Fruit ripening conditions affect the quality of sliced red tomatoes

M. Buccheri[1] and M.I. Cantwell[2,a]

[1]Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria [Unità di ricerca per i processi dell'industria agro-alimentare], Milano, Italy; [2]Department of Plant Sciences, University of California Davis, Davis, CA, USA.

Abstract

Fresh-cut tomato slices can deteriorate rapidly, with a correspondingly short shelf-life. Almost all research to date has focused on fresh-cut tomato preparation and storage, and little research has considered how postharvest handling of the whole fruit could affect the quality of the prepared fresh-cut product. The quality and shelf-life of slices prepared from ripe tomato fruit (hue angle 43) were evaluated in relation to initial ripening stage (breaker, 10% red, or turning, 30% red) ripening temperature (15, 20, or 25°C) and postharvest treatment with ethylene. Tomatoes ripened at a lower temperature (15°C) had higher fruit firmness, while tomatoes kept at 25°C had lower lycopene content and lower firmness. Juice loss increased during the storage of all slices, and was higher in slices from breaker stage fruit and from fruit treated with ethylene, but was not much affected by fruit ripening temperature. Lycopene content of the slices declined consistently during storage at 5°C. This study clearly showed that full red tomatoes can be a fresh-cut product with good slice integrity and adequate shelf-life (8-11 days at 5°C).The results also emphasize the need to assess postharvest handling protocols specific for fresh-cut tomato processing.

Keywords: ethylene, temperature, lycopene, juice loss, fresh-cut

INTRODUCTION

Appropriate postharvest handling is essential to obtain high-quality tomato fruit. Tomatoes (*Solanum lycopersicum* L.) can be harvested at various stages of maturity and ripeness, but field-grown fruit are often picked at mature-green (MG) or breaker stages, with the MG fruit being ethylene-treated to initiate the ripening process. Quality requirements for fresh market tomatoes include that they be firm, have a uniform and shiny color, and not have mechanical damage, shrivel or decay defects (Sargent and Moretti, 2004; USDA, 1991). Ripening temperature is important to final ripe tomato quality. Breaker-stage fruits ripened at 15-20°C have longer shelf-life, greater overall visual quality, and less weight loss, and have more red color and less decay than fruits ripened at higher temperatures (Cantwell, 2010). Other authors have also concluded that the best temperature range for ripening tomatoes is near 20°C (Kader, 1986; Sargent and Moretti, 2004).

A major problem with storage and marketing of fresh-cut tomato slices is their relatively rapid deterioration and short shelf-life (Hong and Gross, 2000; Jeong et al., 2004). Slice integrity is an important quality parameter but, because of the internal structure of the tomato, high juice loss often occurs after cutting. Juice loss is managed commercially by use of absorbents in the bottom of the package and by slicing fruit that are only partially ripe. In addition, most sliced tomatoes are prepared from fruit harvested at the MG stage (often containing less locular tissue than fruit harvested at more advanced stages of development) and treated with ethylene to initiate ripening. The ability to slice fully ripe red fruit with minimal juice loss would be desirable, since red color is highly correlated to lycopene content (Odriozola-Serrano et al., 2008) and higher lycopene content is associated with higher quality and nutritive value (Borguini and Ferraz da Silva Torres, 2009). Lycopene is

[a]E-mail: micantwell@ucdavis.edu

one of the phytochemicals in fruits and vegetables that may act against cancer, stroke, and cardiovascular disease, and most medical and nutrition experts agree that lycopene from a natural food state is preferable to supplements (Collins et al., 2006).

Raw material characteristics (Jeong et al., 2004) or mechanical damage (Buccheri and Cantwell, 2014) have been shown to affect quality attributes of fresh-cut tomato. Almost all research to date has focused on aspects of fresh-cut preparation and storage (Hong and Gross, 2000; Artés et al., 1999; Gil et al., 2002; Odriozola-Serrano et al. 2008; Lana et al., 2005), and very little has been done to understand how postharvest handling of the fruit prior to cutting could affect the quality of the fresh-cut product, including juice loss.

This study aimed to evaluate the impact of fruit ripening conditions on the overall quality of red tomatoes and on the shelf-life of slices produced from them. Ripening temperatures, maturity/ripeness stages, and ethylene treatment were the factors studied.

MATERIALS AND METHODS

Breaker or turning-stage tomatoes, untreated or ethylene-treated, were ripened at 15, 20, or 25°C. Ripe fruit were sliced and the slice quality was evaluated during storage in air at 5°C. Three experiments were carried out, and the two using cultivar '901' are summarized here.

Experiment 1: Quality of slices from fruit ('901') ripened from breaker and turning stages at 15, 20 or 25°C

Large (200 g, 6 cm diameter) tomatoes were handpicked at the MG stage (stage 1; USDA, 1991) from a commercial operation and transported to the lab, where they were stored at 20°C for 2 days. Tomatoes were then classified by ripeness stage. MG fruit only were chosen and, as standard procedure in the US tomato industry, treated with ethylene (50 ppm) at 20°C for 48 h. After treatment, fruit were separated into breaker (BR) or turning (T) fruit (USDA color stages 2 and 3), placed on fiber trays covered with food-grade plastic wrap, and completed ripening at 15, 20 or 25°C (80-85% RH). Ripe fruit (peel color 43 °*h*) were sliced and slices were evaluated after 0, 4, 7, 11, and 14 days at 5°C.

Experiment 2: Slice quality of untreated or ethylene-treated MG fruit ('901') ripened at 15, 20 or 25°C

Fruit were from the same lot as experiment 1. After harvest plus 2 days at 20°C, tomatoes (not treated with ethylene) were selected for size and uniformity and only breaker stage (10% red color) fruit were chosen and further ripened at 15, 20 or 25°C (80-85% RH). These fruit were compared with BR fruit obtained by ethylene treatment of MG fruit. Ripe fruit (43 °*h*) were sliced and slices were evaluated after 0, 4, 7, 11, and 14 days at 5°C. Slices from ethylene treated fruit are referred to as ETH slices, whereas slices from untreated fruit are referred to as NO ETH slices.

Slice preparation

Red ripe fruit were held in a sanitized room at 10°C for 16 h and then disinfected (1 min in NaClO, 50 mg L^{-1}, pH 7), rinsed in water (1 min) and blotted dry with paper towels. A manual tomato slicer (Nemco model II) with razor-sharp blades was used to slice the fruit perpendicularly to the stem axis (slices 4.5 mm thick). To minimize dehydration, all slices were regrouped to reconstruct the initial whole tomato. Each sliced tomato was placed in a small polypropylene tray, and the trays were covered by food-grade plastic film and placed on a large tray inside an unsealed polyethylene bag at 5°C.

Quality evaluation

For external color, fruit were measured on three sides at the equator with a reflectance colorimeter (CR200 colorimeter, Konica Minolta Sensing), measuring CIE L* a*b*, and calculating hue angle [°*h*=arctangent (b*/a*)]. Fruit were considered fully ripe when the peel color reached a hue of 43. Slice color was determined on the parenchymatous tissue at three equidistant points on the top slice of three stacked slices. Firmness was measured on the red fruit by a texture analyzer (TA.XT PLUS Stable Micro Systems) as the force to compress the fruit by 5 mm at the equator, using a flat 25 mm diameter Plexiglas cylinder moving at 1 mm s^{-1}. Juice loss immediately after slicing was determined as the weight difference (nearest 0.01 g) between the whole fruit and the reconstructed sliced fruit. During storage at 5°C, the amount of juice released from the sliced fruit was weighed when slices were evaluated. The total juice loss (g 100 g^{-1}) was calculated as: [(juice loss after slicing (g) + juice loss during storage (g))*100 (g)]/initial fruit weight (g). A visual quality (VQ) evaluation of the slices was carried out by the same evaluator under room light. VQ was scored on a 9 to 1 scale, where 9 = excellent, fresh appearance, 7 = good, 5 = fair, limit of marketability, 3 = poor, limit of usability, 1 = unusable, and intermediate scores were used as appropriate. A score of 6 was considered the limit for marketable quality. Typical aroma, translucency and deterioration of the slices were scored on 1 to 5 scales, where 1 = none, 2 = slight, 3 = moderate, 4 = near full or moderately severe, and 5 = full aroma or severe.

Composition

For soluble solids and acidity, a pool of three central slices of each of three tomatoes was homogenized and filtered to measure soluble solids (SSC) by a digital refractometer, pH and titratable acidity (TA) using 0.1 M NaOH to titrate to a pH 8.1 endpoint, calculating TA as g citric acid 100 g^{-1} fresh weight. Lycopene content was determined by a spectrophotometric assay (Davis et al., 2003). A pooled sample from two central slices of each of three tomatoes was pureed in a blender, and 4 g pulp and 4 mL water were again blended in an Ultra Turax homogenizer. A 0.6 g aliquot was added to 5 mL BHT (0.5 g L^{-1}), 5 mL ethanol 95% and 10 mL hexane 99.9% in an amber glass tube, shaken on ice at 180 RPM for 15 min, and held at 20°C for 15-20 min. Absorbance of the upper solvent was measured at 503 nm (Shimadzu UV-Vis 1700) and lycopene concentration was calculated as mg kg^{-1} fresh weight.

Statistical analysis

Data are based on three replicates per treatment, comprising three slices from each of three fruit. Data were analyzed by ANOVA (Statgraphics 5.1). Differences among treatments were determined by Fisher's least significant difference (LSD) test. Principal component analysis (PCA) was used to extract information from the data, and it was performed on two data matrices of 18 rows (samples) and 17 columns (variables).

RESULTS AND DISCUSSION

Experiment 1: Quality of slices from BR and T fruit ripened at 15, 20 or 25°C

The time needed to reach the full ripe stage varied among ripening temperatures, as would be expected. BR fruit ripened at 15, 20, and 25°C required 15, 11, and 8 days, respectively, to reach 43 °*h*, while T fruits held at the same temperatures required only 12, 8, and 7 days, respectively (Figure 1). Whole-fruit firmness was affected by ripening temperature but not by initial ripeness stage. Fruit ripened at 15°C were significantly firmer than those ripened at 20 or 25°C, with fruit ripened at 25°C being the least firm (Figure 1). These data are consistent with those of previous studies (Kader, 1986; Pinheiro et al., 2013).

After cutting and during shelf-life at 5°C, quality attributes of the slices changed (Table 1). Initial ripeness affected SSC of the slices (T slices < BR slices), while lycopene content was influenced by temperature (25 <20 and 15°C). After storage at 5°C, all treatments showed a high incidence of dehydration, deterioration and translucency, but also discoloration (higher *h*° values), as reported by other authors (Gil et al., 2002; Artés et al., 1999). Slices reached the limit of marketability (VQ score of 6) between 7 and 11 days at 5°C, and this was not affected by ripening temperature.

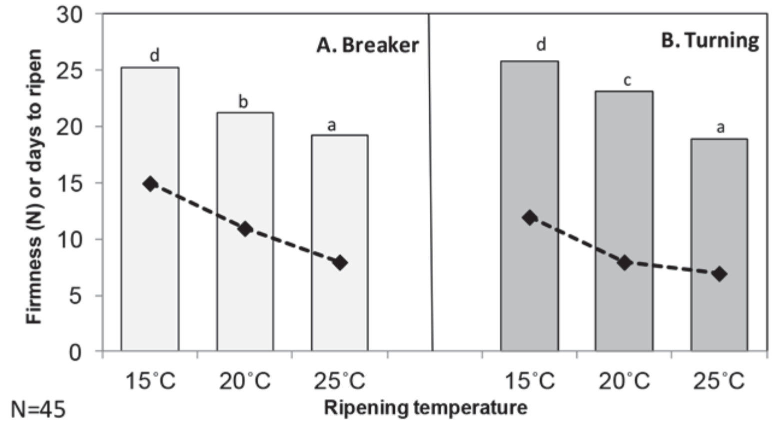

Figure 1. Days to complete ripening (dotted lines) and firmness (bars) of whole tomato '901' fruit ripened at 15, 20 or 25°C from initial breaker (A) or turning (B) stages. Breaker and turning fruit had 10 and 30% external red color, respectively. Firmness was measured at the red ripe stage (peel color=43 °*h*).

Table 1. SSC, pH, TA, lycopene content and color of tomato slices from red fruit ('901'). Fruit were ripened from breaker (BR) or turning (T) stage fruit to a full red (peel with 43°*h*) at 15, 20 or 25°C. Fisher's LSD values were calculated for the main factors and their interaction. Differences are significant at P≤0.05 (*) or P≤0.01 (**); NS, not significant.

Initial stage	Ripening temperature (°C)	Storage at 5°C (days)	SSC (%)	TA (%)	Lycopene (mg kg^{-1})	Slice color (hue angle)
BR	15	0	4.83	0.39	51.7	42.0
		7	5.03	0.38	38.5	41.0
		11	4.77	0.35	42.5	39.0
	20	0	4.53	0.33	52.1	37.2
		7	4.73	0.37	43.1	41.4
		11	4.50	0.34	38.5	44.4
	25	0	4.87	0.37	41.7	37.4
		7	4.87	0.33	31.7	41.3
		11	4.77	0.33	44.4	44.0
T	15	0	4.57	0.37	55.5	40.9
		7	5.07	0.38	49.8	41.0
		11	4.83	0.33	45.7	39.9
	20	0	4.63	0.35	55.1	38.3
		7	4.97	0.35	49.6	41.3
		11	5.27	0.38	33.0	42.6
	25	0	5.40	0.41	41.9	37.7
		7	4.97	0.37	34.3	42.5
		11	4.90	0.36	39.2	43.3
Initial stage			*0.15	NS	NS	NS
Ripening temperature			NS	NS	5.3**	NS
Time			NS	NS	5.3*	1.17**
Stage × temperature			0.27*	0.038*	7.5*	NS
Stage × time			NS	NS	2.6*	1.38**
Temperature × time			NS	NS	9.1**	2.02**
Stage × temperature × time			0.16*	NS	13.0**	2.36**

Lycopene content was reduced by storage at 5°C. The literature is inconsistent regarding lycopene content and low temperatures. Some authors reported a decrease in lycopene in slices stored at 4 or 5°C (Buccheri and Cantwell, 2014; Odriozola-Serrano et al., 2008; Lana et al., 2005), while, in other cultivars, no decrease was observed (Lana et al., 2005). Vallverdú-Queralt et al. (2012) showed that the predominant lycopene isomers (*trans*-lycopene and 5-*cis*-lycopene) were degraded by low temperature. In this study, lycopene content decreased at 5°C in slices from fruits ripened at 15 and 20°C. The initial lycopene content of slices from fruit ripened at 25°C was lower, but content was retained during slice storage, perhaps due to differences in individual isomers (Collins et al., 2006).

For a global picture of differences in quality due to the initial stage and ripening temperature, data were subjected to PCA. Four functions were extracted, explaining 84.7% of the total variance. Considering the first two principal components (Figure 2), PC1 (50% of total variance) was positively related to deterioration, dehydration, and translucency and to high *h*° values, and negatively related to all remaining color parameters, VQ, lycopene, and aroma. PC2 (15%) grouped juice loss, SSC/TA, and pH. The biplot of PC1 versus PC2 showed three main groups. The first was formed by all samples analyzed just after cutting and showed negative values on PC1, related to high VQ, lycopene, and color. In this group, BR slices showed higher values in PC2 and, hence, were more positively related to juice loss, SS/TA, and pH. The second group was formed by the 7-day samples and showed intermediate values on PC1. This group was more scattered than the former. The third group was composed of the 11-day samples and showed high values on PC1 (high deterioration, dehydration, and translucency values).

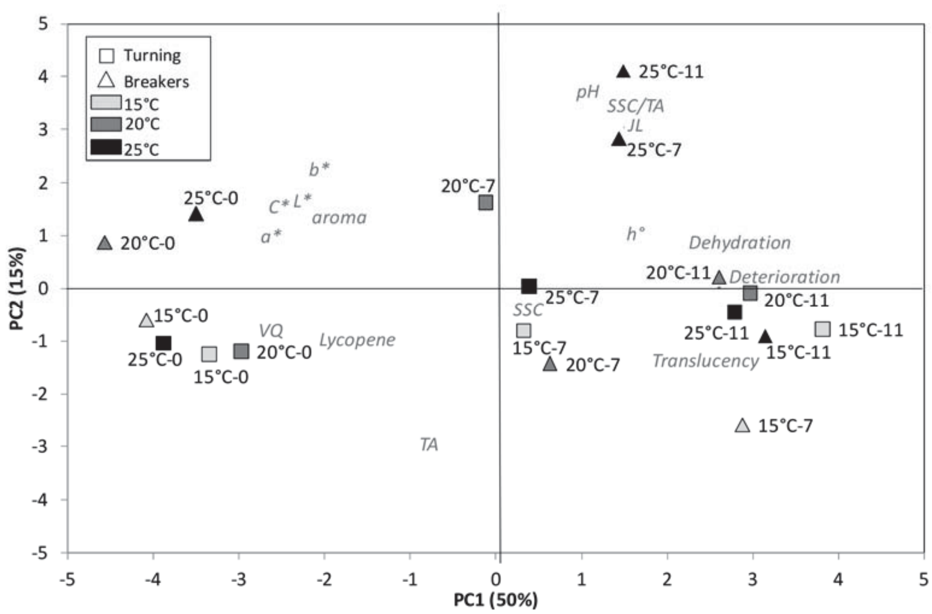

Figure 2. PCA. Biplot of PC1 vs. PC2 showing loadings of quality characteristics (color parameters: L*, a*, b*, C*, h°; VQ = visual quality, aroma, lycopene, TA = titratable acidity, SSC = soluble solids content, SSC/TA, translucency, dehydration, deterioration) of tomato slices and the mean scores of treatments. Slices were from fruit ripened at 15-20 or 25°C, from initial breaker (BR) or turning (T) stage tomatoes, evaluated after 0, 7, and 11 days of shelf-life at 5°C.

Juice loss after slicing and during storage at 5°C was affected by initial ripening stage and increased with time (Figure 3). T slices had, on average, lower juice loss (5.6 g 100 g^{-1} fresh weight) than BR slices (6.9 g 100 g^{-1}). Temperature did not affect juice loss of T slices while, for BR fruit, initial and average juice loss values were higher in fruit ripened at 25°C.

Mealiness and juiciness are negatively correlated in tomato (Devaux et al., 2005). Hong and Gross (2000) found that mealiness occurred in tomato slices stored at 5°C before the appearance of translucent water-soaked areas resulting from chilling injury.

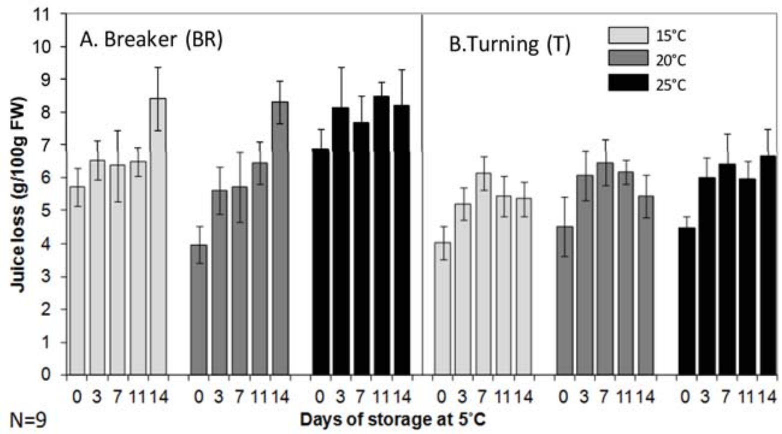

Figure 3. Juice loss of tomato slices stored at 5°C. Slices were from red fruit ('901') ripened at 15, 20 or 25°C from initial breaker (A, 10% color) or turning (B; 30% color) stages. Data are means ± standard error.

Experiment 2: Slice quality of ETH or NO ETH fruit ripened at 15, 20 or 25°C

Firmness of the whole ripe tomato was affected by the ripening temperature (Table 2), with fruit at 15°C being the most firm, followed by those ripened at 20 and at 25°C. Fruit treated with ethylene (ETH) required less time to ripen than untreated (NO ETH) fruit (Table 2). However, ETH fruit had higher firmness than NO ETH tomatoes at the same peel color. The lycopene content was highest in slices from NO ETH tomatoes (47.8 mg kg^{-1}, compared with 42.7 mg for ETH fruit). Slices from fruit ripened at 20°C had mean lycopene content (47.9 mg kg^{-1}) significantly higher than those ripened at 25 °C (43.1 mg kg^{-1}). Juice loss of the slices varied between ethylene treatments and among ripening temperatures, and increased during storage (Figure 4). Slices from NO ETH fruits had a moderate juice loss, while slices from ETH fruit ripened at the three temperatures had higher juice loss.

Table 2. Firmness and days to complete ripening of whole tomato ('901') fruit that were ethylene treated (ETH) or untreated (NO ETH) with ripening completion from breaker color stage at 15, 20 or 20°C.

Treatment	Ripening temperature (°C)	Firmness (N)	Days needed to ripen
Ethylene	15	25.19 e	15
	20	21.25 c	11
	25	19.21 b	8
No ethylene	15	22.98 d	19
	20	21.66 cd	13
	25	15.24 a	11

Values indicated by different lower-case letters are statistically different.

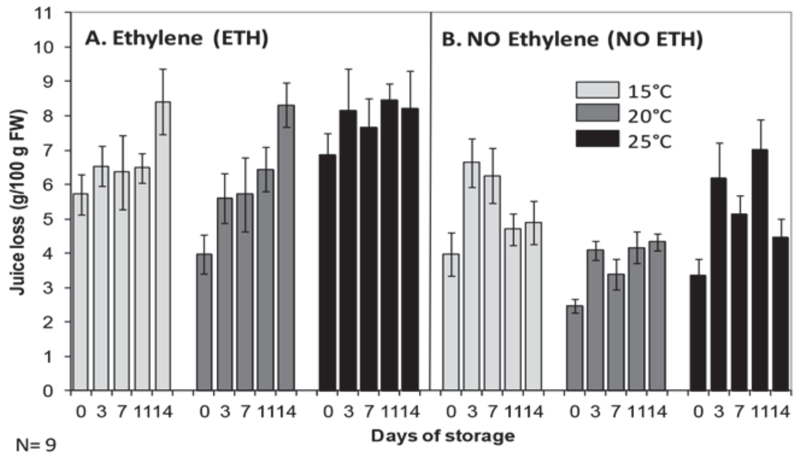

Figure 4. Juice loss of tomato slices held at 5°C for up to 14 days. Slices were from fruit ('901') that were ethylene treated (A) or untreated (B) with ripening completion at 15, 20 or 25°C from initial breaker color stage. Ethylene treatment was 50 ppm at 20°C for 48 h. Data are means ± standard error.

Ethylene treatment of MG fruit increased juice loss. Hong and Gross (2000) showed that ethylene treatment after slicing can suppress chilling injury, with untreated slices having a higher incidence of translucent areas than ethylene-treated slices. Ethylene treatment has been shown to increase locular swelling and tissue liquefaction in tomato (Atta-Aly et al., 2000). In this study, ethylene treatment of MG fruit might have protected the slices at 5°C from the onset of chilling injury as well as promoting gel tissue liquefaction, resulting in higher juice loss. Lower juice loss in slices from untreated fruit could have been caused by tissue mealiness, resulting in more retention of juice (Hong and Gross, 2000).

CONCLUSIONS

A good-quality sliced tomato product requires high-quality raw material. Postharvest handling conditions such as temperature, ripening stage, and ethylene treatment can affect desired attributes of whole and sliced tomatoes. Fruit having the same peel color but ripened at lower temperatures had higher firmness, while tomatoes kept at 25°C had lower lycopene content. Juice loss was higher in slices from fruit ripened from breaker-stage fruit and from fruit treated with ethylene. The results of this study emphasize the need for postharvest handling protocols specific for fresh-cut processing to obtain a high-quality product. This study also clearly showed that full red tomatoes can be a fresh-cut product, with good slice integrity and adequate shelf-life (8-11 days at 5°C). Slicing of partially ripe tomatoes is not necessary, and only results in an inferior, poorly colored sliced product.

Literature cited

Artés, F., Conesa, M.A., Hernández, S., and Gil, M.I. (1999). Keeping quality of fresh-cut tomato. Postharvest Biol. Technol. *17* (*3*), 153–162 http://dx.doi.org/10.1016/S0925-5214(99)00044-7.

Atta-Aly, M.A., Brecht, J.K., and Huber, D.J. (2000). Ripening of tomato fruit locule gel tissue in response to ethylene. Postharvest Biol. Technol. *19* (*3*), 239–244 http://dx.doi.org/10.1016/S0925-5214(00)00099-5.

Borguini, R.G., and Ferraz da Silva Torres, E.A. (2009). Tomatoes and tomato products as dietary sources of antioxidants. Food Rev. Int. *25* (*4*), 313–325 http://dx.doi.org/10.1080/87559120903155859.

Buccheri, M., and Cantwell, M. (2014). Damage to intact fruit affects quality of slices from ripened tomatoes. Food Sci. Technol. (Campinas) *59*, 327–334 http://dx.doi.org/10.1016/j.lwt.2014.05.015.

Cantwell, M. (2010). Optimum procedures for ripening tomatoes. In Fruit Ripening and Ethylene Management, Postharvest Horticulture Series no. 9, J. Thompson, and C. Crisosto, eds. (Davis, CA, USA: Department of Pomology, University of California, Davis), p.106–116.

Collins, J.K., Perkins-Veazie, P., and Roberts, W. (2006). Lycopene: from plants to humans. HortScience *41*, 1135–1144.

Davis, A.R., Fish, W.W., and Perkins-Veazie, P. (2003). A rapid spectrophotometric method for analyzing lycopene content in tomato and tomato products. Postharvest Biol. Technol. *28* (*3*), 425–430 http://dx.doi.org/10.1016/S0925-5214(02)00203-X.

Devaux, M.F., Barakat, A., Robert, P., Bouchet, B., Guillon, F., Navez, B., and Lahaye, M. (2005). Mechanical breakdown and cell wall structure of mealy tomato pericarp tissue. Postharvest Biol. Technol. *37* (*3*), 209–221 http://dx.doi.org/10.1016/j.postharvbio.2005.04.013.

Gil, M.I., Conesa, M.A., and Artés, F. (2002). Quality changes in fresh-cut tomatoes as affected by modified atmosphere packaging. Postharvest Biol. Technol. *25* (*2*), 199–207 http://dx.doi.org/10.1016/S0925-5214(01)00166-1.

Hong, J.H., and Gross, K.C. (2000). Involvement of ethylene in development of chilling injury in fresh-cut tomato slices during cold storage. J. Am. Soc. Hortic. Sci. *125*, 736–741.

Jeong, J., Brecht, J.K., Huber, D.J., and Sargent, S.A. (2004). 1-Methylcyclopropene (1-MCP) for maintaining texture quality of fresh-cut tomato. HortScience *39*, 1359–1362.

Kader, A.A. (1986). Effects of postharvest handling procedures on tomato quality. Acta Hortic. *190*, 209–222 http://dx.doi.org/10.17660/ActaHortic.1986.190.21.

Lana, M.M., van Kooten, O., Dekker, M., Suurs, P., and Linssen, R.F.A. (2005). Effects of cutting and maturity on lycopene concentration of fresh-cut tomatoes during storage at different temperatures. Acta Hortic. *682*, 1871–1878 http://dx.doi.org/10.17660/ActaHortic.2005.682.251.

Odriozola-Serrano, I., Soliva-Fortuny, R., and Martin-Belloso, O. (2008). Effect of minimal processing on bioactive compounds and color attributes of fresh-cut tomatoes. Food Sci. Technol. (Campinas) *41* (*2*), 217–226 http://dx.doi.org/10.1016/j.lwt.2007.03.002.

Pinheiro, J., Alegria, C., Abreu, M., Gonçalves, E.M., and Silva, C.L.M. (2013). Kinetics of changes in the physical quality parameters of fresh tomato fruits (*Solanum lycopersicum*, cv. "Zinac") during storage. J. Food Eng. *114* (*3*), 338–345 http://dx.doi.org/10.1016/j.jfoodeng.2012.08.024.

Sargent, S., and Moretti, C. (2004). Tomato. In The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, USDA Agriculture Handbook 66, K. Gross, C. Wang, and M. Saltveit, eds. (Washington, DC, USA: US Department of Agriculture) http://www.ba.ars.usda.gov/hb66/tomato.pdf.

USDA. (1991). United States Standards for Grades of Fresh Tomatoes. USDA Agricultural Marketing Service, Fruit and Vegetable Division, Fresh Produce Branch, Washington, DC, USA. http://www.ams.usda.gov/sites/default/files/media/Tomato_Standard%5B1%5D.pdf.

Vallverdú-Queralt, A., Arranz, S., Casals-Ribes, I., and Lamuela-Raventós, R.M. (2012). Stability of the phenolic and carotenoid profile of gazpachos during storage. J. Agric. Food Chem. *60* (*8*), 1981–1988 http://dx.doi.org/10.1021/jf204142j. PubMed