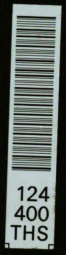

This is to certify that the

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The Application of Calcium to Jonathan Apples by Hydrocooling

presented by

Steven Alonzo Sargent

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of the requirements for

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THE APPLICATION OF CALCIUM TO JONATHAN APPLES BY HYDROCOOLING

By

Steven Alonzo Sargent

A THESIS

Submitted to
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ABSTRACT

THE APPLICATION OF CALCIUM TO JONATHAN APPLES BY HYDROCOOLING

By

Steven Alonzo Sargent

Postharvest physiological disorders of 'Jonathan' apples favored by low fruit calcium can be reduced or retarded by prestorage treatment of harvested apples with calcium chloride ($CaCl_2$). Drench hydrocooling with a calcium solution should increase fruit calcium since fruit cooling aids the infiltration of the drenching solution into the fruit. Cold solutions (3°C) of 0, 2 or 4% $CaCl_2$ with surfactant L-77 were applied for 20 minutes at a rate of 9 gallons per minute per square foot of surface area to warm apples (25°C) held in field crates of 1-bushel capacity. These apples were compared with similar fruits that had been drenched with cold solutions for 1 minute, or drenched with warm solutions for 1 or 20 minutes, and with initially cold apples that had been drenched with warm or cold solutions for 1 or 20 minutes. The apples were not rinsed prior to subsequent storage at 3°C and approximately 90% relative humidity.

Total calcium in the fruit cortex after treatment plus 13 weeks of storage was measured by atomic absorption procedures. The mean for apples hydrocooled with 2% $CaCl_2$ was 3.85 mg of calcium per 100g fresh weight and was equivalent to the fruit calcium of all the 4% $CaCl_2$ treatments except where 4% $CaCl_2$ was applied as a cold solution to cold fruits which was markedly lower in calcium. All other 2% $CaCl_2$ treatments were less effective for increasing fruit calcium than 4% applied in a similar manner. The development of internal breakdown, Jonathan spot and lenticel

spot in apples stored for 17 weeks was generally reduced by calcium application. Surface injury to the fruit by $CaCl_2$ was negligible.

The results indicate that commercial hydrocooling with a 2% $CaCl_2$ solution containing surfactant would be equivalent to the current practice of applying 4% $CaCl_2$ as a brief prestorage drench at ambient temperature. It would serve to precool the apples prior to storage as well as to reduce the hazard of storage disorders.

Dedicated to my parents, Alonzo and Grace Sargent, for their love and encouragement.

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INTRODUCTION

Jonathan apples accounted for approximately 21% of the total Michigan apple production in 1978 (12). The availability of this cultivar for long-term marketing, however, is limited by the development of the postharvest disorders of internal breakdown, Jonathan spot and lenticel spot (28). High levels of fruit calcium (Ca) retard the development of these disorders and since the concentration of Ca within the fruit varies markedly with cultural practices and environmental conditions, the incidence of these disorders varies (26).

Reduction of internal breakdown has been achieved by the application of Ca sprays in the orchard (11; 17), and by direct postharvest application to the fruit (1). Although these physiological or functional disorders are best controlled by the latter method, some epidermal injury occasionally occurs. Lee (15) has shown that a higher initial amount of Ca could be introduced into Jonathan apples by submersion hydrocooling of the apples in 2% calcium chloride ($CaCl_2$) than by momentarily dipping them in 4% $CaCl_2$ solution. Commercial-scale drench hydrocoolers capable of precooling apples are already used in Michigan for highly perishable commodities such as cherries, peaches and asparagus. Apples, however, are normally placed directly into storage rooms and cooled by forced-air circulation (9). The use of hydrocooling with 2% $CaCl_2$ as a means of increasing fruit Ca as well as for precooling apples seems worthy of consideration where hydrocoolers are available, particularly in view of the current interest in energy conservation. This experiment

was designed to examine the feasibility of hydrocooling as a method for increasing fruit calcium in Jonathan apples for control of storage disorders, and to evaluate the effectiveness of 2 and 4% $CaCl_2$ concentrations applied in this manner.

Literature Review

The relationship between the calcium level in the fruit and the development of fruit storage disorders has been verified by a number of researchers (2, 6, 22, 36). Disorders currently associated with low Ca include internal breakdown, bitter pit, corkspot, cracking, lenticel blotch, lenticel breakdown, low temperature breakdown, and watercore (40). Calcium has been determined to be quite mobile within the fruit. As much as 50% of that accumulated in the core region during the growing season migrates outward through the cortex after the first 1-2 months of storage (7). However, it is during the first month of storage that many of the disorders develop in low-Ca regions of the fruit. For example, internal breakdown usually appears as a light brown discoloration in the cortical cells immediately below the epidermis, and during storage this disorder may develop as far as the core, causing mealiness and loss of flavor (42).

The functions of Ca in delaying senescence include the maintenance of membrane integrity and semi-permeability and cell rigidity due to the formation of calcium pectate in the middle lamella (5, 14). Bangerth *et al.* (1) found that postharvest infiltration of $CaCl_2$ in 'Jonathan' apples inhibited internal breakdown, reduced the respiration rate and metabolism of endogenous substrates, and increased the oxidation of exogenous substrates. They suggested that Ca might retard respiration indirectly by limiting the amount of substrates diffusing from the vacuole into the cytoplasm. Similar effects on respiration were obtained by Faust and Shear (10), who cited the respiration rate to be inversely

related to the Ca content of the fruit. Bramlage et al. (6) demonstrated that Ca affects the respiration rate, but independently of maturity and ripening since respiration climacterics for apples with varying Ca levels occurred simultaneously. This independence of Ca and ripening could be species-dependent, however, since Ca application delayed the onset of the climacteric in avocado fruit (44). Cellular disorganization is retarded by Ca, as evidenced by better preservation of organelles in apple tissue high in Ca when compared to tissues which were deficient in fruit Ca (19). The delay in the progress of senescence processes reduces the development of storage disorders (29, 38).

The endogenous Ca level varies greatly with crop loads, orchard location, cultural practices and environmental conditions during the growing season, so it is not unexpected that the severity of disorders fluctuates widely. A comprehensive review of the factors affecting fruit Ca has been compiled by Shear (40). Although methods for increasing the Ca content of apples have been extensively examined, soil applications of Ca sources such as calcium carbonate have not been advantageous due to problems encountered with Ca uptake and translocation by the tree (41). The direct application of Ca salts to the fruit has met with greater success in that Ca can diffuse into the fruit through the direct connection between open lenticels and the intercellular air surrounding the loosely-bound cortical cells. The epidermis and its cuticular layer are the major barriers to Ca entry into the fruit according to Van Goor (45) and Mitchell et al. (24) have shown the number of open lenticels and the thickness of the lipophilic cuticle to vary with apple variety. Since Ca ions are hydrophilic, maximum coverage of the fruit surface by the applied Ca solution is essential.

Repeated preharvest sprays of $CaCl_2$ have increased Ca levels of apples and reduced the incidence of internal breakdown (11), as has a single spray of 5% $CaCl_2$ prior to harvest (17). The former treatment is expensive due to the number of spray applications required, whereas the latter revealed nonuniform distribution of spray droplets on the fruit surface and inconsistent control of breakdown, especially for apples on uppermost branches. The 5% concentration of $CaCl_2$ also caused moderate to severe damage to the foliage.

Postharvest Ca applications have yielded more consistent control of internal breakdown and other disorders than either soil or preharvest spray applications. Rapid movement of Ca into the flesh resulted from fruits being dipped in a 4% $CaCl_2$ solution at ambient temperature, with a significant Ca increase after the first week of storage (21). During subsequent storage for 32 weeks, the Ca continued to migrate toward the core area. This inward movement sufficiently raised the Ca level so as to reduce breakdown in 'Spartan' apples and retard flesh softening (22). The increase in the Ca level during long-term storage under high humidity (85-90%) conditions is attributed by Lidster *et al.* (16) to the hygroscopic properties of $CaCl_2$. Surface-adhering $CaCl_2$ molecules bind with water vapor, forming a thin layer of solution which diffuses through the epidermis to the cortex region.

Ca uptake is enhanced by the addition of food thickeners plus surfactants to the 4% $CaCl_2$ dip solutions (20). The thickeners apparently increase the viscosity of the solution resulting in greater adhesion of the solution to the fruit surface.

Solutions of 6% $CaCl_2$ may cause severe necrosis to the fruit surface of 'Jonathan' apples (1). Some injury from 4% $CaCl_2$ treatments during

long-term storage of 'Jonathan' has been reported (8). Vacuum infiltration of $CaCl_2$ has reduced the incidence of bitter pit (37) and tripled the fruit Ca level in 'James Grieve' apples (13). Ten to 20 pounds per square inch of pressure was employed by Poovaiah (30) to force a 3% solution into the fruit during a 10-minute treatment period. Both methods, vacuum and pressure, substantially increased the amount of Ca infiltrated during a brief period of time so that the remaining surface-adhering Ca could be washed off, thereby preventing the hazard of skin injury during storage.

Hydrocooling has served for many years as a rapid means of precooling highly perishable fruits and vegetables (35). Chilled water (0-3°C) is utilized as a medium to transfer field heat from the commodity to refrigeration coils or crushed ice. Depending upon the capacity of the refrigeration system and the size of the fruit, a temperature reduction of 20°C can be accomplished in 15-30 minutes of hydrocooling (3). Many hydrocooling systems drench water by gravity flow over the commodity as individual items, in crates or in bulk bins, permitting maximal heat transfer at the fruit surface. Other systems use spray nozzles or submergence in agitated water (4). Schomer and Patchen (35), using 3 apple varieties, showed that hydrocooling and air-cooling were equivalent cooling methods, provided the fruits were air-cooled to storage temperature within 7 days. Apples which were slowly air-cooled were of lower quality. The cooling time in many commercial storages may be several weeks due to inadequate refrigeration capacity or air movement. Under these circumstances, the rapid cooling of apples by hydrocooling could permit maximal storage life and a greater percentage of marketable fruits following storage.

Hydrocooling by submergence of the fruit in cold $CaCl_2$ solution has been demonstrated as a means for introducing substantially higher amounts of Ca into 'Jonathan' apples than by dips in $CaCl_2$ solutions at ambient temperature (15). Apples which were hydrocooled a minimum of 10°C in a 2% $CaCl_2$ solution containing 0.1% L-77 surfactant increased in Ca by approximately 6 mg/100g fresh weight per individual fruit. This gain in Ca has been considered to be sufficient for control of internal breakdown and other Ca-related storage disorders of 'Cox's Orange Pippin' (25). A pressure differential between the external solution and the intercellular airspace is created as the volume of intercellular air contracts during fruit cooling, drawing the calcium solution into the fruit via open lenticels, surface breaks, and the calyx canal. Such an increase in Ca could possibly permit the use of the 2% $CaCl_2$ solution instead of 4% which would reduce the incidence of internal breakdown without the hazard of fruit injury (8, 33).

Important considerations in using a $CaCl_2$ hydrocooling solution according to Lee (15) are that a minimum of 10°C reduction in fruit temperature be achieved and that a surfactant be employed to reduce surface tension so as to maintain continuous contact of the solution with the waxy cuticular layer surrounding the epidermis during the treatment period.

Materials and Methods

Commercial drench hydrocooling parameters were considered in the design of equipment for use in this study. Since apples are normally handled in bulk bins, a fruit depth of approximately 24 inches was simulated by placing apples in two vertically-stacked bushel crates which measure 16.75 x 14 x 11.75 inches in height. The drench unit (Figure 1) was constructed of 0.5 inch plywood over a wood frame, with hinged top and front panels and an open bottom. The wood covering provided some insulation from ambient temperature and protection from wind evaporation for the drenching solutions. Plastic drench pans with perforations in the bottom (0.125 inch diameter and spaced 0.5 inch apart) provided a drench pattern identical in area to the top surface of the crate. One drench pan was placed above the top crate and another between the 2 crates. The drench solution flow rate was restricted by the perforations in the drench pans to 9 gallons/minute/square foot of top surface area with sufficient head pressure for adequate dispersion over the fruits as in Figure 2.

An open-top steel tank of about 100 gallons capacity was used to collect the drench solution which was pumped to the top of the drench unit positioned above the collection tank. Six clean 55-gallon steel drums served as storage containers for drench solutions and were located in either a 25°C storage room for warm treatments of 0, 2 and 4% $CaCl_2$ or in a 3°C storage room for the cold treatments of 0, 2 and 4% $CaCl_2$.

Since fruit cooling of at least 10°C is required for a substantial uptake of Ca (15), calculations (Appendix I) revealed that 50 gallons of

Figure 1. The experimental drench hydrocooling unit being prepared for treatment. The circulating pump, foreground, and heater, left, are connected to the system with rubber hoses.

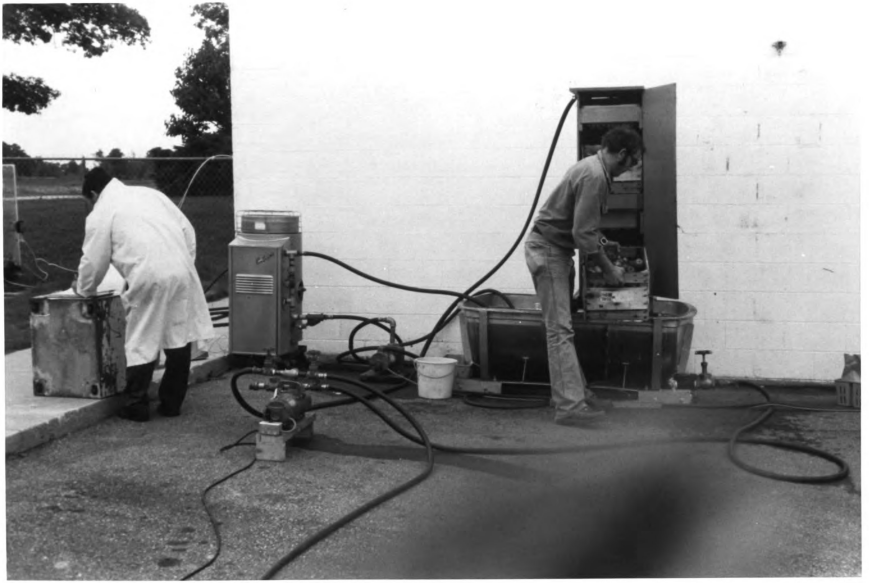

Figure 2. Solution dispersion during drenching as achieved by the use of a plastic pan with 0.125 inch diameter perforations positioned over each of the crates of apples during treatment.


HUNT FARM
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3°C solution would be more than sufficient to remove this amount of heat during a 20-minute hydrocooling drench, when used in combination with ice. Three gallons each of the 0, 2 and 4% $CaCl_2$ drench solutions were frozen, crushed and added to the appropriate solution in the collection tank during treatment. With this procedure, cold drenching solutions warmed only 2-3°C during the 20-minute hydrocooling period. To maintain warm (25°C) solutions during a 20-minute treatment to cold fruits, solutions were circulated through a water heater [1]. Temperatures were held at 25-30°C.

The drench solutions were formulated as follows: 50 gallons of tap water, 0.05 gallon L-77 surfactant [2], 0.08 ounces/gallon of benomyl [3], and either 0, 10.7 lbs. or 21.4 lbs. of $CaCl_2$ [4] for a final concentration of 0, 2 or 4% $CaCl_2$. After mixing, each drench solution was stored in the appropriate storage tank for temperature equilibration prior to treatments.

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[1] Comfort zone LP gas heater, 80,000 B.t.u. Lochinvar Water Heater Corp., Nashville, TN

[2] L-77, organo-modified silicone; surface tension - 20 dynes/cm in 1% solution at 25°C. Application Information Sheet F-44107, Dec. 1972, Union Carbide Corp., 270 Park Ave., New York, NY 10017.

[3] Benlate, A. I. - benomyl (50%), E. I. duPont de Nemours and Co., Inc., Wilmington, DE

[4] Dowflake, 77-80% $CaCl_2$. Dow Chemical Co., Midland, MI

To determine the effectiveness of the drench treatments for coverage of the fruit surfaces, a solution containing 1% Nigrisine dye, tap water and 0.1% L-77 surfactant was drenched over apples in two crates for 1 minute. After air drying, each fruit was visually inspected for the percentage of its surface not covered by dye. For a cold drench applied to warm fruits, 95% of the fruits in the top crate had greater than 90% of their surfaces covered with dye, whereas those in the lower crate had 91% with greater than 90% of the surface covered. The greatest amount of solution channeling and the poorest coverage appeared to be for fruits positioned against the sides or corners of the crates. At these locations 60-70% of a fruit's surface was occasionally found covered by the dye. The points of fruit contact with other fruits resulted in small areas not covered with dye.

The apples were harvested according to the ideal harvest date for long-term storage, based on the M.S.U. system utilizing minimum temperature during the first 15 days after full bloom for each orchard. Sixty bushels of 'Jonathan' apples from the MSU Horticulture Research Center at East Lansing (Orchard 1), were harvested, randomized, labeled and placed at 3 or 25°C overnight for temperature conditioning on October 4, 1978. Each holding room was provided with adequate air circulation to aid temperature conditioning. Treatments were run the following day.

Apples from the Graham Experimental Station at Grand Rapids (Orchard 2) were harvested on October 8, 1978 and handled similarly except they were treated 2 days after harvest. There were marked differences in fruit quality at harvest between the two orchards. Fruits from Orchard 1 had numerous scab infections, which were included in the treatments unless cracked open, as well as 12.5% watercore based upon a random sample of

40 fruits. Apples from Orchard 2 were relatively free from scab and showed no watercore. Fruits from both locations had an average flesh firmness of 14.7 pounds. Flesh firmness determinations were made on 40 fruits (with a press-mounted Effgi tester), with 2 tests performed on opposite sides of each fruit with the epidermis removed prior to testing.

Drenching procedures involved pumping[5/] a given solution from the storage drum (agitated manually) to the collection tank, where it was then pumped to the upper drench pan for application to the fruits. Agitation as a result of the drenching operation maintained solute suspension in the solutions. Depending on the treatment, either the appropriate concentration of frozen solution was added to the cold solutions or the warm solutions were heated to ensure constant temperature of the solution during drenching.

Treatments were run beginning with the cold solutions of 0, 2 and 4% $CaCl_2$ and within each concentration the cold fruits were treated first for 1 or 20 minutes. This was followed by treating the warm fruits for the same drench periods. This entire procedure was reversed for the warm drench solution concentrations. Initial and final temperatures were recorded for each treatment for the drench solutions and from the core region of an apple from the lower crate. After treatment, crates were individually wrapped with perforated polyethylene to provide a high relative humidity environment for the fruits and placed in storage at $3^{\circ}C$.

[5/] Teel centrifugal pump, 1 inch suction and discharge, mounted on a Dayton 1/3 h.p. 3450 rpm 120v motor. Dayton Electric Mfg. Co., Chicago, IL 60648

After 13 weeks of storage, on January 2, 1979, 20 medium-sized fruits were selected from each crate in Orchard 1, labeled and allowed to equilibrate to 22°C overnight in the laboratory. The next day, they were rinsed with 0.5% acetic acid solution, rinsed in tap water to remove surface-adhering Ca and air dried. Flesh firmness mean values were determined for each sample of 20 fruits using the previously described method.

The following day each fruit was sliced twice longitudinally. One slice was made on each side of the core, parallel with the pressure test holes. The center slice containing the core region was discarded and an 8mm diameter cylinder was removed from each apple half with a cork borer. These flesh cylinders were sampled away from surface cuts or holes which may have permitted abnormal Ca entry and contamination. Each cylinder was trimmed to 9mm length immediately below the epidermis so as to sample the Ca only in the cortex. Approximately 10 g of cortex tissue cylinders from each treatment sample was weighed and placed in a 25 ml crucible. The crucibles were covered with plastic to prevent air contamination during tissue sampling and afterward, the tissues were air dried for 70 hours at 82°C.

Upon drying, the tissues were ashed in an electric oven at 560°C for 13 hours. Ash from each crucible was extracted with 5 ml 0.5N HCl with 1% $La(NO_3)_3$ (wt/wt) and the aliquot stored in an air-tight vial (21). If the solution contained any visible carbon due to carmelization of fruit sugars, it was filtered through Whatman #4 paper. The equipment was rinsed and air-dried after each sample was extracted. Fruits from Orchard 2 were sampled in the same manner the following week (January 8, 1979).

A Varian Techtron AA6 spectrophotometer was used for Ca determinations. A standard reference curve for Ca of 0, 10, 20, 30, 40 and 50 ppm was made by dilution of Reference Stock Solution (1000 ppm)[6/] with distilled water. Aliquots from the 2 and 4% $CaCl_2$ drench treatments were diluted 15X with the extracting solution to fit the 0-50 ppm range of the Varian unit, prior to determinations. Calculations for conversion from ppm Ca/aliquot to mg Ca/100 g fresh weight are reported in Appendix 2.

After 16 weeks of storage (February 6, 1979) the crates of fruit from Orchard 1 were removed and placed in the laboratory at 22°C. Immediate examinations of the fruit were made for incidence of the following disorders according to these symptoms:

a. Internal Breakdown - fruit soft when hand squeezed, may show brown to dark brown discoloration on epidermal tissues (28)

b. Jonathan Spot - necrosis not originating from the lenticel, dark blue to black in color (34).

c. Lenticel Spot - any necrosis radiating from the lenticel (34).

d. Calyx Injury - necrosis not related to preharvest injury (e.g. scab, mechanical damage, mite injury) located within the calyx cavity or at the calyx shoulder of the fruit.[7/]

e. Other Injury - lesions on the epidermis other than Jonathan spot or lenticel spot, but obviously arising during storage. Noted especially were small brown streaks at the calyx end, notably on fruits from Orchard 2, possibly an aggravation of preharvest mite injury.

f. Sound Fruit - not having any of the above storage disorder symptoms.

[6/] Fisher Scientific Co., Fairlawn, NJ 07410.

[7/] Injury symptoms, D. H. Dewey, personal communication.

All fruits with pathological decay were discarded and not included in final counts. After a 2-week holding period, to simulate the marketing period, the remaining fruits were examined internally by slicing latitudinally for incidence of internal breakdown. Apples from Orchard 2 were examined in the same manner.

Statistical evaluations of the data after transformation by $\sin^{-1}\sqrt{x}$ (43) were performed by Analysis of Variance (AOV) using the STAT program of the CDC 6500 computer. An initial analysis showed there were no significant differences for fruits in the upper or lower crates as to values for any of the treatment effects (flesh firmness, fruit Ca, disorders, injuries or sound fruits). A second AOV was performed utilizing orchard locations as blocks and the crate positions as replicates. The AOV summary for this analysis in Table 1 shows main treatments, interactions, error terms and the corresponding degrees of freedom (df). Main treatment and interaction effects were compared by Least Significant Difference (lsd) according to the significance of the F-test, using transformed data. Individual treatments were compared by Duncan's Multiple Range Test at the 5% level. The error mean squares used in these means separation tests were based on the sum of Orchard (block) df multiplied by each main treatment and interaction df for a total df of 23. The remaining error consisted of the sum of crate position df multiplied by the df's for block, main treatments and interactions, totaling 48 df. This latter term was not used in the calculations for means separations. Transformed means were converted back to percentage values for data presentation.

TABLE 1

Summation of variation sources and degrees of freedom for analysis of variance

Source	Degrees of Freedom
Main Treatments	
Orchard (Block)	1
Solution Temperature (ST)	1
Fruit Temperature (FT)	1
Drench Duration (DD)	1
$CaCl_2$ Concentration (Ca)	2
2-Way Interactions	
ST x FT	1
ST x DD	1
FT x DD	1
ST x Ca	2
FT x Ca	2
DD x Ca	2
3-Way Interactions	
ST x FT x DD	1
ST x FT x Ca	2
ST x DD x Ca	2
FT x DD x Ca	2
4-Way Interaction	
ST x FT x DD x Ca	2
Total	24
Error (Orchard x Main treatments and interactions)	23
Remaining error (Crate position x all other main treatments and interactions)	48
TOTAL	95

Results

The total calcium of the fruit cortex after the apples had been stored for 13 weeks was greater for apples which were warm (25°C) when subjected to prestorage drenching than those which were cold (3°C), Table 2. The drench period of 20 minutes was more effective for increasing cortex Ca than the 1-minute drench, and as $CaCl_2$ concentration in the drench solution was increased from 0 to 2 and 4%, the fruit Ca was increased (Table 2).

Comparisons of individual treatment means in Table 3 reveal that all treatments of 4% $CaCl_2$ caused significant increases in cortex Ca over the 0% controls, except when cold solutions were applied to cold fruits for 1 or 20 minutes or when a warm solution was applied to cold fruits for 1 minute. Hydrocooling for 20 minutes with 4% $CaCl_2$ (Cold/Warm/20/4) resulted in the highest Ca (4.81 mg/100g fresh weight); it was significantly greater than the 1-minute warm drench of 4% $CaCl_2$ applied to warm fruit (Warm/Warm/1/4, 3.43 mg/100g) which is the treatment currently recommended for the field treatment of Jonathan apples for long-term storage (8).

The most effective treatments containing 2% $CaCl_2$ (Table 3) were those applied to warm fruits for 20 minutes with either warm or cold solutions. Hydrocooling for 20 minutes with 2% $CaCl_2$ (Cold/Warm/20/2) was equivalent to hydrocooling for 20 minutes with 4% $CaCl_2$ and to the 1-minute warm drench of 4% $CaCl_2$ applied to warm fruit for increasing fruit Ca.

The incidence of internal breakdown in fruit which had been stored for 17 weeks at 3°C plus 2 weeks at 22°C was less prevalent in apples from Orchard 2 than from Orchard 1, Table 4. Warm treatment solutions, the

TABLE 2

The effect of treatment on total calcium in the cortex of Jonathan apples after 13 weeks of storage in air at 3°C.

Treatment	Mean[z] (mg/100 g fresh wt.)	l.s.d.
Fruit Temperature		
3°C	2.39 a	0.35**
25°C	2.90 b	
Drench Duration		
1 Minute	2.45 a	0.35**
20 Minutes	2.85 b	
$CaCl_2$ Concentration		
0%	1.82 a	
2%	2.81 b	0.43**
4%	3.31 c	

[z]Means not followed by the same letter are significantly different by lsd, 1% level.

TABLE 3

Mean total calcium in the cortex of Jonathan apples after 13 weeks of storage at 3°C as affected by prestorage treatment

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean[z] (mg/100g fr. wt.)
cold	warm	20	4	4.81
warm	warm	20	4	3.93
cold	warm	20	2	3.85
warm	cold	20	4	3.69
warm	warm	1	4	3.43
cold	warm	1	4	3.01
warm	warm	20	2	3.01
warm	cold	1	4	2.93
warm	cold	20	2	2.82
warm	warm	1	2	2.69
cold	warm	1	2	2.68
cold	cold	1	2	2.67
warm	cold	1	2	2.41
cold	cold	20	4	2.37
cold	cold	20	2	2.35
cold	cold	1	4	2.31
cold	warm	20	0	1.93
warm	warm	1	0	1.88
cold	cold	1	0	1.85
warm	cold	20	0	1.83
cold	warm	1	0	1.82
cold	cold	20	0	1.81
warm	warm	20	0	1.78
warm	cold	1	0	1.69

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range Test, 5% level.

TABLE 4

The effect of treatment on the incidence of internal breakdown in Jonathan apples stored for 17 weeks at 3°C plus 2 weeks at 22°C.

Treatment	Mean (%)[z]	l.s.d.
Orchard		
1	25.9	1.9***
2	6.3	
Solution Temperature		
3°C	18.5	1.1**
25°C	11.3	
Fruit Temperature		
3°C	23.7	1.9***
25°C	7.5	
$CaCl_2$ Concentration		
0%	38.1	1.6***
2%	10.5	
4%	3.4	

[z]Means not followed by the same letter are significantly different.

treatment of warm fruits, and increased concentrations of $CaCl_2$ reduced the occurrence of breakdown.

The individual treatment means presented in Table 5 show that all of the 4% $CaCl_2$ treatments were equivalent to each other in reducing breakdown. All of these, except when applied as a cold solution to cold fruits for 1 or 20 minutes or as a warm solution to cold fruit for 1 minute, caused significant decreases in breakdown over the 0% $CaCl_2$ treatments. The 2% $CaCl_2$ applications reduced breakdown as well as the 4% treatments in most instances. The exceptions were when warm or cold solutions were applied to cold fruits for 1 minute, and when a cold solution was applied to cold fruits for 20 minutes.

The data in Table 6 show less incidence of Jonathan spot after 17 weeks of storage for apples from Orchard 2 than from Orchard 1. Fruits which were cold prior to treatment developed less Jonathan spot than those that were treated while warm. Drenching for 20 minutes reduced the incidence over the 1-minute drench. As $CaCl_2$ concentration of the drenching solution increased, the occurrence of Jonathan spot in storage decreased, ranging from 12.7% for 0%, down to 3.4 and 0.8% for 2 and 4% $CaCl_2$, respectively.

Comparisons of the individual treatment means in Table 7 reveal that Jonathan spot occurred most extensively for the 0% $CaCl_2$ treatments of cold or warm solutions applied to warm fruits for 1 minute and warm solution applied to warm fruits for 20 minutes.

The incidence of lenticel spot after 17 weeks of storage varied by orchard location, with a lower percentage occurring in apples from Orchard 2 than from Orchard 1, Table 8. Increasing the drench period to 20 minutes

TABLE 5

Prestorage treatment effects on the incidence of internal breakdown in Jonathan apples after 17 weeks storage at 3°C and 2 weeks at 22°C.

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean (%)[z]
warm	warm	20	4	0.1
cold	warm	20	4	0.5
warm	warm	1	4	0.6
cold	warm	1	4	1.0
warm	warm	20	2	1.5
warm	cold	20	4	1.6
warm	warm	1	2	2.2
cold	warm	20	2	2.2
cold	warm	1	2	5.3
warm	cold	1	4	9.4
warm	cold	20	2	10.6
cold	cold	1	4	13.3
cold	cold	20	4	14.1
warm	warm	1	0	23.1
warm	cold	1	2	25.6
warm	warm	20	0	27.8
cold	cold	1	2	28.6
cold	warm	1	0	29.2
cold	cold	20	2	29.8
warm	cold	20	0	36.9
warm	cold	1	0	43.0
cold	cold	1	0	45.1
cold	warm	20	0	49.5
cold	cold	20	0	52.5

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range test, 5% level.

TABLE 6

The effect of treatment on the incidence of Jonathan spot after 17 weeks of storage in air at 3°C.

Treatment	Mean (%)[z]	l.s.d.
Orchard		
1	7.5 a	0.9***
2	2.2 b	
Fruit Temperature		
3°C	3.1 a	0.5**
25°C	6.0 b	
Drench Duration		
1 Minute	6.0 a	0.5**
20 Minutes	3.1 b	
$CaCl_2$ Concentration		
0%	12.7 a	1.4***
2%	3.4 b	
4%	0.8 c	

[z]Means not followed by the same letter are significantly different.

TABLE 7

Prestorage treatment effects on incidence of Jonathan spot after 17 weeks storage in air at 3°C.

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean (%)[z]
warm	warm	20	4	0.1
cold	warm	20	4	0.1
cold	warm	20	2	0.6
cold	cold	20	4	0.6
warm	cold	20	4	0.7
cold	cold	1	4	0.9
warm	cold	1	4	1.5
cold	warm	1	4	1.8
warm	warm	1	4	2.0
warm	cold	20	2	2.2
cold	cold	1	2	2.3
cold	cold	1	0	3.1
warm	warm	20	2	3.7
cold	cold	20	2	3.7
warm	cold	1	2	4.3
cold	warm	1	2	5.7
cold	cold	20	0	6.1
cold	warm	20	0	7.0
warm	warm	1	2	7.3
warm	cold	20	0	9.1
warm	cold	1	0	9.7
warm	warm	20	0	22.3
warm	warm	1	0	26.7
cold	warm	1	0	28.6

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range Test, 5% level.

TABLE 8

The effect of treatment on the incidence of lenticel spot after 17 weeks of storage in air at 3°C.

Treatment	Mean (%)[z]	l.s.d.
Orchard		
1	12.1a	1.1**
2	3.7b	
Drench Duration		
1 Minute	8.9a	0.3*
20 Minutes	5.9b	
$CaCl_2$ Concentration		
0%	16.4a	1.0**
2%	4.7b	
4%	3.5c	

[z]Means not followed by the same letter are significantly different.

reduced lenticel spot over the 1-minute period, as did increasing the $CaCl_2$ concentration from 0 to 2% and to 4%.

The individual treatments means in Table 9 show that the highest incidence of lenticel spot resulted from treatments without Ca, especially when applied as warm or cold solutions to warm fruits for 1 minute, or as cold solution to cold fruits for 1 minute, or as a warm solution to warm fruits for 20 minutes. All other treatments were of similar effect in significantly reducing lenticel spot over the above treatments.

Although fruit injury at the calyx end of the apples was relatively slight after 17 weeks of storage, fruits from Orchard 2 were damaged more than those from Orchard 1, Table 10. Comparison of the individual means by Duncan's Multiple Range Test showed there was no significant effect of the individual treatments on occurrence of calyx injury.

Damage classified as "other injury" developed on apples during storage. It occurred most frequently on fruits which were cold when treated and on apples receiving the higher $CaCl_2$ concentrations, Table 11. The individual treatments were of no significant effect on this type of injury.

Apples treated with 4% $CaCl_2$ had a mean flesh firmness of 9.8 pounds when examined after 13 weeks of storage, a decrease of 4.9 pounds from the firmness at treatment of 14.7 pounds. They were significantly firmer than the 9.4 pounds firmness for apples receiving 0%, but not for the 9.6 pounds of those treated with 2% $CaCl_2$. Firmness of fruit for the 0 and 2% $CaCl_2$ treatments were not significantly different. Comparisons of individual treatment means in Table 12 show there was a relatively narrow range of values, and that significantly higher firmness occurred only for

TABLE 9

Prestorage treatment effects on incidence of lenticel spot after 17 weeks of storage in air at 3°C.

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean (%)[z]
warm	warm	20	4	0.8
cold	cold	1	4	1.5
cold	warm	20	2	1.8
warm	cold	1	4	3.1
cold	cold	1	2	3.7
cold	cold	20	4	3.7
cold	warm	1	4	3.9
warm	warm	1	4	4.0
warm	warm	20	2	4.3
warm	cold	20	4	4.4
warm	cold	20	2	4.5
cold	cold	20	2	4.8
warm	cold	1	2	4.9
warm	warm	1	2	5.6
cold	warm	20	0	6.0
cold	warm	20	4	9.1
cold	cold	20	0	9.3
cold	warm	1	2	9.5
warm	cold	1	0	12.1
warm	cold	20	0	12.9
warm	warm	20	0	17.3
cold	cold	1	0	19.4
warm	warm	1	0	28.3
cold	warm	1	0	32.2

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range Test, 5% level.

TABLE 10

The effects of treatment on the percentage of calyx injury after 17 weeks storage in air at 3°C

Treatment	Mean[z]	l.s.d.
Orchard		
1	0.004 a	0.130***
2	0.160 b	
$CaCl_2$ Concentration		
0%	0.004 a	0.060*
2%	0.052 a	
4%	0.071 b	

[z]Means not followed by the same letter are significantly different.

TABLE 11

The effects of treatment factors on the percentage of other injury after 17 weeks of storage in air at 3°C

Treatment	Mean[z]	l.s.d.
Fruit Temperature		
3°C	2.8 a	0.4*
25°C	0.8 b	
$CaCl_2$ Concentration		
0%	0.4 a	1.1***
2%	1.7 b	
4%	3.8 c	

[z]Means not followed by the same letter are significantly different.

TABLE 12

Prestorage treatment effects on flesh firmness of Jonathan apples after 13 weeks of storage in air at 3°C.

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean (lbs.)[z]
cold	warm	20	4	10.47
warm	cold	20	4	10.02
cold	cold	20	2	9.95
warm	warm	1	0	9.94
warm	cold	1	4	9.91
cold	warm	20	2	9.90
cold	cold	20	4	9.77
warm	warm	20	4	9.77
cold	cold	1	2	9.67
cold	cold	1	4	9.61
warm	warm	1	2	9.60
warm	warm	1	4	9.59
warm	cold	1	2	9.59
warm	warm	20	0	9.58
warm	cold	20	0	9.56
cold	warm	1	4	9.53
warm	warm	20	2	9.52
cold	cold	20	0	9.50
cold	warm	1	0	9.49
warm	cold	20	2	9.43
cold	warm	1	2	9.28
warm	cold	1	0	9.18
cold	warm	20	0	9.17
cold	cold	1	0	9.16

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range Test, 5% level.

apples which had been hydrocooled for 20 minutes with 4% $CaCl_2$. This treatment yielded firmer fruits than any of the 0% $CaCl_2$ treatments, with the exception of warm solution applied to warm fruit for 1 or 20 minutes. Hydrocooling with 4% $CaCl_2$ for 20 minutes also maintained firmness over treatments in which 4% $CaCl_2$ was applied as a cold solution to warm fruits for 1 minute, and in which 2% $CaCl_2$ was applied as a warm solution to warm or cold fruits for 20 minutes, or as a cold solution to warm fruits for 1 minute.

Sound apples were so classified when free from internal breakdown, Jonathan spot, lenticel spot, and calyx and other injuries when removed from storage 17 weeks after treatment. Table 13 summarizes the results that show there was a greater number of sound fruits for Orchard 2 than for Orchard 1 and that the application of 2% $CaCl_2$ significantly increased the percentage of sound fruits over the 0% Control, whereas, 4% $CaCl_2$ gave significant increases over both of the 0 and 2% concentrations.

The means for individual treatments in Table 14 show the highest percentages of sound fruits to have resulted from all of the 4% and most of the 2% $CaCl_2$ treatments. For the latter, $CaCl_2$ applied as a cold solution to cold fruits for 1 or 20 minutes was the least effective.

TABLE 13

The effects of treatment on the percentage of sound apples after 17 weeks of storage

Treatment	Mean[z]	l.s.d.
Orchard		
1	71.4 a	1.8***
2	86.1 b	
$CaCl_2$ Concentration		
0%	60.2 a	1.5**
2%	85.7 b	
4%	88.3 c	

[z]Means not followed by the same letter are significantly different.

TABLE 14

Prestorage treatment effects on the percentage of sound Jonathan apples after 17 weeks of storage in air at 3°C.

Solution Temperature	Fruit Temperature	Drench Duration	% $CaCl_2$	Mean [z]
cold	warm	20	2	96.6
warm	warm	20	4	94.9
cold	warm	1	4	91.8
cold	cold	1	4	91.4
warm	warm	20	2	91.3
warm	cold	20	4	90.9
warm	cold	20	2	89.5
warm	warm	1	4	88.0
warm	warm	1	2	88.0
cold	warm	1	2	86.1
cold	cold	20	4	83.8
cold	warm	20	4	82.2
warm	cold	1	2	80.6
warm	cold	1	4	80.3
cold	warm	20	0	74.0
cold	cold	20	2	73.7
cold	cold	1	2	71.7
warm	warm	20	0	63.5
warm	cold	1	0	63.5
cold	cold	1	0	63.0
warm	cold	20	0	62.1
cold	cold	20	0	58.8
warm	warm	1	0	48.2
cold	warm	1	0	47.7

[z]Means not connected by the same line are significantly different according to Duncan's Multiple Range Test, 5% level.

Discussion

The results of this study show that total fruit Ca is increased by the postharvest application of $CaCl_2$ to fruit in agreement with the findings of Mason and Drought (21), Millikan and Hanger (23) and Van Goor (45). The range of Ca values from 1.69 to 4.81 mg/100g fresh weight is similar to those obtained by Lee (15) for the 'Jonathan' variety, Perring (26) for 'Cox's Orange Pippin,' and Sharples and Johnson (38) for 'James Grieve'. Although there were treatment differences in total fruit Ca, the increase in Ca induced by a particular drenching treatment is not known since the determinations were made after the apples had been stored for 13 weeks with $CaCl_2$ adhering to the surface. As demonstrated by Lidster *et al* (16) high humidity conditions in storage favor the migration of Ca from the surface through open lenticels and into the cortex region during the storage period. It is assumed that Ca continued to migrate into the fruits during this 13-week storage period and that this migration was similar for all fruits treated with a given $CaCl_2$ concentration. Therefore, the values for fruit Ca as determined after 13 weeks of storage are the sum of Ca accumulated in the fruits during the growing season, plus the Ca induced during treatment, plus the Ca which moved into the fruits from the surface during the storage period.

The 4% $CaCl_2$ concentration, application to warm fruits and the 20-minute treatment period were the most favorable factors for increasing fruit Ca. The application of 2% $CaCl_2$ by hydrocooling for 20 minutes yielded fruit Ca values similar to those of the commercial method currently practiced, which is the brief drenching with 4% $CaCl_2$ as a warm

solution to warm fruits. Levels of fruit Ca were significantly higher when 4% $CaCl_2$ was applied as a hydrocooling treatment for 20 minutes than when applied by the simulated commercial method. The decision as to which of the above treatments would be the most appropriate for commercial use would be determined by the level of Ca desired in the fruits after treatment, the possibility of $CaCl_2$ injury to fruit surfaces, and the feasibility of hydrocooling to precool the apples.

The higher Ca levels in fruits which were hydrocooled with 2 or 4% $CaCl_2$ solutions is explained by the work of Lee (15) whereby cooling reduces the pressure of the intercellular air below that of the surrounding drench solution. This causes an intake of the solution into the fruit via open lenticels and breaks in the epidermis. Lee considered a minimal decrease of 10°C as necessary for the immediate Ca uptake to be significantly greater than that induced by non-hydrocooled Ca applications. In the experiment reported here the fruits were cooled approximately 10-15°C.

The $CaCl_2$ applied as cold solutions to cold fruits resulted in only a slight increase in total fruit Ca over the non-Ca (0% $CaCl_2$) treatments (Table 3), probably because there was no reduction in the volume of intercellular air and hence, little Ca uptake during the treatment. Lee (15) in measuring Ca uptake by fruit weight gain immediately after treatment, obtained similar results and attributed this ineffectiveness to the fruits being in equilibrium with the drenching solution. Another factor which no doubt affected Ca infiltration during treatment was coverage of the apples by the drench solution. The use of Nigrisine dye to evaluate coverage revealed that as much as 10% of the surface of 5-10% of the apples was not covered after a 1-minute drench with either warm or cold solution.

Channeling of the solution between the fruits appeared to be the major source of incomplete coverage, especially for apples which rested against the side or corners of the crate. During hydrocooling treatments, the exposed surfaces allowed the uptake of air rather than solution since pressure in the fruit equilibrated with atmospheric pressure, negating the driving force for solution uptake by the apples. Incomplete coverage could have reduced Ca uptake during non-hydrocooling treatments as well, but this appears to be less a factor due to Ca movement into the fruits during long-term storage.

Correlations between fruit Ca and disorders, flesh firmness and sound fruits were calculated to aid in the explanation of these relationships. There was a highly significant linear but inverse correlation between fruit Ca and the incidence of internal breakdown ($y=3.37-0.38x$; $r=-0.81$; $P=0.01$). Breakdown is a senescence disorder and it is known that increased Ca delays senescence, since fruit respiration is suppressed with increased fruit Ca levels (1, 10, 6). This reduced respiration is related to better maintenance of cellular integrity so as to retard the development of storage disorders (10). Another hypothesis is that sufficient fruit Ca may maintain proper substrate metabolism so as to prevent the accumulation of toxic products which cause the breakdown disorder (1, 46). Sufficient Ca may also preserve cellular integrity by maintaining protein synthesis (10).

It was found that with a mean Ca level above 3.0 mg/100g fresh weight per fruit, the incidence of internal breakdown was less than 2% (Appendix 3). This is consistent with the results of Perring (25) who reported that Cox's Orange Pippin apples with a collective sample mean greater than

4.5 mg/100g should remain free of senescent breakdown during long-term storage. The threshold level for an individual fruit was lower at 3.0 mg/100g. He (26) also showed that the threshold levels for fruit Ca fluctuate with orchard location as well as seasonally, and postulated that high concentrations of phosphorus, potassium, magnesium and dry matter may offset the otherwise detrimental effects of low Ca. This may partially explain why apples from Orchards 1 and 2 in this study had similar means for fruit Ca, and yet those from Orchard 1 developed significantly more internal breakdown, Jonathan spot and lenticel spot (Tables 2, 4, 6, and 8). Differences in orchard management such as pruning, water relations and nutrition program most likely had a bearing on overall fruit nutrition, as reported by Redmond (32). Another reason for the more frequent occurrence of disorders in fruits from Orchard 1 may have been overmaturity, since 12.5% of the fruits showed watercore at harvest. Apples from Orchard 2 were free from this disorder which, according to Smock (42) is an indication of advanced maturity.

Fruits drenched with 0% $CaCl_2$ which remained warm until placement in storage had significantly less breakdown (23.1% in Table 5, for warm/warm/1/0) than those which were either cooled prior to treatment (52.5%, cold/cold/20/0) or which were cooled during treatment as a result of hydrocooling (49.5%, cold/warm/20/0). Similarly, breakdown was significantly reduced in 'Spartan' apples by holding the fruits for 3 days at 21°C prior to cold storage (31).

The retardation of flesh softening as a result of increased fruit Ca has been reported by other workers (1, 22). In this study, firmness values were significantly correlated to fruit Ca determinations

(y=-12.28+1.55x; r=0.57; P=0.05), Appendix 3. The possible preservation of cellular organization by Ca would have contributed to the reduced amount of softening.

Significant negative linear correlations as determined from the data in Appendix 3 existed between fruit Ca and Jonathan spot (y=3.03-0.06x; r=-0.58; P=0.01) and between fruit Ca and lenticel spot (y=3.08-0.05x; r=-0.57; P=0.01). As with internal breakdown, this inverse relationship of physiological disorders to fruit Ca appears to be more a consequence of delayed senescence due to a higher fruit Ca than to any direct effect of Ca on the development of the disorder (38). The incidence of Jonathan spot was reduced significantly by cooling the fruit prior to drenching without Ca application (Table 7). Fruits which did not receive Ca during treatment, but remained warm until placement into cold storage had the greatest amount of Jonathan spot. Studies by Richmond and Dewey (34) found this disorder was favored by overmaturity at harvest and low fruit nitrogen. Additionally, storage at temperatures below 21°C sometime during the holding period was necessary before Jonathan spot would develop.

Calyx injury to fruits from $CaCl_2$ was less than 1% (Table 10) and of little effect on overall fruit quality. Other injury (Table 11) occurred with greater frequency, but whether it was caused by $CaCl_2$ penetration at points of preharvest injury or by the slow development of damage during storage is unknown.

The percentage of sound apples was correlated to fruit Ca (y=-0.45+0.04x; r=0.71; P=0.01). Significant increases in the amount of sound fruits resulted for all treatments involving the application of Ca over the non-Ca treatments, except for 2% $CaCl_2$ applied to cold fruits (Table 14).

Total fruit Ca and, hence, reduction of internal breakdown was generally affected more by the concentration of $CaCl_2$ applied during treatment than by solution temperature, fruit temperature, or drench duration. Even so, a drench of 2% $CaCl_2$ with proper surfactant applied as by commercial hydrocooling procedure would likely serve the dual purpose of precooling Jonathan apples prior to storage while increasing the fruit calcium level sufficiently to control the development of internal breakdown.

Summary and Conclusion

Drench hydrocooling was examined as a possible means of post-harvest $CaCl_2$ application to 'Jonathan' apples for the control of storage disorders. Experimental conditions utilized to assure maximum effectiveness of the hydrocooling treatments were the inclusion of the surfactant L-77 in the drench solution, a solution flow rate of 9 gallons per minute per square foot of surface area, and a 10°C or greater decrease in fruit temperature during the 20-minute treatment period. Hydrocooling for 20 minutes with 4% $CaCl_2$ significantly increased total fruit Ca over the current practice of drenching apples momentarily with 4% $CaCl_2$ at ambient temperature, whereas hydrocooling for 20 minutes with 2% $CaCl_2$ was equivalent to both of the above 4% treatments. Reductions in the occurrence of internal breakdown, Jonathan spot and lenticel spot after 17 weeks of storage in air at 3°C were related to the increase in fruit Ca. Fruit injury from $CaCl_2$ treatment was of minor importance.

APPENDIX

APPENDIX 1

Calculations for the cooling requirements of treatments utilizing 3°C drench solutions.

1) Field heat = (specific heat of apple) x (temperature differential) x (sample weight)

[Lutz and Hardenburg, 1968]

= (0.87) x (20°F) x (40 lbs/crate) x (2 crates/treatment)

= 1392 B.t.u.

2) Heat loss due to poor insulation = 50% [Mitchell et al, 1972]

= 1392 x .50

= 2784 B.t.u.

3) Vital heat (heat of respiration) and field heat of crates were negligible sources of heat

4) 1 gallon = 8.33 lbs.

5) Acceptable solution temperature increase = 6°F.

6) Heat capacity of water = 8.33 x 6°F = 50 B.t.u./gallon

7) Heat capacity for 40 gallons of solution = 50 x 40 gal = 2000 B.t.u.

8) Heat capacity of ice (32°F) = 144 B.t.u./lb.

9) Heat capacity of 25 lbs. ice = 144 x 25 = 3600 B.t.u.

10) Total heat capacity of 40 gallons solution with 25 lbs. crushed ice

= 2000 + 3600 = 5600 B.t.u.

The safety range of 2816 B.t.u. (5600-2784) should have been more than sufficient for maintaining the drench solution within the range of 3 - 6°C during the 45 minutes necessary for running all of the cold solutions.

APPENDIX 2

Calculations for conversion of ppm fruit Ca to mg Ca/100g fresh weight.

1) mg Ca in 5 ml aliquot

$= (5ml) \times (10^{3} mg\ g^{-1}) \times (ppm\ aliquot) \times (10^{-6}) \times (15$ dilution factor, if applicable)

2) mg Ca/100g fresh weight

= [(mg Ca in aliquot) / (g fresh weight)] x (100g)

APPENDIX 3

Comparison of cortex Ca after 13 weeks of storage to occurrence of disorders, flesh firmness, and amount of sound Jonathan apples after 17 weeks of storage[z]

		Disorders				
Treatment	Cortex Ca	Internal Breakdown	Jonathan Spots	Lenticel Spots	Flesh Firmness	% Sound
C/W/20-4	1 4.81	2 0.5	2 0.1	16 9.1	1 10.47	12 82.2
W/W/20-4	2 3.93	1 0.1	1 0.1	1 0.8	8 9.77	2 94.9
C/W/20-2	3 3.85	8 2.2	3 0.6	3 1.8	6 9.90	1 96.6
W/C/20-4	4 3.69	6 1.6	5 0.7	10 4.4	2 10.02	6 90.9
W/W/ 1-4	5 3.43	3 0.6	9 2.0	8 4.0	12 9.59	8 88.0
C/W/ 1-4	6 3.01	4 1.0	8 1.8	7 3.9	16 9.53	3 91.8
W/W/20-2	7 3.01	5 1.5	13 3.7	9 4.3	17 9.52	5 91.3
W/C/ 1-4	8 2.93	10 9.4	7 1.5	4 3.1	5 9.91	14 80.3
W/C/20-2	9 2.82	11 10.6	10 2.2	11 4.5	20 9.43	7 89.5
W/W/ 1-2	10 2.69	7 2.2	19 7.3	14 5.6	11 9.60	9 88.0
C/W/ 1-2	11 2.68	9 5.3	16 5.7	18 9.5	21 9.28	10 86.1
C/C/ 1-2	12 2.67	17 28.6	11 2.3	5 3.7	9 9.67	17 71.7
W/C/ 1-2	13 2.41	15 25.6	15 4.3	13 4.9	13 9.59	13 80.6
C/C/20-4	14 2.37	13 14.1	4 0.6	6 3.7	7 9.77	11 83.8
C/C/20-2	15 2.35	19 29.8	14 3.7	12 4.8	3 9.95	16 73.7
C/C/ 1-4	16 2.31	12 13.3	6 0.9	2 1.5	10 9.61	4 91.4
C/W/20-0	17 1.93	23 49.5	18 7.0	15 6.0	23 9.17	15 74.0
W/W/ 1-0	18 1.88	14 23.1	23 26.7	23 28.3	4 9.94	23 48.2
C/C/ 1-0	19 1.85	22 45.1	12 3.1	22 19.4	24 9.16	20 63.0
W/C/20-0	20 1.83	20 36.9	20 9.1	20 12.9	15 9.56	21 62.1
C/W/ 1-0	21 1.82	18 29.2	24 28.6	24 32.2	19 9.49	24 47.7
C/C/20-0	22 1.81	24 52.5	17 6.1	17 9.3	18 9.50	22 58.8
W/W/20-0	23 1.78	16 27.8	22 22.3	21 17.3	14 9.58	18 63.5
W/C/ 1-0	24 1.69	21 43.0	21 9.7	19 12.1	22 9.18	19 63.5

[z]Rank within each classification - ascending for disorders, descending for firmness and sound fruit.

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