They may, in fact, inhibit or delay emergence by reducing aeration around the imbibing or germinating seed.

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Tomato Fruit Temperature Before Chilling Influences Ripening After Chilling

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Abstract. **Tomato fruit (*Lycopersicon esculentum* Mill., cv. Castlemart) either harvested hot (e.g., 32°C) and chilled for 7 days at 7°, or harvested cool (e.g., 19°) and held in the laboratory at 37° for 7 hr before chilling at 2.5° for 4 days ripened slower (a symptom of chilling injury) than fruit that were either harvested cool (19°) or held at 12.5° for 7 hr before chilling.**

The storage life of many commodities is prolonged at low temperatures. Tomatoes, however, are chilling-sensitive and are injured at temperatures below 12.5°C (13). Tomato fruit are particularly susceptible to chilling injury at the mature-green stage, when they are normally harvested and shipped. Chilling injury of tomatoes usually is not visually apparent at the chilling temperature, but is expressed upon exposure to ripening temperatures of around 20°. Chilled tomatoes exhibit slow and abnormal ripening, increased disease susceptibility, and increased rates of respiration and ethylene production (13).

Treatments that reduce symptoms of chilling injury include conditioning near the chilling temperature, intermittent warming during chilling, low-pressure storage, increased atmospheric CO_2 levels, and pretreatments with Ca or ethylene (13). Chilling injury was reduced in fruit of bell pepper (12) and grapefruit (3, 6), and seedlings of tomato (8, 19) and ornamentals (15) by conditioning at a cool, but nonchilling temperature. Intermittent warming also can reduce chilling injury in citrus (4), cucumbers and sweet peppers (18), peaches and nectarines (2, 17), and potatoes (7). Susceptibility of tomato fruit to chilling varies with the cultivar, growing season, and time of harvest during the year (1, 9).

This paper reports experiments that show that chilling sensitivity of harvested tomato fruit changes during the day, that this change is related to fruit temperature at the time of harvest, and that similar changes in chilling sensitivity can be induced in the laboratory by holding harvested fruit at different temperatures before chilling.

Mature-green tomato fruit ('Castlemart') were hand-harvested at various times during the day from plants grown at the Vegetable Crops field station in Davis, Calif. Only uniform, healthy fruit with no external defects were retained. Fruit were washed in dilute commercial bleach (1:20 dilution of 5% sodium hypochlorite) and randomly divided into groups of 20 fruit each. Fruit were placed in paper cup trays so that each group could be handled as a unit.

Temperature treatments involved transferring trays of fruit to walk-in controlled-temperature rooms. After temperature treatments, trays were covered loosely with plastic wraps to reduce water loss, and the fruit ripened at 20°C. Tomatoes were scored periodically for

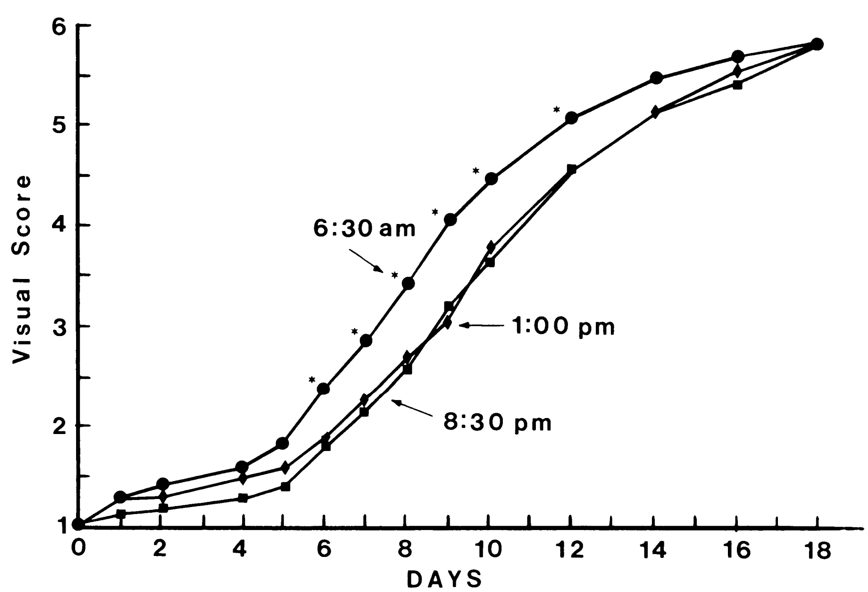

Fig. 1. Effect of chilling at 7°C for 7 days on the subsequent ripening at 20° of mature-green tomato fruit harvested during a sunny day at sunrise (6:30 AM) when cool (19°), at 1:00 PM when hot (32°), or at sunset (8:30 PM) when warm (29°). Ripeness scores of the sunrise harvest with asterisk are signficantly different at the 5% level from observations on the same day for the other harvest times. A subjective scale of ripeness was used where 1 equaled mature-green and 6 equaled red-ripe. The x-axis represents the days after transfer to 20°.

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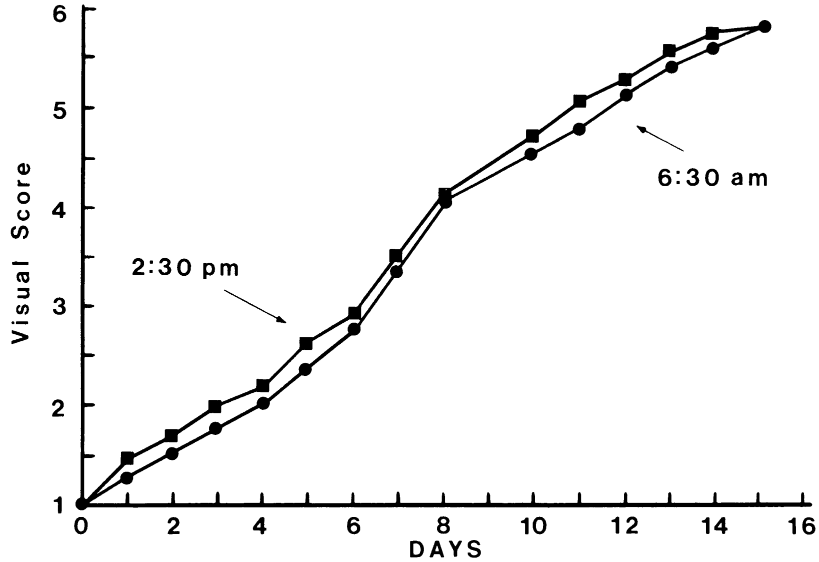

Fig. 2. Effect of chilling at 7°C for 7 days on the subsequent ripening at 20° of mature-green tomato fruit harvested during a cloudy day at sunrise (6:30 AM) when 21° or at 2:30 PM when 23°. A subjective scale of ripeness was used where 1 equaled mature-green and 6 equaled red-ripe. The x-axis represents the days after transfer to 20°.

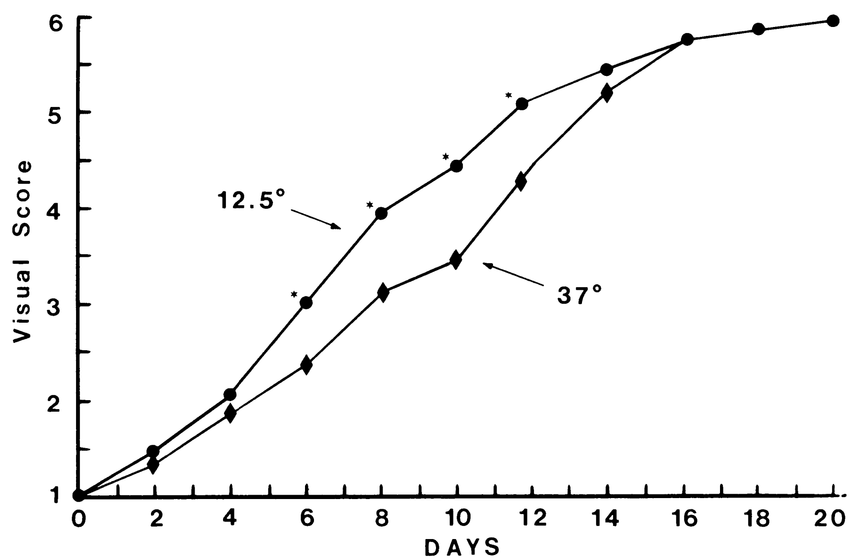

Fig. 3. Effect of holding mature-green tomato fruit at 12.5° or 37°C for 7 hr before chilling at 2.5° for 4 or 8 days on subsequent ripening at 20°. Ripening scores are means of values for 4- and 8-day storage. A subjective scale of ripeness was used where 1 equaled mature-green and 6 equaled red-ripe. Ripeness scores of 12.5° fruit with an asterisk are significantly different at the 5% level from observations on the same day for 37° fruit. The x-axis represents the days after transfer to 20°.

ripeness on a subjective scale, where 1 equaled mature-green and 6 equaled red-ripe (16). Decreased rates of ripening are a symptom of chilling injury (13) and were used as a measure of chilling injury.

Results from preliminary experiments allowed the selection of conditions that induced a moderate level of chilling injury to accentuate differences among treatments. In 1984, chilling treatments consisted of exposing freshly harvested fruit to 7°C for 7 or 12 days. In 1985, a similar series of experiments was done in which the fruit were held at 2.5° for 4 or 8 days. Additional laboratory studies were done in 1985 in which fruit were first exposed to either 12.5° or 37° before storage at 12.5° or 2.5° for 4 or 8 days. All experiments in 1984 and 1985 were repeated with similar results. Data were subjected to analysis of variance. Treatment means were grouped using LSD values if analysis showed significant differences at the 5% level.

Fruit harvested at sunrise (6:30 AM), with a pulp temperature of 19°C, were more resistant to chilling than were fruit harvested at 1:00 PM or at sunset (8:30 PM) with a pulp temperature of 32° or 29°, respectively (Fig. 1). Differences between the sunrise and other harvests were statistically significant at the 5% level from day 6 to day 12. Around day 10, ripening of fruit harvested at sunrise was over 2 days more advanced than the other fruit. Chilling fruit for 12 days at 7° eliminated any differences among the harvest (data not shown).

To check whether the observed differences resulted from harvesting the fruit at different times of day, or at different temperatures, fruit were harvested at sunrise (6:30 AM) and 2:30 PM during cool, cloudy days. Fruit temperatures in the morning and afternoon were roughly the same (e.g., 21° and 23°C, respectively). There were no statistically significant differences in ripening rate of these fruit after chilling at 7° for 7 days (Fig. 2).

Two years of data showed that diurnal fluctuations in temperature affected fruit ripening after chilling. Laboratory experiments then were performed to see if this measure of chilling sensitivity could be affected by holding fruit at different temperatures prior to chilling. Fruit were harvested in the late morning and held for 7 hr at either 12.5° or 37°C before being chilled at 2.5° for 4 or 8 days (Table 1). It took the fruit 2 hr to attain the holding temperature. Since values for the 4- and 8-day holding times were similar (Table 1), their means are used in Fig. 3.

Fruit held at 37°C for 7 hr before chilling at 2.5° ripened slower than fruit held at 12.5° before chilling (Fig. 3). Differences were statistically significant at the 5% level between day 6 and day 12 at 20°. The 12.5° fruit were about 2 days more advanced in ripeness than the 37° fruit. These results were similar to those observed with fruit harvested at different temperatures (Fig. 1).

Comparison of treatments at 10 days after transfer to the ripening temperature showed that chilling at 2.5°C slowed ripening at all holding temperatures and chilling intervals (Table 1). Fruit conditioned at 37° were less ripe (average of 4.3 ± 0.7) at all storage temperatures and intervals than were fruit conditioned at 12.5° (average of 4.8 ± 0.3). Examination of the effect of chilling within each holding temperature showed that chilling reduced ripening from 5.1 to 4.5 (a 12% reduction) in fruit held at 12.5°, while it reduced ripening from 4.9 to 3.6 (a 29% reduction) in fruit held at 37°. Chilling reduced ripening irrespective of the holding temperature, but fruit conditioned at 37° were more sensitive than fruit conditioned at 12.5°.

Fruit kept at 12.5°C had ripened to 5.1 if conditioned at 12.5°, or 4.9 if conditioned at 37° (a 3.2% reduction). This difference implies that the conditioning temperature had little effect on the ripening rate of unchilled fruit. While prolonged exposure to temperatures around 37° is known to inhibit lycopene synthesis during tomato fruit ripening, our results agree with those of Hall (5) that short periods of exposure to high temperatures did not affect color development significantly (Table 1). Hall (5) reported that holding tomato fruit for 6 hr at 32° to 43° did not significantly affect either softening or color development following 7 days of ripening at 20°.

In contrast to the small effect of the conditioning temperature on ripening of unchilled fruit, the conditioning temperature had a pronounced effect on ripening of chilled fruit. Fruit chilled at 2.5°C had ripened to 4.5 if conditioned at 12.5°, but only to 3.6 if conditioned at 37° (a 21% reduction).

Table 1. Effect of holding mature-green tomato fruit for 7 hr at a conditioning temperature before storage for 4 or 8 days on the stage of ripeness after 10 days at 20°C. A subjective scale of ripeness was used where 1 equaled mature-green and 6 equaled red-ripe.

Temperature (°C)		Days in storage	Mean ripeness score
Conditioning	Storage		
12.5	12.5	4	5.03[x] a
12.5	12.5	8	5.08 a
12.5	2.5	4	4.53 b
12.5	2.5	8	4.45 b
37	12.5	4	4.90 a
37	12.5	8	4.88 a
37	2.5	4	3.63 c
37	2.5	8	3.65 c

[x]Means were separated by LSD at the 5% level. Means followed by the same letter are not statistically different at the 5% level.

Our field data showed that differences in fruit temperature at harvest, not differences in the time of harvest, were the cause of differences in chilling sensitivity. Fruit harvested on cool, cloudy days, during which all fruit were roughly the same temperature, did not show significant differences in the rate of ripening. A similar difference in chilling sensitivity could be induced by holding fruit at different temperatures in the laboratory prior to chilling.

There is evidence that changes in the physical properties of cellular membranes at chilling temperatures can be a source of injury (10, 11). Many organisms maintain optimal membrane viscosity and function as environmental temperature varies by altering the proportion of unsaturated fatty acids in their phospholipids, a response termed "homeoviscous" adaptation (14). Homeoviscous adaptation may play a role in regulating membrane-bound enzyme activity, particularly in maintaining appropriate reaction rates when cells are at different temperatures. Although our results are consistent with the hypothesis that chilling sensitivity would vary during the day as plants changed the composition of their membranes to maintain a constant viscosity at different temperatures, other metabolic changes may have occurred during conditioning that altered the response of the fruit to our measure of chilling injury.

Holding harvested fruit at different temperatures to induce chilling resistance could provide tissue for experiments to examine the basis of chilling injury. For example, separate parts of a tomato fruit could be induced to different levels of chilling sensitivity. Tissue, nearly identical except for induced differences in chilling sensitivity, could be compared to detect differences too small to be observed in more heterogenous tissue. Practically, mature-green tomato fruit could be conditioned at 12.5°C prior to a short-term exposure to chilling temperature to prevent a reduced rate of ripening after returning to nonchilling temperatures.

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