

# Influence of Fruit Maturity on the Effect of Postharvest Calcium Treatment on Decay of Golden Delicious Apples

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## ABSTRACT

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Golden Delicious apples harvested at three stages of fruit maturity were pressure-infiltrated (68.95 kPa) at harvest with 0, 2, 4, 6, or 8% solutions of CaCl<sub>2</sub> and stored at 0 C. After 4 mo, the fruits were removed from storage, wound-inoculated with *Penicillium expansum*, and incubated for 7 days at 20 C. Fruits were then rated for decay severity and injury and analyzed for calcium content. Fruits harvested 2 wk before the prime harvest period and infiltrated with 8% CaCl<sub>2</sub> solution had twice as much calcium in the flesh as untreated fruits, 25% less decay, and little injury. Fruits picked at prime harvest and infiltrated with 8% CaCl<sub>2</sub> solution had five times the flesh calcium concentration of untreated fruits, 57% less decay, and showed extensive superficial injury. Fruits picked 2 wk after prime harvest and infiltrated with 8% CaCl<sub>2</sub> solution had seven times the flesh calcium concentration of untreated fruits and 67% less decay, but injury extended into the cortex.

Additional key words: *Malus pumila*

Postharvest treatments of apples with calcium (Ca) salt solutions have been shown to delay senescence and deterioration of apples in storage. Internal breakdown (2), bitter pit (10), and softening (9) have been significantly inhibited by Ca treatment. Increase in water-soluble polyuronide content, which results in decreased fruit firmness, as well as ethylene production were retarded by postharvest Ca treatment

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than twice that resulting from vacuum infiltration, and treated fruits had 50% less decay area than untreated fruits. The objective of this experiment was to determine the effect of fruit maturity at harvest on the uptake of Ca applied by pressure infiltration and the resulting effect on decay of Golden Delicious apples by *P. expansum*.

## MATERIALS AND METHODS

Golden Delicious apples (*Malus pumila* Mill.) were harvested at 2-wk intervals from one block of trees in a commercial orchard in Pennsylvania. These three harvests occurred 2 wk before the prime harvest period, at the prime harvest period, and 2 wk later. Differences in maturity were reflected in measured differences in ethylene production, respiration rate, acidity, and percent soluble solids (11). Immediately after harvest, each lot of fruits was randomized and infiltrated under 68.95 kPa pressure for 2 min with laboratory-grade USP CaCl<sub>2</sub> (76%) made up as 0, 2, 4, 6, or 8% solutions in distilled water. After treatment, the fruits were placed in storage (0 C).

After 4 mo, the three lots of fruits were removed from storage at 2-wk intervals in the same order as they were harvested. Each lot was then wound-inoculated by dipping in a conidial suspension of *P. expansum* and rated for decay development as described previously (5). Fifteen fruits were used for each treatment. Ca concentration was determined after removing the peel and outer flesh of the entire fruit to a depth of 2 mm with a mechanical peeler. The next 3 mm of flesh was then removed similarly and analyzed for Ca content. The flesh from three apples made up one sample, and three samples from each treatment were analyzed. For analysis, the flesh was

(12). Similarly, the Ca content of fruit affects losses in storage caused by decay. An application of Ca as an orchard spray during the growing season increased the Ca content of fruit and reduced the incidence of decay in storage caused by *Gloeosporium perennans* L. (13). Also, an increase in Ca content of fruit caused by postharvest application can decrease the severity of fruit decay (5).

The level of control of storage disorders including decay is determined by the amount of Ca that can be successfully taken into the fruit, and this in turn depends on the method of treatment. In a recent study of the effect of postharvest Ca treatment on decay caused by *Penicillium expansum* Link ex Thom (6), the concentration of Ca in the flesh of apples dipped in calcium chloride (CaCl<sub>2</sub>) increased as the concentration of the solution increased but not enough to reduce decay. Vacuum infiltration of a 12% CaCl<sub>2</sub> solution doubled the Ca content of fruit compared with a dip treatment in the same solution and resulted in 30% less decay. Pressure infiltration of the 12% CaCl<sub>2</sub> solution increased the Ca content of fruit to more

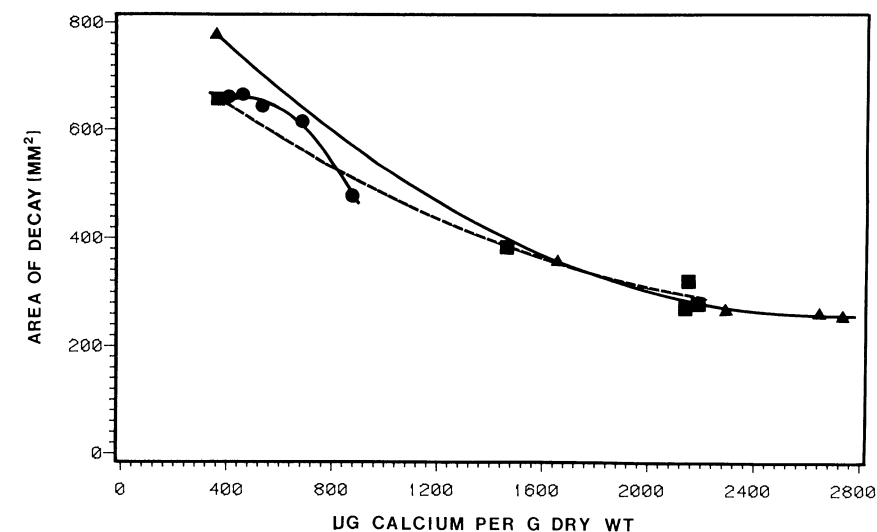
frozen in liquid nitrogen, freeze-dried, and ground to pass through a 60-mesh screen. Samples ( $0.500 \pm 0.005$  g) were ashed at 500 C overnight and the residue was dissolved in 5 ml of 6N HCl. The samples were then diluted and analyzed with a Jarrell-Ash atomic absorption spectrophotometer, and Ca values were calculated on a dry-weight basis.

## RESULTS

Differences in Ca uptake and in decay inhibition caused by Ca treatment were related to time of harvest (Fig. 1). In fruits picked 2 wk before prime harvest, infiltration with 8% CaCl<sub>2</sub> solution doubled the Ca concentration of the flesh, and treated fruits had 25% less decay area than untreated fruits. Lower concentrations of Ca induced lesser changes. Little surface injury occurred in fruits thus treated. Infiltration of 8% CaCl<sub>2</sub> solution into fruit picked at prime harvest increased the Ca concentration of flesh five times that of untreated fruits, with 57% less area of decay. For the lot picked at prime harvest, increasing the Ca concentration higher than 4% did not appreciably increase the Ca concentration of fruit flesh or significantly retard decay. However, surface injury, resulting in a brown discoloration of the peel, increased as the concentration of the CaCl<sub>2</sub> solution was increased beyond 4%. Although examinations of cross sections of fruits indicated that the injury was superficial and limited mainly to the peel, the apples would not have been suitable for the fresh market. The optimum treatment for fruits picked at prime harvest was pressure infiltration with 2% CaCl<sub>2</sub> solution. This resulted in 40% less area of decay than occurred in untreated fruit and no peel injury. Pressure infiltration of 8% CaCl<sub>2</sub> solution into fruit picked 2 wk after prime harvest increased the Ca concentration in the flesh almost seven times that of untreated fruits, with 67% less area of decay. In this lot of fruit, as in fruit picked at prime harvest, increasing the CaCl<sub>2</sub> concentration higher than 4% did not further suppress decay. It did, however, significantly increase the Ca concentration in the flesh, amounting to a 25% increase in Ca concentration over that of the fruits picked at prime harvest and infiltrated with the same solution. It also resulted in more fruit injury than occurred in fruit from the prime harvest. Whereas injury to fruits picked at prime harvest was primarily limited to the peel surface, the brown discoloration resulting from the 6 and 8% CaCl<sub>2</sub> solutions infiltrated into the late-harvested fruits extended approximately 10 mm into the cortex, making them unsuitable for the fresh market or for processing.

## DISCUSSION

The level of decay control in stored apples is related to the amount of CaCl<sub>2</sub>



**Fig. 1.** Relationship between area of decay and calcium concentration of apple tissue when fruits were pressure-infiltrated with calcium chloride (CaCl<sub>2</sub>) solutions. Regression curves indicate fruit picked 2 wk before prime harvest (●) ( $y = 435.61 + 0.97x - 0.001x^2$ ,  $r^2 = 0.99$ ), at prime harvest (■) ( $y = 782.2 - 0.36x + 0.00006x^2$ ,  $r^2 = 0.99$ ), and 2 wk after prime harvest (▲) ( $y = 954.64 - 0.52x + 0.000097x^2$ ,  $r^2 = 0.99$ ). Data points indicate the concentrations of CaCl<sub>2</sub> solutions (0, 2, 4, 6, or 8% from left to right, respectively).

taken up by the fruit (5). The amount of uptake, in turn, is influenced by changes in the structure of the fruit as it matures on the tree. Several early workers studied fruit development (14,15,17). Cell division ceases within about 4 wk of pollination; all subsequent increase in fruit size is due to the enlargement of both cells and intercellular spaces. As the cells enlarge, they gradually separate as the middle lamella becomes gelatinous, and large, irregularly shaped intercellular spaces develop (16). Cell enlargement and increase in intercellular spaces continue throughout the life of the fruit on the tree (1). Ca from postharvest treatments enters the fruit through epidermal openings, primarily lenticels (3), and if the fruit is left on the tree past the prime picking date, it enters through cracks in lenticels or the epidermis (4). Recent work involving postharvest treatment of apples with Ca showed that most of the Ca taken into the fruit during vacuum infiltration was found in the intercellular spaces (8). Leakage experiments indicated that localization of native Ca and that originating from postharvest treatment were the same (18). The effect of calcium on decay, as discussed previously (6), appears to be one of stabilizing or strengthening the cell wall, making it somewhat more resistant to enzymes produced by fungal pathogens and thus slowing fungal colonization. The increase in intracellular spaces in the fruit as it matures would allow for increased uptake of the CaCl<sub>2</sub> solution and increased availability of Ca for cell wall stabilization. However, this and previous studies (6,7) have shown a curvilinear relationship between Ca concentration and decay. Ca in excess of the optimum amount does not further suppress decay but does cause increased injury to the peel

of the fruit.

Fruit maturity at the time of harvest and treatment with Ca can significantly affect the benefits achieved. If the fruit is harvested and treated too early, too little CaCl<sub>2</sub> solution is taken into the fruit and little decay inhibition is realized. If the fruit is harvested too late, however, more Ca is taken up than is needed for optimum decay control and severe fruit injury may result.

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