1-Methylcyclopropene (1-MCP) for Maintaining Texture Quality of Fresh-cut Tomato

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Abstract. A study was conducted to determine the effect of 1-methylcyclopropene (1-MCP) on textural changes in fresh-cut tomato (Lycopersicon esculentum Mill.) slices during storage at 5 °C. The relationship between fruit developmental stage and tissue watering development also was determined. Fresh-cut tomato slices prepared from light-red fruit that had been exposed to 1-MCP (1 µL·L–1 for 24 h at 5 °C) retained significantly higher pericarp firmness during storage at 5 °C for 10 d than slices from nontreated fruit or slices stored at 10 or 15 °C and also had a significantly higher ethylene production. 1-MCP (1 or 10 µL·L–1 for 24 h at 5 °C) had no affect on the firmness of fresh-cut, red tomato slices at 5 °C or on slices prepared from 5 °C-stored, intact red tomatoes. Nor did 1-MCP treatment have a significant effect on electrolyte leakage of tomato slices or intact fruit stored at 5 °C. Slices from fruit of the same developmental stage but with higher initial firmness values had less watering development and responded better to 1-MCP treatment during 8 d storage at 5 °C. 1-MCP (1 µL·L–1) was more effective in reducing watering in light red stage tomato slices when applied at 5 °C for 24 h compared with 1-MCP applied at 10 or 15 °C. Watersoaking development was more rapid in fresh-cut tomato slices as initial fruit ripeness advanced from breaker to red stage. Our results suggest that watering development in fresh-cut tomato slices is an ethylene-mediated symptom of senescence and not a symptom of chilling injury as had previously been proposed.

Fresh-cut fruit products have limited shelf life due to excessive tissue softening, which is coordinated by ethylene and has been demonstrated to be a consequence of alteration in cellular metabolism (Beaulieu and Gorny, 2002). There are numerous chemical and physical preservation strategies that can be used to retard fruit tissue softening after cutting (Reyes, 1996). Hong and Gross (1998) and Gil et al. (1999; 2002) reported that modified atmosphere packaging, surface sterilization with sodium hypochlorite, and the use of potassium bicarbonate, calcium chloride, or calcium lactate are effective supplements to cold storage in extending the shelf life of fresh-cut tomato.

Ethylene production is enhanced when plant tissues are injured by the physical action of fresh-cut processing, and ethylene can accumulate in packages of fresh-cut products (Watada and Qi, 1999), leading to undesirable effects on quality during subsequent handling. Thus, removal of ethylene from the storage environment may help maintain quality and extend the shelf life of fresh-cut products.

The application of ethylene action inhibitors, which bind to receptors so that ethylene cannot dampen signal transduction (Sisler and Serek, 1997; Yueming and Jarui, 2000), has enabled a more in-depth analysis of the relationship between ethylene and fruit ripening.

1-Methylcyclopropene (1-MCP) has been reported to block ethylene receptors, preventing ethylene effects in various plant tissues for extended periods (Sisler and Serek, 1997; Sisler et al., 1996a; 1996b). 1-MCP has provided a valuable tool to investigate ethylene metabolism in ripening climacteric fruit (Nakatsuka et al., 1997). Thus, 1-MCP has the potential for control of ripening and senescence of harvested fruits and vegetables and also to extend the shelf life of fresh-cut products.

The objectives of this study were to characterize the physiological responses of intact and fresh-cut tomato to 1-MCP, applied either before or following processing, and to evaluate its ability as a postharvest tool for extending the shelf life and textural quality maintenance of fresh-cut tomato.

Materials and Methods

Plant material. ‘Florida 47’ tomatoes were used for these experiments. Fruit were obtained from commercial growers in Palmetto, Florida and Newport, Tennessee. Tomatoes were selected to ensure that they were free from visual defects and relatively uniform in size and mass (265.0 ± 14.5g). To obtain fruit of uniform color, tomatoes were stored at 20 °C and 85% relative humidity (RH) and selected visually by surface color as they reached three different ripeness stages: (breaker stage, approximately 10% of fruit surface having some red color development; light red stage, 60 to 90% of the fruit surface light red to red; and red stage, 90 to 100% of the fruit surface red).

Slice preparation and 1-MCP treatment. Intact fruit were dipped in 100 µL·L–1 sodium hypochlorite prepared by diluting a 5.25% commercial bleach solution with deionized water. Eight to nine slices (each 6 mm thick) were prepared by slicing perpendicular to the polar axis with a commercial slicing machine (Tomato Saber model 943; Prince Castle Inc., Carol Stream, III.). The proximal and distal slices were discarded. Intact fruit or six slices (center slices of each tomato) used for each replication (eight replications per treatment) were placed in 1.25-L plastic containers (13 × 13 × 8 cm, FridgeSmart, Tupperware, Orlando, Fla.) equipped with two toggle switches for air ventilation. Tomato slices were horizontally stacked with average 60% overlap between slices. Containers were vented to avoid development of modified atmospheres.

1-MCP (1 or 10 µL·L–1) was applied to both tomato slices and intact tomatoes by releasing the gas from a commercial powder formulation (SmartFresh, AgroFresh Rohm & Haas, Philadelphia, Pa) for 24 h (85% RH) in a sealed, 174-L chamber with two applications at 12-h intervals. 1-MCP was typically applied at 5 °C, but in one experiment, 1-MCP at 1 µL·L–1 was applied to slices at three exposure temperatures (5, 10, or 15 °C). Concentrations of CO2 in the treatment chambers were monitored by gas chromatography (GC) and found to remain below 0.5% in all cases. After 1-MCP treatment, the slices or intact fruit were stored at 5 °C for 8 or 10 d, depending on the experiment. Control intact fruit and control slices were maintained under identical storage conditions as the samples treated with 1-MCP. Quality evaluations were performed every other day during storage using fresh-cut tomato slices (FCS), FCS treated with 1-MCP (FCS+M), slices from intact tomatoes, and slices from intact tomatoes that had been treated with 1-MCP. Slices from intact tomatoes were prepared immediately before each evaluation.

Another experiment was conducted to evaluate the relationship between the fruit developmental stage and watering development. Fruit selected at the breaker stage were stored at 20 °C for 0, 2, 4, 6, or 8 d to permit partial ripening, sliced, and then stored at 5 °C. Fruit quality was assessed on the basis of pericarp firmness, electrolyte leakage, watersoaked slices, and microbial count (total aerobic count) every other day. CO2 and C2H4 production were also monitored by GC.

Firmness. Firmness was determined on two sites per slice at the junction of the outer and radial pericarp walls using an Instron Universal Testing Instrument (model 4411; Canton, Mass.) fitted with a 5-mm flat-faced cylindrical probe and 5-kg load cell. After establishing zero force contact between the probe and the surface of the slice, the probe was driven with...
Electrolyte leakage. Electrolyte leakage was measured using a modification of the method of Elkashif and Huber (1988). Ten pericarp disks (about 2 g) were excised from slices with a 10-mm-diameter corkborer, rinsed briefly with distilled water, and blotted dry. The disks were placed in 10 mL of 300 mM mannitol and incubated for 4 h at room temperature (about 24 °C) with slow shaking. Conductivity was measured with a YSI conductivity bridge (model 31A; Yellow Springs, Ohio) equipped with a YSI conductivity cell (model 3403) immediately after addition of the bathing solution to the disks and at the end of the incubation period. Total electrolytes were also determined after freezing at –20 °C for 24 h, thawing at room temperature, transferring to a boiling water bath for 10 min, and then cooling to room temperature. Electrolyte leakage was expressed as a percent of total electrolyte content.

Watersoaking. The onset of watersoaking was judged based on the incidence of transparent regions in the tomato slices (Hong and Gross, 2000). A tomato slice exhibiting at least 50% transparent area was considered as having watersoaking. The incidence of watersoaking was expressed as a percentage of slices clearly showing symptoms, i.e., the number of slices with watersoaking divided by the total number of slices multiplied by 100.

Respiration and ethylene production. Respiration and ethylene production were measured every other day using another subsample of four fruit from each treatment. Six slices from each fruit processed on day 0 were sealed for 2 h in a 1.85-L plastic containers. A 0.5-mL headspace sample was withdrawn by syringe, and CO2 determined using a Gow-Mac syringe, and CO2 determined using a Gow-Mac headspace analyzer (Tracor Instruments, Austin, Texas) equipped with a thermal conductivity detector (TCD). The carrier gas (helium) flow rate was 30 mL·min⁻¹. The oven was set at 40 °C, and detector and injector were operated under ambient conditions (26 to 27 °C). Ethylene was measured by injecting a 1.0 mL headspace sample into a Tracor 540 gas chromatograph (Tracor Instruments, Austin, Texas) equipped with a photoionization detector (PID). The carrier gas (helium) flow rate was 30 mL·min⁻¹. Oven, injector, and detector were at 45, 27, and 100 °C, respectively.

Microbial count (total aerobic count). Tissue (5 g) from slices or intact fruit was placed in a 50-mL centrifuge tube containing 45 mL sterile phosphate buffered solution (PBS), pH 7. The centrifuge tube was hand-shaken vigorously for 1 min. One milliliter of the bathing solution was inoculated on a Petri film aerobic count plate (3M, St. Paul, Minn.) and incubated for 3 d at 30 °C. Petri film plates were counted on a standard colony counter.

Statistical analysis. The experiments were conducted using a completely randomized design. Statistical procedures were performed using the PC-SAS software package (SAS-Institute, 1985). Data were subjected to ANOVA using the General Linear Model (Minitab, State College, Pa.). Differences between treatments were determined by Duncan’s multiple range test where appropriate.

**Results and Discussion**

When 1 µL·L⁻¹ 1-MCP was applied to intact, red tomatoes for 24 h at 5 °C before slicing, 1-MCP did not significantly affect maintenance of pericarp firmness during storage at 5 °C for fresh-cut tomato slices or slices from stored, intact fruit, nor did 1-MCP have a significant effect on the electrolyte leakage of fresh-cut tomato slices or slices from stored, intact fruit (data not shown). Slices from intact fruit showed little change in electrolyte leakage over 8 d storage at 5 °C, whereas leakage of fresh-cut tomato slices significantly increased and was 1.3- to 1.4-fold higher at day 8 than the values noted for slices from intact fruit (data not shown). Electrolyte leakage is generally considered to be a measure of cell membrane deterioration. These results indicate that the metabolism of fresh-cut tomato slices compared with intact tomatoes changes rapidly during storage. Varoquaux and Wiley (1994) noted that fresh-cut products are significantly more perishable than the intact commodity. Further increase in the concentration of 1-MCP to 10 µL·L⁻¹ for 24 h did not result in a greater effect on pericarp firmness and electrolyte leakage compared with treatment with 1 µL·L⁻¹ 1-MCP for 24 h (data not shown).

In experiments 1 and 2 (Fig. 1a and b), 1 µL·L⁻¹ 1-MCP was applied to light red tomato slices for 24 h at 5 °C, and in experiment 3 (Fig. 1c), 1 µL·L⁻¹ 1-MCP was applied for 24 h at 5, 10, or 15 °C. Before air or 1-MCP treatments, the light red tomato slices in experiments 1, 2, and 3 exhibited initial firmness values of 8.4, 12.6, and 16.9 N, respectively (Fig. 1). 1-MCP treatment did not significantly affect firmness of fresh-cut, light red tomato slices in experiments 1 and 2, whereas the application
of 1-MCP at 5 °C in experiment 3 retained significantly higher firmness than any other treatment after 10 d storage at 5 °C (Fig. 1). In experiment 3, the pericarp firmness of fresh-cut tomato slices treated with 1-MCP (FCS+M) at 5 °C was significantly higher (p < 0.05) than the values noted for fresh-cut tomato slices (FCS) at 5 °C or for FCS and FCS+M initially held for 24 h at 10 or 15 °C. Pericarp firmness of FCS+M at 5 °C decreased by only about 7.6% of the day 0 value after 10 d storage at 5 °C compared with 29.6% loss of firmness in FCS at 5 °C (Fig. 1c). There was no difference in firmness after storage for 10 d at 5 °C for FCS or FCS+M prepared at 10 or 15 °C. In these experiments, only tomatoes with high initial firmness values (>16.5 N; i.e., experiment 3) responded to 1-MCP application at 5 °C with improved firmness retention during 10 d storage at 5 °C. Initial pericarp firmness of fresh-cut tomatoes varied even at similar color (light red) stage as shown Figure 1. The results of these experiments with light red fruit imply that the efficacy of 1-MCP is dependent upon the firmness of the fruit at the time of application.

1-MCP reduced the incidence of watersoaking in fresh-cut light red tomato slices after 8 d storage at 5 °C (Fig. 1). In experiments 1 and 2, the percentage of watersoaked FCS was 1.2- or 1.4-fold higher, respectively, than the values noted for FCS+M after 8 d storage at 5 °C (Fig. 1a and b). The influence of 1-MCP on watersoaking was most evident in experiment 3 (Fig. 1c). After 8 d storage at 5 °C, there was no development of watersoaking on FCS+M initially held at 5 °C, whereas some watersoaking appeared on FCS (>3.6%). In contrast, the percentage of watersoaked FCS among those initially held at 10 or 15 °C was 2.0- or 5.9-fold higher, respectively, than the values noted for FCS+M at those temperatures. These data show that 1-MCP treatment reduced the development of watersoaking on light red FCS and that slices with higher initial firmness values showed less watersoaking development during 8 d storage at 5 °C (Fig. 1).

Ethylene production of FCS and FCS+M from all treatments increased during the first 2 d after slicing and subsequently declined (Fig. 2). There were no significant differences in ethylene production maxima between FCS and FCS+M at 10 or 15 °C. The application of 1-MCP at 5 °C, however, significantly increased the magnitude of the ethylene production peak in FCS+M compared to FCS at 5 °C. The maximum level of ethylene produced by FCS+M at 5 °C was 4.2 µL·kg⁻¹·h⁻¹, representing a greater than 39% increase compared with the maximum production by FCS at 5 °C. 1-MCP treatment has typically resulted in a suppression of ethylene production from a variety of plant tissues (Blankenship and Dole, 2003), although it has also been reported to increase wound-induced ethylene production of avocado fruit (Owino et al., 2002) and to enhance ethylene production by mature-green banana (Golding et al., 1998). In mature-green tomatoes, the photoactivatable ethylene action inhibitor, diazocyclopentadiene (DACP), inhibited ethylene production initially, followed by the onset of production rates considerably higher than that of control fruit (Sisler and Blankenship, 1993). 1-MCP may block the normal feedback regulation of ethylene production, and this regulation may be exerted in the pathway of ethylene biosynthesis. There were no significant effects of 1-MCP on the respiration pattern of fresh-cut light red tomato slices during storage at 5 °C. However, initial exposure to 10 or 15 °C with or without 1-MCP significantly increased the respiration rate during subsequent storage at 5 °C (data not shown).

The relationship between pericarp firmness and watersoaking of FCS was examined by preparing slices from fruit that were harvested at the same developmental stage (i.e., breaker) and allowed to ripen to different extents before slicing (Table 1). Pericarp firmness of FCS from different initial ripeness stages declined during the first 4 d storage at 5 °C and then remained constant through day 8. The FCS with lower initial firmness values showed rapid watersoaking development and high incidence of watersoaking after 8 d storage at 5 °C. These data indicate that the watersoaking development of FCS is related to initial fruit ripeness stage. Gil et al. (1999) reported that loss of firmness of FCS was probably linked to the ripeness stage of the whole fruit.

Hong and Gross (2000) speculated that watersoaking of FCS is a symptom of chilling injury because the disorder developed in slices held at low temperatures. Our results, however, indicate that watersoaking is unrelated to low-temperature but rather is a consequence of slicing. Watersoaking incidence was progressively greater as the temperature during the initial 24 h after slicing increased from 5 to 10 and 15 °C (Fig. 1c) and was not observed at all in intact tomatoes stored at 5 °C (data not shown). In one of our experiments, all tomato slices stored at 10 °C developed severe watersoaking within 4 d while watersoaking development was delayed by 3 d in 5 °C storage (data not shown). Furthermore, watersoaking incidence increased as initial ripeness stage advanced (Table 1) while it is well established that tomatoes become less susceptible to chilling injury as ripening progresses (Paull, 1990). These observations indicate that fresh-cut tomato watersoaking is not related to chilling injury.

Hong and Gross (2000) also reported that ethylene exposure during storage of FCS reduced the incidence of watersoaking. In contrast, we found that the ethylene action inhibitor 1-MCP significantly reduced the incidence of watersoaking. We have also shown that watersoaking is increasingly prevalent as tomatoes advance in ripeness and senescence. For example, we observed that the occurrence of watersoaking is greater in slices derived from fruit with either lower initial firmness (Fig. 1) or more advanced ripeness stage (Table 1). We also observed that the development of watersoaking was consistently more rapid and severe in slices derived from the physiologically older (Brecht, 1987) blossom portion compared with the stem end of the fruit (data not shown).

There was no visible microbial development at any time during storage, probably due to initial selection of healthy specimens, surface sanitation, short storage time, and low temperature. The total microbial count slightly increased throughout storage although populations at the end of the storage period for all conditions remained low (<5.6 CFU/g) (data not shown).

Many factors may affect the shelf life of...
Table 1. Pericarp firmness (N) and percent watersoaked slices for tomato slices stored at 5 °C. Data are means ± standard deviation of 8 independent samples.

<table>
<thead>
<tr>
<th>Development stage</th>
<th>Firmness</th>
<th>Attributes</th>
<th>Storage days at 5 °C</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaker stage</td>
<td>30.3±1.0</td>
<td>2.8±2.8</td>
<td>27.3±3.5</td>
<td>27.3±2.2</td>
<td>24.5±5.1</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Plus 2 days at 20 °C (turning – pink stage)</td>
<td>23.4±4.3</td>
<td>22.2±4.8</td>
<td>20.0±3.0</td>
<td>19.0±2.7</td>
<td>20.7±3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plus 4 days at 20 °C (pink – light red stage)</td>
<td>19.5±4.5</td>
<td>16.8±5.1</td>
<td>14.8±1.0</td>
<td>14.8±3.3</td>
<td>14.5±3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plus 6 days at 20 °C (light red – red stage)</td>
<td>14.7±4.6</td>
<td>13.2±0.6</td>
<td>11.9±2.0</td>
<td>11.6±2.7</td>
<td>11.3±1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plus 8 days at 20 °C (red stage)</td>
<td>12.3±1.9</td>
<td>10.7±4.3</td>
<td>8.7±1.4</td>
<td>8.9±1.1</td>
<td>8.7±1.8</td>
<td>42.9</td>
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*The number of slices with watersoaking divided by the total number of slices multiplied by 100.

fresh-cut tomatoes including stage of ripeness and firmness at cutting, as well as the storage regime before processing. 1-MCP reduced, but did not eliminate, the negative textural consequences of slicing (accelerated softening; watersoaking), and was most effective when applied to less ripe tomatoes and those with relatively high initial pericarp firmness. Watersoaking development is associated with various factors. The most important appear to be tissue softening and physiological age. It is clear from these data (Table 1, Fig. 1) that high initial pericarp firmness is not only associated with low incidence of watersoaking development in FCS but also improves the efficacy of 1-MCP treatment in maintaining pericarp firmness and reducing watersoaking development during storage.

Literature Cited