

posed to intermittent or continuous propylene (an ethylene analog) (1). Changes in respiratory substrate(s) and/or acid compartmentalization therefore appear likely.

Overall, we have shown that storage of carambolas at 5C maintains fruit quality to a greater extent than previously recommended conditions (5). No CI occurred at 5C, and normal color development and ripening resumed in fruit transferred to 23C. The concentrations of soluble sugars and organic acids also remained at levels similar to those of freshly harvested fruit.

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Temperature-conditioning Affects Polyamines of Lemon Fruits Stored at Chilling Temperatures

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Abstract. Chilling injury (CI) of lemons (*Citrus limon* Burm. f.) was reduced by temperature-conditioning at 10, 15, 21, or 27C immediately before storage at 1C. CI was less severe in lemons temperature-conditioned for 7 vs. 3 days. However, the process is not recommended for avoiding CI in lemons stored at low temperatures because of the wide range in treatment effects. Following conditioning at 21 and 27C, putrescine concentrations increased in flavedo tissue and were also higher in fruit after storage at 1C than at 10C, regardless of conditioning temperature. After holding fruit for 2 weeks at 21C, putrescine levels were higher in lemons that had been stored at 10C than in those stored at 1C. Prestorage temperature-conditioning did not affect spermidine levels, which tended to be higher in fruit stored at 10C than at 1C after storage and subsequent holding at 21C.

Chilling injury (CI) is a time- and temperature-dependent problem that seriously affects the marketability of many fruits and vegetables. Holding chilling-sensitive commodities below 10 to 12C for 1 to 2 weeks often results in damage. The most common symptoms of CI include pitting of surface tissue and increased susceptibility to decay fungi and bacteria. A high-temperature pre-storage conditioning or curing treatment has been successful in preventing or reducing CI in cucumber (Hirose, 1985; Nakamura et al., 1985), eggplant (Abe and Chachin, 1985; Nakamura et al., 1986), grapefruit (Chalutz et al., 1985; Hatton and Cubbedge, 1983), lime (Spalding and Reeder, 1983), papaya (Chen and Paull, 1986), pepper (McColloch, 1962; Thompson, 1978), sweet potato (Picha, 1987), and watermelon (Picha, 1986). In earlier work (McDonald, 1986), I found that holding lemons for 3 days at 21C before storage at chilling temperature reduced CI. However, none of these references related biochemical changes and the reduction of CI

by temperature conditioning.

Changes in polyamine biosynthesis in plant tissues have been correlated with various kinds of stress. Most recently, putrescine (Guye et al., 1986; McDonald and Kushad, 1986) and spermidine (Wang, 1987) have been linked to chilling stress. However, it is not known what role polyamines play in CI. The present study was initiated to: 1) determine the effectiveness of temperature-conditioning treatments on reducing external CI development in low-temperature-stored lemon fruit; and 2) determine polyamine levels in lemon fruits and if changes in polyamine metabolism are involved in the events leading to the development of CI.

'Bearss' lemons were obtained from a commercial packinghouse on 30 July and 13 and 27 Aug. 1986. On each occasion, fruit were hand-harvested the previous day into bulk field bins, transported to the packinghouse, and left overnight. Fruit for experimental purposes were then selected that were free from blemishes and green. They were hand-sized to 115 to 200 count (150 to 86 g) per shipping carton and transported to the U.S. Horticultural Research Laboratory in Orlando, Fla. All fruit were dipped for 30 sec in 600 µg benomyl/liter. Lemons were cured (degreened), without added ethylene, at 15 ± 0.5C and 80% to 92% RH. When the lemons were yellow, they were washed, again drenched with 600 µg benomyl/liter, and waxed with Fresh Wax 3202 (Fresh Mark Chemical, Orlando, Fla.), a water-emulsion-type wax. Fruit were then temperature-conditioned for 3 or 7 days at either 10, 15, 21,

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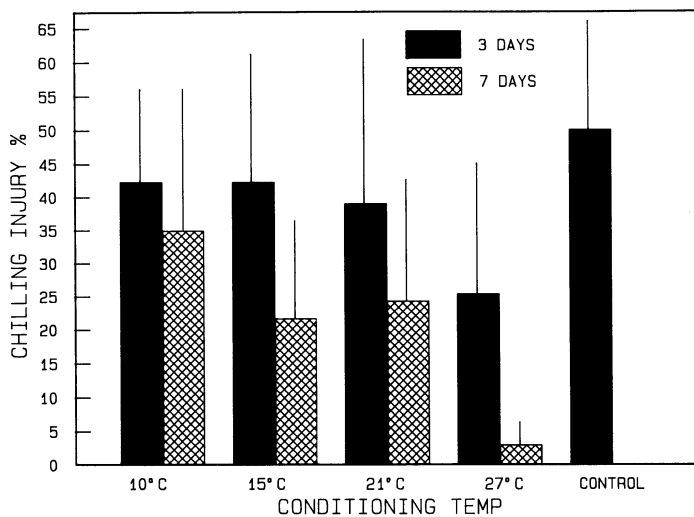


Fig. 1. Incidence of chilling injury in lemons not conditioned (control) and conditioned at 10, 15, 21, or 27C and stored for 3 weeks at 1 or 10C plus 2 weeks at 21C. Vertical bars represent SE.

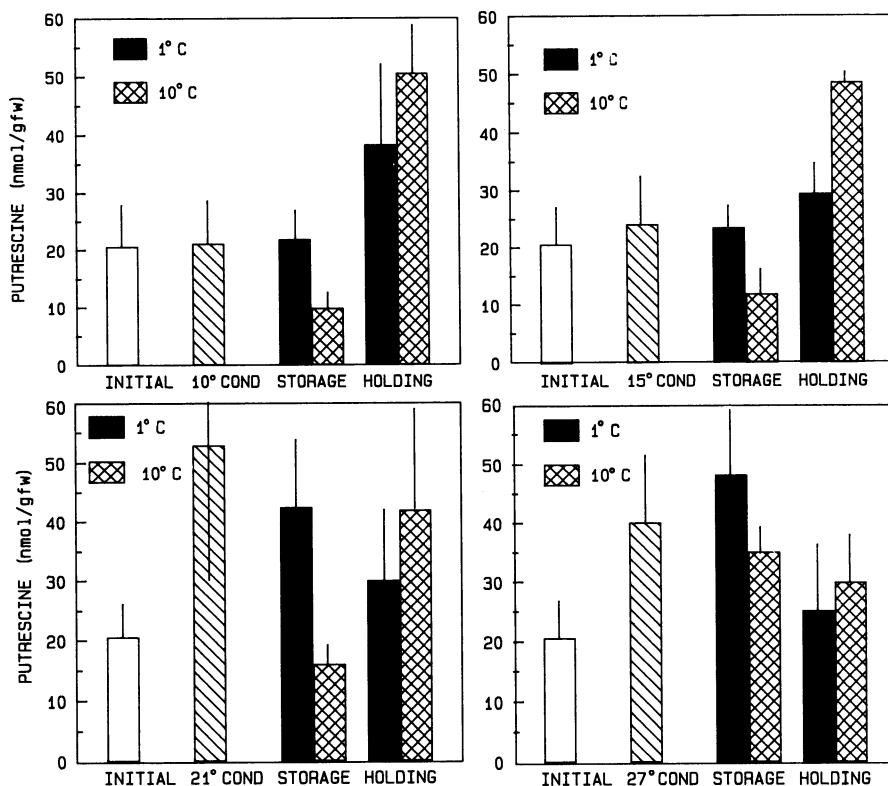


Fig. 2. Putrescine concentrations in lemon fruit flavedo initially; after 7 days of conditioning at 10, 15, 21, or 27C; after 3 weeks of storage at 1 or 10C; and following holding at 21C for 2 weeks. Vertical bars represent SE.

or $27 \pm 0.5C$ before storage. In each of three different experiments (harvests), 120 fruit per treatment were held for 21 days at either 1 or $10 \pm 0.5C$ under 80% to 92% RH. Fruit were inspected for CI on removal from storage and after holding for 14 days at $21 \pm 0.5C$ and 88% to 92% RH.

Polyamine determinations were made on five single-fruit random samples after the curing, conditioning, storing, and holding periods. Fresh lemon flavedo (5g) was extracted and analyzed as described by McDonald and Kushad (1986), except that the analysis was carried out on an LDC/Milton

Roy HPLC (LDC/Milton Roy, Riviera Beach, Fla.). The means of subsamples were subjected to analysis of variance.

Pitting of the rind was the primary symptom of chilling, followed by a very small amount of brown staining. No distinction was made between the degree of severity of CI or the relative amounts of pitting vs. brown staining. The data are expressed as the percentage of fruit with CI based on 100 stored fruit for each of the three harvests.

All conditioning treatments were partially effective in reducing CI of lemons stored at 1C, but no treatment eliminated it (Fig. 1).

CI was more severe following conditioning for 3 days than for 7 days. Because lemons conditioned for 7 days at 27C had minimal CI, it could be concluded that this conditioning regime should be considered as a way of alleviating CI when lemons are stored at chilling temperatures. However, due to large variations in lemons harvested in different years (data not shown) and within treatments, temperature conditioning of lemons cannot be recommended at this time to mitigate CI.

Putrescine and spermidine levels in flavedo tissues were affected significantly by harvest date and storage temperatures (Table 1). Additionally, putrescine levels were significantly affected by conditioning temperatures. However, after holding the fruit for 14 days at 21C following 1 or 10C storage, only putrescine levels were significantly affected by storage temperatures.

Conditioning at 21 or 27C caused putrescine levels to increase, whereas conditioning at 10 and 15C had little or no effect (Fig. 2). Putrescine levels were higher in lemons after storage at the chilling temperature of 1C than in those stored at the optimal 10C regardless of the prior conditioning temperature. However, putrescine levels were higher in fruit conditioned at 21 or 27C than at 10 or 15C. After fruit were held at 21C for 2 weeks following storage, putrescine levels were greater in fruit that had been stored at 10C than in those stored at 1C.

Spermidine levels were not affected by 7 days of conditioning at test temperatures of 10, 15, or 21C (Fig. 3). However, conditioning at 27C lowered spermidine levels. Spermidine was lower in fruit after storage at 1C than at 10C and after holding at 21C for 2 weeks.

Conditioning and chilling apparently influenced putrescine more than spermidine. The increase in putrescine, in response to exposure to chilling temperatures found in this study, is consistent with the results reported for bean plants (Guye et al., 1986) and grapefruit, lemon, and pepper fruits (McDonald and Kushad, 1986). By contrast, exposure to chilling temperatures did not affect the putrescine level in cucumber seedlings, but did cause a significant increase in spermidine (Wang, 1987). Kushad and Yelenosky (1987) also reported that spermidine accumulated more significantly than either putrescine or spermine following a period of cold-hardening treatment in three citrus cultivars. These two latter reports indicate that spermidine accumulation may contribute toward maintaining cell membrane integrity.

Although the physiology of stress-induced accumulation of putrescine in whole plants and in vitro systems is now well-documented, there is no general consensus as to the role or significance of the elevated level of putrescine during stress. It has been observed that temperature alone (30 to 35C) did not affect the putrescine titer in oat leaf segments (Flores and Galston, 1984). At present, there is no direct evidence linking the metabolism of putrescine or of other polyamines to the physiology of CI.

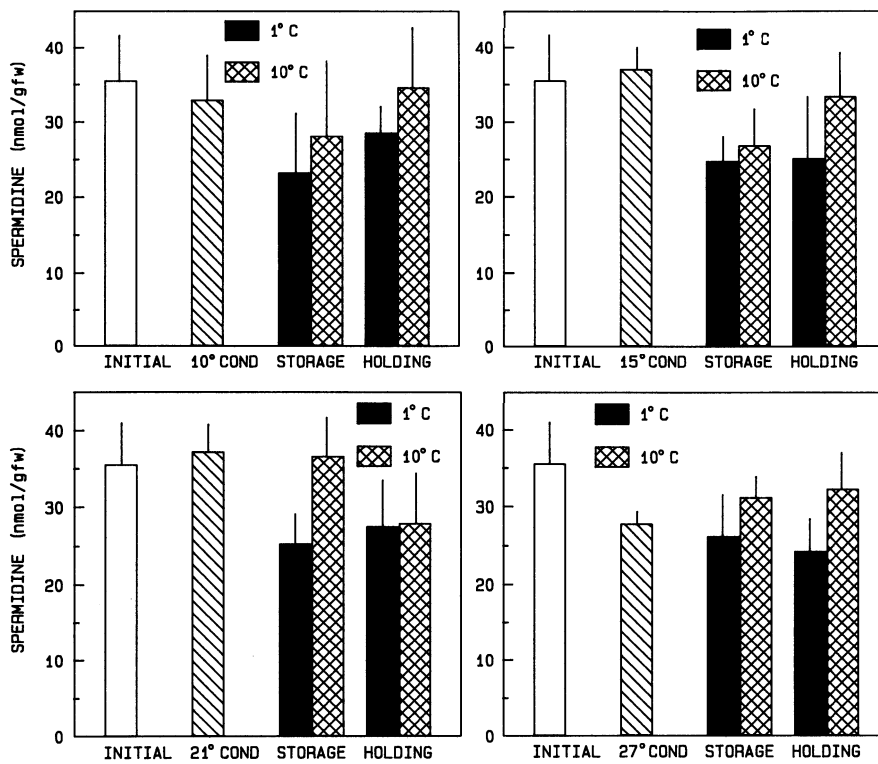


Fig. 3. Spermidine concentrations in lemon fruit flavedo initially; after 7 days of conditioning at 10, 15, 21, or 27°C; after 3 weeks of storage at 1 or 10°C; and following holding at 21°C for 2 weeks. Vertical bars represent SE.

Table 1. Analysis of variance for putrescine (Put) and spermidine (Spd) levels in lemons conditioned at various temperatures and then stored at 1 or 10°C for 3 weeks plus 2 weeks at 21°C.

Source	After 3 weeks of storage		After holding 2 weeks at 21°C	
	Put	Spd	Put	Spd
Harvest	*	**	NS	NS
Temp. conditioning (TC)	***	NS	NS	NS
Temp. storage (TS)	***	**	*	NS
TC × TS	NS	NS	NS	NS

NS,*,**,***Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively.

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