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Combined use of mild heat treatment and refrigeration to extend the postharvest life of organic pepper sticks, as affected by fruit maturity stage

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Given the proscription of using chemicals from synthesis, the alternatives for postharvest management of organic produce are limited. Consequently, great interest is being devoted to develop and optimize alternative postharvest approaches. In this work we tested mild heat treatments for green and red fresh-cut peppers and evaluated their effect on quality maintenance under normal distribution and retail temperatures (4 °C). Pepper sticks (1 × 5 cm) at red and green ripening stages were heat-treated (HT) by immersion in water at 45, 50 or 55 °C (1, 3 or 5 min) and quality maintenance during storage was evaluated. Green peppers were more tolerant to HT than red fruit. Both green and ripe peppers subjected to hot water dips at 45 °C for 3 min showed lower spoilage than the control. The treatments markedly reduced soft rots (2 and 4 fold for red and green fruit respectively). Hot water dips also prevented shriveling, weight loss, color changes and contributed to maintain lower fruit respiration during storage. The treatments did not alter sugar content, acidity or antioxidant capacity. Despite of the effective control of soft rots only a slight reduction of microbial counts (<1 log CFU g^{-1}) was found. This suggests that other responses besides biocide effects or microbial wash-off are involved. The treatments delayed pectin solubilization and softening and prevented membrane leakage. Short mild heat treatments (45 °C, 3 min) may be a simple and appealing non-chemical approach to supplement the benefits of low temperature management, extending the shelf life of organic fresh-cut green and red peppers.

1. Introduction

Interests in eco-friendly food production systems and changing lifestyle have contributed to the rapid growth of organic vegetables in the last decade (James and Ngarmsak, 2011). Once limited to a few products, the organic fresh-cut vegetables segment currently includes a large variety of commodities (Goodburn and Wallace, 2013). Quality maintenance in these products is highly challenging, given their high perishability, and the limitation of using preserving agents which narrows the palette of postharvest alternatives. In addition, some studies have suggested that organic vegetables may be more perishable products than conventionally grown commodities (Amodio et al., 2007). In this scenario, the reassessment of physical treatments has gained great interest (Ölmez and Kretzschmar, 2009).

Postharvest heat treatments (HT) group a very diverse set of treatments in terms of their temperature range (35–60 °C), exposure time (few s to days) and heating conditions (microwave, infrared, hot vapor, hot air, hot water) (Fallik et al., 1996; Lurie, 1998; Inkha and Boonyakiat, 2010; Kusajima et al., 2012). They have been used for time in whole fruit and vegetables mainly to control insect pests (Schirra et al., 2000). HT have been reported to effectively control decay, reduce chilling injury (Sivakumar and Fallik, 2013), delay ripening (Lurie et al., 1996), senescence (Martínez and Civello, 2008) and browning (Kim et al., 1993; Saltveit, 2000). However, the outcome of postharvest HT is highly variable depending on treatment schedule, on the commodity and even on the cultivar considered (Lurie, 1998). Fruit ripening stage

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and degree of processing may have great impact on the benefits obtained (Koukounaras et al., 2008).

Peppers are, together with potato, tomato and eggplant among the most popular fruit crops in the Solanaceae family (Martínez et al., 2007). They have been traditionally marketed as whole fruits, but more recently fresh-cut forms have started to be distributed as well (Tadesse et al., 2002). Chilling injury, a common disorder in whole peppers held at temperatures below 7 °C, is not a main limiting factor in fresh-cut fruit (González-Aguilar et al., 2004). Instead, the main factors reducing the postharvest life of fresh-cut pepper include soft rots, shriveling of cut areas and extensive softening (Rodoni et al., 2015a). Field practices such as fertilization and the maturity at harvest may have a high impact in the quality and postharvest behavior of pepper strips (Piazzolla et al., 2012). Even under proper temperature management fresh-cut peppers have a relatively short postharvest life (7-10 days). Modified atmospheres (MAP) with 5 kPa CO_2 and 5 kPa O_2 were reported to provide moderate benefits on quality maintenance of fresh-cut peppers (Rodoni et al., 2015a). Postharvest HT has shown promising effects in whole peppers (Fallik et al., 1996). Hot water rinses (55 °C for 15 s) over brushes reduced decay and chilling injury incidence (Fallik et al., 1999). Sgroppo and Pereyra (2009) reported that hot water treatments (55 and 60 °C, 3 min.), before processing, improved antioxidant retention in fresh-cut green peppers. Post-cutting treatments may be more easily adaptable to current processing lines (Artés and Allende, 2005) and in some cases could be exploited to limit microbial loads in the washing water (Wulfkuehler et al., 2014). Although post-cutting hot water dips may be a relatively simple postharvest approach to extend the shelf life of organically grown fruits, they have not been tested to date. Whether or not the optimal treatment conditions and/or the induced responses differ depending on the ripening stage has not been established either.

In this work, we selected a proper post-cutting HT for fresh-cut organic green and red peppers. We also characterized the effect of combining HT and low temperature storage on quality maintenance.

2. Materials and methods

2.1. Plant material

Bell peppers (*Capsicum annuum* L.) cv. Jaen organically grown in La Plata, Argentina were harvested at both green and red stages and immediately transported to the laboratory. Fruit was washed with water, the peduncles, placenta and seeds were removed, and the pericarp was cut into 5 × 1 cm sticks and rapidly cooled to 4 °C.

2.2. Treatment selection

Red and green peppers sticks were immersed in a stirred hot water stainless steel tank at 45, 50 or 55 °C for 1, 3 or 5 min. The water temperature was carefully monitored. The ratio of water to product was 10:1 to prevent temperature variations. After the treatments, the sticks were rapidly transferred to a cool water tank (2 °C) for 5 min and subsequently drained. One group of pepper sticks, without heat treatment, processed and cooled as indicated above was used as a control. The sticks (~150 g) were subsequently packed in polyethylene terephthalate (PET) trays, covered with perforated PVC and stored at 4 °C for 3 and 12 days. Eight trays per treatment, storage time and maturity stage were evaluated. Two independent experiments from different harvests were conducted. The percentage of sticks showing heat damage symptoms (loss of tissue turgor, exacerbated softening and decay) for each experiment was registered. Fruit deterioration was also visually assessed based on a hedonic four level intensity scale (0 = excellent; 1 = good; 2 = acceptable and 3 = poor). Sticks decayed or having extensive softening or shriveling, were classified as poor. Samples with moderate softening or shriveling, but without decay, were categorized as acceptable. Sticks showing no marked softening and slight shriveling were considered good. Excellent sticks showed no visual symptoms of decay, dehydration or softening. A deterioration index (DI) was subsequently calculated as:

$$DI = \frac{\sum(\text{Injury level} \times \text{Number of sticks in this level})}{\text{Total number of sticks}}$$

2.3. Quality retention of heat-treated green and red pepper sticks during refrigerated storage

Fresh-cut red and green organic pepper sticks were immersed in water at 45 °C for 3 min and cooled as described in Section 2.2. Thirty PET trays containing pepper sticks (~150 g) and covered with perforated PVC were prepared for each ripening stage. Corresponding peppers without treatments, cooled and packed as previously mentioned, were used as controls. Samples were stored for 0, 7 or 12 days at 4 °C. At each sampling date, 10 trays were taken and used for quality assessment. When required representative

Table 1
Heat damage (%), deterioration index (DI), (0—excellent to 3—poor) and analyses of variance (ANOVA) probabilities values in control and heat-treated (45, 50 or 55 °C for 1, 3 or 5 min) red and green organic pepper sticks stored at 4 °C and 90–95% RH for12 days.[d]

	Temperature (° C)	Time (min)	Heat damage (%)[a]		DI[b,c]	
			Red	Green	Red	Green
Control	–	–	–	–	2.2 ± 0.2ab	1.8 ± 0.3c
	45	1	0c	0b	1.7 ± 0.3bc	1.2 ± 0.6d
	45	3	0c	0b	1.4 ± 0.6c	0.8 ± 0.2e
	45	5	0c	0b	1.7 ± 0.3bc	1.4 ± 0.3de
	50	1	0c	0b	1.9 ± 0.6bc	1.0 ± 0.3de
	50	3	0c	0b	2.6 ± 0.3a	0.9 ± 0.4de
	50	5	4 ± 3c	0b	2.6 ± 0.4a	2.0 ± 0.3c
	55	1	0c	0b	2.0 ± 0.6b	2.0 ± 0.3c
	55	3	74 ± 19b	0b	2.7 ± 0.4a	2.8 ± 0.4b
	55	5	96 ± 5a	20 ± 19a	3 ± 0a	3 ± 0a
	Temperature (*T*)		<0.0001	0.0002	<0.0001	<0.0001
	Time (*t*)		<0.0001	0.001	0.0344	<0.0001
	T × *t*		<0.0001	<0.0001	0.0829	<0.0001

[a] Registered after 3 days of storage (*n* = 16). Heat damaged sticks showed excessive juice exudate and exacerbated softening.
[b] Registered after 12 days of storage.
[c] Means ± standard deviation (*n* = 16).
[d] Values followed by different letters indicate significant differences within a column based on a Fisher test at a level of significance of $P < 0.05$.