Research Updates

Pilot Test for the Commercial Use of Postharvest Pressure Infiltration of Calcium into Apples to Maintain Fruit Quality in Storage

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Summary. A pilot test was conducted over a 3-year period to determine the feasibility of using postharvest pressure infiltration of calcium into apples to maintain and/or improve the quality of fruit under commercial storage conditions. Fruits obtained from three different orchards were treated each year. 'Golden Delicious' fruits were treated the first year, while 'Delicious' fruits were treated the 2nd and 3rd years. In all treatments and years, there was a significant increase in calcium concentration of apples from all calcium chloride (CaCl_2) treatments. In general, calcium concentration of treated fruit varied significantly among the three orchards. Firmness also varied among orchards, and was related to fruit calcium concentration. 'Golden Delicious' apples were more susceptible to skin injury caused by CaCl_2 treatment than were 'Delicious' fruits. There was also an increase in infection as a result of some of the treatments, possibly due to injury caused to lenticels by the pressure applied or as a result of calcium injury.

Enhancing calcium (Ca) content of apple fruit maintains fruit quality during storage. Preharvest sprays of Ca have reduced bitter pit significantly (Jackson, 1962; Watkins et al., 1989). Postharvest dipping, vacuum-infiltration and pressure-infiltration of Ca have been used with varying degrees of success to maintain fruit quality (Sams and Conway, 1984; Scott and Wills, 1979; Scott et al., 1985). Calcium treatments maintain quality by reducing softening (Mason et al., 1975), internal breakdown and respiration (Bangerth et al., 1972),

ethylene production, and decay (Sams and Conway, 1984, 1987).

Most research on pressure-infiltration of high concentrations of Ca into apple fruit has been conducted on small lots of fruit in a laboratory environment, where sanitation and fruit treatment were strictly controlled. In commercial situations (where larger amounts of fruit are to be treated), conditions are less optimal. This investigation examined postharvest treatments of apples with CaCl_2 solutions at commercial locations where fruits are stored for processing or the fresh market. Quality parameters evaluated included concentration of Ca in the fruit flesh and fruit firmness, decay, and injury.

Materials and methods

Experiments in 1990 were conducted at Knouse Foods (Musselman's) in Biglerville, Pa. Knouse Foods is a processor of apple juice, sauce, and slices. 'Golden Delicious' apples at this facility were treated with solutions of CaCl_2 and placed in commercial storage until sampled. In 1991 and 1992; similar experiments were conducted at the Rice Fruit Company in Gardners, Pa., which stores fruit intended for the fresh market. Prior to sampling, 'Delicious' apples were treated with various CaCl_2 solutions and placed in commercial storage under conditions similar to the 'Golden Delicious' fruit in the 1990 test.

Fruit source. Fruits from three different growers' orchards were used each year for a total of nine orchards sampled for this study. The fruits were harvested either 1 day before or on the day of treatment and bins of fruit at the commercial facility were selected at random upon arrival. Nonetheless, fruit size and maturity varied considerably within each lot.

Calcium chloride treatment. Fruit were treated in a pressurized vessel containing 115 liters of either water or various concentrations of CaCl_2 . In 1990, a pressure of 103 kPa (15 psi) was applied to the 'Golden Delicious' apples in 0%, 2%, or 4% solutions (w/v) of CaCl_2 for 6 min. The 'Delicious' fruits treated in 1991 and 1992 were pressure-infiltrated with 0%, 4%, 6%, or 8% CaCl_2 solutions for 6 min at 103 kPa. There was also a nontreated control in each test. The protocol of each treatment included immersing 500 fruit per replication in

a 100-ppm solution of sodium hypochlorite for 1 min, rinsing the fruit in water, pressure-infiltrating the fruit in water or CaCl_2 solutions, rinsing once again in water, and then lightly drying each fruit with paper towels and storing them in tray pack boxes at 0C for 5 to 6 months.

Calcium content analysis. The peel and outer flesh (to a depth of 2 mm) of the entire fruit was removed and discarded. The next 2 mm of fleshy tissue was used for Ca analysis. It was freeze-dried immediately and ground. One gram of dried tissue was dry-ashed, dissolved in 8 ml of 2 N hydrochloric acid, and filtered. The samples then were analyzed for Ca content by inductively coupled plasma atomic emission spectrometry. All Ca samples are reported on a dry-weight basis. Each sample was made up of the flesh of five fruits and four samples were analyzed per replication of each treatment.

Firmness measurements. Firmness measurements were taken with an electronic pressure tester (EPT-1; Lake City Technical Products, Kelowna, B.C., Canada) interfaced to a personal computer. Apples were placed at 20C overnight before being tested. Firmness was measured at two opposite sites (skin removed) on the equator of each fruit. Forty fruits were measured per replication of each treatment.

Injury rating. Fruits were rated for injury immediately after removal from storage. Injury was rated visually between 1 (severe) and 5 (no injury). Forty fruits per treatment were examined. Injury rating indicates the severity of injury on individual fruit, whereas percent fruit injured indicates the percentage of the 40 fruit showing any indication of injury. The 'Delicious' fruits at the Rice Fruit Company were cut longitudinally into two sections and examined for internal injury. Decay also was evaluated at this time by determining the percentage of the 80 fruit per treatment showing any sign of decay.

Statistical analysis. Each experiment (year) was a factorial arrangement with the three orchards, three or four treatment concentrations of CaCl_2 , and three replications. Statistical analysis was performed by analysis of variance. Within each experiment, differences among orchards were determined with Duncan's multiple range test and the significance of the effects

of Ca concentration were evaluated by treatment contrasts.

Results and discussion

Fruits that were pressure-infiltrated with distilled water were not significantly different in Ca content or firmness from nontreated fruit in all orchards and years, and only results from the distilled-water-treated fruit (0% CaCl_2) are reported for these parameters. In all 3 years, analysis of variance indicated a significant difference among orchards and Ca concentrations and the Ca effects were similar at all sites. Therefore, within-years orchard differences were determined by Duncan's multiple range test and the effect of Ca concentration was evaluated by linear and quadratic treatment contrasts.

Calcium concentrations of treated 'Golden Delicious' fruit were significantly different among the three orchards (Table 1). The concentration of CaCl_2 in the treatment solution also affected the amount of Ca taken up by the fruit. The mean of the Ca concentration in the fruit taken over all three

orchards indicated that, as the Ca concentration in the solution increased, the resulting fruit Ca concentration increased (Table 1).

Fruit firmness of 'Golden Delicious' was influenced by Ca solution concentration (Table 2). Higher Ca concentrations resulted in firmer fruit in most instances. Thus, firmness followed the same statistical trend as Ca uptake. Firmness (Table 2) was correlated positively with fruit Ca concentration (Table 1) in 1990 ($r^2 = 0.99$) when averaged across all orchards and Ca concentrations.

Surface injury on stored 'Golden Delicious' fruit was evident in all orchards (Table 3). Fruit from Orchard 1, which, on average, absorbed the most Ca from the treatments, had some fruit injury at all concentrations of CaCl_2 , while fruit from Orchards 2 and 3 only exhibited injury from the 4% CaCl_2 solution. Decay was more prevalent in Orchard 1 than in the others (Table 3), perhaps as a consequence of higher solution uptake.

In the 1991 test, fruit were removed after 5 months at 0C. The

Table 1. Calcium concentration of 'Golden Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl_2 solutions at harvest in 1990.

CaCl_2 (%)	Calcium concn ($\mu\text{g}\cdot\text{g}^{-1}$ dry wt) ^a			
	Orchard 1	Orchard 2	Orchard 3	Mean
0	138	175	213	175
2	1421	1512	736	1223
4	2362	1375	870	1536
Mean	1307 a ^y	1021 b	606 c	
Significance				
Linear	**	*	**	**

^aCalcium concentration was determined after 6 months of storage at 0C.

^yOrchard means within this row followed by different letters are significantly different at $P = 0.05$ by Duncan's multiple range test.

*,** Contrast within columns significant at $P = 0.05$ or 0.01 , respectively.

Table 2. Firmness of 'Golden Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl_2 solutions at harvest in 1990.

CaCl_2 (%)	Firmness (N) ^a			
	Orchard 1	Orchard 2	Orchard 3	Mean
0	64.2	59.0	59.2	60.8
2	80.6	69.0	62.4	70.7
4	87.4	70.1	62.3	73.3
Mean	77.4 a ^y	66.0 b	61.3 c	
Significance				
Linear	**	**	*	**

^aFirmness was determined after 6 months of storage at 0C followed by 24 h at 20C.

^yOrchard means within this row followed by different letters are significantly different at $P = 0.05$ by Duncan's multiple range test.

*,** Contrast within columns significant at $P = 0.05$ or 0.01 , respectively.

Table 3. *Fruit surface injury and decay of 'Golden Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl₂ solutions at harvest in 1990.*

CaCl ₂ (%)	Injury rating $\pm$ SD ^z	Fruit decayed (%) ^y
<i>Orchard 1</i>		
Nontreated	5.0 $\pm$ 0.0	2.5
0	5.0 $\pm$ 0.0	1.3
2	4.9 $\pm$ 0.2 (5.0) ^x	6.3
4	4.7 $\pm$ 0.6 (13.8)	10.0
<i>Orchard 2</i>		
Nontreated	5.0 $\pm$ 0.0	1.3
0	5.0 $\pm$ 0.0	0
2	5.0 $\pm$ 0.0	0
4	4.6 $\pm$ 0.6 (16.0)	2.5
<i>Orchard 3</i>		
Nontreated	5.0 $\pm$ 0.0	0
0	5.0 $\pm$ 0.0	0
2	5.0 $\pm$ 0.0	0
4	4.9 $\pm$ 0.2 (15.0)	2.5

^zFruits were rated for injury after 6 months of storage at 0C. Injury rating; 5 = no injury, 1 = severe injury.

^yFruits were rated for decay after 6 months of storage at 0C. Percent fruit decayed indicates the percent of the 80 fruit per treatment evaluated showing any sign of decay.

^xPercent fruit injured.

mean tissue Ca concentration taken over all levels of CaCl₂ indicated that Orchard 2 had the highest Ca concentration, followed by Orchard 3 and finally Orchard 1 (Table 4). The concentration of CaCl₂ with which the fruit were treated affected Ca uptake (Table 4). The mean Ca concentration of fruit flesh from all orchards treated with 0%, 4%, 6%, or 8% CaCl₂ increased as the Ca concentration of the treatment solutions increased (Table 4).

Fruit firmness was related to Ca treatment, with significant differences among orchards and Ca concentrations (Table 5). Firmness of fruit from Orchards 2 and 3 were the same, but significantly firmer than fruit from Orchard 1. There was no injury to the fruit in 1991, and no surface decay occurred that could be attributed to pressure infiltration. A small number of fruit had what appeared to be internal breakdown and, in some cases, a black fungal growth caused by an *Alternaria* spp., was associated with this breakdown.

In 1992, 'Delicious' apples, harvested from three orchards different from those used in 1991 were removed from storage after 6 months at 0C. As in 1990, fruit from the three orchards took up significantly differ-

Table 4. *Calcium concentration of 'Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl₂ solutions at harvest in 1991 and 1992.*

CaCl ₂ (%)	Calcium concn (μ g·g ⁻¹ dry wt)			
	Orchard 1	Orchard 2	Orchard 3	Mean
<i>1991^z</i>				
0	159	157	153	156
4	588	1081	1036	902
6	725	903	1099	909
8	921	1598	1260	1260
Mean	598 c ^x	935 a	887 b	
Significance				
Linear	**	**	**	**
Quadratic	*	NS	*	*
<i>1992^y</i>				
0	210	214	172	199
4	1361	540	526	809
6	1506	661	452	873
8	1028	806	366	733
Mean	1026 a ^x	555 b	379 c	
Significance				
Linear	*	**	NS	*
Quadratic	**	*	*	**

^zCalcium concentration was determined after 5 months of storage at 0C.

^yCalcium concentration was determined after 6 months of storage at 0C.

^xOrchard means within this row followed by different letters are significantly different at P = 0.05 by Duncan's multiple range test.

NS, *, ** Contrast within columns nonsignificant or significant at P = 0.05 or 0.01, respectively.

Table 5. *Firmness of 'Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl₂ solutions at harvest in 1991 and 1992.*

CaCl ₂ (%)	Firmness (N)			
	Orchard 1	Orchard 2	Orchard 3	Mean
<i>1991^z</i>				
0	69.4	65.0	66.6	67.0
4	70.6	71.3	70.7	70.9
6	69.3	83.2	75.3	75.9
8	65.2	77.0	83.7	75.3
Mean	68.6 b ^x	74.1 a	74.1 a	
Significance				
Linear	NS	*	**	*
Quadratic	*	**	**	**
<i>1992^y</i>				
0	78.5	76.5	72.0	75.7
4	81.2	76.3	73.1	76.9
6	80.3	80.5	72.6	77.8
8	79.7	82.3	79.9	80.6
Mean	79.9 a ^x	78.9 b	74.4 c	
Significance				
Linear	NS	*	*	**
Quadratic	*	NS	NS	*

^zFirmness was determined after 5 months of storage at 0C followed by 24 h at 20C.

^yFirmness was determined after 6 months of storage at 0C followed by 24 h at 20C.

^xOrchard means within this row followed by different letters are significantly different at P = 0.05 by Duncan's multiple range test.

NS, *, ** Contrast within columns nonsignificant or significant at P = 0.05 or 0.01, respectively.

ent amounts of Ca (Table 4). Fruit concentration (Table 5). In both 1991 firmness was directly affected by Ca ($r^2 = 0.78$) and 1992 ($r^2 = 0.72$),

firmness (Table 5) was positively correlated to fruit Ca concentration (Table 4) when averaged across all orchards and Ca concentrations. Fruit from Orchard 1 was significantly firmer than that from Orchard 2, which was significantly firmer than fruit from Orchard 3. There was some injury to 'Delicious' fruit harvested in 1992 (Table 6). Fruit from Orchard 3 had no surface injury, whereas fruit from Orchard 2 had only a small amount of injury from the 6% CaCl_2 solution. Fruit from Orchard 1, which absorbed the most Ca, also had the most injury, with fruit treated with the 8% solution of CaCl_2 having the greatest number of fruit affected. There was some decay in 1992 (Table 6). A small amount of decay occurred in fruit from Orchard 3 treated with the 8% CaCl_2 solution, but an equal amount was present on nontreated fruit. A small amount of decay also occurred in fruit from Orchard 2 at all CaCl_2 levels. Fruit from Orchard 1, with the highest level of CaCl_2 absorption, had the most decay, especially at the 8% CaCl_2 level. This seemed to be related to the amount of injury. This trend was similar to that

observed in 'Golden Delicious' fruit treated in 1990, although overall injury was much less. As in 1991, some of the fruit exhibited symptoms of what appeared to be internal breakdown associated with, in some cases, black fungal growth.

In all cases, infiltration of CaCl_2 solutions into apple fruit resulted in a significant increase in Ca concentration in the tissue regardless of CaCl_2 concentration, cultivar, or site. It generally is accepted that Ca tissue concentrations should exceed $250 \mu\text{g}\cdot\text{g}^{-1}$ dry weight to control many Ca-related physiological disorders such as breakdown and bitter pit (Meheriuk and Moyls, 1989), and pressure-infiltration of any of the CaCl_2 solutions was successful in achieving this $250 \mu\text{g}\cdot\text{g}^{-1}$ level. In order to affect firmness or decay significantly, however, it is necessary to raise the level of tissue Ca to $800\text{--}1000 \mu\text{g}\cdot\text{g}^{-1}$ dry weight. Concentrations significantly higher than $1000 \mu\text{g}\cdot\text{g}^{-1}$ may cause surface injury to the fruit (Sams and Conway, 1984; Conway and Sams, 1985). Previous research demonstrated that fruit tissue Ca concentrations of up to $\approx 2800 \mu\text{g}\cdot\text{g}^{-1}$ can be achieved using pressure-infiltration of Ca (Sams and Conway, 1984). In these experiments, firmness was positively correlated with tissue Ca concentration, and the response is quadratic when taken over a wide range in Ca concentrations. However, many factors can affect the amount of CaCl_2 taken into the fruit, and the resultant increase in tissue Ca concentration. Calcium probably enters the fruit primarily through the lenticels (Betts and Bramlage, 1977) and through cracks in the cuticle and epidermis (Glenn et al., 1985). Annual variation in the severity of cracking may lead to a variation in the amount of Ca that enters the fruit (Glenn et al., 1985). Cracks on the surface of 'Golden Delicious' fruit are wider and more numerous than those on 'Delicious' apples (Faust and Shear, 1972). In studies in which fruit of various apple cultivars were dipped in a CaCl_2 solution, the resulting tissue Ca concentration was greater in 'Golden Delicious' than in 'Delicious' fruit (Lidster and Porritt, 1978). These various differences in the fruit surface among cultivars can affect Ca uptake from postharvest CaCl_2 treatments.

Fruit maturity is also important in determining Ca uptake from posthar-

vest treatments. If fruit were harvested too early and then pressure-infiltrated with solutions of CaCl_2 , there would be little increase in tissue Ca; but, if fruit were harvested and infiltrated when over-mature, too much CaCl_2 could be absorbed, resulting in severe injury (Conway and Sams, 1985).

In all years there was a significant difference in effectiveness of CaCl_2 treatments in raising Ca levels in fruit from different orchards, indicating a difference in the capacity of fruit from different orchards to absorb exogenous Ca. 'Spartan' apples from two similar orchards in western Canada also exhibited a greater uptake of Ca in one orchard than the other (Lidster et al., 1978).

Postharvest pressure-infiltration is an effective method for increasing tissue Ca concentration in apple fruit. However, several problems are inherent in using this procedure commercially. Different cultivars take up different amounts of CaCl_2 , and fruit of the same cultivar from different orchards and growing seasons may take up different amounts of Ca. A model using specific gravity or density of the fruit may give some indication of the potential for CaCl_2 uptake. Passing fruit through the sizing line before treatment would result in greater fruit uniformity and perhaps more-uniform Ca uptake.

Another potential problem is the possibility of an increase in infection and fruit-surface injury. In our study, 'Golden Delicious' fruit was very susceptible to skin injury; 'Delicious' was much less so—even at the higher concentrations of CaCl_2 used in treating 'Delicious' fruit. The majority of the Ca injury was limited to the peel area. Such injury would prohibit sale as fresh fruit, but these fruit would still be acceptable for processing.

The increase in decay as a result of pressure-infiltration of fruit with CaCl_2 solutions also can be a major problem. If the CaCl_2 infiltrated into fruit is contaminated with fungal spores that normally infest the fruit surface, postharvest decay may be increased. Alternatively, the fruit surface may be more susceptible to decay because of injury to lenticel tissue as a result of the pressure treatment (Sholberg et al., 1989). This injury then may be exacerbated by the CaCl_2 injury and serve as infection courts for spores on the fruit surface or in the infiltration solutions.

Table 6. Fruit surface injury and decay of 'Delicious' apples from three orchards pressure-infiltrated (6 min; 103 kPa) with CaCl_2 solutions at harvest in 1992.

CaCl_2 (%)	Injury rating $\pm$ SD ^a	Fruit decayed (%) ^b
<i>Orchard 1</i>		
Nontreated	5.0 $\pm$ 0.0	5.0
0	5.0 $\pm$ 0.0	2.5
4	2.8 $\pm$ 0.2 (7.5) ^x	5.0
6	3.5 $\pm$ 0.6 (10.0)	10.0
8	3.1 $\pm$ 1.3 (32.5)	25.0
<i>Orchard 2</i>		
Nontreated	5.0 $\pm$ 0.0	0
0	5.0 $\pm$ 0.0	0
4	5.0 $\pm$ 0.0	2.5
6	2.0 $\pm$ 1.0 (5.0)	5.0
8	5.0 $\pm$ 0.0	5.0
<i>Orchard 3</i>		
Nontreated	5.0 $\pm$ 0.0	5.0
0	5.0 $\pm$ 0.0	0
4	5.0 $\pm$ 0.0	0
6	5.0 $\pm$ 0.0	0
8	5.0 $\pm$ 0.0	5.0

^aFruits were rated for injury after 5 months of storage at 0°C. Injury rating; 5 = no injury, 1 = severe injury.

^bFruits were rated for decay after 6 months of storage at 0°C. Percent fruit decayed indicates the percent of the 80 fruit per treatment evaluated showing any sign of decay.

^xPercent fruit injured.

A possible solution to this problem would be to expose the fruit for longer periods of time to a stronger chlorine solution than the 100-ppm sodium hypochlorite solution used in this study.

A small percentage of the 'Delicious' fruit from 1991 and 1992 exhibited an internal browning (similar to internal breakdown) in the core of fruit infiltrated with the CaCl_2 solutions or water. Isolation of this browned tissue onto fungal culture media revealed that there was no fungus associated with this symptom. CaCl_2 solutions pressure-infiltrated into the fruit may enter the open calyx end and from there move into the core area. The possible decrease of gaseous exchange due to excessive solution in the core area combined with lenticel blockage due to Ca infiltration may lead to injury in the form of internal browning (Hewett and Thompson, 1992). Associated with this internal browning in some cases was a black-colored decay, which, upon isolation and culture, was found to be caused by an *Alternaria* spp., a fungus often associated with moldy core disease of apples.

The data from these experiments indicate that postharvest CaCl_2 infiltration can be effective in increasing fruit Ca concentration and maintaining firmness of apples under commercial conditions. However, inadequate Ca uptake is a problem for some fruit, and excessive Ca uptake is a problem for others. If CaCl_2 treatments are to be used on a commercial scale for long-term storage, fruit must be sorted by size and maturity before treatment. A model to predict the influence of fruit size, maturity, and other factors on Ca uptake must be developed to ensure optimum benefit from the Ca treatments. Proper sanitation will also be essential before CaCl_2 pressure-infiltration can be implemented as a successful commercial treatment.

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