Development and Prevention of Chilling Injury in Papaya Fruit

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Abstract. Papaya (Carica papaya L.), a climacteric fruit, became progressively less susceptible to chilling injury as it ripened. Symptoms of chilling injury included skin scal, hard areas in the pulp around the vascular bundles, and water soaking of tissue. Mature green fruit were most sensitive to chilling and began showing injury after 10 days of storage at 2°C. Chilling injury symptoms began to occur after 20 days at 7.5°C. Fruit that showed 60% yellowing could be kept at 2°C for 17 days without developing injury. Preconditioning papaya fruit for 4 days at 12.5°C before storage for 12 or 14 days at 20°C reduced chilling sensitivity. The decrease in chilling sensitivity with preconditioning was associated with partial fruit ripening. Waxing and wrapping papaya with polyethylene reduced chilling injury, but the fruit had an off-flavor. Controlled atmospheres of low oxygen (1.5% to 5%) with or without high CO₂ (2% or 10%) delayed ripening, but did not reduce chilling injury symptom development. Calcium treatment led to increased chilling injury of papaya fruit. Delaying storage until the fruit ripened decreased chilling susceptibility and increased storage life at chilling temperatures. Shipping 60% yellow fruit at 2°C could provide a procedure for achieving fruit fly disinfestation. Differences in cultivar response to chilling injury were noted.

Papaya is chill-injured (CI) during cold storage or refrigerated transportation. Damage develops when the temperature is below 10°C to 12°C (10). The symptoms of CI in papaya include delayed ripening with blotchy coloring, skin scal, increased susceptibility to decay fungi, tissue breakdown in pulp, and lack of a climacteric rise (10, 13, 17, 18, 29). These symptoms develop following exposure to chilling temperatures. It is the development of these symptoms that translates into postharvest losses and limits the cold storage life of papaya to about 7 days at 10° (10). Very little work has been directed toward the alleviation of CI in papaya. There is evidence that chilling sensitivity decreases during ripening of climacteric fruit such as avocado (12, 19, 36), papaya (34), and muskmelon (21).

In Hawaii, papaya is infested by 3 species of fruit flies: Mediterranean fruit fly (Ceratitis capitata Wiedemann), Oriental fruit fly (Dacus dorsalis Hendel), and melon fly (Dacus cucu-batae Coquillett). Fruits require quarantine treatment before shipment to mainland United States or Japanese markets. This treatment had been 8 g-m⁻³ of ethylene dibromide (EDB) for 2 hr combined with a hot water treatment at 49°C for 20 min (32). However, EDB has been banned by the United States Environmental Protection Agency as a food fumigant.

Under normal field conditions, papayas that are one-quarter ripe or less are not infested with fruit flies, while ripe papayas have a 3-fold chance to be infested (28). It has been shown that fruit fly eggs and larvae cannot survive long exposure to temperatures below 10°C (11). This study was done to determine whether a cold-storage treatment of papaya could be a possible disinfestation procedure for fruit fly. This study involved determining the relationship between storage temperature and exposure time of papaya at different stages of ripening for CI to develop. Postharvest treatments to reduce CI were also tested.

Materials and Methods

Papayas (‘Kapoho Solo’) were harvested at the mature green stage from commercial fields in Puna, Hawaii. The fruit were shipped by barge to Honolulu and received 48 hr after harvest. Random checks of fruit indicated that the fruit pulp temperature was 16°C. Fruit of ‘Sunrise’ were obtained from the experimental station on Oahu, and used to check cultivar differences. The fruit were treated for 30 min in water at 49°C (1) and dipped in 5% thiabendazole (TBZ) for 5 sec (9) to control fungal decay. Preliminary tests indicated that TBZ did not reduce papaya skin or internal chilling injury symptoms.

Storage procedures. Treated fruit were packed into fiberboard boxes and stored at 0.5°, 2°, 4°, 5°, 6°, 7.5°, 8°, or 10°C from 4 to 24 days for mature green fruit and 18 to 30 days for 60% yellow fruit. After each cold storage period, the fruit were removed to room temperature (22°C). Ten fruit were evaluated upon removal from chilling temperature and at 2-day intervals at 22°C for 8 days. All tests were repeated using fruit received at different times of the year.

Preconditioning. Fruit were preconditioned at 12.5°C for 4 days before storage at 2°C for 12 or 14 days. Control fruit were stored at 2°C for 12 or 14 days. Fruit were inspected 4 days after removal from cold storage to 22°C.

Alternating temperatures. Two 17-day cycles of alternating temperatures were tested, one of 5 days at 2°C alternating with one day at 20°C, the other of 8 days at 2°C alternating with one day at 20°C.

Controlled atmosphere. Fruit were packed into 114-liter controlled atmosphere chambers and sealed. The gas mixtures were supplied continuously at about 2 liter-min⁻¹ through a side port, with the air in the tank being circulated by a small impedance fan. Tank relative humidity was in the range of 90% to 98%. Gas mixtures were checked twice daily with an infrared gas analyzer and paramagnetic oxygen meter.

HDPE wrap. Fruit were sealed individually with high-density polyethylene (HDPE, 7 mil thickness) (FMC, Riverside, Calif.),

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then packed into fiberboard boxes and stored either at 2°C for 14 days or 10°C for 24 days. Fruit were evaluated 4 days after removal from cold storage to 22°C.

Waxing treatment. Sta-Fresh 7051 (FMC) wax solution (1:10, v/v) was used. Fruit were dipped into the solution for 5 sec then allowed to air-dry. Treated fruit were stored either at 2°C for 14 days or at 10°C for 24 days. Evaluation of fruit was made 4 days after removal to 22°C.

Calcium. Papaya fruit were immersed in CaCl₂ solutions ranging from 0% to 10% (w/v) and subjected to a vacuum of 94.8 to 101.6 kPa for 30 min.

Fruit evaluation. The external and internal evaluation criteria used were as follows: a) surface color estimated as the percentage of surface yellowing; b) deformation force—measured by penetrometer (Am-Tek LKG-14) fitted with a 1.5-cm disk, (force required to depress the disk 1 mm into the fruit); c) skin scald—based on the surface area affected by brown scald; and d) internal injury including white hard areas and tissue breakdown.

Results

Symptoms of chilling injury. Chilling injury on the skin included dark olive spots 1 to 2 mm in diameter that, in severe injury, coalesced and formed areas of scald-like areas in mature green fruit. Mild bruises and marks became pronounced during ripening and appeared as green areas sometimes surrounding a pitted area of the skin, giving the fruit a blotchy appearance. Similar mild bruises and marks during ripening of unchilled fruit did not show the same severity. Light brown spots, which frequently coalesce, occurred in more-yellow fruit. These spots can be associated with collapsed tissue.

Internal chilling injury symptoms were hard white areas that do not soften during ripening of the flesh of fruit chilled at the mature green stage, and cavities that developed in the flesh, especially near the vascular tissue in fruit that has started to ripen and then is chilled. These injuries occurred from the seed cavity outwards during ripening. Off-flavors and odors also developed in severely chilled fruit.

Chilling injury symptom development. Mature green papaya were stored at 2°C for 4, 8, 10, or 12 days. During storage at 2°C there was no change in skin color (Fig. 1A); however, the fruit deformation force decreased (Fig. 1B). Increasing the storage time to 12 days at 2°C decreased the rate of skin yellowing after chilled storage (Fig. 1A), although the rate of fruit softening was not significantly affected (Fig. 1B). Symptoms of chilling injury developed only after removal from the 10-day treatment at 2°C (Fig. 1C and D). Skin scald due to chilling injury developed in fruit stored at 2°C for 8 days followed by 6 days at 22°C (Fig. 1C). Fruit stored for 10 days at 2°C developed skin scald within 2 days of removal to 22°C. Internal injury also became significant immediately following 10 days storage at 2°C (Fig. 1D).

Time-temperature relationship. A cutoff point was determined that marked the boundary between chilling injury symptom development (skin scald and internal injury) and mild to no symptom development at different temperatures. This point was 10 days at 2°C (Fig. 1). Fruit stored <10 days required >4 days at 22°C on removal from 2°C for the development of mild skin scald and internal injury, if any symptoms developed. Fruit stored >10 days at 2°C had more severe symptom development. Similar trials using storage temperatures of 0.5°C, 4°C, 5°C, 6°C, 7.5°C, 8°C, and 10°C produced a positive linear relationship between storage temperature and the cutoff time for symptom development on mature green fruit (Fig. 2). The linear regression equation describing the cutoff line was cutoff (days) = 1.75 Temp (°C) + 6.85. The coefficient of determination (r²) was 0.973.

A similar positive linear relationship was found for 60% yellow papaya (Fig. 2). The cutoff for the 60% yellow papaya had
Fig. 2. Time and temperature relationship of incipient surface and internal chilling symptom development in mature green and 60% yellow ‘Kapolo Solo’ papaya. Points obtained from data similar to that presented in Fig. 1.

a slightly lower slope than for mature green fruit and was displaced upward, with about 7 more days being required at 2°C for the development of symptoms. The linear regression equation describing the cutoff line was cut off (days) = 1.46 Temp (°C) + 14.65.

Fruit of ‘Sunrise’ showed a similar time-temperature response for skin scald development due to chilling injury, as described above for ‘Kapoho Solo’. However, a longer time (at least 4 days) was required to develop internal injury due to chilling temperatures in ‘Sunrise’. The coefficient of determination was 0.993.

Preconditioning. Fruit preconditioned at 12.5°C for 4 days were ripened partially with yellower skin and softer flesh than control fruits (Table 1). Preconditioned fruit had less skin scald than nonpreconditioned fruit after 14 days at 2°C. Internal injury was greater in preconditioned fruit than nonpreconditioned fruit stored for 12 days at 2°C. However, there was a nonsignificant change for fruit stored at 14 days at 2°C.

Alternating temperatures. Two periods of fruit storage at 20°C between the chilled storage (5-day cycle) led to a significant increase in skin scald without any increase in internal injury when compared to control fruit (Table 2). The treatment also led to considerable increase in skin color as compared to the control, even though fruit softening was less. The second alternating temperature treatment (8-day cycle) was similar to the control fruit at evaluation.

Controlled atmospheres. Low oxygen (1.5%) with 2% CO₂ treatment reduced skin scald of chilled papaya, but internal injury was not significantly reduced (Table 3). High levels of

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Table 1. Effect of preconditioning on chilling injury of ‘Kapoho Solo’ papaya.

<table>
<thead>
<tr>
<th>Preconditioning</th>
<th>No. of days at 2°C</th>
<th>Color (%) yellow</th>
<th>Deformation force (kg)</th>
<th>Skin scald</th>
<th>Internal injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>12</td>
<td>9.0 c</td>
<td>6.3 a</td>
<td>1.8 b</td>
<td>1.0 b</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>8.8 c</td>
<td>6.6 a</td>
<td>2.6 a</td>
<td>1.6 a</td>
</tr>
<tr>
<td>4 days at 12.5°</td>
<td>12</td>
<td>66.0 a</td>
<td>4.3 b</td>
<td>1.2 b</td>
<td>1.7 a</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>48.0 b</td>
<td>4.4 b</td>
<td>1.4 b</td>
<td>1.3 ab</td>
</tr>
</tbody>
</table>

a Fruit evaluated after 4 days at 22°C. Each value is a mean of 10 replicates.

b Mean separation within columns by Duncan’s multiple range test, 5% level. Data not transformed in tests indicated normal error distribution.

c Fruit evaluated after 5 days of holding at 22°C. Each value is a mean of 10 replicates. See Table 1 for scales of scald and injury.

Table 2. Chilling injury development in alternating temperature storage of ‘Kapoho Solo’ papaya.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Color (%) yellow</th>
<th>Deformation force (kg)</th>
<th>Skin scald</th>
<th>Internal injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (16 days 2°C)</td>
<td>23 b</td>
<td>3.06 b</td>
<td>2.4 a</td>
<td>2.0 a</td>
</tr>
<tr>
<td>Alternate temp. (5-day cycle)x</td>
<td>65 a</td>
<td>4.48 a</td>
<td>1.5 b</td>
<td>1.0 b</td>
</tr>
<tr>
<td>Alternate temp. (8-day cycle)x</td>
<td>29 b</td>
<td>3.85 ab</td>
<td>1.6 b</td>
<td>1.2 b</td>
</tr>
</tbody>
</table>

a Fruit evaluated after 5 days of holding at 22°C. Each value is a mean of 10 replicates. See Table 1 for scales of scald and injury.

b Mean separation within one column by Duncan’s multiple range test, 5% level.

c Alternating temperature with a 5-day cycle. Mature green fruit stored fro 5 days at 2°C, one day at 20°C, 5 days at 2°C, one day at 20°C, then 5 days at 2°C before removal to 22°C.

d Alternating temperature with an 8-day cycle. Mature green fruit stored for 8 days at 2°C, one day at 20°C, then 8 days at 2°C before removal to 22°C.

Table 3. Effect of controlled atmosphere treatment on ‘Kapoho Solo’ papaya chilling injury symptom development.

<table>
<thead>
<tr>
<th>Treatment storage</th>
<th>Color change (%)</th>
<th>Deformation force (kg)</th>
<th>Skin scald</th>
<th>Internal injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (None)</td>
<td>92 a</td>
<td>3.16 c</td>
<td>1.0 b</td>
<td>1.0 b</td>
</tr>
<tr>
<td>Air (17 days at 2°C)</td>
<td>77 b</td>
<td>3.38 c</td>
<td>1.4 a</td>
<td>1.6 a</td>
</tr>
<tr>
<td>1.5% O₂ + 2% CO₂</td>
<td>37 d</td>
<td>5.92 b</td>
<td>1.0 b</td>
<td>1.2 b</td>
</tr>
<tr>
<td>5% O₂ + 2% CO₂</td>
<td>57 c</td>
<td>6.62 b</td>
<td>1.1 ab</td>
<td>1.5 ab</td>
</tr>
<tr>
<td>5% O₂ + 10% CO₂</td>
<td>29 d</td>
<td>8.31 a</td>
<td>1.1 ab</td>
<td>1.5 ab</td>
</tr>
</tbody>
</table>

a Fruit evaluated after 6 days holding at 22°C. Each value is a mean of 10 replicates. See Table 1 for scales of scald and injury.

b Mean separation within columns by Duncan’s multiple range test, 5% level.

c Mature green fruits stored at 2°C for 17 days and each treatment has different storage atmospheres.
oxygen (5%) with 2% or 10% CO₂ did not significantly reduce external and internal CI symptoms. All controlled atmosphere treatments reduced the rate of ripening, as seen by the delay in color change and softening.

Wax and HDPE wrap. Wax papayas stored at 2°C or 10°C tended to be firmer with less skin-scald development than others (Table 4). However, wax treatment led to the development of off-flavor. Wrapped fruit degreened at the same rate as control fruit after 2°C and 10°C storage. Wax and HDPE-wrapped fruit were rated as having less apparent skin shrivel than control fruit.

Calcium treatment. Treatments of mature green papaya with 0%, 1%, and 5% (w/v) concentrations of CaCl_2 significantly (r² = −0.232) reduced the rate of color change without significantly affecting the rate of fruit softening. Chilling induced skin scald (r² = 0.215) and internal injury (r² = 0.329) showed positive linear correlations with Ca concentrations. In both instances, the slope of the linear regression line was low.

Discussion

Published figures for mature green fruit indicate chilling symptoms developed a) after 1 week at 2°C (31), b) <15 days at 7.5°C (34), c) <10 days at 0°C (13), d) <11 days at 1.7°C (17), and e) between 4 to 7 days at 5°C (7). Changes in respiration and ethylene production patterns could be found in papaya fruit stored at temperatures <15°C for >7 days (7, 25). These results essentially are in agreement with the results presented here (Fig. 2). The relationship between time and temperature and CI of leaves has been described as a log function (20), which directly conflicts with papaya fruit response (Fig. 2). This difference might be explained by a different mechanism of CI development in leaf tissue exposed to light vs. commodities stored in the dark.

Temperature conditioning of grapefruit at 10°C or 15°C prior to low-temperature storage prevented or significantly reduced CI symptoms (16). Preconditioning papaya reduced CI symptom development but the fruit had a reduced postharvest life (Table 1). These results suggest that some ripening took place at the preconditioning temperature (12.5°C) and thereby decreased the susceptibility of fruit to the subsequent chilling stress. When climacteric fruit ripen, there is generally a decrease in chilling sensitivity (19, 21, 36).

Table 4. Effect of wax and high-density polyethylene (HDPE) film wrap on ‘Kaphoh Solo’ papaya chilling injury symptom development.

<table>
<thead>
<tr>
<th>Storage</th>
<th>Treatment</th>
<th>Color (% yellow)</th>
<th>Deformation force (kg)</th>
<th>Skin scald</th>
<th>Internal injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 days at 10°C</td>
<td>None</td>
<td>71 a</td>
<td>3.2 ab</td>
<td>1.0 b</td>
<td>1.8 ab</td>
</tr>
<tr>
<td></td>
<td>HDPE</td>
<td>64 a</td>
<td>2.4 b</td>
<td>1.0 b</td>
<td>1.4 b</td>
</tr>
<tr>
<td></td>
<td>Waxed</td>
<td>3 b</td>
<td>3.1 ab</td>
<td>1.2 b</td>
<td>2.0 ab</td>
</tr>
<tr>
<td>14 days at 2°C</td>
<td>None</td>
<td>67 a</td>
<td>2.5 b</td>
<td>2.1 a</td>
<td>2.4 a</td>
</tr>
<tr>
<td></td>
<td>HDPE</td>
<td>64 a</td>
<td>3.3 ab</td>
<td>2.1 a</td>
<td>1.7 ab</td>
</tr>
<tr>
<td></td>
<td>Wax</td>
<td>3 b</td>
<td>3.7 a</td>
<td>1.2 b</td>
<td>1.4 b</td>
</tr>
</tbody>
</table>

*Fruit evaluated after 4 days at 22°C. Each value is a mean of 10 replicates. See Table 1 for tables of scale and injury.

In the present experiment, alternating temperatures increased chilling-related skin scald but did not increase internal injury (Table 2). The 5-day alternating cycle treatment lead to considerable color change but delayed softening.

The use of controlled atmospheres of low oxygen and high CO₂ has been shown to be of little use for extending postharvest life of papaya and for controlling decay (2, 3). Low oxygen and high CO₂ were beneficial for the control of CI in avocado (30). The hypobaric storage (2.67 kPa, 10°C, 92% RH) of papaya inhibited both ripening and disease development but caused abnormal softening (4). Similarly, we found low oxygen treatment of papaya reduced external and internal CI symptoms (Table 3). High and low CO₂ with oxygen significantly decreased the rate of ripening. However, the effect of controlled atmospheres would not be of practical significance, as the fruit had a marked off-odor.

Waxing treatment reduced CI of grapefruit, but greatly increased that of limes (26). Seal-packing of orange, grapefruit, and lemon with HDPE film delayed softening, inhibited weight loss and deformation of fruits, and also inhibited CI (35). Sealed, packed avocado also had reduced CI symptom expression (27). The reduced chilling symptoms found with waxed and wrapped fruit was due mainly to a reduction in water loss (33). Wax and HDPE-wrapped mature green papaya tended to reduce CI symptom development and gave an improved appearance (Table 4). However, off-flavor developed in the fruit.

Calcium has been shown to have a significant role in fruit ripening (6, 14), and has been suggested to have a crucial role in the development of chilling injury (24). Avocado fruit vacuum-infiltrated with CaCl_2 had less CI (8). The lowest concentration of CaCl_2 (1% w/v) reduced CI in papaya fruit, with higher concentrations of CaCl_2 causing increased CI. Although this result was found in other experiments, the quadratic component of the regression was nonsignificant. The reason for the difference in response between avocado and papaya to Ca is unknown.

The major problem in the export of Hawaiian fruit is the presence of 3 major species of fruit flies (15). All fruit flies are sensitive to low temperatures (22, 23). Complete mortality of all immature stages of the Mediterranean fruit fly (Ceratitis capitata Wiedemann) requires 11 days at −0.5°C (22) and 16 days at 2.5°C (5). Chilling injury symptoms have developed in mature green papaya fruit after 7 days at 0°C and 10 days at 2°C (Fig. 2); hence, low temperature cannot be used as a disinfestation treatment for mature green papaya. Modification of mature green papaya response to chilling temperatures by preconditioning, alternating temperatures, controlled atmospheres, waxing, and film wrap was insufficient to make chilling treatment a viable disinfestation procedure. Partially ripened papaya fruit (60% yellow) can withstand the storage period at chilling temperatures to achieve fruit fly disinfestation.

Literature Cited

5. Baker, A.C. 1939. The basis for treatment of products where fruit flies are involved as a condition for entry into the United States. USDA Circ. 551.


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**CORRIGENDUM**

In the article “Effect of Light Intensity and Carbohydrate Reserves on Flowering in Olive” by G.W. Stutte and G.C. Martin (J. Amer. Soc. Hort. Sci. 111:27–31, Jan. 1986), the following correction should be noted. On p. 28, under Materials and Methods, the sentence “The 80% methanol insoluble materials were suspended in saturated CaSO4 at pH 12.0 and boiled . . . .” should read “The 80% methanol insoluble materials were suspended in saturated CaOH at pH 12.0 and boiled . . . .”.

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