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Postharvest Water Loss from Freeze-damaged Citrus Fruit

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Abstract. **Freeze-damaged 'Marsh' grapefruit (*Citrus paradisi* Macf.) and 'Pineapple' orange [*Citrus sinensis* (L.) Osbeck] fruit were sealed in polyethylene shrink film and stored for 6 weeks at 15°C in an attempt to prevent segment dehydration. Although the film greatly restricted water loss from the fruit, segment dehydration was similar to that observed for waxed fruit. During dehydration of freeze-damaged segments of 'Valencia' orange fruit, the relative water content of the adjacent mesocarp tissue increased. However, no differences were found in the soluble carbohydrate levels in mesocarp tissue adjacent to damaged and undamaged segments. The results indicate that the mesocarp tissue is not only in the pathway of water loss from free-damaged citrus fruit, but also accumulates water from damaged tissues. Furthermore, segment tissue membranes and walls appear to be differentially permeable to sugars and water.**

The major citrus producing areas of Florida have experienced 5 freezes since early 1977. Freezing injury of individual citrus fruit tends to follow definite patterns according to the type of freeze. Injury resulting from radiation freeze is greatest in the coldest top portion of the fruit, whereas injury from a windy, advective freeze occurs first on the windward side of the fruit and is sometimes restricted to only 1 side of the fruit (8). Freezing disrupts the juice vesicles and sometimes the tough segment tissues of the citrus fruit, subsequently resulting in the loss of juice. However, it is difficult to evaluate quantitatively freeze-damaged fruit immediately following a freeze. Dehydration of the fruit occurs most rapidly when temperatures return to normal. The pathway of water loss has not been delineated clearly, but results of 1 study indicate that water evaporates through the peel rather than moving back into the tree (7).

Carter (2) reported that juice weight of 'Valencia' oranges decreased as a 12-week period following the Mar. 1980 freeze, but pulp and peel fresh weights increased as did peel thickness. This change implies that water moves from the ruptured juice vesicles into the peel. In addition, polyethylene bags reduced water loss from 'Valencia' oranges remaining on the tree following the Jan. 1982 freeze, but the percentage of visibly damaged tissues in the bagged fruit was not different from that of the unbagged fruit 11 weeks after the freeze (7). Thus, at least for fruit remaining on the tree, restricting water loss through the peel significantly reduced segment drying but not enough to improve visual appearance of serially cross-sectioned fruit.

Polyethylene shrink films effectively restrict moisture loss from citrus fruit during postharvest storage (1, 4), and reduce chilling injury of grapefruit stored at low temperatures (5). Therefore, the purpose of this study was to determine if sealing previously frozen citrus fruit in polyethylene shrink films would prevent segment drying during postharvest storage.

'Marsh' grapefruit and 'Pineapple' orange fruit was harvested from the orchards of the Citrus Research and Education Center at Lake Alfred 2 weeks after the freeze in Dec. 1983. The fruit were washed and treated with 600 $\mu g \cdot ml^{-1}$ benomyl [methyl 1-(butyl-carbomyl)-2-benzimidazole-carbamate] to minimize decay during storage. Fifty grapefruit and 60 oranges were waxed with a solvent-type wax. Another 50 grapefruit and 60 oranges were individually seal-packaged in 21 μm polyethylene film (Cryovac D-925). The fruit were numbered and weighed at the start and end of each experiment. Storage room temperature was 15° ± 1°C, and vapor pressure deficits ranged from 0.85 to 2.5 mbars. Since most of the weight loss from fruit during storage can be accounted for by water loss (1), all weight loss was considered to be a measure of transpiration. Freeze injury was scored by using U.S. grades for freeze damage (8). Fruit with extensive freeze injury that exceeded U.S. grade 2 were assigned a numerical value of 3. Thus, a score of 3 represented the maximum injury and a score of 0 represented no injury.

'Valencia' oranges were harvested 21 weeks after the freeze of Dec. 1983. Relative water content of the mesocarp tissue was determined by removing tissue disks, 6 mm in diameter and 2 mm thick, and determining the fresh weights and turgid weights after floating them for 4 hr on distilled water in covered petri dishes at ambient temperature. The disks were dried in a 70°C oven for 24 hr, and the dry weights then were used to calculate the relative water content of the tissue.

For carbohydrate analyses of 'Valencia' mesocarp tissue, 3 to 5 g of tissue were removed from the fruit, weighed to the nearest milligram, and extracted in boiling 80% ethanol as previously described (6). Total soluble carbohydrate contents were determined by the methods of Johnson et al. (3) using α-D-glucose as a standard.

When grapefruit and oranges were placed in storage 2 weeks after the freeze, only a few fruit had visible evidence of freeze-damage on the exterior or interior of cross-sectioned fruit. Segment walls appeared to be intact, and there was little evidence of segment drying from 0.5-cm serial sections of the top part of the fruit (Table 1). During 6 weeks of storage at 15°C, however, most of the fruit had segments which were visibly dehydrated. Sealing the fruit in polyethylene shrink film did not prevent dehydration of the segments. Freeze injury scores increased from 0.7 to 2.7 or 2.8 during storage (Table 1). Results were similar for freeze-damaged grapefruit and oranges. Sealing fruit in poly-

Table 1. Freeze injury scores, percentage of water content of tissue, and percentage of exocarp and mesocarp weight loss of 'Marsh' grapefruit and 'Pineapple' oranges damaged during the freeze of Dec. 1983, and waxed with a solvent wax or sealed in polyethene shrink film and stored at 15°C for 6 weeks.

Fruit		Freeze injury score[z]	Water content (%) (exocarp + mesocarp)[y]	Wt loss during storage[z] (%)
'Marsh' grapefruit	Initial	0.7 a[x]	79.6 a	---
	Waxed	2.7 b	81.0 b	4.77 a
	Sealed	2.8 b	82.6 c	0.79 b
'Pineapple' orange	Initial	0.7 a[x]	75.7 a	---
	Waxed	2.8 b	75.4 a	5.34 a
	Sealed	2.8 b	76.8 a	1.35 b

[z]Scores of 0 represented no drying and 3 represented drying beyond two 0.5-cm serial cuts from the top of the fruit segment, respectively. Means of 50 grapefruit and 60 oranges.
[y]Means of 6 fruit.
[x]Means followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test). Data for grapefruit and oranges were analyzed separately.

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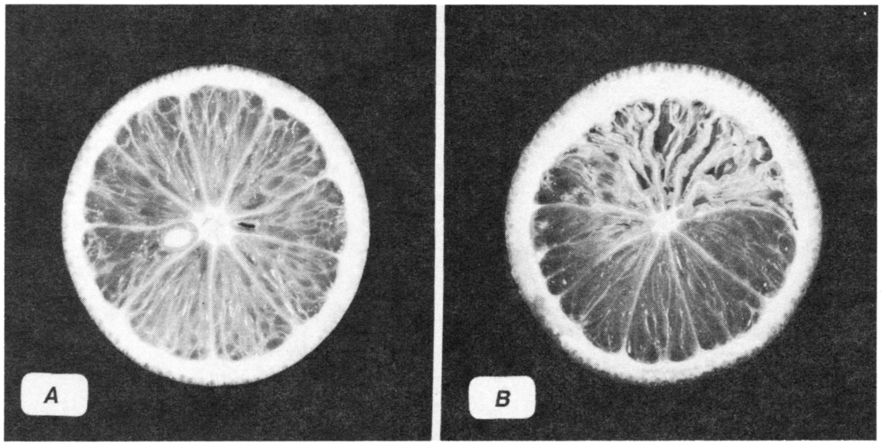

Fig. 1. Undamaged (**A**) and freeze-damaged (**B**) 'Valencia' orange fruit 21 weeks after the freeze of Dec. 1983. Note the thickened mesocarp tissue adjacent to the damaged segments in (**B**).

ethylene shrink film reduced water loss compared to waxed fruit (Table 1). During storage, water content of grapefruit peel increased, and water content of the peel of sealed fruit was 1% to 2% greater than that of unsealed fruit (Table 1). Thus, dehydration of the segments appears to result from the movement of water from the damaged segments into the peel tissues. Water accumulation was not apparent in the thin peel of 'Pineapple' oranges (Table 1).

The freeze of Dec. 1983 was a windy, advective freeze, and the fruit in some orchards showed the pattern of injury typical of a "windy freeze" where injury is restricted to 1 side of the fruit (Fig. 1). Carter (2) previously reported peel (mainly mesocarp tissue) thickening of drying 'Valencia' orange several weeks following the freeze of Mar. 1980. In the present study, mesocarp thickening was noted only in the tissue adjacent to the dehydrated segments (Fig. 1). Mesocarp tissue adjacent to undamaged segments was similar in thickness to that of fruit which had no visible freeze damage.

The mesocarp tissue adjacent to segments which were dehydrated in all instances had relative water contents which were significantly higher ($P < 0.001$, paired t test) than those of tissue adjacent to undamaged segments (Table 2). However, the soluble carbohydrate contents of the 2 sides were not significantly different (Table 2). Thus, if juice sugars moved into the mesocarp tissue along with water from the damaged segments, they did not accumulate. Alternatively, photosynthate produced after the freeze could have been translocated differentially to the mesocarp adjacent to the undamaged segments. If the undamaged, tough segment tissue membrane and walls are differentially permeable to water and sugars, however, water then would move into the mesocarp tissue during the dehydration of the freeze-damaged segments at a faster rate than the sugars. Thus, the increased thickening of the mesocarp following the freeze would be related to the hydrophilic nature of the tissue. This hypothesis is supported by the increased percentage water content of the mesocarp tissue adjacent to the damaged segments (Table 2). Furthermore, Carter (2) reported higher concentrations of sugars in the juice of freeze-damaged fruit than in sound fruit 12 weeks after the freeze of Mar. 1980. This observation suggests that sugars and water do not move out of the damaged segments at the same rate.

This study strongly suggests that the peel tissue, especially the mesocarp, is an accumulation point in the pathway of water loss from citrus fruit following freezes. Furthermore, whether fruit are on or off the tree (7), preventing moisture loss from the fruit via evaporation from the peel does not prevent drying of the damaged segments.

Table 2. Relative water content, total soluble carbohydates and reducing sugar concentrations, and percentage of water content of mesocarp tissue from 'Valencia' orange fruit damaged during the freeze of Dec. 1983.

Measurement	Damaged sector[z]	Undamaged sector	Significance[y]
Relative water content	0.56	0.48	***
Total soluble carbohydrate (mg·dry wt^{-1})	474	445	NS
Water content (%)	79.4	77.7	***

[z]Damaged and undamaged sectors correspond to those depicted in Fig. 1. Analyses were made on fruit harvested 21 weeks after the freeze of Dec. 1983. Means of 19 samples for relative water content and percentage of water content and 14 samples for total soluble carbohydrates.

[y]Significant at $P = 0.001$ (***), nonsignificant at $P = 0.05$ (NS), paired t test.

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