Heat Treatment Alleviation of Chilling-induced Suppression of Aroma Volatile Levels

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Chilling exposure of tomatoes to 5 ºC for longer than six to eight days can cause surface pitting, irregular (blotchy) color development and other symptoms of chilling injury (CI). The objectives for this study were to investigate whether a four-day exposure of tomato fruit to 5 ºC chilling temperature at the mature green stage of development would impact flavor quality after ripening, and if a pre-chilling heat treatment could alleviate the internal CI. Mature green ‘FL 47’ tomatoes were gassed with ethylene and then divided into the following four treatments: 1) heat treated in 52 ºC hot water for five minutes, then exposed to 5 ºC for four days before being transferred to 20 ºC; 2) heat treated then placed directly at 20ºC without chilling; 3) chilled at 5 ºC for four days then transferred to 20 ºC without prior heat treatment; and 4) untreated control, stored and ripened at 20 ºC. All samples were held at 20ºC until ripened. Fruit were analyzed at the red-ripe stage for volatile components and submitted to a sensory panel for aroma evaluation. Results showed that chilling treatment generally suppressed production of aldehyde, alcohol, ketone, ester, sulfur, and terpene volatile compounds, including the following abundant and/or important volatiles: hexanal, 6-methyl-5-hepten-2-one, β-ionone, 2-methylbutanal, 2-phenylethanol, guaiacol and 2-isobutylthiazole. Heat treatment alone did not affect most volatile levels after ripening. Heat treatment prior to chilling alleviated the reduction of volatile compounds caused by chilling exposure, which agreed with the sensory panel results that “heating + chilling” treated fruit had greater “tomato odor” than fruit that were chilled only.

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Inappropriate postharvest conditions, such as temperature, humidity, and atmosphere may cause flavor loss in tomato fruit. Like many other tropical and subtropical horticultural crops, tomato fruit are sensitive to low temperature, which can cause chilling injury (CI). Decreased aromatic volatile production is one of the many signs of chilling damage (Baldwin, 2004; Boukobza and Taylor, 2002; Maul et al., 2000). While heat treatment of tomatoes has been shown to be an effective means to reduce microbes, disinfest insects, delay ripening, and alleviate pathological and physiological disorders (Lurie, 1998; McDonald et al., 1999; Yahia et al., 2007), a disadvantage of heat treatment is marked loss of volatile production (Baldwin, 2004; McDonald et al., 1996). Pretreatments with heat was found to reduce CI of many tropical and subtropical horticultural crops, such as mango (McCollum et al., 1993), pomegranate (Mirdeghian et al., 2007), avocado (Woolf et al., 1995), and tomato (Hakim et al., 1995; Lurie and Klein, 1991; Lurie and Sabehat, 1997; Paull and McDonald, 1994). Tomatoes pretreated with either hot water (42 ºC for 1 h) or hot air (38 ºC for 48 h), did not suffer external chilling injury (McDonald et al., 1996), and had less volatile flavor loss (McDonald et al., 1999) at 2 ºC storage. Our previous research shows that both chilling and heating treatments at the red stage suppressed production.

Flavor is a critical quality characteristic in acceptance of fresh tomatoes (Solanum lycopersicum L.) and consumers are willing to pay a premium for full-flavored fruit and vegetables (Baldwin et al., 2000; Petro-Turza, 1986). More than 400 volatile compounds have been identified in ripe tomato fruit (Baldwin et al., 1991; Petro-Turza, 1986). Of those, only 15–20 are present in sufficient quantities to impact flavor (Buttery, 1993; Klee, 2010). Over the last 50 years, much effort was focused on yield, appearance and storability, which has resulted in cheaper, year-round produce availability; however, less attention was paid to another important aspect of quality, flavor. Consumers have noticed a significant decline in flavor quality over the years and lack of flavor in produce is a major source of consumer complaints (Klee, 2010).
of fatty acid-derived volatiles, which did not fully recover after transferring tomatoes to 20 °C for four days (Bai et al., 2011b).

As previously reported, mature green tomatoes exposed to 10 °C or lower temperature for longer than 2 weeks or at 5 °C for longer than 6–8 days suffered surface pitting, irregular (blotchy) color development and other surface symptoms of CI during the ripening process (Suslow and Cantwell, 2013). But few studies focused on the impact of short-term exposure to chilling temperatures on tomato flavor components, although no visible CI symptoms occur. The objectives of this study were to investigate whether a 4-day exposure of tomato fruit to 5 °C at the mature green stage would impact flavor quality after ripening at 20 °C, and if a pre-chilling heat treatment, such as 52 °C hot water dipping for 5 min, reported to improve sensory quality in tomatoes (Loayza et al., 2012), could alleviate such internal CI.

Materials and Methods

**Plant materials.** Mature green ‘FL47’ tomatoes (120), defect free with an average size of 150 g, were harvested from a commercial field in Fort Pierce, FL, on December 3, 2013 and then were exposed to 80 µL L⁻¹ of ethylene for 40 h at 20 °C to initiate and synchronize ripening. The fruits were then divided into the following four treatments: 1) heat treated in 52 °C hot water for 5 min, then exposed to 5 °C for 4 d before being transferred to 20 °C; 2) heat treated then placed directly at 20 °C without chilling; 3) chilled at 5 °C for 4 d then transferred to 20 °C without prior heat treatment; and 4) untreated control, continuously stored and ripened at 20 °C. Fruit samples were taken at the red stage (color a* value ≈ 20). Nine out of a total of 30 fruit per treatment at the red-ripe stage were selected for volatile analysis: three fruit per replicate x three replicates. For sampling, pericarp tissue from the three fruit composite replicate was quickly removed from the fruit with a sharp stainless steel knife, immersed in liquid N₂, fractured to roughly 0.5 cm diameter pieces and then stored at –80 °C until analyzed.

**Volatile analysis by headspace, solid-phase-microextraction, and gas chromatography–mass spectrometry system (HS-SPME-GC-MS).** The HS-SPME-GC-MS analysis was applied following Bai et al (2011a)’s methods with modifications. Frozen pericarp tissue was ground to powder under liquid nitrogen and 4.3 g of powder, together with 1.7 mL of saturated CaCl₂ solution were transferred to a 20-mL vial and sealed with Teflon-lined septa. The sample vials were thawed under tap water, vortexed for 30 s, and loaded onto an autosampler (Model MPS2, Gerstel Inc., Linthicum, MD) equipped with a cooling tray (Laird Tech, Sweden) controlled by a Peltier Thermostat (CTC Analytics AG, Switzerland) with temperature setting at 4 °C, and held until headspace analysis. For headspace sampling, the homogenized samples were incubated for 30 min at 40 °C, after which time a 2-cm solid phase microextraction (SPME) fiber (50/30 µm DVB/Carboxen/PDMS; Supelco, Bellefonte, PA) was exposed to the headspace for another 30 min at 40 °C. After exposure, the SPME fiber was inserted into the injector of a GC-MS (Model 6890, Agilent, Santa Clara, CA) to desorb the extract for 15 min at 250 °C. The GC-MS equipment and settings were: DB-5 (60 m length, 0.25 mm i.d., 1.00 µm film thickness; J&W Scientific, Folsom, CA) columns, coupled with a 5973 N MS detector (Agilent Technologies). The column oven was programmed to increase at 4 °C/min from the initial 40 °C to 230 °C, then ramped at 100 °C/min to 260 °C and held for 11.70 min for a total run time of 60 min. Helium was used as carrier gas at flow rate of 1.5 mL/min. Inlet, ionizing source and transfer line were kept at 250, 230, and 280 °C, respectively. Mass units were monitored from 30–250 m/z and ionized at 70 eV. Data were collected using the ChemStation G1701 AA data system (Hewlett-Packard, Palo Alto, CA). A mixture of C₅ to C₁₈ n-alkanes was run at the beginning of each day to calculate retention indices (RIs). Volatile compounds were identified by comparison of their mass spectra with library entries (NIST/EPA/NIST Mass Spectral Library, version 2.0d; National Institute of Standards and Technology, Gaithersburg, MA), as well as by comparing RI with authorized standard aroma compounds purchased from Sigma-Aldrich (St. Louis, MO) or Fluka Chemical Corporation (Buchs, Switzerland).

**Sensory evaluation.** Paired-comparison tests (Meilgaard et al., 1999) were performed comparing heat-treated fruit with control, and heat-treated then chilled fruit with chilled only fruit. The two taste panels had to be performed at one week intervals because the chilled fruit had delayed ripening. Sensory evaluation was carried out by a panel of 21 members for overall flavor. Tomatoes were cut in ~2 cm³ pieces, and two or three pieces were placed in 4-oz (118 mL) plastic soufflé cups (Solo® Cups Co., Lake Forest, IL) with lids and labeled with three-digit coded numbers. Panelists were presented the two coded samples with alternate order of presentation. They were asked to open the lids, smell the samples and indicate which one had the most tomato odor. The time between cutting fruit and sensory evaluation was less than one hour. All panel members were familiar with sensory evaluation of tomatoes and other fruits.

**Statistical analysis.** Data presented were the mean values of three biological replicates for volatile compounds. Total ion current (TIC) was used to represent the abundance of the volatile components. SAS Version 9.1 (SAS Institute, Gary, NC) was used to analyze the data, using analysis of variance (PROC ANOVA). Mean separation was determined by Duncan’s multiple range test at the 5% level. For multivariate statistical analyses, principal component analysis (PCA) was performed using JMP (SAS Institute). For panel data, the number of samples that were marked as having more tomato flavor was compiled and compared with the critical number of correct responses in a two-sided directional difference test (Meilgaard et al., 1999).

Results

**Volatile components detected in full ripe ‘FL47’ tomatoes by HS-SPME-GC-MS.** Seventy six compounds were detected after HS-SPME-GC-MS analysis, including 20 aldehydes, 14 alcohols, 12 ketones, 7 alkanes, 7 esters, 4 terpene hydrocarbons, 4 furans, 4 sulfur compounds, 2 alkenes, and 1 acid. Aldehydes had the most abundance followed by ketones and alcohols, and the top three compound groups constituted more than 90% of total volatile abundance (Table 1).

Twelve out of 19 important tomato volatile compounds suggested by (Klee, 2010) were detected by HS-SPME-GC-MS, including 1-penten-3-one, cis-3-hexenal, hexanal, trans-2-hexenal, 6-methyl-5-hepten-2-one, geranylacetone, β-ionone, 2-methylbutanal, 3-methylbutanol, 2-phenylethanol, 2-isobutylthiazole and guaiacol (Table 2). They can be divided to four groups depending on their biochemical origin: 1-penten-3-one, cis-3-hexenal, hexanal, and trans-2-hexenal are fatty acid-derived volatiles; 6-methyl-5-hepten-2-one, geranylacetone and β-ionone come from carotenoids; amino acids are the precursors for 2-methylbutanal, 3-methylbutanol and 2-phenylethanol;
Meanwhile, 2-isobutylthiazole and guaiacol are derived from unknown precursors (Klee, 2010).

Response of volatile production to chilling exposure. Chilling tomatoes did not result in visible CI symptoms following 4 d at 5 °C exposure and 11 d post chilling ripening at 20 °C until full ripe (data not shown). However, the total volatile abundance in chilled tomatoes suffered a 35% reduction (Table 1). The highest reduction occurred in terpenes with a 51% loss, followed by alcohols (43%), alkenes (37%), aldehydes (37%), esters (36%), furans (25%), acids (23%), and ketones (18%) (Table 1). Meanwhile, 7 out of 12 important flavor compounds were suppressed by the chilling treatment (Table 2). In comparison to controls, chilling treatment reduced abundance of carotenoid-derived 6-methyl-5-hepten-2-one and β-ionone by 19% and 40%, respectively; reduced fatty acid-derived hexanal by 48%; and reduced amino acid-derived 2-phenylethanol and 2-methylbutanal by 70% and 52%, respectively (Table 2 and Fig. 1). Synthesis of guaiacol and 5-hepten-2-one and β-ionone by 70% and 51%, respectively, reduced fatty acid-derived hexanal by 48%; and reduced amino acid-derived 2-phenylethanol and 2-methylbutanal by 70% and 52%, respectively (Table 2). The sensory panel did not separate heated fruit from controls (Fig. 3a).

Responses of volatile production to heating alone and heating + chilling treatments. Heating at the mature green stage did not affect most volatiles in full ripe fruits (Table 1), except alcohols, furans, acids and miscellaneous compounds. Four out of 12 important volatiles, including β-ionone and volatiles derived from amino acids, were suppressed by heat treatment (Table 2). The sensory panel did not separate heated fruit from controls (Fig. 3a).

Pre-chilling heat treatment alleviated the flavor loss caused by chilling exposure of tomato fruit as noted by sensory panel-

A PCA was performed using a matrix containing the data of the 12 important tomato volatile compounds (Fig. 2). Score plots show that chilled tomatoes were separated from control along both principal components, which explained 59.8% of the total variability (Fig. 2a). Volatile loading analyses (Fig. 2b) indicated that the majority of volatiles were positive on PC1, except for 3-methylbutanol. Non-chilled samples had positive scores on PC1, which shows most volatile content, and chilled samples had negative scores on PC1, opposite to the non-chilled samples.

### Table 1. Abundance of volatile groups detected in full ripe ‘FL 47’ tomato fruits pretreated by heating and/or chilling at the mature green stage.

<table>
<thead>
<tr>
<th>Compound group</th>
<th>Number of compounds</th>
<th>Abundance (total ion current x 10^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>20</td>
<td>227.09 a</td>
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<tr>
<td>Alcohols</td>
<td>14</td>
<td>113.36 a</td>
</tr>
<tr>
<td>Ketones</td>
<td>12</td>
<td>157.04 a</td>
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<tr>
<td>Alkanes</td>
<td>7</td>
<td>4.69 a</td>
</tr>
<tr>
<td>Esters</td>
<td>7</td>
<td>13.42 a</td>
</tr>
<tr>
<td>Sulfur compounds</td>
<td>4</td>
<td>0.73 ab</td>
</tr>
<tr>
<td>Furans</td>
<td>4</td>
<td>11.03 a</td>
</tr>
<tr>
<td>Terpenes</td>
<td>4</td>
<td>15.13 a</td>
</tr>
<tr>
<td>Alkenes</td>
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</tr>
<tr>
<td>Acids</td>
<td>1</td>
<td>0.99 a</td>
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<tr>
<td>Total</td>
<td>76</td>
<td>528.11 a</td>
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<table>
<thead>
<tr>
<th>Compound group</th>
<th>Compound</th>
<th>Number of compounds</th>
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<tbody>
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<td></td>
<td></td>
<td></td>
<td>Control</td>
</tr>
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<td>Fatty acids</td>
<td>1-Penten-3-one</td>
<td>0.82 ab</td>
<td>0.72 ab</td>
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<td></td>
<td>cis-3-hexenal</td>
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<td>9.47 a</td>
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<td></td>
<td>Hexanal</td>
<td>140.03 a</td>
<td>145.15 a</td>
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<td></td>
<td>trans-2-hexenal</td>
<td>30.80 ab</td>
<td>40.0 a</td>
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<tr>
<td>Carotenoids</td>
<td>6-Methyl-5-hepten-2-one</td>
<td>147.47 a</td>
<td>154.73 a</td>
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<tr>
<td></td>
<td>Geranylacetone</td>
<td>1.75 a</td>
<td>1.65 a</td>
</tr>
<tr>
<td></td>
<td>β-Ionone</td>
<td>0.48 a</td>
<td>0.38 b</td>
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<tr>
<td>Amino acids</td>
<td>Isoleucine</td>
<td>3.09 a</td>
<td>1.61 b</td>
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<td>Leucine</td>
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<td>6.75 b</td>
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<tr>
<td></td>
<td>Phenylalanine</td>
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</tr>
<tr>
<td></td>
<td>Others</td>
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<td>3.97 ab</td>
</tr>
<tr>
<td></td>
<td>Guaiacol</td>
<td>0.33 a</td>
<td>0.25 ab</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>349.69 a</td>
<td>370.34 a</td>
</tr>
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</table>

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Mean values that are not followed by the same letter within the same row show significant difference using Duncan’s multiple range test ($P < 0.05$).
ists (Fig. 3b). Thirteen out of 19 panel members thought that heating + chilling treated tomatoes had more tomato flavor than the chilled only fruit ($P < 0.2$). Based on HS-SPME-GC-MS analysis, in comparison with chilled fruit, heating + chilling treatment increased the synthesis of ketones by 34% ($P < 0.05$), followed by slight increases in terpenes (26%), esters (16%), acids (14%), and alcohols (14%) (Table 1); similarly, the abundance of 6-methyl-5-hepten-2-one, β-ionone and 2-phenylethanol were 37%, 48%, and 122% higher in heating + chilling treated fruits than chilled fruits ($P < 0.05$) (Table 2 and Fig. 1). The results of PCA confirmed this tendency (Fig. 2), heating + chilling treated fruit were closer to the control in comparison with fruit treated by chilling alone (Fig. 2a).

**Discussion**

The symptoms of chilling injury (CI), including surface pitting, irregular (blotchy) color development, and *Alternaria* decay, can

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**Fig. 1**. Total abundance of volatiles derived from different precursor in full ripe ‘FL 47’ tomato fruits pre-treated by heating and/or chilling at mature green stage.

**Fig. 2**. PCA analysis using abundance (TIC) of 12 important volatile compounds in full ripe ‘FL 47’ tomato fruits pre-treated by heating and/or chilling at mature green stage. (a) PCA scores plot and (b) PCA loadings plot.
occur during the ripening process if mature green tomatoes are stored at 5 °C for longer than 6–8 days (Suslow and Cantwell, 2013). Although information has been reported on tomato flavor change after chilling treatment and reduction of CI by pre-heat treatment (Maul et al., 2000; McDonald et al., 1996; McDonald et al., 1999), it is not known if short-term chilling treatment at the mature green stage would have any impact on red-ripe tomato flavor (internal CI), and if pre-heat treatment prevents the internal CI. In order to address this question, a combination of volatile and flavor analyses by sensory panel and headspace GCMS were used to assess the difference in flavor between control and temperature-treated samples.

**Short-term Chilling Treatment at Mature Green Stage Reduced Flavor in Red-Ripe Tomato Fruits.** Internal CI occurs prior to visible CI symptom (Baldwin et al., 2000). In this study, chilling treatment at the mature green stage at 5 °C for 4 d did not cause visible CI symptom in full ripe fruit, however, the volatile flavor components were generally suppressed (Table 1).

The production of two carotenoid-derived volatiles, 6-methyl-5-hepten-2-one and β-ionone were decreased after chilling treatment in this research. Carotenoid-derived volatiles are among the most important contributors to the flavor of tomato and many economically important foods, as diverse as citrus and saffron (Klee, 2010). The cyclic β-ionone aroma is characterized as “fruity/floral”. Humans are sensitive to this molecule and it has extremely low odor thresholds for some people (Plotto et al., 2006). Thus, it is important to flavor despite its very low abundance (Buttery, 1993; Klee, 2010). The linear 6-methyl-5-hepten-2-one is also described as “fruity/floral” although its odor threshold is significantly higher than the cyclic aroma compounds. The two volatiles can be directly derived from their carotenoid precursors in tomato by the action of a pair of carotenoid cleavage dioxygenases, encoded by LeCCD1A and LeCCD1B (Simkin et al., 2004). These enzymes are promiscuous, cleaving linear carotenoids at either the 5,6, the 7,8, or the 9,10 positions, and cyclic carotenoids at the 9,10 position (Ilg et al., 2009). In tomato fruit, an important limiting factor for the synthesis of carotenoid derived volatiles is substrate availability (Klee, 2010), which is correlated with color development (Arias et al., 2000). In our experiment, chilling also inhibited the color development (low a* values) in tomato fruits (data not shown), which might have resulted from the reduction of total carotenoids and hence perhaps carotenoid-derived aroma compounds.

Chilling also down-regulated the synthesis of amino acid derived volatiles, 2-methylbutanal and 2-phenylethanol. 2-Methylbutanal is reported to impart “green” or “fruity” aroma noted in tomato fruit (Baldwin et al., 2008), and it is synthesized from intermediates in the pathway of the branched-chain amino acid isoleucine (Klee, 2010). The proposed pathway begins with the action of branched chain aminotransferases (BCATs) that remove the amino groups from the respective amino acids. Subsequently, there is a decarboxylation to produce the aldehydes and a reduction to form the alcohols (Mathieu et al., 2009). For branched-chain volatiles, much of the regulation of their production is suggested to occur downstream of precursor supply (Kochevenko et al., 2012). So in our study the lower 2-methylbutanal suppressed largely by chilling in this study is possibly due to the down-regulation of BCAT activity responsible for its biosynthesis.

The 2-phenylethanol has a “rose” top-note, and was described as “floral”, “fruity”, and “rose like” in aqueous or aqueous alcohol solutions, but as “alcoholic” and “nutty” in tomato puree (Baldwin et al., 2008; Tandon et al., 2000). It enhanced tropical
and fruity flavors when spiked in combination with sugar or sugar plus acid in a tomato puree, as well as overall aftertaste in combination with acid (Baldwin et al., 2008). Although 2-phenylethanol is also an amino acid derived volatile from phenylalanine as shown by Tieman et al. (2006) in tomato fruit, Klee (2010) suggested a different metabolic pathway might be responsible for its synthesis. In tomato fruit, 2-phenylethanol is synthesized by a series of enzymes, including amino acid decarboxylases (AADCs), amine oxidase and phenylacetaldehyde reductases (PAR) (Klee, 2010). The first and rate-limiting step is performed by AADCs, which converts phenylalanine to phenethylamine. In plants, phenylalanine ammonia-lyase (PAL), which shares a substrate with AADCs, plays an important role to resist low temperature stress (Chen et al., 2008; Lafuente et al., 2003; Leyva et al., 1995). It is assumed that chilling induced PAL activity, and resulted in lower substrate availability for production of 2-phenylethanol.

Of the 4 volatiles derived from fatty acids, only hexanal showed a reduction by chilling treatment (Table 2). Hexanal was described as having a “green,” “grassy,” or “minty” odor when added to tomato puree (Baldwin et al., 2008). Mail et al. (2000) reported that the hexanal was positively correlated with sweetness and ripe tomato ratings. In our study the reduction of hexanal after chilling treatment might be due to the lower hydroperoxide lyase (HPL) activity in red-ripe tomato fruits (data not shown), which is a key enzyme for carbon six (C6) volatiles synthesis (Canoles et al., 2005). However, other C6 volatiles did not show any difference between control and chilled fruit, which might be correlated with the availability of the different substrates for the various C-6 compounds. Further study is needed to confirm this relationship.

Two important volatiles, 2-isobutylthiazole and guaiacol, derived from unknown precursors were also suppressed by chilling treatment. 2-Isobutylthiazole, a volatile in the earthy/musty/medicinal category, is described as having a “pungent,” “medicinal” aroma in tomato puree (Baldwin et al., 2004) and is unique to tomato (Baldwin et al., 2000). Baldwin et al. (2008) found that 2-isobutylthiazole could enhance “viney”, “earthy,” and “musty” aromas, while generally decreasing perception of “sweet tomato”, “tropical”, and “floral” aromas. Guaiacol is not commonly found in fresh fruits and vegetables, but is an important contributor to tomato flavor. It has been described as “smoke”, “sweet”, and “medicinal” aroma (Eisele and Semon, 2005).

Effect of pre-heat treatment on volatile production in tomato fruit with or without chilling exposure. In comparison to substantial reduction of volatile abundance caused by chilling treatment, heat-treated fruit exhibited less volatile changes, even though, 4 out of 12 important tomato volatiles were significantly suppressed: 2-methylbutanal, 3-methylbutanol, 2-phenylethanol and β-ionone. 3-Methylbutanol is described as “sweet” or “fresh” in tomato homogenate (Baldwin et al., 2008). Both 2-methylbutanal and 3-methylbutanol are synthesized from the pathways for the branched-chain amino acids isoleucine and leucine, respectively. Similar to chilling, the reduction caused by heating might be due to limited substrate availability (Arias et al., 2000; Kaplan et al., 2004; Klee, 2010; Martinez-Tellez and Lafuente, 1997; Mitcham and McDonald, 1992).

Heat treatment, applied at the red stage directly before sampling showed significant suppression to all carbon 6 aldehydes and alcohols (Bai et al., 2011b), indicating there might be a recovery process in fruit which overcome the internal CI during the extended storage at room temperature in this study. Heat treatments have been used to alleviate CI and other physiological disorders in different fruits (Bai et al., 2011b; Bai et al., 2004; Lurie, 1998).

Our data showed that the abundance of the ketones 6-methyl-5-hepten-2-one and β-ionone, as well as 2-phenylethanol, were higher in heating + chilling-treated tomatoes compared to chilling treated fruit (Table 1 and 2), agreeing with results from McDonald et al. (1999). Both β-ionone and 6-methyl-5-hepten-2-one have been reported to impart a “fruity” aroma to tomato fruits (Kazeniac and Hall, 1970) and “sweet/floral” aroma when added to bland tomato homogenate (Baldwin et al., 1998; Baldwin et al., 2004). The sensory results were consistent with the GCMS analysis that heating + chilling resulted in greater tomato flavor than chilling alone. As discussed above, the higher abundance of carotenoid derived volatiles in heating + chilling treated tomatoes were positively correlated to higher carotenoid content, which was reflected in higher color development (a*) in comparison to chilled fruit.

Conclusion

This study provides strong evidence that a 4-day exposure of tomato fruit to chilling (5 °C) at the mature-green stage negatively influenced flavor quality of tomatoes after ripening without visual CI symptoms and that heat treatment prior to chilling alleviated some of this flavor loss. Both sensory panels and volatile profiles distinguished the effect of different treatments. Furthermore, heat treatment alone at the mature green stage did not affect levels in most volatiles after ripening.

Literature Cited


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