Calcium Chloride Treatment of Fruits and Vegetables

By

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Executive Summary:

Calcium Chloride is proving to have a significant impact on the shelf life of various fruits and vegetables. The benefits of applying calcium chloride to select fruits and vegetables include:

- Delays aging or ripening.
- Reduces post-harvest decay.
- Controls the development of many physiological disorders.
- Increases the calcium content, thus improving their nutritional value.

The application of calcium chloride on the following fruits and vegetables has had the indicated results:

- **Apples**:
  - retains fruit firmness
  - increases Vitamin C content
  - decreases storage breakdown and rot
- **Strawberries and blueberries:**
  - extends the shelf life
  - slows down the rate of decay
  - maintains the firmness of the fruit for extended periods
- **Peaches:**
  - reduces their brown rotting and disease index
  - improves the quality
  - extends the shelf-life
- **Pears:**
  - maintains firmness and freshness of sliced ***pears*** for extended periods
- **Oranges and pineapples:**
  - extends the shelf life
  - improves the quality
- **Cantaloupe:**
  - extends the shelf life

- **Carrots:**
  - improves the firmness
  - extends the shelf life
- **Tomatoes and mushrooms:**
  - improves the firmness and quality
  - improves the shelf life
- **Potatoes:**
  - extends the storage life
  - improves quality of French fries
    - reduces the oil consumption
    - reduces the darkening

Introduction:

Early research into the effect of calcium on fruit and vegetable quality was concerned with calcium's association with physiological disorders (DeLong, 1936). Subsequently, more than 30 calcium related disorders in various crops have been identified (Shear, 1975). *It has been established that the disorders of storage organs of fruits and vegetable appear closely related to low calcium content in tissues.*

Pre- and post-harvest calcium applications have been used to delay aging or ripening, to reduce post-harvest decay, and to control the development of many physiological disorders in fruits and vegetables (Poovaiah, 1986; Conway et al, 1994). Firming and resistance to softening resulting from addition of calcium have been attributed to the stabilization of membrane systems and the formation of Ca-pectates, which increase rigidity of the middle portion and cell wall of the fruit (Grant et al, 1973; Jackman and Stanley, 1995). This inhibits the degradation of the middle portion and cell wall (Buescher and Hobson, 1982) and improves the skin strength (Mignani et al., 1995).

Foliar application of calcium chloride has been reported to delay ripening and retard mold development in strawberries (Cheour et al., 1990; Cheour et al., 1991) and raspberries (Montealegre and Valdes, 1993).

Post-harvest dips in calcium chloride solutions are also combined with heat treatment. Heat allows the formation of COO^- groups from the pectin content of the fruits or vegetables with which Ca^{2+} ions can form salt-bridge cross-links (Stanley et al, 1995). This makes the cell wall less accessible to the enzymes that cause softening. This practice controls ripening, softening, and decay at the same time (Sams et al, 1993). Conway and Sams (1984) have indicated that *calcium enhanced tissue develops resistance to fungal attack by stabilizing or strengthening cell walls, thereby making them more resistant to harmful enzymes produced by fungi, and that it also delays aging of fruits.*

The demand for fresh-cut fruits and vegetables is growing, with an estimated retail market of $11 billion (Anon, 1998). Although these products have met the consumer's desire for convenience, product freshness and shelf life are still important challenges to the retailers. Use of calcium chloride for the treatment of fresh-cut fruits and vegetables is potentially an attractive market.

Calcium dips have been used as firming agents to extend post-harvest shelf life of a wide range of fruits and vegetables. Some of them are as follows:

- apples (Abbott et al., 1989; Laurie and Klein, 1992; Mir et al., 1993; Sams et al., 1993)
- strawberries (Garcia et al, 1996)
- sliced cantaloupe (Luna-Guzman et al (1999)
- sliced pears and sliced strawberries (Rosen and Kader, 1989)
- sliced zucchini (Izumi and Watada, 1995)
- blueberries (Camire et al., 1994)
- peaches (Postlmayr et al, 1956)
- tomatoes (Floros et al, 1992)
- oranges (Potjewijd, et al, 1995; Pathmanaban et al, 1995; Vilas Boas et al, 1998)
- pineapples (Boas et al, 1998; Goncalves et al, 2000)

Calcium can also reduce pathogen germination, sporulation and growth (Conway et al., 1994) that are common in much root vegetable, like potato. *This ultimately reduces the storage decay of fruits or vegetables.*

Apples:

Storage disorders of apples, such as water core, bitter pit, internal breakdown, and softening, have been reduced by post-harvest calcium chloride treatment (Bangerth et al., 1972; Mason et al., 1975; Reid and Padfield, 1975).

There are various ways calcium has been applied to apples. Pre-harvest application of calcium has the following effects:

- Calcium sprays reduce storage losses (Sharples and Johnson, 1977; Drake et al., 1979). In a later publication (anon, 1995), Drake makes the following statement: *"On delicious and Golden delicious apples, calcium sprays reduced the incidence of bitterpit and may also diminish scald and internal breakdown three disorders that render some apples unmarketable. And in most instances, the firmness, total acidity and juiciness rating of apples were improved by timely applications of calcium during the growing season"*

- The amount of calcium taken into apples can vary from year to year and by the degree of fruit maturity and the type of apple.

- Differences in growing condition, environmental factors, and fruit development can influence the amount of calcium uptake by fruits (Conway et al., 1994; Wojcik and Swiechowski, 1999). To increase calcium concentration, foliar sprays should be conducted at late fruit growth stages (Wojcik, 2001).

- A minimum of 3 sprays applied at monthly intervals beginning in May or June are usually required to achieve control (Cparile, 2001). Fore more severe calcium deficiency cases, shorter treatment intervals (every 2 weeks) over the same 3-month period are recommended. Early treatment, when the fruits are about 1-inch size may be more effective in varieties (including Granny Smith, Golden Delicious, Mutsu, Gravenstein, Yellow Newtown, Jonathan and Red Delicious) that are very susceptible to bitter pit due to calcium deficiency.

- Ferguson (2001) states *"Maximizing calcium concentration in apple fruit, without incurring damage, will reduce risk of disorders and help in maintaining firmness and other desirable quality properties".* He emphasizes the need to concentrate on the fruit on the tree in efforts to increase post harvest quality, and goes on to recommend calcium chloride being the most effective source of calcium. He further points out that *calcium nitrate is an effective source of calcium but its use can cause russet problems later in fruit development.*

Post-harvest applications have the following effects:

- It increases calcium content of the apple tissues, which reduces the postharvest decay (Conway, 1982; Conway and Sams, 1983).

- Direct application of calcium is considered to be the best method of increasing flesh calcium content.

- Dipping apples in $CaCl_2$ solution can increase the calcium content of tissues (Bangerth et al, 1972).

- Active infiltration procedures, such as vacuum or pressure that force solutions into fruit are more effective in controlling bitter pit (Scott and Wills, 1979).

- Conway and Sams (1983) treated 'Golden Delicious' apples for 2 min. with 0 to 12% $CaCl_2$ solutions by dipping , vacuum infiltration (4.83 psi) or pressure infiltration (10 psi). Over the range of $CaCl_2$ treatment solutions, dipping (250 to 700 mg Ca/kg dry weights) was least effective in increasing the calcium concentration of the tissue. Vacuum infiltration (250 to 1500 mg Ca/kg dry weight) was superior to dipping, but pressure infiltration was most effective (250 to 3250 mg Ca/kg dry weight) in increasing the calcium concentration in apple tissues.

- Calcium treatment help to retain fruit firmness (Table 1), increases Vitamin C content (Table 2), and decreases storage breakdown and rot (Poovaiah, 1986; Conway and Sams, 1984).

- A single post harvest dip of calcium chloride, in place of in-season sprays, has been effective on some varieties, including Granny Smith and Yellow Newtown, but not on Mutsu and others (Cparlie, 2001). A 1-minute dip in 2% (for Yellow Newtown) or 3% (for Granny Smith) solution has typically been used. Dip time and the concentration of calcium chloride solution should be carefully tested on individual fruits, as higher dip time and concentrations can lead to fruit damage.

Table 1

Relationship between peel and flesh calcium content and fruit Firmness in Golden Delicious apples infiltrated with 3-4% calcium Chloride *(after Poovaiah, 1986)*

	Results after 90 days of storage at 32°F		
	Calcium Content (mg/kg)		Fruit Firmness* (lb)
Treatment	**Peel**	**Flesh**	
Control (without $CaCl_2$)	890	190	12.20
350 mm Hg (6.77 psi) with $CaCl_2$	1,442	287	13.27
250 mm Hg (4.83 psi) with $CaCl_2$	1,642	359	14.72

**Initial fruit firmness at harvest time was 16.58 lb*

Table 2
Effect of calcium infiltration on Ascorbic Acid content in Golden Delicious apple. Fruits were vacuum infiltered with calcium chloride soon after harvest and stored at 32°F prior to analysis *(after Poovaiah, 1986)*

		Ascorbic Acid Content (mg/kg dry wt.)					
Treatment	**Week →**	**0**	**3**	**6**	**9**	**12**	**15**
Control		140	125	130	120	135	130
Water		140	127	132	130	120	130
2% $CaCl_2$		140	148	172	180	160	158
4% $CaCl_2$		140	146	165	220	235	228

Strawberries:

It is one of the most readily perishable fruits. Garcia et al (1996) have demonstrated that the post-harvest dip in calcium chloride reduced strawberry decay during shelf life. The treatment with 1% solution of calcium chloride at 77°F was noted to be most effective. Test data are summarized in Table 3.

Table 3
Effect of Calcium Chloride Dip on Strawberries
(after Garcia et al., 1996)

	Rotted Fruits (%)		Fruit Firmness (N/cm^2)	
	Control	**1% $CaCl_2$**	**Control**	**1% $CaCl_2$**
Shelf Life* at 3 days and 64.4°F	100	35	6	15

N (Newton) = 0.22481 lb

**Prior to this shelf life test, strawberries were submerged in a 1% $CaCl_2$ solution at 77°F for 15 minutes and stored for 1 day at 33.8°F.*

Garcia et al (1996) have noted the following:

- Fruits that were dipped in 1% $CaCl_2$ solution at 77°F had significantly higher concentration of calcium content than the control.
- However, the calcium content of these fruits was significantly lower than that of fruits dipped in 1% $CaCl_2$ solution at 113°F.

- The calcium contents for the control, 1% $CaCl_2$ at 77°F and 1% $CaCl_2$ at 113°F were reported to be about 0.28%, 0.38% and 0.54%, respectively of the fruit on the dry weight basis.

This increase in the calcium content by about 36% and 37% at 77°F and 113°F, respectively, could also be considered nutritional value that has been added to the fruit

Table 4
Effect of $CaCl_2$ Dips on Firmness (Relative Shear Force) of 'G-3' Strawberries Stored at 36.5°F for 7 Days and at 68°F for 1 Day *(after Rosen and Kader, 1989)*

Treatment	Day 0 Firmness (N)	Day 0 Ca (mg/kg)	Day 7 Firmness (N)	Day 7 Ca (mg/kg)	Day 8 Firmness (N)	Day 8 Ca (mg/kg)
Water	52.2	103	47.1	114	47.3	110
0.5% $CaCl_2$	54.3	167	56.3	167	53.4	168
1.0% $CaCl_2$	53.4	214	57.0	231	56.7	228
No Dip, Freshly Sliced	51.4	101	48.9	104	53.7	107

Test data reported by Rosen and Kader (1989), as given in Table 4, show the following:

- Calcium chloride dips result in higher calcium content.
- While initially there was little differences in the fruit firmness, after 7 days at 36.5°F, both 0.5% and 1.0 % $CaCl_2$ dips resulted in firmer fruit with higher calcium contents than either water-dipped slices or whole, freshly sliced fruit.
- They also note that by increasing the $CaCl_2$ concentration from 0.5% to 1.0 % the calcium content of the fruit slices increased, but their firmness value was not different.
- After transfer to 68°F (i.e. Day 8), the $CaCl_2$ treated slices were as firm as whole, freshly cut sliced fruit, and they were firmer than water-dipped slices.

In a separate investigation, Morris et al (1985) have demonstrated the following:

- Calcium treatment maintains firmness in sliced strawberries even better than what was noted to be in the case of whole strawberries.

This could be attributed to more surface area being available for the adsorption of $CaCl_2$ when strawberries were sliced.

Peaches:

Similar to strawberries, peaches are highly perishable. A method of delaying their ripening would be of considerable value. On the basis of post-harvest treatment tests, Wills and Mahendra (1989) report the following:

- Use of 1% calcium chloride at about 3 psi significantly extended the time to ripen on 7 of the 9 groups of peaches examined.
- The average time to ripen at 68^{o}F in all 9 groups was extended from 11.1 days to 14.4 days.

This increase in ripening time by about 30% is of significant commercial value.

Souza et al (1999) have shown the following:

- Post-harvest application of calcium chloride at the site of injury in peaches that had occurred during harvesting reduced the enzyme levels, and increased the levels of neutral sugar in the fruit.
- It also reduced the brown rotting by about 34% and disease index by about 29% as compared to untreated peaches.

From pre-harvest foliar applications of calcium chloride Robson et al (1989) conclude the following: *This research shows that foliar applications of calcium to peach trees throughout the growing season can have a positive affect on peach fruit quality in storage. Calcium treated fruit maintained their quality longer than non-treated fruits.*

Robson et al (1989) further states: *A surprising result was the effect of calcium had on the organoleptic acceptance of the fruit. Not only they were the Ca-treated fruit rated superior in appearance, aroma, flavor, and texture after harvest, but this overall acceptance of the Ca-treated fruit continued to be greater than the control fruit even after four weeks of storage.*

On the basis of their pre-harvest treatment tests that involves application of 0.5% and 1.0% $CaCl_2$ solutions being sprayed on peach plants at pit hardening stage of the fruits, Mahajan and Sharma (2000) show the increase in size and improvement in quality of the fruits. These treatments also enhanced the shelf life of the fruits. For the determination of the storage life, the fruits of different treatments were packed in wooden boxes and kept at room temperature. Selected test data are summarized in Tables 5 and 6.

Table 5
Effect of Pre-harvest Application of Calcium Chloride on the Quality of Peach

Treatment	Length (cm)	Diameter (cm)	Weight (g)	Pulp-Stone Ratio (%)	Total Sugar (%wt)
Control	4.5	4.1	49.8	4.0	5.0
0.5%	5.3	4.6	52.5	4.8	5.8
1.0%	5.5	4.9	54.5	4.9	6.1

Table 6
Effect of Pre-harvest Application of Calcium Chloride on the Storage Life of Peach

Treatment	PLW* (%)		TSS** (%)			Total Sugar (%)		
Days	***3***	***6***	***0***	***3***	***6***	***0***	***3***	***6***
Control	10.5	28.0	10.0	12.5	9.7	5.0	5.8	4.3
0.5%	5.8	14.3	10.0	13.1	11.6	5.8	6.8	6.0
1.0%	5.3	13.2	10.8	13.7	12.0	6.1	7.2	6.6

* Physiological Loss in Weight
** Total Soluble Solid

As both strawberries and peaches are delicate fruits, to avoid physical damages, precautions must be taken in their handling during the treatment process.

Pears:

Application of calcium to Anjou pear trees has been reported to have increased yield by 13% over six year period (anon, 1995). It reduced the incidence of cork spot, which reduces the fruit's intensity, keeping quality and market value. In the same publication, it has been reported that on Bartlett pears, calcium sprays reduced black end or hard end abnormalities by more than 50%.

Rosen and Kader (1989) have demonstrated the effect of calcium chloride on the firmness and calcium contents of the sliced pear, as shown in Table 7.

Table 7
Effect of $CaCl_2$ Dips on Firmness of 'Bartlett' Pears Stored at 36.5^oF for 7 Days and at 68^oF for 1 Day *(after Rosen and Kader, 1989)*

Treatment	Day 0 Firmness (N)	Day 0 Ca (mg/kg)	Day 7 Firmness (N)	Day 7 Ca (mg/kg)	Day 8 Firmness (N)	Day 8 Ca (mg/kg)
Water	45.4	78	20.0	73	15.1	68
1.0% $CaCl_2$	49.4	206	35.1	158	28.0	189
No dip, Freshly sliced	45.4	73	27.1	68	20.9	61

Test data in Table 7 show the following:

- 1.0% $CaCl_2$ had an immediate firming effect on the slices, since they were significantly firmer than water-dipped slices and whole, freshly sliced fruit.
- The trend was consistent on Day 7 and Day 8.
- They also report that *$CaCl_2$ dipped slices of pears after 7 days of storage at 36.5^oF were lighter in color than water-dipped slices*. This further confirms the reduction in the rate of degradation of pears when treated with calcium chloride.
- From their studies Rosen and Kader (1989) have also concluded that a combination of 1.0% $CaCl_2$ and 0.5% O_2 produces even greater maintenance of firmness than either treatment alone after return to air.

Similar to strawberries and peaches, pears are readily perishable fruit. $CaCl_2$ treatment can be of considerable economic value to the producers or consumers.

Oranges:

With oranges, application of calcium chloride at the pre and post harvest stages has shown to improve the quality of the fruit. Many investigators have studied the effect of pre-harvest application of calcium chloride on citrus fruits. Hsiung and Iwahori (1984) have found that calcium chloride treatment of Ponkan mandarin delayed its maturity.

Schirra and Mulas (1994) have reported calcium chloride had retarded the maturity and improved the storability of treated fruits.

El-Hammady et al (2000) have further confirmed the positive effects of calcium chloride on a citrus fruit that were earlier reported. This study was carried out on Balady mandarin, in which the fruits in the trees were sprayed with 4 and 6% calcium chloride solutions. Each treatment was replicated four times and the randomized complete block design was followed. The treatments were done on the same day at the mature-green stage of fruits, by spraying the trees in early morning with 5 liters (about 1.34 gallon) at the selected concentrations of calcium chloride solution. Harvested fruits were stored at 5°C (41°F) ± 1°C and 90% Relative Humidity. Weight losses of the fruits and their ascorbic acid content at different storage time intervals are summarized in Table 8.

Table 8
Effect of $CaCl_2$ Sprays on Weight Loss % and the Ascorbic Acid Content (mg/100 g) of the Fruits *(after El-Hammady et al, 2000)*

	% Weight Loss					
Days in Cold Storage →		**15**	**30**	**45**	**60**	**75**
Control		5.5	9.8	*	*	*
4% $CaCl_2$		2.0	3.2	4.3	5.3	6.5
6% $CaCl_2$		2.0	2.8	3.2	4.4	5.8
	Ascorbic Acid Content (mg/100g)					
Days in Cold Storage →	**0**	**15**	**30**	**45**	**60**	**75**
Control	42.7	40.7	32.3	*	*	*
4% $CaCl_2$	47.2	42.3	40.5	38.2	33.3	30.7
6% $CaCl_2$	48.3	43.8	44.5	40.7	35.5	32.7

*Analyses were terminated after the decay of 50% of fruits

From a pre-harvest treatment of orange fruits in trees, Chikaizumi et al (1997) have reported that spraying oranges 6 times during the period of three weeks prevented development of disorders that occurs during post-harvest storage period.

Florida is the largest citrus fruit producing state in the United States. On-tree value of Florida citrus crop is estimated at $1.1 billion. However, due to Florida's warm and humid climate, the disease problems of citrus in Florida are much greater than what is encountered in many citrus producing areas of the country. California, though a very large citrus fruit producing state, does not have the same intensity of problems.

Pineapples:

Pineapples grow and produce best where the temperature is warm and relatively uniform throughout the year. Hawaii is the major producer of pineapples. In the mainland USA, although the climate of Florida is not ideally suited to large-scale commercial production of pineapples, the state is a major producer of this fruit. Planting is restricted to the southern coastal area. Major problems with the growing of pineapples are extreme temperatures. Prolonged exposure to temperature in the low 40's result in internal breakdown or "heart-rot" of the flesh. On the other hand, extreme high temperatures cause sunburning and cracking of the fruit.

There are several varieties of fruit grown in Florida. In general the shelf life of the harvested pineapples allows them to be shipped to markets in different parts of the country. However, some fruits that are of superior eating quality, such as "Alaska" and "Permambuco" have a short shelf life. Any extension of their shelf life will improve their marketability.

Goncalves et al (2000) have reported that the post-harvest treatment of pineapples with calcium chloride retards their decay rate. Harvested fruits of "Smooth Cayenne" variety (grown extensively in Florida) were soaked in calcium chloride solution at different temperatures for different length of time. Fruits were stored at 9^oC (about 48^oF) and 90% Relative Humidity for 15 days, and assessed 7 days after removal from the storage. The samples that were treated with calcium chloride, regardless of temperature and duration of treatment, reduced internal browning of the fruit. Calcium chloride treatment also reduced the phenolics (indicative of decaying) content of the fruit. In an earlier publication Boas et al (1998) report the treatment of the same species of the fruit as described above resulted in adsorption of calcium species into the pineapple cell walls. This helped maintaining the level of pectic substances in the cell walls.

Melons:

Fresh-cut melons have become popular among consumers. Operations involved in the preparation of fresh-cut melons may affect their shelf life, eating quality and acceptance by consumers. For fresh cut melons, a 10-day shelf life is considered to be desirable in the distribution chain (Anon, 1996), but the retail stores get an average shelf life of only 3 days. Any improvement in their shelf life will substantially improve the retail profits.

Luna-Guzman et al (1999) have shown that calcium chloride treatment improves the firmness and the quality of freshly cut cantaloupes. A Texture Analyzer was used to measure the firmness of the melon slices. The melon quality or its metabolism was evaluated in terms of the respiration rates (CO_2 production) and the ethylene production rates of the freshly cut slices.

Test results show the following:

- Melon slices when treated with calcium chloride have reduced rate of change in the metabolism as has been indicated by the lower respiration rate.

- Calcium chloride dips also improve the firmness of the freshly cut melons, and the calcium content of the fruit has been noted to be significantly greater than the control slices.

Temperature of the dip also has influence on the firmness of the slices. For example:

- In the dip of 2.5% $CaCl_2$ solution the respective firmness of the treated slices for control, 68^{o}F, 104^{o}F and 140^{o}F was measured to be about 5, 7, 8 and 9 N after the storage period of 4 days.

- Treatment at 140^{o}F the firmness of the melon slices was maintained at about the same level of about 9 N even after 12 days of storage period.

Carrots:

Extending the earlier work of Bruemmer (1987) on carrot sticks showing that the calcium treatment maintained the firmness for extended period, Izumi and Watada (1994) have studied the effect of calcium on the storage quality of sticks, sliced and shredded carrots. Test results are summarized as Tables 9 and 10.

Table 9
Calcium Concentration of Carrot Slices, Sticks and Shreds Treated with $CaCl_2$ Solutions *(after Izumi and Watada, 1994)*

Treatment (% $CaCl_2$)	**Cut Form**	**Ca Conc. (mg/kg dry wt.)**
0	Shreds	2000
1	Slices	2300
1	Sticks	3500
1	Shreds	7400

Table 10
Calcium Concentration of Carrot Shreds
Treated with $CaCl_2$ Solutions *(after Izumi and Watada, 1994)*

Treatment	**Ca Conc. (mg/kg dry wt.)**
Control-water dip	2000
0.5% $CaCl_2$	5100
1% $CaCl_2$	7400

Test results in Tables 9 and 10 indicate the following:

- By dipping carrots, sticks, slices or shreds, in calcium chloride it increases their calcium content.

The greater calcium concentration in the shredded carrots could be attributed to the larger surface area that is available for the adsorption of chemical.

From the study of the effects of calcium chloride dip on the weight loss and texture of the carrot shreds, it is noted that the treatment substantially maintained their quality during the storage period. For example:

- At 32°F and 41°F and storage period of 30 days, the % weight loss and texture of the control and the treated shreds in 1.0 % $CaCl_2$ solution were noted to be as shown in Table 11.

- $CaCl_2$ treatment results in increased texture value by 69% (32°F) to 93% (41°F); and reduction in weight loss by about 25% (41°F) to 60% (32°F).

Table 11
Effect of $CaCl_2$ Dip on the Texture and Weight Loss
of Shredded Carrots during Storage Period of 30 Days at 32°Fand 41°F
(after Izumi and Watada, 1994)

	Texture (N)		**Weight Loss (%)**	
	(32°F)	**(41°F)**	**(32°F)**	**(41°F)**
Control	2900	2700	5	4
1% $CaCl_2$	4900	5200	2	3

N (Newton) = 0.22481 lb

The total microbial count, a measure for the quality of carrots, was substantially reduced when the shreds were treated with 1% $CaCl_2$ solution. The differential between the control and the treated carrots, like the effects on the texture and weight loss, was greater at the extended period of storage. *This inhibitory effect of calcium chloride is attributed probably to the increased resistance of tissues to the bacterial infection rather than to a bactericidal action.*

Tomatoes:

Calcium is a critical nutrient for the growth, quality and the shelf life of tomatoes. It is, therefore, needed for both pre and post-harvest applications to tomatoes.

While calcium application to the soil is essential for healthy growth of tomatoes, foliar application during the fruit growth period considerably improves the quality of produce. Subbiah and Perumal (1990) conclude the following:

- Among the different sources and concentrations (calcium oxide, calcium chloride and calcium sulfate were included in the test), application of 0.2% sprays of $CaCl_2$ was found to be better to improve lycopene (responsible for the color of the tomato fruit), ascorbic acid content and firmness index of tomato fruits.

In a later study Subbiah (1994) reports: *Application of 0.5% $CaCl_2$ sprays significantly increased the firmness index of tomato fruits.* He has also noted that *the firmness index was lowered by the increase in levels of added N.* This behavior suggests that $Ca(NO_3)_2$ may not be a desirable calcium source for such applications.

Hong and Lee (1999) have demonstrated the effect of infiltrated calcium on ripening of tomato fruits. In this test, mature-green tomato fruits were vacuum-infiltrated with 1 ml of 0, 2 and 8% calcium chloride and calcium nitrate solutions in distilled water. Vacuum infiltration was accomplished by applying ml of solution on the stem-scar, placing the fruit under 250 torr (4.834 lb/in.^{2}) for 10 seconds and slowly releasing vacuum, allowing the solution to enter the fruit. They have concluded the following:

- As ripening progressed, bound calcium content of control fruit decreased.
- In contrast, fruits treated with 8% $CaCl_2$ or 8% $Ca(NO_3)_2$ had increase in the bound calcium content.

Effect of calcium on firmness of mature-green tomato is shown in Table 10. As can been noted, increase in the concentration of $CaCl_2$ or $Ca(NO_3)_2$ increases the firmness of the fruit. However, test data indicate that the treatment with $CaCl_2$ produces greater degree of fruit firmness than $Ca(NO_3)_2$.

Table 12
Effect of Calcium on Firmness of Mature-Green Tomato Fruit During Storage

Days after Treatment	Control	Firmness (N) after Treatment CaCl$_2$ 2 %	CaCl$_2$ 8 %	Ca(NO$_3$)$_2$ 2%	Ca(NO$_3$)$_2$ 8 %
0	**97.6**	**97.7**	**97.6**	**97.7**	**97.6**
9	**44.0**	**50.0**	**70.2**	**54.7**	**54.5**
18	**36.9**	**38.1**	**44.0**	**30.0**	**34.5**

Mushrooms:

With steadily increasing consumption of fresh mushrooms, the demand for premium quality product at the point of sale mainly focuses on whiter, firmer mushrooms. In literature following claims have been made:

- Applications ranging from 0.01 to 0.5% calcium chloride can affect the following:
  - Improve the color of fresh mushrooms (Beelman et al, 1987; Burton, 2000), stored (Desrumaux et al., 2000)
  - Improve the color of canned mushrooms (Kalberer, 1991)
  - Prolong their shelf life (Solomon et al., 1991; Mikulus and Beelman, 1996).

- From their studies Diamontopoulou and Philippoussis (2001) conclude the following:
  - 0.10% calcium chloride dose has beneficial effects on yield, size and improvement of mushroom firmness.
  - Color improvement at the dosage of 0.25% calcium chloride.

These findings suggest that calcium chloride treatment could be used in the commercial production of mushrooms to improve its quality, in terms of firmness and their brightness.

Potatoes:

For potato, calcium has important roles to play at the various stages: growing, storage and the process stages. At the growing stage, calcium has the following effects:

- Reduction in decay depends on the amount of calcium present in the tubers.

- High calcium containing tubers are less susceptible to decay (McGuire and Kelman, 1984, 1986), and consequently could be stored for a longer period of time.

- Calcium application increases the calcium concentration in the tubers, and the incidence of internal defects was lower in the tubers that contained higher concentration of calcium (Kleinhenz et al., 1999)

Post-harvest and pre-storage treatment of potatoes with calcium is used to extend their storage life. One of the methods to firm up the tissues of potatoes is by heating it at a moderate temperature of 122^{o}F to 176^{o}F (Bartolome and Hoff, 1972). The firming effect has been attributed to the following:

- At temperature lower than 120^{o}F the native pectin of the tissue is inactive.
- At higher temperature free carboxyl groups are produced, which cross-link with the calcium or magnesium ions that are present in the cell interior, and render the tissue firmer.

This behavior has indicated that calcium as an additive could play a role in the firming of potato tissues.

Walter et al. (1993) have shown that when strips of sweet potato were treated with calcium chloride in conjunction with their treatment with Na_2CO_3, there were increased firmness in the strips. The process could be applied to other types of sweet potato products ranging from dice to chunks.

Warren (1992) claims a process for treatment of freshly cut plant parts, which extends the storage life of the parts. The process involves the following:

- Dipping the plant parts in an aqueous solution that contained ascorbic acid, citric acid, sodium polyphosphate and calcium chloride.
- This treatment is claimed to extend the storage life of potatoes, apples, pears and lettuce.
- In this patent, calcium chloride is being claimed to be an enzyme inhibitor.

One of the major problems in the making of french fries has been the darkening of the final product. Calcium chloride can be used as darkening inhibitor. *A combination of gum acacia, gelatin and calcium chloride pretreatment is an effective method for the prevention of after-cooking darkening of french fries (Mazza and Qi, 1991).*

On the treatment of french fries with calcium chloride following further information is available in literature:

- A treatment, which involved a single coating of potato french fries with a combination of 0.5 % calcium chloride and 5% pectin or sodium alginate, reduced the oil content of the fries by 40% (Khalil, 1999). French fries still retained high moisture content.

- A second coating with 1.5% carboxy methyl cellulose (CMC) reduced the oil content by 54%.

- This double coated french fries had higher moisture content than the single coated french fries.

- Scanning electron microscope examination of these treated french fries revealed that both single and double coating process were effective in protecting the cellular structure of potato tissues from damage produced during deep-fat frying.

Market Information: United States produces about 23.75 million tons (1998 Estimated figure) potatoes. Their major consumer usages are approximately as follows:

- Fresh market 26%
- Frozen products (mostly fries) 35%
- Potato chips 11%
- Dehydrated products 12%

Calcium chloride treatment can be applied at the various stages of potato production, post-harvest preparation and processing.

While potato production is spread out in the various parts of the country, Idaho still remains the largest producer followed by Washington, Oregon, Wisconsin and Colorado.

Concluding Remarks:

It is clearly established that calcium deficiency has influence on the disorders of storage organs of fruits and vegetables. Post-harvest treatment or treatment at the processing stage extends their shelf life and also improves their quality. While calcium chloride can be used in a wide range of fruits and vegetable, market potential for apples, potatoes and some of the highly perishable fruits, like strawberries, peaches, pears, cantaloupe etc., is substantial.

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