Inducible Chilling Injury of Grapefruit on Trees

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Summary. Potted Marsh grapefruit [*Citrus paradisi* (Mad.)] trees with mature fruit were subjected to successive 7-day exposures to 20, 15, 10, and 5C, followed by 7 days at 25C in controlled-environment walk-in rooms. Circular depressions (pits), characteristic visible symptoms of chilling injury, developed in the peel of the fruit. To the best of our knowledge, this is the first report of inducible chilling injury of grapefruit on trees under artificial environments. The ability to induce chilling injury in the peel of grapefruit on trees enhances opportunities to study the mechanism of resistance to chilling injury that can be developed by various preharvest strategies.

Chilling injury of grapefruit is a major postharvest physiological disorder that develops when freshly harvested grapefruit are stored at temperatures below 10 to 12C. The fruit is injured more rapidly at 5C than at lower or higher temperatures (Purvis, 1985; van der Plank and Davies, 1937). Circular depressions (cell collapse) on the peel surface are characteristic visible symptoms of chilling injury in grapefruit, usually developing after 2 to 3 weeks of continuous storage at 5C (Purvis, 1980; Purvis and Grierson, 1982; Purvis et al., 1979). Injury is more severe at low relative humidity than at high relative

humidity (Pantastico et al., 1968). Depressions (pits) in the peel tend to develop more rapidly if the fruit are transferred to nonchilling temperatures after chilling injury has been initiated.

Chilling injury is minimized when low-temperature storage is interrupted with one or more periods of warm temperatures (Davis, 1973; Davis and Hofmann, 1973). Thus, chilling injury of grapefruit on the tree under natural conditions is less likely to occur, apparently because of natural diurnal fluctuations between chilling and nonchilling temperatures. Leaves of various citrus selections also do not readily develop visible symptoms of chilling injury in the field, but injury can be induced within 8 days during constant 1.7C and continuous-light regimes in controlled-temperature facilities (Yelenosky, 1982). Thus, it was hypothesized that grapefruit on trees would exhibit chilling injury if trees were exposed to constant low temperatures.

Potted 5-year-old Marsh grapefruit trees budded on trifoliate orange were grown outdoors in a soil mix of 1 sand : 1 sphagnum peat : 1 vermiculite (by volume). The trees were about 1.1 m tall with 9-cm trunk diameters 5 cm above the bud union and had 8- to 11-cm-diameter fruit. The trees were conditioned at constant 25C for 1 week in a controlled environment walk-in room using cool-white fluorescent and incandescent lighting to supply 400

$\mu\text{mol m}^{-2} \text{ s}^{-1}$ (PAR.) during 12-hr photoperiods. Automatic steam injection maintained relative humidity at $60\% \pm 5\%$. The trees were watered daily to maintain the soil near field capacity. After 1 week at 25C, half of the trees were subjected to successive 7-day exposures to 20, 15, 10, and 5C. Temperatures were maintained within $\pm 0.5\text{C}$. After 1 week at 5C, the temperature was increased to 25C for an additional week and the fruit were examined for chilling injury symptoms. The 12-h photoperiod was maintained during the chilling and postchilling treatments. The other half of the trees were maintained at 25C throughout the experimental period and served as controls.

Most of the grapefruit on trees exposed to the decreasing temperature regime followed by constant 25C for 1 week developed surface pits (Fig. 1). None of the fruit on the control trees developed pits. The pitting was similar to that on fruit stored at low temperature after harvest (Purvis, 1980). This supported observations in a previous study (Nordby et al., 1987) where grapefruit harvested from potted trees that had been maintained acclimated for 1 week at a constant temperature of 5C developed considerable pitting during the first week of postharvest storage at 5C. Thus, preharvest chilling appears to shorten the time required for postharvest chilling injury, as has been reported for

Fig. 1. Induced chilling injury in grapefruit peel, showing pits (cell collapse) on fruit still attached to the tree. Trees were subjected to successive 7-day exposures to 20, 15, 10, and 5C, followed by 7 days at 25C in a controlled-environment room.

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Fig. 2. Chill-injured fruit that abscised during the 1 week post-chilling exposure to 25C. Chilling exposure (7 days at 10C followed by 7 days at 5C) was as described in Fig. 1.

tomato (Morris, 1954). In contrast, fruit harvested from orchard trees generally do not pit in <2 weeks of storage at 5C (Purvis, 1980; Purvis and Grierson, 1982; Purvis et al., 1979). Hence, chilling injury seems easier to induce on fruit of potted trees in controlled environments than on fruit harvested from orchard trees. Reasons for the apparent difference in chilling injury susceptibility between postharvest fruit and fruit on the tree are not known. The lower relative humidity of the controlled environment room compared to postharvest storage rooms (60% and 95%, respectively), however, may contribute to symptom development (Purvis, 1985).

Some chill-injured fruit abscised during the 1 week of postchilling exposure to 25C (Fig. 2). Although citrus fruits are considered to be non-climacteric and normally do not produce ethylene, injured citrus fruits produce ethylene and abscise (Young, 1972).

It has been postulated that fruit from trees that have undergone low-temperature hardening are resistant to chilling injury (Purvis and Yelenosky, 1982; Purvis and Grierson, 1982). However, the constant temperatures in the present and previous (Nordby et al., 1987) studies undoubtedly limited the response of the plant to low-temperature hardening. Diurnal fluctuations between chilling and nonchilling temperatures may be necessary for citrus trees and fruit to harden against low temperatures. Steponkus (1971)

suggested that the low-temperature acclimation of *Hedera helix* consisted of two phases, the first phase involving the accumulation of carbohydrate in the tissue, and a second phase, where proteins with a greater affinity to bind sugar molecules are synthesized. Carbohydrates accumulate in the flavedo tissue of grapefruit on trees exposed to low temperatures (Purvis et al., 1979; Purvis and Grierson, 1982; Purvis and Yelenosky, 1982; Nordby et al., 1987) and grapefruit that have been exposed to diurnal fluctuations between chilling and nonchilling temperatures appear to be more resistant to chilling injury (Purvis et al., 1979; Purvis and Grierson, 1982).

Our observations confirm that grapefruit on trees will exhibit chilling injury when trees are exposed to prolonged constant low temperatures. It is unlikely, however, that fruit in the orchard will be chill-injured because of diurnal fluctuations between chilling and nonchilling temperatures, which are similar to postharvest intermittent warming treatments. To the best of our knowledge, this is the first report of inducible chilling injury of grapefruit on trees under artificial environments. The ability to induce relatively quick symptoms of chilling injury in the peel of grapefruit on trees via controlled temperatures enhances opportunities to develop greater understanding and preharvest strategies for reducing postharvest chilling injury during commercial and domestic storage.

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