Ripening Recovery and Sensory Quality of Pink Tomatoes Stored in Controlled Atmosphere at Chilling or Nonchilling Temperatures to Extend Shelf Life

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Abstract. Harvesting before ripening initiation (i.e., mature green) may negatively affect the flavor of fresh tomatoes (*Solanum lycopersicum*) even though the ripening process off the vine is physiologically the same as that on the plant. Low temperature storage at or below the putative chilling injury (CI) threshold can also have detrimental effects on fresh tomato flavor regardless of the developmental stage of the fruit at harvest, but sensitivity to CI declines with ripening. Controlled atmospheres (CA) using reduced oxygen and elevated carbon dioxide partial pressures can extend the shelf life (SL) of tomatoes while possibly minimizing the negative effects of low temperatures. In this study, we explored the possibility that a combination of temperature and CA could be used to achieve similar SL for pink-harvested tomatoes as has been found in other studies with green-harvested fruit while avoiding the negative effects of CI on sensory quality. Consumer panels were given samples of pink-harvested tomatoes after they had reached the red ripeness stage in terms of surface hue following storage for 7 days in air or CA at 7.5, 15, or 20 °C followed by 2–7 days ripening in air at 20 °C. Exposing pink tomatoes to 7.5 °C before ripening to the full-red stage at 20 °C negatively affected fruit sensory quality, holding fruit constantly at 20 °C until they reached the full-red stage resulted in better quality for one taste panel, whereas there was no difference in another taste panel. The time to reach the full-red stage was extended by CA. Sensory quality of air- and CA-stored fruit was similar at the nonchilling temperatures of 15 and 20 °C. Pink stage tomato fruit stored in CA at 7.5 °C for 7 days did not attain full red color within the subsequent 7 days in air at 20 °C.

Initial consumer purchases are driven by the appearance and textural quality of the produce, with subsequent purchases being

influenced by flavor (Maul et al., 1997). Dissatisfaction among consumers with the quality, particularly flavor, of fresh market tomatoes (*S. lycopersicum*) is a long-standing issue. Researchers have suggested several reasons for the poor flavor of fresh market tomatoes. Commercial breeding programs have emphasized selection for disease resistance, productivity, and fruit firmness, with less focus on flavor and texture qualities (Tieman et al., 2017). Also, a few studies have shown that the common practice of harvesting tomato fruit before ripening initiation and at early ripeness stages negatively affects the sensory profile compared with fruit ripened on the vine (Auerswald, 1999; Babitha, 2006; Baldwin et al., 2000; Carrari and Fernie, 2006).

Commercial postharvest handling practices and storage temperature and their effect on tomato flavor quality are not very well understood. Mature green tomatoes incur significant CI from postharvest exposure to temperatures below 13 °C (Deltsidis et al., 2015; Maul et al., 2000; Mutari and Debbie, 2011). Visible CI symptoms in tomato include uneven blotchy color development during ripening, abnormal fruit softening, increased susceptibility to fungal pathogens, reduced flavor, and surface pitting (Hobson, 1987). The severity of CI depends on the storage temperature, the storage duration, and the stage of fruit maturity or ripeness (Paull, 1999). Generally, fruit of more advanced developmental stages are more resistant to low temperature storage (Autio and Bramlage, 1986).

Historically, commercial storage temperature recommendations for tomato have been formulated as a result of CI studies and have been based on determination of threshold temperatures for different maturity or ripeness stages that do not induce the development of visual CI symptoms or major compositional changes (Hobson, 1987). Thus, 7 to 10 °C for ripe tomatoes and 10 to 12.5 °C for mature green tomatoes are commonly recommended as safe storage temperatures (Kader, 1986). However, more recent research has shown that flavor profiles of tomato fruit are negatively affected at temperatures higher than those previously reported to be safe with regard to CI (Bai et al., 2011; Maul et al., 2000).

The use of other postharvest techniques that slow down the ripening process, such as controlled atmospheres (CA) or modified atmospheres (MAs), has been suggested as a means to avoid CI by allowing longer storage of more developmentally advanced fruit at nonchilling temperatures (Kader, 1980). Scientists have shown that elevated CO₂ storage can alleviate CI symptoms in various crops such as mango (Pesis et al., 2000), cucumber (Wang and Qi, 1997), and melons (Flores et al., 2004). Furthermore, Hong and Gross (2001) showed that fresh-cut tomatoes stored in elevated CO₂ plus ambient O₂ atmospheres had reduced CI incidence rates compared with those stored in low O₂ without elevated CO₂.

The objectives of this work were to determine the impact of putative chilling and nonchilling storage temperatures on many flavor-related quality attributes of fresh tomatoes, as they are perceived by actual consumers. In addition, the potential for CA to mitigate the expected negative effects of low storage temperature on tomato flavor was explored. Finally, the use of CA as a tool to reduce the rate of ripening at higher, nonchilling temperatures was also investigated.

Materials and Methods

Plant material. The experiments were performed in Apr. 2014 using the commercial tomato variety ‘Tasti Lee’ (Bejo Seeds). The fruit were obtained from a commercial

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packinghouse in the Ruskin, FL, area and had been grown conventionally. The experiment was performed using fruit from four separate harvests conducted at 2-d intervals. The tomatoes from each harvest were grown in the same production area using the same production practices and packed at the same packinghouse. The tomatoes were harvested at turning to pink ripeness (part of the “vine ripe” commercial categorization), washed, graded, and packed at the packinghouse following normal commercial practices. The 20-lb boxes of uniform large (“6 × 6”) size (USDA, 1991) tomato fruit were transported to the University of Florida postharvest laboratory in an air-conditioned vehicle and stored overnight at 20 °C. The following day, the fruit were sorted again to ensure that only fruit of the same ripeness stage, uniform in size, and free from defects and blemishes were used for the experiment.

Storage and sampling. Tomatoes were obtained for presentation to consumers at the same ripeness stage by using fruit from the staggered harvests described previously. Three storage temperatures were used, 7.5, 15, and 20 °C, and the fruit were stored in either air or CA for 7 d. Based on preliminary experiments (Deltsidis et al., 2015), a non-injurious, beneficial CA regime of 8% O₂ plus 6% CO₂ was selected. After storage, the fruit were held for a period of 2–7 d in air at 20 °C to allow for full red color development. Ripening was considered complete at the full-red stage, which we defined as when the surface color [i.e., the *a** value in the CIE *L*a*b** scale (see the following paragraphs)] measured at the blossom end of a fruit remained constant for two consecutive daily measurements, indicating no further increase in red pigmentation (Chomchalow et al., 2002). The SL duration of 7 d was chosen to encompass the longest likely distribution period for tomatoes within the North American market. The period in air at 20 °C following air or CA storage at lower temperatures allowed potential recovery of tomato flavor after CA and low temperature storage to occur, as would normally happen in a supermarket display or on a kitchen counter before consumption.

Tomatoes for consumer evaluation were selected from the four harvests and different storage regimes so that the consumer panelists received fruit samples representing every treatment at about the same ripeness stage in terms of color development (Table 1). The experiment was conducted twice on different dates with different groups of consumers, using fruit from different harvest and storage regime combinations. The fruit from all four harvests that were stored in CA at 7.5 °C did not reach full red color within 7 d in air at 20 °C and, thus, were not used for sensory evaluation.

CA was established using specially constructed 70 × 70 × 35 cm (0.175 m³ volume) chambers with a set of mixing boards with needle valve flowmeters to regulate the flow of gases under constant, equal pressure. Tanks of compressed CO₂, N₂, and air were

connected to the mixing boards. When calculating the flow rates of each gas that were needed to achieve the desired atmospheres, compensation was made for the respiration of tomatoes at the given temperature to avoid respiratory CO₂ accumulation greater than 0.3%. The chambers were hermetically sealed with a Plexiglas cover with a closed-cell foam gasket and allowed for tubing carrying the gases to be attached. There was also a venting tube on each chamber for the gas to exit and for monitoring the gas composition. The fruit were placed in Styro-foam fruit trays and the front cover was closed to allow for establishment of the CA.

Color measurements were performed daily for all temperatures. Tomato color was measured using the CIE parameters (*L**, *a**, and *b**) using a Minolta Colorimeter CR-400 (Konica Minolta, Inc., Osaka, Japan). The measurement was carried out at the blossom end with three measurements per fruit, avoiding the blossom end scar, if present.

Sensory analysis. Two sensory analyses were conducted 5 d apart. There were 91 panelists on the first analysis and 100 panelists on the second (different panelists for each analysis). The fruit selected for tasting represented different harvests, but all had *a** values that had reached a plateau (i.e., no longer increasing) for at least 2 d, indicating full red color development, and were very similar in appearance. The mean blossom end *a** values for the two experiments were 20.7 ± 0.65 and 29.4 ± 0.46. The sensory quality of the tomato fruit was evaluated by the consumer panel in terms of aroma liking, overall liking, texture liking, and flavor liking. Washed and dried tomatoes were cut into eight wedges per fruit. Wedges from several tomatoes were combined together to create a composite sample for testing. Two wedges per treatment were placed in plastic cups labeled with three-digit random numbers (Fig. 1). The panelists evaluated the samples in private booths equipped with a computer data entry system (Compusense, Ontario, CA). The panelists were recruited from the University of Florida campus. Panelists were 38% male and 62% female, and most panelists were between the ages of 18 and 29 years.

The panelists received full ripe tomato samples representing the following 7-d storage treatments plus storage at 20 °C: 1) air at 20 °C; 2) CA at 20 °C; 3) air at 15 °C; 4) CA at 15 °C; and 5) air at 7.5 °C. All five samples were presented simultaneously to the panelists, along with water and unsalted crackers. Panelists were instructed to take a bite of a cracker and sip of water before starting and between each sample and to bite each sample, chew it, and swallow it. A labeled magnitude scale (gLMS) from 0 to 100 (i.e., least to most pleasurable experience) (Bartoshuk et al., 2003, 2004, 2011; Tieman et al., 2012) was used to evaluate the intensity of several sensory experiences, including intensity of tomato aroma, overall liking, texture, and tomato flavor. The gLMS scale is employed to mediate valid comparisons across subjects and sessions.

Statistical analysis. A randomized complete block design, with the block(s) consisting of three samples, was used for statistical analysis of the results from each taste panel. Results from each taste panel were subjected to analysis of variance (significance at *P* < 0.05 and *P* < 0.10) and means were separated using least significant difference using SAS software (v. 9.1; SAS Institute, Cary, NC).

Results

Each treatment in this study consisted of storage of the pink stage tomatoes in air or CA at 7.5, 15, or 20 °C for 7 d (5 d for the air at 20 °C storage treatment) plus the number of days in air at 20 °C required for full red color to be attained. The *a** value of ripening tomato fruit increases as the fruit ripen, corresponding to increasing development of red color. However, when measured at the same location repeatedly over time, the *a** value eventually reaches a maximum and ceases to increase, which we identified as an objective measure of attainment of full red color (Chomchalow et al., 2002). The total postharvest period for fruit to advance from pink to full red ranged from 5 to 14 d (Table 1), with the fruit stored in CA at 7.5 °C failing to reach full red color in 14 d.

In the first taste panel evaluation, aroma liking was significantly affected by the different storage regimes (*P* = 0.0447). More specifically, fruit stored for 5 d at 20 °C in air were rated significantly higher in aroma liking than the fruit stored for 7 d at 7.5 °C in air plus 4 d of SL at 20 °C (Table 2). Storing fruit at 20 or 15 °C with or without the use of CA did not affect the overall liking scores compared with either the 7 d at 20 °C in CA plus 2 d of SL 20 °C or the 7 d at 7.5 °C in air plus 4 d of SL at 20 °C treatments. Overall liking was strongly affected by the different treatment regimes used (*P* = 0.0066) with fruit stored for 5 d at 20 °C in air (as well as fruit stored at 15 °C in CA for 7 d plus 4 d of SL at 20 °C for 10% significance level) receiving higher overall liking ratings compared with fruit stored for 7 d at 7.5 °C in air plus 4 d of SL at 20 °C.

Texture ratings were slightly affected by the different storage regimes, with fruit stored for 5 d at 20 °C in air trending toward higher rating scores compared with the 7 d at 7.5 °C in air plus 4 d of SL at 20 °C stored fruit (*P* = 0.1220). The flavor liking ratings were affected by storage regime as well (*P* = 0.0044). Fruit stored for 5 d at 20 °C in air and fruit stored at 15 °C in CA for 7 d plus 4 d of SL at 20 °C received higher flavor ratings compared with fruit stored for 7 d at 7.5 °C in air plus 4 d of SL at 20 °C. The rest of the storage regimes did not show any differences and their flavor liking ratings fell between the best and the worst rated fruit.

In the second taste panel, there were no effects of the different treatments on any of the four attributes tested (aroma liking, overall liking, texture liking, and flavor liking; Table 3).

Table 1. Storage conditions and durations used for the sensory evaluations and the CIE a^* values on the day of the tasting.

Harvest date	Storage temp (°C)	Atmosphere	CA/LT storage time (d)	Shelf life in air at 20 °C (d)	Total postharvest period	a^* value	SE
First taste panel (11 Apr. 2014)							
6 Apr.	20	Air ^z	5	N/A	5	19.32	0.92
31 Mar.	20	CA	7	4	11	21.95	0.95
2 Apr.	15	Air	7	2	9	19.35	0.41
31 Mar.	15	CA	7	4	11	20.98	0.53
31 Mar.	7.5	Air	7	4	11	22.04	0.46
Second taste panel (16 Apr. 2014)							
10 Apr.	20	Air	7	N/A	7	30.49	0.45
4 Apr.	20	CA	7	5	12	28.30	0.50
6 Apr.	15	Air	7	3	10	30.13	0.35
4 Apr.	15	CA	7	5	12	28.57	0.54
2 Apr.	7.5	Air	7	7	14	29.53	0.45

Air = storage in atmospheric air conditions; CA = controlled atmosphere storage of 8% O₂ plus 6% CO₂; LT = low temperature storage of 7.5, 15, or 20 °C.

Fig. 1. Tomato wedges in sealed plastic cups being filled and labeled for the taste panel (photo courtesy of author).

Discussion

First taste panel. Based on the results of the first taste panel evaluation, we can state that when consumers could distinguish between prior storage temperature treatments, the pink-harvested ‘Tasti Lee’ tomatoes that had been ripened for 5 d in air at 20 °C received significantly higher aroma liking ratings than those stored for 7 d at 7.5 °C and ripened for 4 d. This supports the hypothesis that storing pink ripeness stage tomatoes at the commonly recommended temperature for that ripeness stage of 7.5 °C negatively affected the aroma quality for one of two taste panel evaluations even after the fruit from 7.5 °C storage had been allowed to recover and ripen for 4 d in simulated SL conditions (air storage at 20 °C) and both sets of fruit being compared were at similar red ripeness stages. Holding pink stage tomatoes in CA at 15 °C for 7 d extended the total postharvest period (i.e., the time to reach full red) from 5 d for fruit kept in air at 20 °C to 11 d,

with overall and flavor liking scores that were superior to fruit stored in air at 7.5 °C.

All of the fruit that were evaluated had very similar, if not identical, appearance, so red coloration differences between treatments were not likely to have been an issue in consumer scoring. The results suggest that storage of pink tomatoes in air for 7 d at 7.5 °C may result in permanent impairment of aroma production. On the other hand, lycopene production and subsequently red color development did not seem to have been inhibited by any of the storage treatments because the red color development continued to progress during low temperature storage in both air and CA and eventually reached levels that were similar to control fruit during storage in air at 20 °C. The exception was the fruit from CA at 7.5 °C, which did not attain full red color development in air at 20 °C within the 7-d time frame for SL in this experiment and, thus, were not used for the consumer taste panel. This behavior could be attributed to the combination of low temperature

storage and CA atmosphere, which impaired ripening and did not allow full recovery of normal red color development on transfer to ambient conditions.

The overall liking ratings for pink-harvested ‘Tasti Lee’ tomatoes were significantly higher for fruit stored for 5 d in air at 20 °C than in other treatments, whereas the lowest ratings were recorded for fruit stored at 7.5 °C in air for 7 d plus 4 d of SL (Table 2). The rest of the treatments were in between the aforementioned ratings and showed no significant differences. Tomato flavor and texture liking were also significantly affected by storage regimes. Interestingly, fruit stored for 5 d at 20 °C in air and fruit stored for 7 d at 15 °C in CA (8% O₂ plus 6% CO₂) plus 4 d of SL were both rated higher in overall liking and flavor liking than fruit stored at the lowest temperature (7.5 °C) in air for 7 d plus 4 d of SL recovery. This suggests that CA storage of pink tomatoes at a higher than usually recommended temperature does not necessarily hinder the fruit’s subsequent flavor potential.

These findings are in accordance with previous studies in which sensory panels gave lower ratings to ‘BHN-189’ and ‘Solimar’ tomatoes stored for 8 d in air at 5 °C (or up to 12.5 °C for ‘Solimar’) compared with fruit stored at 20 °C (Maul et al., 2000). Also, Plotto et al. (2007) found that breaker stage ‘Florida 47’ tomatoes stored at 18 °C had the highest ratings for overall tomato aroma and flavor, fruity aroma, and sweetness when compared with fruit picked at earlier ripeness stages or fruit that had been stored at 13 °C.

Second taste panel. In the second taste panel, it appears that fruit of a more advanced ripeness stage may have been used (maximum, ripe a^* values increased from an average of 20.7 for panel 1 to 29.4 for panel 2, which denotes more red component). During the second taste panel session, no significant differences were reported for any of the four sensory traits tested. More specifically, taste panelists did not find any significant differences between the five different storage regimes on aroma liking, overall liking, texture liking, and flavor liking of ripened pink-harvested ‘Tasti Lee’ tomato fruit.

A possible explanation for the lack of differences in scores assigned by the second

Table 2. Storage conditions used for the consumer evaluations and rating mean scores with statistical results for probability (*P*) at 0.1 and 0.05 levels (panel 1).

Storage temp (°C)	Atmosphere	Mean score	<i>P</i> ≤ 0.1	<i>P</i> ≤ 0.05
Aroma liking				
20	Air	24.55	a	a
20	CA	19.56	ab	ab
15	Air	22.96	ab	ab
15	CA	22.63	ab	ab
7.5	Air	16.68	b	b
Overall liking				
20	Air	25.92	a	a
20	CA	21.87	ab	ab
15	Air	20.14	ab	ab
15	CA	22.89	a	ab
7.5	Air	15.03	b	b
Texture liking				
20	Air	27.82	a	a
20	CA	24.34	ab	a
15	Air	22.29	ab	a
15	CA	24.43	ab	a
7.5	Air	20.91	b	a
Flavor liking				
20	Air	24.31	a	a
20	CA	19.03	ab	ab
15	Air	18.00	ab	ab
15	CA	20.14	a	ab
7.5	Air	12.42	b	b

Different letters assigned to storage treatments denote significant differences.

Scores represent perceived intensity of tomato aroma, overall liking, texture, and tomato flavor scaled in the context of each subject's sensory experiences using sensory gLMS scoring that ranges from 0 to 100. Air = storage in atmospheric air conditions; CA = controlled atmosphere storage of 8% O₂ plus 6% CO₂.

Table 3. Storage conditions used for the consumer evaluations and rating mean scores with statistical results for probability (*P*) at 0.1 and 0.05 levels (panel 2).

Storage temp (°C)	Atmosphere	Mean score	<i>P</i> ≤ 0.1	<i>P</i> ≤ 0.05
Aroma liking				
20	Air	20.45	a	a
20	CA	22.74	a	a
15	Air	20.48	a	a
15	CA	23.53	a	a
7.5	Air	21.01	a	a
Overall liking				
20 °C	Air	20.45	a	a
20 °C	CA	22.74	a	a
15 °C	Air	20.48	a	a
15 °C	CA	23.53	a	a
7.5 °C	Air	21.01	a	a
Texture liking				
20 °C	Air	20.00	a	a
20 °C	CA	27.51	a	a
15 °C	Air	20.57	a	a
15 °C	CA	22.05	a	a
7.5 °C	Air	20.89	a	a
Flavor liking				
20 °C	Air	18.25	a	a
20 °C	CA	23.88	a	a
15 °C	Air	19.64	a	a
15 °C	CA	21.04	a	a
7.5 °C	Air	19.57	a	a

Different letters assigned to storage treatments denote significant differences.

Scores represent perceived intensity of tomato aroma, overall liking, texture, and tomato flavor scaled in the context of each subject's sensory experiences using sensory gLMS scoring that ranges from 0 to 100. Air = storage in atmospheric air conditions; CA = controlled atmosphere storage of 8% O₂ plus 6% CO₂.

panel could be that there may have been a bias by the panelists for darker red tomatoes that affected aroma, texture, and flavor scores. Another possibility is that the fruit used in the second panel may have been developmentally more advanced at the start of the storage treatments and, thus, more resistant to CI. Tomato fruit resistance to CI increases as the fruit ripen (Autio and Bramlage, 1986). Greater resistance to CI

may have allowed for greater recovery of the aroma volatiles (Maul et al., 2000) than in the first panel, to a point that there were no differences between the treatments. This suggestion would need to be confirmed by analysis of the flavor volatiles. Also, Fernqvist and Hunter (2012) who stored red ripeness stage 'Arvento' and 'Tiësto' tomatoes for 2 d at refrigerator temperature (7 °C) or room temperature (21 °C) considered the

effects of chilling to be overstated when it comes to actual consumer experiences.

Conclusions

The storage temperature and CA conditions used in this study significantly affected the taste panel ratings for tomato fruit when the same full red ripeness stage fruit were presented to the panelists. The panelists in the first taste panel rated fruit stored for 5 d in air at 20 °C to be significantly higher in all aspects compared with those stored at 7.5 °C in air for 7 d plus 4 d of SL; storing tomatoes at 20 °C in CA, or at 15 °C in air or CA resulted in significant extension of post-harvest life compared with ripening in air at 20 °C, and those fruit were given equal or intermediate scores by the panelists. All individual descriptors, flavor, texture, overall liking, and aroma, had similar scores on the gLMS scale. This confirms that storing pink tomatoes at 7.5 °C negatively affects the sensory quality, including aroma, whereas fruit stored at the nonchilling temperature of 20 °C have a better aroma profile, even though fruit from the different treatments were ripened to the same color.

The fruit used in the second panel had significantly higher *a** values (deeper red color), which could be the reason for the absence of differences between storage treatments that was found in the second test.

Storing fruit from different harvests using color as a visual factor to decide which fruit are at the same ripeness stage visually is an easy way to standardize the sampling process; however, other quality parameters could be used to complement the aforementioned index such as firmness and soluble solids content.

Literature Cited

- Auerswald, H. 1999. Sensory analysis and instrumental measurements of short-term stored tomatoes (*Lycopersicon esculentum* Mill.). *Postharvest Biol. Technol.* 15:323–334.
- Autio, W.R. and W.J. Bramlage. 1986. Chilling sensitivity of tomato fruit in relation to ripening and senescence. *J. Amer. Soc. Hort. Sci.* 111:201–204.
- Babitha, K.C. 2006. Physiological basis of extending postharvest shelf life in tomato. *Univ. Agr. Sci., Dharwad*.
- Bai, J., E.A. Baldwin, Y. Imahori, I. Kostenyuk, J. Burns, and J.K. Brecht. 2011. Chilling and heating may regulate C6 volatile aroma production by different mechanisms in tomato (*Solanum lycopersicum*) fruit. *Postharvest Biol. Technol.* 60:111–120.
- Baldwin, E.A., J.W. Scott, C.K. Shewmaker, and W. Schuch. 2000. Flavor trivia and tomato aroma: Biochemistry and possible mechanisms for control of important aroma components. *HortScience* 35:1013–1022.
- Bartoshuk, L.M., V.B. Duffy, K. Fast, B.G. Green, J. Prutkin, and D.J. Snyder. 2003. Labeled scales (e.g., category, Likert, VAS) and invalid across-group comparisons: What we have learned from genetic variation in taste. *Food Qual. Prefer.* 14:125–138.

- Bartoshuk, L.M., V.B. Duffy, B.G. Green, H.J. Hoffman, C.W. Ko, L.A. Lucchina, L.E. Marks, D.J. Snyder, and J.M. Weiffenbach. 2004. Valid across-group comparisons with labeled scales: The gLMS versus magnitude matching. *Physiol. Behav.* 82:109–114.
- Bartoshuk, L.M., K. Fast, D.J. Snyder, and J. Snyder. 2011. Differences in our sensory worlds: Invalid comparisons with labeled scales differences invalid comparisons in our with sensory labeled scales. *Psychol. Sci.* 14:122–125.
- Carrari, F. and A.R. Fernie. 2006. Metabolic regulation underlying tomato fruit development. *J. Expt. Bot.* 57:1883–1897.
- Chomchalow, S., N.M. El Assi, S.A. Sargent, and J.K. Brecht. 2002. Fruit maturity and timing of ethylene treatment affect storage performance of green tomatoes at chilling and nonchilling temperatures. *HortTechnology* 12:104–114.
- Deltsidis, A.I., E.D. Pliakoni, E.A. Baldwin, J. Bai, A. Plotto, and J.K. Brecht. 2015. Tomato flavor changes at chilling and non-chilling temperatures as influenced by controlled atmospheres. *Acta Hort.* 1071:703–710.
- Fernqvist, F. and E. Hunter. 2012. Who's to blame for tasteless tomatoes? The effect of tomato chilling on consumers' taste perceptions. *Eur. J. Hort. Sci.* 77:193–198.
- Flores, F.B., M.C. Martínez-Madrid, M. Ben Amor, J.C. Pech, A. Latché, and F. Romojaro. 2004. Modified atmosphere packaging confers additional chilling tolerance on ethylene-inhibited cantaloupe *Charentais melon* fruit. *Eur. Food Res. Technol.* 219:614–619.
- Hobson, G.E. 1987. Low-temperature injury and the storage of ripening tomatoes. *HortScience* 65:55–62.
- Hong, J.H. and K.C. Gross. 2001. Maintaining quality of fresh-cut tomato slices through modified atmosphere packaging and low temperature storage. *J. Food Sci.* 66:960–965.
- Kader, A.A. 1980. Prevention of ripening in fruits by use of controlled atmospheres. *Food Technol.*
- Kader, A.A. 1986. Effects of postharvest handling procedures on tomato quality. *Acta Hort.* 190:209–221.
- Maul, F., S.A. Sargent, D.J. Huber, M.O. Balaban, D.A. Luzuriaga, and E.A. Baldwin. 1997. Non-destructive quality screening of tomato fruit using “electronic nose” technology. *Proc. Florida State Hort. Soc.* 110:188–194.
- Maul, F., S.A. Sargent, C.A. Sims, E.A. Baldwin, M.O. Balaban, and D.J. Huber. 2000. Tomato flavor and aroma quality as affected by storage temperature. *J. Food Sci.* 65:1228–1237.
- Mutari, A. and R. Debbie. 2011. The effects of postharvest handling and storage temperature on the quality and shelf of tomato. *J. Food Sci.* 5:446–452.
- Paull, R.E. 1999. Effect of temperature and relative humidity on fresh commodity quality. *Postharvest Biol. Technol.* 15:263–277.
- Pesis, E., D. Aharoni, Z. Aharon, R. Ben-Arie, N. Aharoni, and Y. Fuchs. 2000. Modified atmosphere and modified humidity packaging alleviates chilling injury symptoms in mango fruit. *Postharvest Biol. Technol.* 19:93–101.
- Plotto, A., E.A. Baldwin, K. Goodner, and J. Narciso. 2007. Sensory evaluation quality of tomato “Florida”47: Effect of maturity, storage temperature and 1-MCP. *American Society of Horticulture Science Meeting.* p. 1018–1019.
- Tieman, D., P. Bliss, L.M. McIntyre, A. Blandon-Ubeda, D. Bies, A.Z. Odabasi, G.R. Rodríguez, E. Van Der Knaap, M.G. Taylor, C. Goulet, M.H. Mageroy, D.J. Snyder, T. Colquhoun, H. Moskowitz, D.G. Clark, C. Sims, L. Bartoshuk, and H.J. Klee. 2012. The chemical interactions underlying tomato flavor preferences. *Curr. Biol.* 22:1035–1039.
- Tieman, D., G. Zhu, M.F.R. Resende, T. Lin, C. Nguyen, D. Bies, J.L. Rambla, K.S.O. Beltran, M. Taylor, B. Zhang, H. Ikeda, Z. Liu, J. Fisher, I. Zemach, A. Monforte, D. Zamir, A. Granell, M. Kirst, S. Huang, and H. Klee. 2017. A chemical genetic roadmap to improved tomato flavor. *Science* 355:391–394.
- USDA. 1991. United States standards for grades of fresh tomatoes. U.S. Dept. Agr./AMS, Washington, DC.
- Wang, C.Y. and L. Qi. 1997. Modified atmosphere packaging alleviates chilling injury in cucumbers. *Postharvest Biol. Technol.* 10:195–200.