}^{th}$ cooling time (h), R = momentary cooling rate (°C/hour), and T_s = temperature at $\frac{7}{8}^{th}$ cooling time (°C)

Physiological evaluation

After the storage period, the cartons were removed from storage and a physiological evaluation of scald and stem end rind breakdown (SERB) was performed. Percentage SERB was determined by calculating the percentage of affected fruit per total number of fruit in each cell (Fig. 1b). Scald severity was calculated as an index, assessed between 0 (no scald) and 3 (severe scald). The percentage scald index was calculated as follows (Beattie et al,. 1989).

Where:

CI=Scald index (%), E_0= number of fruit with no scald, E_1=number of fruit with minor scald, E_2= number of fruit with mild scald, and E_3=number of fruit with severe scald.

Statistical analysis

Experimental data were subjected to analysis of variance using SAS software (SAS, North Carolina, USA). Data on incidence of physiological disorders were transformed where necessary (Clever and Scarisbrick, 2001). Bonferoni comparisons were made on all the normally distributed data, Wilcoxon tests on non-parametric data and an alpha of 0.05 was used in all tests.

RESULTS AND DISCUSSION

Fruit cooling rate

Cartons A and B revealed no statistically significant difference between the top and middle layers (Table 2 and Fig. 3). The bottom layer of carton A, achieved a 31% faster cooling rate than the upper layers and a 25% faster rate than in carton B. In an ideal situation, most of the heat is removed from the carton through the process of convection (Moureh et al., 2009). The bottom layer however, was in direct contact with the concrete of the floor which was at 8.4°C. This highlights the presence of conduction as well as convection properties acting on the cartons and emphasizes the importance of proper insulation inside cold rooms. Non-insulated flooring could result in energy loss and higher pre-cooling costs. Improved insulation along the floor would isolate the conducting properties of the floor. This could be in the form of a pallet or a thermally insulating material.

The front layer of the box (Fig.1 and Fig.2) faced the cooling unit. The airflow pattern inside of a cold store room is well documented in Delele et al. (2009) and Hoang et al. (1999). The predicted airflow direction inside such cold storage was from the back layer to the front layer.

Table 2 and Fig. 3 show a significantly slower cooling rate along the core layer line of the carton in both carton A and B, forming a prominent valley shaped curve in Fig. 3. This pattern of cooling can be explained by airflow direction as well as vent area percentage (Table 1). The carton width had the fastest cooling rate (4.0°C/hour) (Fig. 3a), while the length had the lowest cooling rate (3.8°C/hour) (Fig. 3b). The application of computational fluid Dynamics (CFD) modeling could further explain the airflow and cooling relationship phenomenon in the cartons (van der Sman, 2002, de Castro et al., 2004). Overall, the carton had a cooling rate of 3.7°C/hour.

Superior methods for the design and testing of carton ventilation are now available. For example, CFD computer modeling can be used to predict the airflow behavior between cartons and their environment (Delele et al., 2009). Accurate, numerical methods are considerably cheaper and more efficient than trial and error methods in the lab. They must however be validated with experimental research.

Relative humidity

The RH (%) experienced a high variability. This was due to the hysteresis of the on/off cycling by the air refrigeration unit in the cold room. The average RH was 84% and fluctuated by ±6% with a period of about 40 minutes (Table 3). No significant difference between the top, middle and bottom layers or the left, core and right layers was observed. There was thus no statistically relevant spatial variation with regards to relative humidity in the carton.

Fruit physiological quality

Each layer of the carton was assessed for stem end rind breakdown (SERB) and scalding. No significant differences between the inner three layers of the X, Y or Z planes (Fig.1) were found for SERB or Scalding. It is recommended that future experiments make use of more replicates per layer.

CONCLUSIONS

The citrus Super-vent carton is a new and innovative design over the more traditional carton design. Traditional designs made use of center ventilation hole/s in the cartons side wall, while the Super-vent has ventilation holes along the top and bottom edges, as well as on the top and bottom walls, which facilitate both horizontal and vertical airflow during pre-cooling treatments. Results obtained on fruit cooling rates using the Super-vent corroborate the evidence in the literature for ventilated packaging of different types of fruit (de Castro et al., 2004, de Castro et al., 2005a and Vigneault et al., 2006). The Super-vent carton's performance was examined under static cooling conditions (7.3°C, 88% RH). A mean overall cooling rate of 3.7°C/hour was observed, and the bottom layer of the carton cooled significantly faster than the other vertical layers, which was possibly due to heat transfer by conduction from the carton into the concrete floor. A significantly lower cooling rate was also observed along the Core layer, when compared to the Left and Right layers.

Relative humidity was spatially monitored in two of the cartons. A mean of 84% was recorded overall, and had a range of 12%. This range was due to the defrost cycle of the cooling unit and had a period of about 40 minutes.

Fruit quality was evaluated at the end of the experiment. A mean scald index of 23% was observed and a 41% incidence of SERB was observed. No significant difference was found between any of the spatial layers within the carton, presumably due to limited number of cartons used in the experiment. This could be considered in future studies.

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Tables

Table 1: Total area (a) and ventilation area (b) specifications for the Super-vent carton.

(a)

	Top	Bottom	Width	Length
Total area of carton (cm^2)	1113.90	1113.90	716.30	1003.30
Total area of vents (cm^2)	91.71	92.82	37.70	25.13
Vent area to carton area percentage	8.2	8.3	5.3	2.5

(b)

	Design	Number	Area (cm^2)
Top	Semi-circle	10	6.3
	Full Circle	4	7.1
	Rectangle	1	0.6
Bottom	Semi-circle	10	6.3
	Full Circle	4	7.1
	Rectangle	1	1.7
Width	Semi-circle	6	6.3
Length	Semi-circle	4	6.3

Table 2: Mean cooling rate (°C/hour) per each layer for both cartons.

		Carton A			Carton B		
	Layer	Mean	SE		Mean	SE	
Z	Top	3.28	0.13	a[1]	3.05	0.14	a
	Middle	3.65	0.17	a	3.12	0.16	a
	Bottom	4.90	0.27	b	4.20	0.23	b
X	Left	4.26	0.25	a	3.65	0.18	a
	Core	3.28	0.21	b	2.88	0.17	b
	Right	4.29	0.34	a	3.84	0.27	a
Y	Front	3.98	0.26	a	3.69	0.20	a
	Center	3.74	0.34	a	3.38	0.32	a
	Back	4.10	0.33	a	3.31	0.22	a

[1]Data shown are mean and standard error of the mean. Letters indicate statistically significant differences between the three layers ($p \leq 0.05$).

Table 3: The mean percentage relative humidity experienced by the cartons. Mean %RH: shows the mean %RH for each layer in the carton. Mean Range: shows the amount of %RH fluctuations experienced by the carton for each layer.

Layer	Mean RH%	Mean Range
Top	86	12
Middle	84	12
Bottom	82	13
Left	85	13
Core	85	13
Right	83	11

Table 4: Mean Scald and SERB ratings for cartons C and D.

		Scald			SERB		
		Mean	SE		Mean	SE	
Z	Top	16.7	7.74	a[1]	38	5.84	a
	Middle	21.8	8.39	a	41.7	8.78	a
	Bottom	31.5	7.96	a	43.5	6.48	a
X	Left	33.8	9.68	a	34.7	5.96	a
	Core	18.5	7.12	a	46.8	7.1	a
	Right	17.6	6.8	a	41.7	8	a
Y	Front	36.6	8.71	a	36.6	6.07	a
	Center	13	4.58	a	36.1	7.16	a
	Back	20.4	9.29	a	50.5	7.64	a

[1]Data shown are mean and standard error of the mean. Letters indicate statistically significant differences between the three layers ($p \leq 0.05$).

Figures

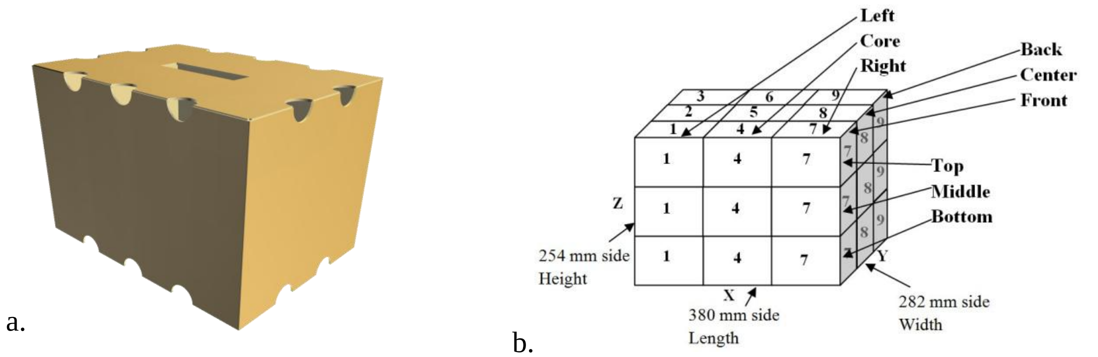

Fig.1.A CAD diagram of the Super-vent carton (a), and diagram of the hypothetical cells that the fruit were divided into within each carton (b).

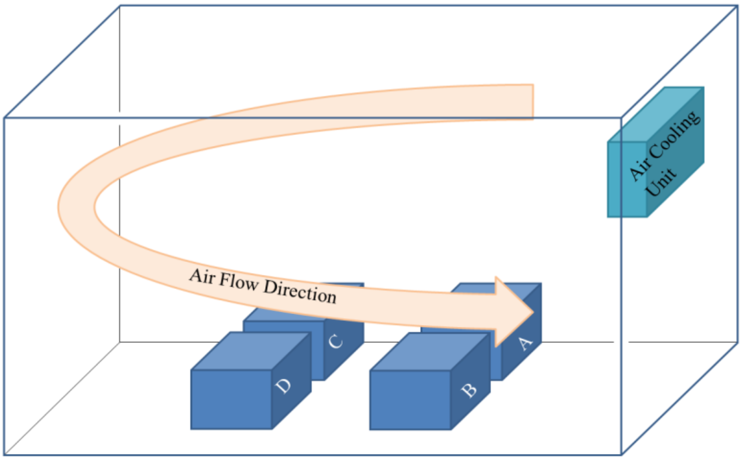

Fig. 2. Layout of the super vent cartons cold room. Letters in the diagram show the position of the cartons. Airflow moved from carton C & D to carton A & B

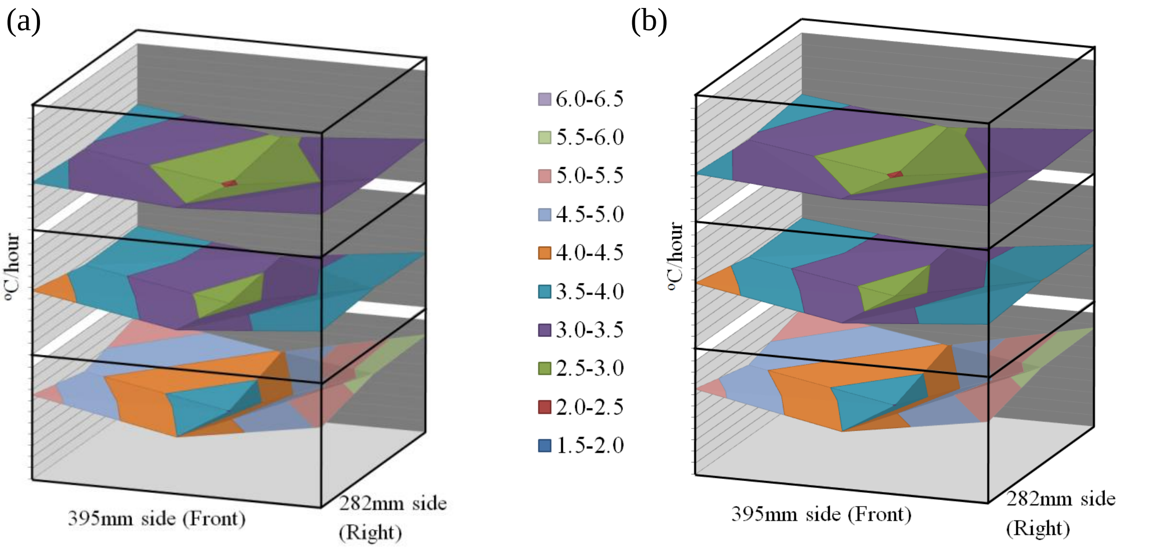

Fig.3. Cooling rate (°C/hour) for each of the Z (vertical) layer of the carton. Carton A (a) and carton B (b) demonstrate the spatial cooling rates within the carton.