REDUCING SUSCEPTIBILITY OF HORTICULTURAL COMMODITIES TO CHILLING INJURY DURING COLD TREATMENT

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Abstract

As a result of a proposed ban on ethylene dibromide (EDB) fumigation and with methyl bromide (MB) fumigation being reviewed for possible elimination, it is imperative that alternative, preferably nonchemical, quarantine treatments be developed. For many years fumigation with EDB or MB was satisfactory and accepted throughout the world for numerous kinds of insects infesting many commodities; consequently, little research was undertaken to develop alternatives. The cold treatment also has been in use for many years as a quarantine measure, but has generally been restricted to fruits that can withstand temperatures near freezing for various periods of time. Insects indigenous to the tropics and subtropics tend to be more readily eradicated by the cold treatment than insects found in temperate climates. Similarly, commodities such as tropical fruits are usually more susceptible to chilling injury (CI) than temperate fruits. Conditioning commodities prior to the cold treatment shows potential in avoiding CI. Grapefruit, for example, are susceptible to CI at temperatures below 10°C; however, by temperature conditioning, the fruit becomes less susceptible to CI up to 3 weeks at temperatures just above freezing. Research is urgently needed to develop practical and effective quarantine treatments, and the cold treatment with associated conditioning is one approach.

The international trade of some horticultural commodities faces a quarantine dilemma due to the proposed ban of ethylene dibromide (EDB) fumigation. Methyl bromide (MB) fumigation is being reviewed for possible elimination; consequently, few potential quarantine treatments remain. Among those remaining are hot water, vapor heat, controlled atmospheres, gamma irradiation and the cold treatment. Unfortunately, often the required treatment to give proper mortality to the pest results in injury to the host commodity.

The primary objective of this review is to give insight into the use of the cold treatment by showing how temperature manipulation can condition the commodity to tolerate low temperatures thus eliminating or reducing chilling injury (CI). The cold treatment is compatible for a number of fruits: apple, apricot, cherry, nectarine, peach, pear, plum, quince, grape, kiwi, and persimmon. Most citrus fruits, including the citron and some orange and mandarin cultivars, are compatible, while grapefruit, lemon, and lime show little tolerance to the cold treatment.

Because of its importance in both domestic and export markets, Florida grapefruit, Citrus paradisi Macf., has been the focus of considerable research with various quarantine methods, particularly the cold

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treatment. Since 1975, Florida citrus fruits have been fumigated with EDB to eliminate possible infestations of the Caribbean fruit fly, Anastrepha suspensa Loew., in fruit shipped to Japan. The U.S. Environmental Protection Agency (EPA) cancelled its registration of EDB for most uses, effective September 1, 1984 (Federal Register, 1984). Subsequent to cancellation, EPA revised its requirement but restricted the use of EDB to citrus destined for markets outside the U.S.

Recommended storage temperatures for Florida grapefruit are 10°C for mid- and late-season fruit and 16°C for early-season fruit. Grapefruit sustain CI when exposed to temperatures below 10°C and the susceptibility to CI varies throughout the harvesting season (Purvis et al., 1979). Preharvest conditions in the grove, as well as postharvest handling, may directly affect the extent of CI in stored grapefruit (Grierson and Hatton, 1977). Pre- and postharvest fungicidal applications of benomyl (Wardowski et al., 1975) and postharvest applications of thiabendazole (Schiffman-Nadel et al., 1975) reduced CI. Waxing grapefruit and packaging in film minimized CI (Purvis, 1985). Raising the relative humidity to 100% during storage (Pantastico et al., 1968), as well as intermittent warming (Hatton et al., 1981), greatly reduced CI.

Constant storage at 1°C for 28 days resulted in excessive CI; however, conditioning similar fruit throughout the season for 7 days at 10°, 16°, and 21°C significantly reduced CI during 21 days of storage at 1°C under high humidity conditions (Hatton and Cubbedge, 1982). There were indications that conditioning at 10° and 16°C resulted in less CI than conditioning at 21°C. Conditioning of grapefruit at 16°C was better than at 21° and 27°C in minimizing CI of fruit stored at 1°C (Table 1).

Although citrus fruits may be mature internally, degreening with ethylene (C_2H_4) gas is practiced during the early months of each season. Ridding the peel of chlorophyll or green color during degreening operations may take from one to several days; however, the longer the exposure time the more susceptible the fruit becomes to peel disorders and decay (Wardowski and McCornack, 1979). Early conditioned grapefruit were successfully stored for 17 days at 1°C after degreening for 72 hours (Table II). Nevertheless, caution is advised and prolonged degreening should be avoided regardless of conditioning.

During the 1981-82 season, four relatively large-scale grapefruit tests were conducted at a commercial storage facility in Florida. Only 1% CI was observed for the entire season on fruit that had been conditioned at 16°C for 7 days and stored at 1°C for 21 days; a slight increase in CI occurred during a 7-day holding period at 21°C (Table III). These tests were followed late in the 1982-83 season with an experimental break-bulk shipment of 16,000 boxes of grapefruit to Japan. Sixty boxes of fruit representing 15 separate lots were retained in Tokyo for study; less than 0.4% of the conditioned fruit showed CI while the fruit that was not conditioned showed 2.2%.

Table I. Chilling injury of conditioned and stored 'Marsh' grapefruit (Hatton and Cubbedge, 1983).[z]

Conditioning (°C)	Storage[x] (°C)	Chilling injury (%)[y] Immediately after storage	After holding at 21°C 7 days
None	28 days, 1°	23a[w]	27a
None	28 days, 10°	0c	0c
7 days, 16°	21 days, 1°	0c	0c
7 days, 21°	21 days, 1°	11b	13b
7 days, 27°	21 days, 1°	11b	11b

[z]Each value represents 360 fruit (120 from each of 3 sources) collected April 15, 1981. Regardless of surface area affected, values were derived from number of affected fruit.

[y]Mostly brown-staining of the rind, with some pitting.

[x]Relative humidity ranged from 88% to 92% for those at 1° to 10°C, and from 80% to 92% for those at 16°C and above.

[w]Means in each column not followed by the same letter indicate significant difference at 5% level by Duncan's multiple range test.

Grapefruit infested with Caribbean fruit fly and stored for 14 days at 2°C resulted in 100% mortality (Benschoter, 1983). Based on this research, the Government of Japan recently approved an abbreviated cold treatment schedule for Florida grapefruit that is on a sliding scale beginning with 0.6°C for 10 days and extending to 2.2°C for 17 days with the stipulation that 1,500 fruit be held at 27°C for 10 days and then cut to determine presence or absence of Caribbean fruit fly larvae. In the event larvae are found, the former nonabbreviated schedule would need to be followed.

In Israel, recent studies showed that by combining the fungicide thiabendazole with cooling of grapefruit susceptibility to CI can be reduced, and the cold treatment can be practiced with a low CI risk (Chalutz *et al.*, 1985).

The use of EDB will be curtailed further each year until no citrus fruits will be fumigated with EDB after the 1988-89 season (Federal Register, 1986). Meantime, the cold treatment will most likely replace EDB fumigation for quarantine treatment of grapefruit exported from Florida.

Table II. Effects of ethylene treatment and conditioning (16°C for 7 days) on chilling injury of early 'Marsh' grapefruit during storage (Hatton and Cubbedge, 1981).[z]

Conditioning, storage and ethylene treatment (hr)[y] °C	Chilling injury (%) After storage	After holding at 21°C for 7 days
24 days at 16°		
0	0	0
24	0	0
48	0	0
72	0	0
24 days at 1°[x]		
0	0	0
24	0	0.5
48	2.2	6.9
72	13.4	20.4
7 days at 16° followed by 17 days at 1°		
0	0	0
24	0	0
48	0	0
72	0	0

[z]In each treatment a total of 689 fruit were used representing a single grove harvested on October 23, November 7, November 20, and December 4, 1978.

[y]Ethylene dispensed at 5 ppm at 29°C and a relative humidity of 90 to 95%.

[x]Statistical analysis ($P < .05$) showed that fruit stored constantly at 1°C for 24 days were progressively affected by C_2H_4 exposure time.

Four citrus tests in California demonstrated that van containers could maintain fruit with temperature uniformity throughout the load of 1.6° or 2.2°C for 14 days (Houck and Hinsch, 1983). During the 1985-86 season, a number of break-bulk as well as van container shipments of almost a quarter of a million boxes of Florida grapefruit arrived in Japan in satisfactory condition after undergoing the cold treatment (Ismail, Personal Communications 1986).

Table III. Chilling injury of conditioned Florida grapefruit in a large-scale commercial facility (Hatton and Cubbedge, 1986).[z]

Conditioning storage treatment[y] °C	Chilling injury (%)		
	Number of fruit	After storage	After holding (7 days at 21°C)
28 days at 1°	4,425	14a[x]	17a[x]
28 days at 16°	4,431	0b	0b
7 days at 16° followed by 21 days at 1°	13,232	1b	2b

[z]Each value represents the combined data of 4 separate tests from 8 to 11 different lots. Tests were conducted in November 1981, December 1981, February 1982, and April 1982.

[y]Relative humidity ranged from 88 to 92% for fruit at 1°C and from 80 to 92% for those at 16°C.

[x]Means in each column not followed by the same letter indicate significant difference at 5% level by Duncan's multiple range test.

'Tahiti' limes conditioned by holding at various temperatures for one week prior to storage for 2 weeks at 2°C, developed less CI than nonconditioned limes (Spalding and Reeder, 1983). Recently it has been found that conditioning papaya fruit for 4 days at 12.5°C before storage for 12 or 14 days at 20°C reduced CI; the decrease in CI with conditioning was associated with partial fruit ripening (Chen and Paull, 1986).

Method of degreening Florida lemons with and without C_2H_4 was not related to CI (McDonald *et al.*, 1985).

In conclusion, continued research is urgently needed to develop feasible alternatives to EDB and MB fumigation, and the cold treatment with associated conditioning for horticultural commodities is only one approach.

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