DELAYED RIPENING DOES NOT ALLEVIATE SYMPTOMS OF INTERNAL BRUISING IN TOMATO FRUIT

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Abstract. The present work was carried out to evaluate the application of delayed ripening (employing controlled atmosphere (CA) storage) to minimize or alleviate the development of the ripening disorder known as internal bruising. Tomato (Lycopersicon esculentum Mill.) fruits, cv. Solimar, were harvested in Bradenton (Florida) at the mature-green stage and gassed with 100 mL-L⁻¹ of ethylene at 20°C to screen out immature-harvested fruits. Breaker stage tomatoes were either dropped from a 40-cm height to induce internal bruising or not dropped. Half of the two treatments was stored in CA (3% O₂; 4% CO₂; balance N₂) for 8 days at 20°C and 85-95% relative humidity, then transferred to air until completely ripe. The other tomatoes were stored continuously in air at the same temperature and RH. At the ripe stage, dropped tomatoes from CA or continuous air treatments exhibited visible symptoms of internal bruising in locule tissues. Storage atmosphere did not cause significant differences in vitamin C, total carotenoids for bruised locule or pericarp tissues. However, bruised locule tissue from CA storage had titratable acidity 15% higher (about 162 meq citric acid-kg⁻¹) than tissue from air storage (about 140 meq citric acid-kg⁻¹), and was similar to air-stored, unbruised locule tissue (about 174 meq citric acid-kg⁻¹). Pericarp tissue was also analyzed for electrolyte leakage (EL) and polygalacturonase (PG) activity. Pericarp tissue from the impacted region had similar PG activity for CA or air treatments (705 and 710 μmol GA-kg⁻¹ h⁻¹, respectively). EL of bruised, pericarp tissue was similar for CA and air storage (about 50%) and about 40% for unbruised tissues from either storage treatment. Internal bruising can be minimized only by reducing the number and intensity of drops during harvest and handling operations.

Material and Methods

Plant material. Mature-green tomatoes (Lycopersicon esculentum Mill.), cv. 'Solimar', were harvested in Bradenton (Florida) in 1997. After harvest, fruits were placed into polystyrene cell-pack trays (Niles Packaging, Niles, MI) to avoid mechanical damage and transported to the postharvest laboratory in Gainesville the same day.

Ethylene treatment, impact bruising and CA storage. Fruits were sorted for blemishes and graded for size (medium fruits = 63 to 72 mm) and weight (140 ± 10 g) and gassed with 100 μL-L⁻¹ of ethylene in an enclosed chamber using a flow-through system (flow rate = 50 mL·s⁻¹) at 20°C. At breaker stage (<10% red coloration; USDA, 1976), half of the fruits were dropped from a 40-cm height onto a solid, metallic, smooth surface to induce internal bruising. Each fruit was dropped twice, one at each of two equidistant points on the fruit equator avoiding radial pericarp walls. Following the drop, half of the two treatments (dropped and control fruits) was stored in CA (3% O₂; 4% CO₂; balance N₂) for 8 days at 20°C and 85-95% relative humidity (RH), then transferred to air until completely ripe. The remaining tomatoes were stored continuously in air at the same temperature and RH.

Chemical and physical analysis. At table-ripe stage, pericarp and locule tissue were individually excised before being analyzed. The table-ripe stage was defined as the point at which fully red fruit had a deformation of 3-4 mm when a static force of 9.8 N was applied to the equator with a metallic, convex characteristics. Halsey (1955) observed that bruised tomato fruit had no external evidences of physical damage, although it showed internal cellular breakdown in radial pericarp and locule tissue. Several factors such as variety, impact energy and number of impacts are associated with the development of internal bruising. MacLeod et al. (1976) verified that increasing the number of impacts increased CO₂ and ethylene evolution and Sargent et al. (1992) observed that this disorder is cumulative during handling operations. Studies of bruised tomatoes demonstrated increased extractable polygalacturonase (PG) and electrolyte leakage in the pericarp tissue and decreased vitamin C content, total carotenoids and titratable acidity in the locule tissue, whereas placental tissue was not affected, suggesting that evidence of abnormal ripening was confined to pericarp and locule tissue (Moretti et al., 1998). Bruised tomatoes also have lower consumer acceptance, indicating that, besides quality, impact bruising modifies tomato fruit flavor (Moretti et al., 1997).

Reducing the number and intensity of drops during harvest and handling operations could be a way to minimize the incidence of internal bruising in tomato fruit. However, Kader (1986) stated that storage under controlled atmosphere (CA) conditions could have indirect effects on the consequences of physical injuries, alleviating undesirable symptoms.

The present work was carried out to evaluate the application of delayed ripening (employing controlled atmosphere (CA) storage) to minimize or alleviate the development of the ripening disorder known as internal bruising.

Internal bruising is a physiological disorder caused by physical impacts incurred during postharvest handling of tomato fruit. It is associated with impaired ripening causing significant alterations in visual, chemical, physical and sensory

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probe (11 mm in diameter) for 5 seconds. Firmness was measured using the Cornell device (Hamson, 1952) as modified by Gull et al. (1980). Pericarp and locule tissue were analyzed for total soluble sugars, vitamin C, total carotenoids and titratable acidity. Pericarp was also analyzed for polygalacturonase activity and electrolyte leakage.

Total soluble sugars were determined according to Dubois et al. (1956). Vitamin C analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1979). Total carotenoids were analyzed according to methods described by Lime et al. (1957) and Umiel and Gabelman (1971). For the determination of titratable acidity, 40 g fresh tissue were homogenized in a commercial blender at high speed and centrifuged for 20 min at 18,000 g (JA-20). Aliquots of the supernatant were diluted with 50 mL of deionized water and titrated with 0.1 N NaOH to an end point of pH 8.2 using an automatic titrimeter (Model 395, Fisher Scientific Co, Pittsburgh, PA). The amount of NaOH was converted to milliequivalents of citric acid per kg of fresh weight (mL NaOH x 0.1 N x 0.064).

Electrolyte leakage was determined according to Whitlow et al. (1992) and extractable polygalacturonase (PG) activity was measured as described by Huber and O'Donoghue (1993).

Statistical analysis. Analyses were performed using a completely randomized design, with four treatments (from a factorial arrangement: bruised and unbruised fruit and CA and normal atmosphere conditions) and four replications (n = 10 fruits). All comparisons were made at P = 0.05.

Results and Discussion

Total soluble sugars. Pericarp and locule tissues responded differently to the CA treatment (Tables 1 and 2). Pericarp tissue was statistically affected by the ripening treatment (Table 1), whereas locule tissue was not (Table 2). At table-ripe stage, unbruised pericarp stored under CA conditions had 16% more total soluble sugars than the same tissue stored under normal air conditions (Table 1). Our results are in agreement with those observed by Goodenough and Thomas (1981), who verified that tomatoes stored for 2 months at 12.5°C and controlled atmosphere (2.5% O₂/4% CO₂) showed higher levels of total soluble sugars than fruits stored under normal air by the end of the storage period. These authors stated that the increase of total soluble sugars in fruits stored under CA conditions may be related to the increase in monosacharides concentration and to starch metabolism. Apparently, the storage period employed in the present experiment (8 days) was long enough to induce such alterations in total soluble sugars content in the pericarp tissue but not for the locule tissue.

Vitamin C. Both pericarp (Table 1) and locule tissue (Table 2) were not affected by the ripening treatment. Watada (1987) observed that vitamin C degradation is dependent on the type of product, temperature and gas composition. He verified that reducing O₂ concentration in the storage environment retarded ascorbic acid degradation. However, he stressed that different species responded distinctly to different gas combinations.

Titratable acidity. Pericarp was not significantly affected by the ripening treatment (Table 1), whereas locule tissue was affected (Table 2). Bruised locule tissue from CA storage had titratable acidity about 15% higher (161.57 meq citric acid·kg⁻¹) than from air storage (140.71 meq citric acid·kg⁻¹), and was similar to unbruised locule tissue stored in air (173.79 meq citric acid·kg⁻¹). This was the only variable in which the ripening treatment was effective in alleviating the chemical symptoms of internal bruising. By reducing the respiratory activity, CA storage reduced organic acid degradation in the bruised locule tissue, which showed to be more sensitive to impact bruising than pericarp or placental tissues (Moretti et al., 1998). Lau and Looney (1982) verified that storage under CA conditions (2.5% CO₂) reduced organic acids degradation in apples.

Total carotenoids. Pericarp (Table 1) and locule (Table 2) tissues were similarly affected by the ripening treatment. Storage under CA conditions reduced total carotenoid levels for both pericarp (Table 1) and locule tissue (Table 2), bruised or unbruised. Bruised pericarp tissue stored under CA had 10.7% less total carotenoids than bruised pericarp stored under normal air conditions (Table 1). On the other hand, bruised locule tissue stored under CA conditions had 12.3% less total carotenoids than the same bruised tissue stored under normal air conditions (Table 2). Goodenough and Thomas (1980) observed that tomatoes stored under CA conditions (2.5-4% O₂/4% CO₂) at 12.5°C for 2 months showed a decrease in lycopene synthesis, whereas different combinations of O₂ and CO₂ (O₂ and CO₂ ranging from 3 to 4%) also reduced lycopene and β-carotene synthesis (Nakhasi et al., 1991) in tomato fruits.

Polygalacturonase activity. Pericarp tissue from the impacted region had similar PG activity for CA or air treatments (705 and 710 umol GA·kg⁻¹·h⁻¹, respectively). The same tendency was observed for pericarp tissue taken from non-impacted region for either CA or air treatments (433.37 and 477.65 μmol GA·kg⁻¹·h⁻¹, respectively). As observed for other variables, CA storage did not minimize the undesirable effects of impact bruising for PG activity.

Table 1. Chemical and physical characteristics of pericarp tissue with or without internal bruising and stored under normal air or controlled atmosphere (CA) conditions.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Air storage¹</th>
<th>CA storageΔ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Bruised</td>
</tr>
<tr>
<td>Total soluble sugars (g·kg⁻¹ FW)</td>
<td>23.20 b</td>
<td>23.25 b</td>
</tr>
<tr>
<td>Vitamin C (g·kg⁻¹ FW)</td>
<td>202.47 a</td>
<td>176.55 a</td>
</tr>
<tr>
<td>Titratable acidity (meq ca⁻¹·kg⁻¹ FW)</td>
<td>126.42 a</td>
<td>126.67 a</td>
</tr>
<tr>
<td>Total carotenoids (g·kg⁻¹ FW)</td>
<td>62.20 ab</td>
<td>63.05 a</td>
</tr>
<tr>
<td>PG activity (μmol GA·kg⁻¹·h⁻¹)</td>
<td>477.65 b</td>
<td>710.65 a</td>
</tr>
<tr>
<td>Electrolyte leakage (% total)</td>
<td>41.92 b</td>
<td>53.02 a</td>
</tr>
</tbody>
</table>

¹Means with different letters within each quality attribute row are significantly different at P < 0.05 (Tukey test).
ΔControlled atmosphere (5% O₂; 4% CO₂ balance N₂).
ca = citric acid.
GA = galacturonic acid.
Table 2. Chemical and physical characteristics of locule tissue with or without internal bruising and stored under normal air or controlled atmosphere (CA) conditions.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Air storage</th>
<th>CA storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Bruised</td>
</tr>
<tr>
<td>Total soluble sugars (g·kg⁻¹ FW)</td>
<td>10.86 a</td>
<td>10.89 a</td>
</tr>
<tr>
<td>Vitamin C (g·kg⁻¹ FW)</td>
<td>197.25 a</td>
<td>179.30 a</td>
</tr>
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