CONTROL OF INTERNAL BREAKDOWN IN JONATHAN APPLE FRUITS BY PREHARVEST REGULATION OF SORBITOL CONTENT

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ABSTRACT

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By

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The close relationship of the occurrence of watercore in Jonathan apple fruits at the time of harvest to the subsequent development of internal breakdown during fruit storage and marketing indicated that the internal breakdown disorder could be controlled by preharvest regulation of the sorbitol content of the fruit. Orchard treatments designed to modify the supply or metabolism of sorbitol were applied to replicated 8-year old Jonathan trees in a commercial orchard beginning in 1970. Fruit samples were taken at several harvest dates, stored in air or controlled atmosphere at 0^{o} and $2^{o}C$, and evaluated for various quality characteristics, sorbitol content, and incidence of watercore, internal breakdown and other disorders. Treatments utilizing calcium as a tree spray or fruit dip were extensively examined during the 1971-72 fruit production and storage season.

Defoliation of the trees approximately one week before fruit harvest was effective in reducing sorbitol and watercore at harvest and the subsequent development of internal breakdown.

Complete defoliation, either chemically or by hand, was more effective than partial defoliation by pruning of the terminal growth. Since there was a significant positive correlation of sorbitol with watercore and of sorbitol with internal breakdown, it is concluded that defoliation regulated internal breakdown as a result of its effect on the sorbitol content of the fruit.

Fruit thinning, injection of sorbitol into the tree and orchard sprays of ethephon increased sorbitol and watercore at harvest and the subsequent development of internal breakdown. Fruits from trees receiving these treatments had higher rates of respiration and ethylene evolution than apples from chemically defoliated or kinetin-sprayed trees. It is probable that the significant increase in sorbitol and watercore, and therefore internal breakdown, of ethephon-sprayed trees was due to acceleration of fruit ripening.

Several applications of calcium chloride and single applications of lime sulfur as orchard sprays significantly reduced sorbitol and watercore, and eventually internal breakdown during storage. The significant negative correlations of fruit sorbitol with fruit Ca and internal breakdown with fruit Ca, when considered with the findings of other investigators, indicate that Ca facilitates the metabolism of sorbitol and its storage as fructose in the cells.

Fruits sprayed with calcium or lime sulfur solutions had lower respiration rates and less C_2H_4 evolution than nontreated fruits of the same chronological age. This lower metabolism would decrease the possibilities for accumulation of toxic compounds that may develop as a result of watercore. Apples free of watercore would be unlikely to accumulate toxic quantities of volatile metabolites because of good gas exchange properties of the fruit tissues. Tissue porosity, as measured by gas flow from the pith outward, decreased markedly with increases in watercore content at harvest.

Several possibilities for the practical control of internal breakdown of Jonathan apples are suggested by the results of these experiments. One is to prevent the accumulation of sorbitol in the fruit by regulation of its source of supply, as accomplished by the preharvest defoliation of the tree. Another is by the facilitation of fruit sorbitol metabolism with calcium applied as a preharvest spray or post-harvest dip.

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A THESIS

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To My Wife and Children

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INTRODUCTION

The Jonathan variety is of great importance to the apple industry of Michigan since it accounts for 27% of the apples produced (Michigan Agricultural Statistics, 1970) and 29% of the fruit stored (Michigan Apple Council, 1971). Internal breakdown is a physiological disorder of considerable importance to this variety since its occurrence can cause significant economic losses during storage and marketing. Numerous investigators (Brooks et al. 1920; Palmer, 1931; Kemp et al. 1939; Ceponis and Friedman, 1969; Lord and Damon, 1966) have related the incidence of internal breakdown to the watercore content of the harvested apples. Watercore is a physiological disorder which occurs mostly in late harvested fruits. It is characterized by clear translucent areas of tissue in which the intercellular spaces are filled with a liquid recently identified by Williams (1966) as containing sorbitol which is the D-glucitol analog of glucose. Sorbitol is produced in the leaves and translocated to the fruit where it is usually transformed to fructose and stored. Most varieties lose their capacity to convert sorbitol after a given degree of ripeness is attained. They then accumulate sorbitol in the intercellular spaces, forming the condition known as watercore (Kollas, 1968).

Recent work by Smagula et al. (1968) has associated watercore with abnormal metabolic processes in the cells leading to the accumulation of toxic compounds mainly ethanol, acetaldehyde and ethylacetate. These workers demonstrated that these substances alone or together applied exogenously or developed endogenously, would cause cell damage and browning of the cortical tissue.

The close relationship of watercore at the time of fruit harvest to the development of internal breakdown in storage, and of watercore to sorbitol metabolism suggest that internal breakdown and watercore could be controlled by regulation of the sorbitol content in apples. Accordingly, a study was undertaken to attempt to modify by orchard practices the sorbitol content of Jonathan apples before harvest and to relate such modifications to the subsequent development of internal breakdown.

LITERATURE REVIEW

Some of the factors affecting internal breakdown, a serious physiological disorder that develops during the storage of Jonathan apples, have been studied in recent years by graduate students at Michigan State University. The literature has been extensively reviewed by Bunemann (1958), Chace (1959), Kerawala (1968), Stebbins (1970) and Kilby (1971). Additionally, an excellent review on internal breakdown as well as other disorders, including watercore, was recently published by Faust et al. (1969). The latter authors have dealt with these disorders in respect to their relation to carbohydrate metabolism within the fruit.

Stebbins (1970) demonstrated a highly significant positive correlation of fruit watercore and susceptibility to the development of internal breakdown in Jonathan apples. Similar results were reported as early as 1931 by Palmer (1931) and in recent years attempts have been made to reduce the incidence of breakdown in Delicious apples by sorting out fruit with watercore by light transmittance procedures (Bramlage and Shipway, 1969).

The close correlation of watercore symptoms at harvest and the subsequent development of internal breakdown suggest a possible cause-effect relationship. And, perhaps controlling watercore would be a means of reducing the extent of the internal breakdown disorder.

Watercore, depending on the variety, is usually confined to the interior fruit tissues but occasionally may be visible externally. When the affected fruit is cut in half, transversely, circular areas of translucent tissue associated with vascular bundles can clearly be distinguished from the adjacent normal white flesh. The cells of affected tissue are highly turgid and the intercellular spaces are filled with liquid containing solutes at a higher concentration than that of adjacent healthy cells (Williams, 1966). Tissues being affected by watercore are characterized by a rapid decrease in starch and a corresponding increase in soluble sugars as compared to unaffected tissue (Norton, 1911). On the basis of these results, Carne (1948) proposed that rapid, premature hydrolysis of starch raises the osmotic concentration, and causes a rapid movement of sap from the vascular strands to the adjacent cells, resulting in watercore. However, Brown (1943) measured the starch and soluble solids of tissues with and without watercore and concluded that factors other than the conversion of starch to sugar may be responsible for its development. He also observed that areas around the vascular bundles were the last to become free of starch and these were the areas in which watercore first appeared. Brown also noted that watercored apples upon removal from the spur, showed an exudation of liquid from the stem and cluster base, thereby suggesting that physiological changes in the tree rather than in the fruit contributed to watercore

development. Kollas (1968) concluded that watercore was due to a condition of the fruit rather than tree or foliage conditions by grafting a branch of an early variety onto a tree of a late variety. The early variety matured early as usually and developed watercore.

It is generally accepted that carbohydrates move freely within a woody tree or herbaceous plant. Assimilates labelled with ^{14}C moved into developing fruits of apples and grapes from leaves situated either above or below (Hale and Weaver, 1962; Hansen, 1969). Fruit thinning and defoliation experiments have shown that growth of fruit can be sustained by leaves situated a considerable distance away (Haller and Magness, 1925); for apples (Haller, 1930) and grapes (Winkler, 1932), fruit growth was maintained with leaves no closer than 4 and 10 feet.

The sugar alcohol, sorbitol (D-glucitol) is known to be a major constituent of the leaves and fruits of a number of Rosaceae sp, such as apple and plum; for example the sorbitol content in apple leaves and fruits is approximately 2.2% and 0.6% of the fresh weight, respectively (Anderson et al. 1961; Whetter and Taper, 1963; Taper and Liu, 1969). Following application of $^{14}CO_2$ to leaves on an apple shoot, Webb and Burley (1962) found three times as much radioactivity in sorbitol extracted from the bark at distances of up to 60 cm., as in sucrose.

These findings, together with the observation that sorbitol and glucose were major constituents of the sieve tube exudate of apples, led Webb and Burley, (1962) to conclude that sorbitol was an important transport carbohydrate in this species. In support of this view, Williams (1967) found that ^{14}C from ^{14}C-sorbitol applied to apple leaves moved much faster than from application of ^{14}C-sucrose.

Williams (1966) found that watercored fruits of Delicious apples were consistently low in sugars and at least twice as high in sorbitol as nonwatercored fruits picked the same day. Sorbitol levels of the leaves declined sharply and simultaneously with watercore development in the fruit. The sorbitol levels in the fruit increased as severity of watercore increased. Since total sugars were not related to the severity of watercore, Williams concluded that high sugar contents resulting from rapid starch hydrolysis could not be responsible for the development of watercore. He suggested that the movement of sorbitol from the leaves to the fruits would cause an accumulation of sorbitol in the intercellular spaces of the fruit and development of the watercore symptoms. On the other hand, Golden Delicious leaves show a decline in sorbitol levels as the fruits mature, yet high levels of sorbitol and watercore are not found in the fruits (Williams, 1966). The findings of Chong and Taper (1971) and Whetter and Taper (1963) on daily variations in sorbitol and related carbohydrates in Malus leaves, and of Bieleski (1969) on

accumulation and translocation of sorbitol in apple phloem, support the interrelationship of sorbitol and watercore as proposed by Williams (1966). The possible relation of sorbitol to other physiological disorders of apples was reported by Fidler and North (1970). With Cox's Orange Pippin and Chiver's Delight apples, they found that an accumulation of sorbitol during storage at $0^{o}C$ was correlated with core flush and low temperature breakdown injury, but a causal relationship was not established.

The specific relationship of watercore to internal breakdown is not clear. Studies by Smagula et al. (1968) on the effect of watercore on respiration and mitochondrial activity revealed that watercored tissue consumed 26% less O_2 in an aerobic environment that nonwatercored tissue. The watercored tissue exhibited a respiratory quotient of 1.71; for nonwatercored it was 1.51. There was no apparent adverse effect of watercore on the mitochondria. Watercored tissue contained more ethanol, acetaldehyde and ethyl acetate than nonwatercored tissue and these substances persisted in the fruit after the watercore symptoms disappeared. All three of these substances, individually or in combination injected into the atmosphere surrounding the fruit caused cortical tissue browning. They suggested that watercore alters the metabolism of Red Delicious apples to induce fermentation. Toxic substances then accumulate and cause browning and breakdown.

Further evidence that the accumulation of acetaldehyde is important to the development of internal breakdown was reported by Clijsters (1965). He found that diseased tissue produced acetaldehyde more readily than ethanol, whereas the reverse was true for healthy tissues. It was shown that acetaldehyde accumulation preceded the normal development of internal breakdown in Jonathan apples, and that injection of 30 umol of acetaldehyde or 50 umol of ethanol produced browning artificially within one week at 20°C. More recently Wills (1970), using the injection technique, found that acetate and mevalonate were more effective than acetaldehyde in producing tissue browning symptomatic of low temperature breakdown. He further found that geraniol, a monoterpene derived from two mevalonate molecules, was the most effective isoprenoid compound in producing breakdown symptoms.

The accumulation of acetate or acetate derived compounds may be directly involved in creating physiological conditions leading to breakdown. This may explain Scott and Roberts observation (1968) that amounts of breakdown decreased when fruit was stored at low relative humidity. Wills (1968) found an increasing loss of acetate in the form of n-butylacetate, isoamylacetate and n-hexylacetate with an increasing rate of waterloss from the fruit during storage. Later Wills and McGlasson (1971) reported that low temperature breakdown does not occur at intermediate storage temperatures of 5°C because there is an increased loss of acetates as

esters which results in a reduction of the amount of acetic acid available to produce the disorder.

In cork spot, another physiological disorder of apples, Faust and Shear (1968) found acetate to be the major respiratory substrate in diseased tissue while glucose catabolism was dominant in healthy tissue.

The incidence of some fruit physiological disorders can be markedly reduced or eliminated by the application of calcium. Noteworthy examples are bitter pit of apples (Garman and Mathis, 1956; Askew et al. 1960; Drake et al. 1966; Bangerth, 1972) and blossom end rot of tomatoes (Geraldson, 1957; Fisher, 1967). It now appears likely that the symptoms of such disorders result from localized deficiencies of calcium in developing fruits, even though such fruits are borne on plants with supplies of calcium considered to be adequate according to the leaf analysis criterion.

An inverse relationship between Ca content of the fruit and susceptibility to internal breakdown has been shown by Schreven et al. (1963) and Perring(1968). Sharples (1967) and Stebbins (1970) found a high positive correlation between K and Mg and internal breakdown and a high negative correlation between Ca and breakdown incidence. The movement of calcium into the fruit occurs primarily during the first few weeks of development (Perring, 1968). Apparently some calcium remains mobile in the later stages of fruit development since Martin (1967) showed that ^{45}Ca applied to the fruit could be

detected in the tree. Wilkinson (1968) demonstrated that as much as 1.0 mg of Ca may move out of the fruit in seasons when the weather is dry. This may be of the same order of magnitude, as shown by fruit analysis, as that contributed by calcium sprays (Wilkinson, 1968). There is evidence pointing to Ca involvement in metabolism in the cell walls, plasma membranes and in enzyme activation (Jones and Lunt, 1967). The full role of each to the development of fruit physiological disorders is not known.

Information on the sugar uptake mechanisms of fruit cells is limited, but there is information on carbohydrate uptake mechanisms in sugar cane. According to a scheme developed by Glasziou (1960) and Sacher et al. (1963), exogenously supplied sucrose is hydrolysed by an invertase in the free space of immature storage parenchyma of sugar cane.

After inversion of sucrose, the glucose and fructose or their phosphorylated derivatives are transported into the cellular storage compartment before sucrose is resynthesized (Bowen and Hunter, 1972). Sacher (1966) reported that hexoses appeared to be converted to sucrose during uptake in bean pod tissue and the accumulated sucrose is rapidly hydrolysed in the vacuole. Investigations of sugar uptake in sugar beet tissue indicate that sucrose could be taken up directly without hydrolysis (Kursanov et al. 1964). Kollas (1968), working with Delicious fruit tissue, concluded that sorbitol translocated to the fruit was rapidly converted to fructose and

sucrose. This occurred up to a given state of maturation without watercore development. Upon further fruit maturation, the sorbitol was not as readily converted to fructose and sucrose, and watercore then appeared. It was found with tissue discs that fructose and sucrose were effectively retained within the parenchyma cells, whereas intercellular sorbitol escaped readily to the isotonic bathing solutions. He concluded that the watercore condition occurred as a result of sorbitol accumulation in the intercellular spaces of the fruit tissue. Recently Bangerth et al. (1972) found that the addition of calcium to isotonic solutions considerably reduced the tissue leakage of previously infiltrated sorbitol and inhibited the tissue browning that is characteristic of internal breakdown.

(Mothes et al. 1959; Mothes and Engelbrecht, 1961) suggest that translocation is under some sort of hormonal control. This may be so in the fruit. In excised leaves for example, kinetin will bring about movement of amino acids and phosphate to localized areas of application. In intact plants it has been demonstrated that auxin, (Davies and Wareing, 1965), gibberellin, (Denisova and Lupinovich, 1961), or cytokinin, (Muller and Leopold, 1969), increase the movement of phosphate and other inorganic ions. When either cytokinins or gibberellins were applied to grape shoots or portions of shoots, the normal pattern of translocation of labeled

assimilate was altered so there was increased movement into the treated areas (Shindly and Weaver, 1970). Although these effects are easily explained by the hypothesis that application of plant growth substances increases the capacity of some tissues to accumulate photosynthetic products, there is increasing evidence that hormone-directed transport is important in the normal redistribution of nutrients from various parts of the plant to growing organs. Crane (1965) and Crane and Van Overbeck (1965) considered the induction of parthenocarpic fruits in figs by growth regulators to be the result of the movement of metabolites produced in other parts of the tree into the developing fruits. They suggest that the fertilized ovule or seed synthesize hormones which initiate a similar metabolic gradient following normal pollination.

Regulation of aging processes in attached and detached leaves has been demonstrated for auxins, kinins, and gibberellins (Osborne, 1967). With fruits, considerable progress has been made in the use of growth regulators to accelerate the ripening process (Kidd and West, 1933; Burg and Burg, 1962; Maxie and Crane 1967; Hansen and Blanpied, 1968, and Iwahori et al, 1968). In some cases ripening is retarded, for example, gibberellic acid has been reported to retard ripening of tomatoes (Dostal and Leopold, 1967; Abdel-Kader et al. 1966; bananas (Russo et al. (1968); oranges (Coggins and Lewis, 1962) and apricots (Abdel-Gawad and

Romani, 1967). The latter authors also reported that benzyladenine applied as a postharvest treatment retarded the rate of ripening of apricots. Preharvest application of 100 ppm benzyladenine to Jonathan apples one week prior to harvest slightly reduced fruit respiration, but had no effect on flesh firmness or soluble solids (Dilley, 1969). N-dimethylamino succinamic acid (SADH) delays ripening of Lodi and Yellow Newton Transparent apples according to Edgerton and Hoffman (1965), and of McIntosh according to Dilley and Austin (1967), and decreases watercore of Winesap and Delicious apples (Batjer and Williams, 1966). No reference has been made of the possible effects of this growth regulator on the translocation of solutes from the leaves to the fruit.

Applications of exogenous auxins, gibberellins and cytokinins however, have been shown to influence the distribution of organic compounds within plants or detached plant parts (Mothes et al. 1959; Gunning et al. 1963; Morris and Thomas, 1968). Of special interest in this respect are the findings of Seth and Wareing (1967). Working with bean plants (Phaseolus vulgaris) they found increased accumulation of ^{32}P and increased movement of photosynthates when fruit peduncles were treated with auxin, gibberellic acid, or kinetin. Kriedemann (1968), found with Washington Navel oranges that kinetin enhanced the movement of photosynthates

to the fruit. Weaver et al. (1969) found significant increases in weight of berries whose clusters had been dipped in 4-chlorophenoxyacetic acid, gibberellic acid or benzyladenine. Gibberellic acid was most effective in increasing the amount of assimilates into the grape berries. Dipping clusters of fruit of Black Corinth grape in gibberellin caused more assimilates to accumulate in berries on unsprayed shoots than on shoots sprayed with gibberellin. They proposed that gibberellin enhanced the mobilizing power of the shoots, thus enabling them to compete more effectively with the fruits for assimilates.

Recently Hatch and Powell (1971) found that ^{14}C-sorbitol could be mobilized in an acropetal direction in apple seedlings under the influence of IAA+GA+Benzyladenine applied in agar or lanolin paste, once the root competition had been removed by stem girdling. Combinations of two growth regulators or any one regulator alone was not as effective as the three together. They concluded that exogenously applied growth regulators can direct the movement of certain compounds in apple shoots, and that growing regions and developing fruits or seeds, which are known to compete for many substances, are able to do so because they contain relatively high concentrations of various hormones as compared with other plant parts.

MATERIALS AND METHODS

An experiment to regulate watercore and sorbitol content of apples was conducted in 1970 in a nearby commercial orchard of 8-year old Jonathan apple trees growing in sod on seedling roots. Fairly uniform single trees in respect to size, vigor and crop load were selected to provide 8 replications for each treatment. The treatments were designed to increase (+) or decrease (-) accmulation of sorbitol in the fruit, as compared with a nontreated control, as follows:

1. Control (nontreated)
2. Sorbitol injection (+), whereby 0.1 M sorbitol solution was injected into several apple limbs and branches through 2 cm deep x 0.5 cm diameter holes. Sorbitol absorption by trees varied from 12 to 25 liters during an injection period that varied from 12 to 72 hours.
3. Fruit thinning (+), in which an approximate ratio of 40-60 leaves/fruit or 1 fruit per 6 linear inches of limb was provided.
4. Ethephon spray (+), at 100 ppm by spraying to leaf run-off at 10 days before harvest.
5. N^6-benzyladenine (+) or (-), at 250 ppm by spraying to leaf run-off at 2 weeks before harvest.

6. Partial defoliation (-), accomplished by pruning away 2/3 of the current season's growth.
7. Lime sulfur (calcium polysulfide) sprays (-), a 5% solution was sprayed to run-off at 10 days before harvest (chemical defoliation).
8. SADH (N-dimethylaminosuccinamic acid) (-), a 2000 ppm solution was sprayed to leaf run-off at 45 days before harvest.

The first harvest was made at the ideal time for long term storage on September 25. A second harvest was made on October 9. The apples were collected in 1 bu. field crates lined with polyethylene film to minimize fruit moisture loss and stored on the day of harvest. One bu. fruit samples were randomly assigned to storage conditions in air at $2^{o}C$ and in 3% O_2 and 5% CO_2 at $0^{o}C$. The controlled atmosphere was established within one week after the final harvest by means of a Tectrol controlled atmosphere generator. Fruit samples were removed for examination from air storage after 3 and 6 months of storage, and from CA after 6 months. Final examination was made after 10 days at $20^{o}C$ to facilitate the development of disorders.

Ground color was determined by visual comparison with Ditton Laboratory green-yellow apple and pear color charts, numerically rated as 4 = green and 8 = yellow.

The presence of watercore, internal breakdown, core browning and brown heart was observed by cutting each fruit transversely and progressively from the calyx end toward the equator. The severity of the disorder was numerically rated as 0 = none, 1 = trace, 2 = slight, 3 = moderate, 4 = severe. An index was then calculated by multiplying the number of fruit by each rating, summing the results within a replication and dividing by the total number of fruits examined. The presence or absence of lenticel spots, and Jonathan Spot disorders was observed and noted. Flesh firmness was measured using a U.C. Fruit Firmness Tester with a 7/16 inch tip and recorded in pounds. One measurement was taken from a peeled portion of each 10 fruits.

Sampling procedures for nutrient element determinations of fruits were made as described by Perring and Wilkinson (1965). K was extracted with water and then measured with flame spectrophotometry. Levels of P, Ca, Mg, Mn, Fe, Cu, and Na were determined using photoelectric spectrometry (Kenworthy, 1960). Respiration was measured as CO_2 evolution by infra-red analysis (Dilley et al. 1969), and ethylene by gas chromatography (Burg and Burg, 1962).

Apple fruit sorbitol was determined by gas chromatography (Farshtche and Moss, 1969). Sample preparation was as follows: Two wedge shaped slices selected from the center

part of the fruit were further cut into smaller pieces with a Vegomatic food preparer and frozen immediately at -10°C. In order to facilitate the making of a very fine powder, the apple pieces were later frozen in liquid nitrogen for 2 minutes and blended immediately for 30 seconds in a Waring blender. A 30 gm sample was freeze-dried at -20°C. The resulting mass of apple tissue was powdered with a small pestle and samples of 20 mg were placed in centrifuge tubes to which 0.4 ml of trimethylsilyl (TMS) reagent was added. Composition of the TMS reagent was 3 parts hexamethyldisilazane, 1 part trimethylchlorosilane and 1 part piridine by volume. The TMS reagent was reacted with apple tissue for 1/2 hour and afterward the mixture was centrifuged 30 minutes at 2000 rpm. A 2 ul aliquot of the supernatant solution was injected into a U-shaped glass column, 6 ft x 2 mm I.D. packed with 15% carbowax 20 M coated on 80-100 chromosorb U, at a temperature of 165°C. Retention times were 2 minutes for fructose, 3.5 minutes for sorbitol, 4.2 for α D glucose and 9.2 minutes for β D glucose.

The following orchard treatments were applied to Jonathan apple trees in 1971 in the same orchard used the previous year:

1. Control (nontreated).
2. Calcium sprays, applied 4 times at intervals of two weeks beginning 12 weeks after full bloom, using lime sulfur at 2%, $CaCl_2$ at 1%, or $Ca(NO_3)_2$ at 5%.

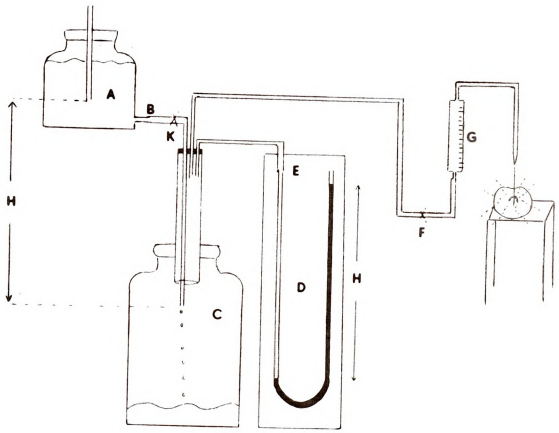
3. Calcium sprays, applied once at 8 days before harvest, as lime sulfur at 5%, $CaCl_2$ at 4%, or $CA(NO_3)_2$ at 10%.
4. Defoliation, whereby leaves were completely removed from several limbs that were girdled to impede translocation of photosyntates from other foliage.
5. Postharvest dips, using 4% $CaCl_2$ solution for 10 minutes, or 5% lime sulfur solution for 15 seconds.

The apples were collected in 1 bu. field crates lined with polyethylene film and stored immediately at 3°C. Fruit samples were removed for examination after 6 and 8 months of storage. Final evaluation was made after an additional 2 weeks at 20°C. The role of leaves on size, watercore and porosity characteristics of the fruit from 5-year-old Jonathan apple trees grown at the Horticulture Research Farm was examined. Treatments consisted of individual girdled granches with 0 or 40 leaves per fruit on 4 trees.

The internal atmosphere of harvested fruits was sampled immediately in the orchard by the method of Johnson (1971). Porosity was measured by gas flow through the apples by the system shown in Fig. 1. A barostat was employed to maintain a constant atmospheric pressure at point A. The water outlet (B) was connected to a two gallon bottle (C). From bottle (C)

Fig. 1. Method used for evaluation of porosity characteristics of Jonathan apples.

Fig. 2. Method used to measure porosity of pith discs of Jonathan apples.


A
B
K
E
G
H
F
D
H
C


A
B
C
← From G as in Fig. 1

came two connections, one to a manometer and another one to a two way stopcock (F). When water was allowed to flow freely upon release of clamp (K) a given amount of pressure developed in bottle (G) which was registered on the manometer. This pressure was equal to (H) or the distance between the outlet connecting to atmospheric pressure and the water outlet connecting to bottle (C). The pressure to be developed inside bottle (C) could be readily adjusted by increasing or decreasing (H). All measurements were taken at 50 mm pressure on the manometer. When the stopcock outlet was open, the pressure inside bottle (C) was maintained by water flow from the bottle (A). The outlet of the two way stopcock was connected to a rotometer (G) calibrated from 0 to 80 ml of air/min over a scale distance of 10 cm. The outlet of the rotometer was connected to a 7 inch 18 gauge hypodermic needle. The hypodermic needle with a cleaning wire inserted was pushed into the seed cavity of the apple fruit through the calyx end. The wire was necessary to prevent plugging of the needle with juice and/or cortical tissue during insertion. Care was taken to move the wire in and out to insure free flow of air through the needle. By turning the stopcock, air was allowed to flow through the apple to the ambient atmosphere. To insure that leakage was not occurring at the point of entrance of the needle, the apple was immersed for a few seconds in a beaker with water. Flow of air was clearly observed through the apple lenticels. Approximately

one minute was allowed for equilibration of flow before making the final reading on the flow meter. The data are expressed as ml/min/inch^2 of fruit surface area, calculated according to the method by Baten and Marshall (1943).

For measurements of gas flow through flesh and core tissue disks, the procedure outlined in Fig. 2 was followed. Cylinders of 20 mm diameter were cut with a stainless steel cork borer. A section of two mm thickness was cut from pith tissue and located in position A. High vacuum grease was used on the inner wall of the cylinder (B) and the threaded cap surface to prevent leakage. Gas diffusion measurements were made as described above for whole apples.

RESULTS

The effects of orchard treatments applied in 1970 are summarized in Tables 1-5, in which the treatments are listed in order of increasing or decreasing effectiveness on fruit disorders or other parameters investigated.

A significant reduction in watercore index (Table 1) occurred in fruits from the chemically defoliated trees which had the lowest amount of watercore. The control, sorbitol injection and ethephon treated fruits had the highest watercore index. The ethephon treatment yielded more watercore than the partial defoliation treatment accomplished by pruning of the terminal growth.

The sorbitol content of the fruit was lowest from the chemically defoliated trees and was significantly lower than the sorbitol injection, ethephon and SADH treatments (Table 2).

Fruits from chemically defoliated trees were significantly lower in breakdown incidence than fruits from trees receiving sorbitol injection, the control, or ethephon treatment when examined after 3 months of air storage (Table 3). After 6 months of storage in air or CA, the chemical defoliation treatment yielded the lowest amount of internal breakdown. It was significantly lower than control, sorbitol injection, ethephon, or fruit thinning treatments after 6 months of air storage and significantly lower than all other treatments

Table 1. Effect of orchard treatments on watercore of Jonathan apples at harvest, 1970.

Treatment	Watercore (index)			
Chemical defoliation	0.91	a		
Partial defoliation	1.08	a	b	
SADH spray	1.18	a	b	c
Fruit thinning	1.20	a	b	c
N^6-benzyladenine spray	1.21	a	b	c
Control (nontreated)	1.22		b	c
Sorbitol injection	1.27		b	c
Ethephon spray	1.49			c

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 2. Effect of orchard treatments on sorbitol of Jonathan apples at harvest, 1970.

Treatment	Sorbitol % dry Wt.	
Chemical defoliation	3.20	a
N^{6}-benzyladenine spray	3.95	a b
Partial defoliation	4.06	a b
Fruit thinning	4.15	a b
Control (nontreated)	4.35	a b
SADH Spray	4.57	b
Sorbitol injection	4.57	b
Ethephon spray	4.79	b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

Table 3. Effect of orchard treatments on internal breakdown of Jonathan fruit after 3 months of storage at 2°C in air, 1970.

Treatment	Internal Breakdown (index)	
Chemical defoliation	0.174	a
SADH spray	0.682	a b
N^6-benzyladenine spray	0.774	a b
Partial defoliation	0.786	a b
Fruit thinning	0.996	a b
Sorbitol injection	1.356	b
Control (nontreated)	1.437	b
Ethephon	1.555	b

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

after 6 months of CA storage (Tables 4 and 5). With the exception of SADH on sorbitol content, treatments designed to decrease watercore, sorbitol content, and internal breakdown accomplished the objective. Likewise, all treatments applied to increase watercore, sorbitol and internal breakdown (Tables 1, 2, 3, 4, 5) were effective in the desired manner.

A delay in fruit harvest resulted in a highly significant increase in watercore index, sorbitol content and internal breakdown after 6 months air storage and after 6 months of CA storage plus 2 weeks at 20°C (Table 6). Weight, ground color, K content and the K/Ca and Mg+K/Ca ratios also increased significantly with a delay in fruit harvest (Table 6).

As shown in Fig. 3, watercore index and sorbitol content were positively correlated (r = 0.688 ****) at the late harvest. The square enclosure in the lower left portion in this graph (and the rectangular enclosures in subsequent graphs) outline the results from treatments that yielded relatively low amounts of sorbitol and low incidences of watercore or breakdown. Sorbitol content at harvest and breakdown index after 3 and 6 months of air storage, and after 6 months of CA storage, were positvely correlated (r = 0.633 ****, r = 0.696 **** and r = 0.692 ****, respectively) see Figs. 4, 5 and 6. Watercore index and internal breakdown after 3 and 6 months of air storage and after 6 months of Ca storage were positively correlated (r = 0.767 ****, r = 0.727 **** and r = 0.780 ****, respectively)

Table 4. Effect of orchard treatments on internal breakdown of Jonathan apples after 6 months of storage in air at 2°C, 1970.

Treatment	Internal Breakdown (index)			
Chemical defoliation	0.293	a		
N^{6}-benzyladenine spray	0.894	a	b	
Partial defoliation	1.113	a	b	c
SADH spray	1.171	a	b	c
Control (nontreated)	1.480		b	c
Sorbitol injection	1.516		b	c
Ethephon spray	2.072			c
Fruit thinning	2.226			c

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 5. Effect of orchard treatment on internal breakdown of Jonathan fruit after 6 months of storage in CA at 0°C plus two weeks at room temperature, 1970.

Treatment	Internal Breakdown (index)	
Chemical defoliation	0.44	a
SADH spray	1.33	b
Partial defoliation	1.63	b
N^6-benzyladenine	1.85	b
Fruit thinning	1.92	b
Sorbitol injection	2.00	b
Control (nontreated)	2.01	b
Ethephon spray	2.71	b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

Table 6. Effect of time of harvest on watercore index, sorbitol content, internal breakdown, lenticel spot, fruit weight, ground color, firmness, K, Ca, Mg, K/Ca, Mg/Ca, Mg+K/Ca, as measured at harvest, 1970.

Fruit Characteristic	Harvest date		
	Sept. 25	October 9	
Watercore (index)	0.99	1.40	****
Sorbitol content (% dry wt.)	2.91	5.49	****
Internal breakdown after 6 mo. air storage at 3°C	0.78	1.65	****
Internal breakdown after 6 mo. CA storage at 0°C plus two weeks at 20°C	1.14	2.33	****
Lenticel spot after 6 mo. air storage at 3°C.	1.42	5.68	****
Weight (gm)	132.8	148.5	****
Ground color (rating)	5.34	6.34	****
Firmness (lbs)	16.18	15.53	***
K	0.84	0.76	****
Ca	0.056	0.056	
Mg	0.030	0.029	
K/Ca	15.09	13.52	**
Mg/Ca	0.53	0.52	
(Mg + K)/Ca	15.63	14.04	**

**** = $P < 0.0005$
*** = $P < 0.001$
** = $P < 0.01$

Fig. 3. The correlation of sorbitol content and watercore index at harvest.

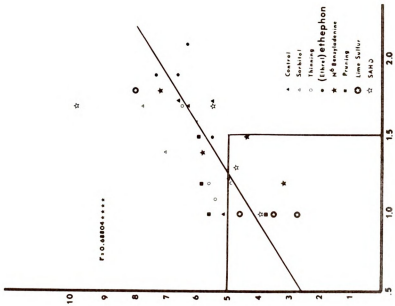
**** $P < 0.0005$

$y = 1.112 + 3.16(x)$

Fig. 4. The correlation of sorbitol content at harvest and internal breakdown index after 3 months of air storage at 2°C plus 2 weeks at 20°C.

**** $P < 0.0005$

$y = 4.229 + 1.037(x)$


SORBITOL CONTENT (% DRY WT.)
WATERCORE INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
nAA Benzyladenine
Pruning
Lime Sulfur
SAMO

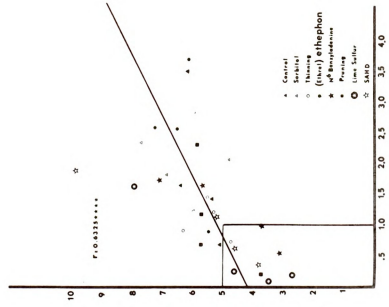

SORBITOL CONTENT (% DRY WT.)
BREAKDOWN INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
nAA Benzyladenine
Pruning
Lime Sulfur
SAMO

Fig. 5. The correlation of sorbitol content at harvest and internal breakdown index after 6 months of air storage at 2°C.

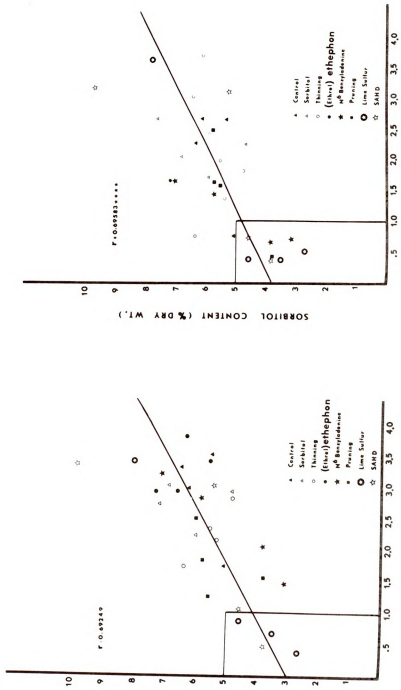
**** $P < 0.0005$

$y = 3.791 + 1.053(x)$

Fig. 6. The correlation of sorbitol content at harvest and internal breakdown index after 6 months of Ca storage at 0°C plus two weeks at 20°C.

**** $P < 0.0005$

$y = 3.050 + 1.066(x)$


SORBITOL CONTENT (% DRY WT.)
BREAKDOWN INDEX
Control
Sensitive
Thinning
(Ethrel) ethephon
6th Benzyladenine
Pruning
Lime Sulfur
Sand

SORBITOL CONTENT (% DRY WT.)
BREAKDOWN INDEX
Control
Sensitive
Thinning
(Ethrel) ethephon
6th Benzyladenine
Pruning
Lime Sulfur
Sand

see Figs. 7, 8 and 9. Calcium content was negatively correlated with breakdown index ($r = -0.505$ **), as shown in Fig. 10.

Measurements of CO_2 and C_2H_4 evolution revealed that the fruit was picked preclimacteric at the first harvest and postclimacteric at the second and third harvests (Fig. 11 and 12). SADH-treated fruits of the first and second harvests had the lowest respiration and ethylene evolution rates, whereas fruits from the ethephon, sorbitol injection, and control treatments had the highest. The trend toward a lower rate of CO_2 evolution observed for lime sulfur-treated fruits at the second harvest, was verified at the third harvest when it yielded the lowest rate of respiration of all treatments. Lime sulfur treated fruits had the second lowest rate of C_2H_4 evolution, with SADH-treated fruits being the lowest. Respiration measurements after 3 months of storage revealed similar differences to those measured shortly after harvest (Fig. 13).

Examination of the effect of orchard treatment on mineral composition of the fruit revealed that fruits from ethephon, control and fruit thinning treatments had a significantly lower amount of calcium than SADH-treated fruits. K was significantly higher as a result of the ethephon treatments than that of fruit thinning. The ratios of K/Ca and (K+Mg)/Ca were significantly higher for ethephon than for partial defoliation, N^6 benzylademine and SADH. No significant differences were found between treatments for Mg content or

Fig. 7. The correlation of watercore index at harvest and internal breakdown index after 3 months of air storage at 2°C plus two weeks at 20°C.

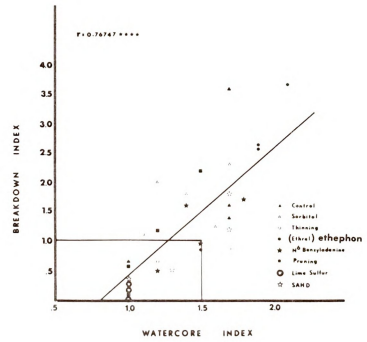
**** $P < 0.0005$

$y = 1.721 + 2.154(x)$

Fig. 8. The correlation of watercore index at harvest and internal breakdown index after 6 months of air storage at 2°C.

**** $P < 0.0005$

$y = 1.408 + 2.213(x)$


r = 0.76747 ****
BREAKDOWN INDEX
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
WATERCORE INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
N⁶ Benzyladenine
Pruning
Lime Sulfur
SAND

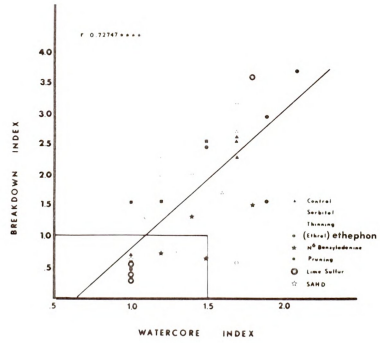

r 0.72747 ****
BREAKDOWN INDEX
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
WATERCORE INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
N⁶ Benzyladenine
Pruning
Lime Sulfur
SAND

Fig. 9. The correlation of watercore index at harvest and internal breakdown index after 6 months of CA storage at 0°C plus two weeks at 20°C.

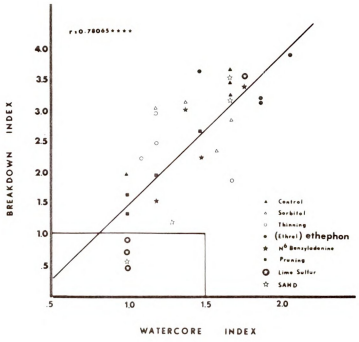
**** $P < 0.0005$

$y = -0.908 + 2.332(x)$

Fig. 10. The correlation of calcium content and internal breakdown index after 6 months of air storage at 2°C.

** $P < 0.01$

$y = 0.0623 - 0.000318(x)$


r=0.78065****
BREAKDOWN INDEX
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3.5
3.0
2.5
2.0
1.5
1.0
.5
.5
1.0
1.5
2.0
WATERCORE INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
N⁶ Benzyladenine
Pruning
Lime Sulfur
SAND

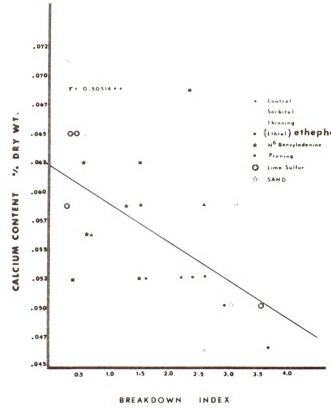

F= 0.30514**
CALCIUM CONTENT %, DRY WT.
.072
.070
.067
.065
.063
.060
.057
.055
.052
.050
.047
.045
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
BREAKDOWN INDEX
Control
Sorbitol
Thinning
(Ethrel) ethephon
N⁶ Benzyladenine
Pruning
Lime Sulfur
SAND

Fig. 11. Effect of the different treatments on the respiration rate of Jonathan apples.

Sep 25 Harvest
Oct 9 Harvest
Oct 28 Harvest
Control
Sorbitol ingest
Fruit thinning
Ethephon
MH benzylaminine
Pruning
Lime Sulfur
SADH
ml CO2/Kg/Hr
DAYS AFTER HARVEST 20° C

Fig. 12. Effect of the different treatments on the ethylene evolution of Jonathan apples.

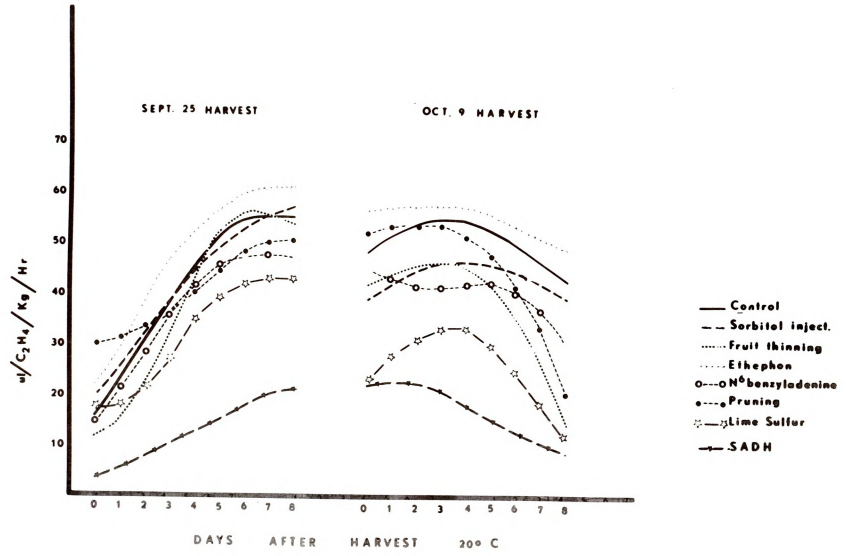
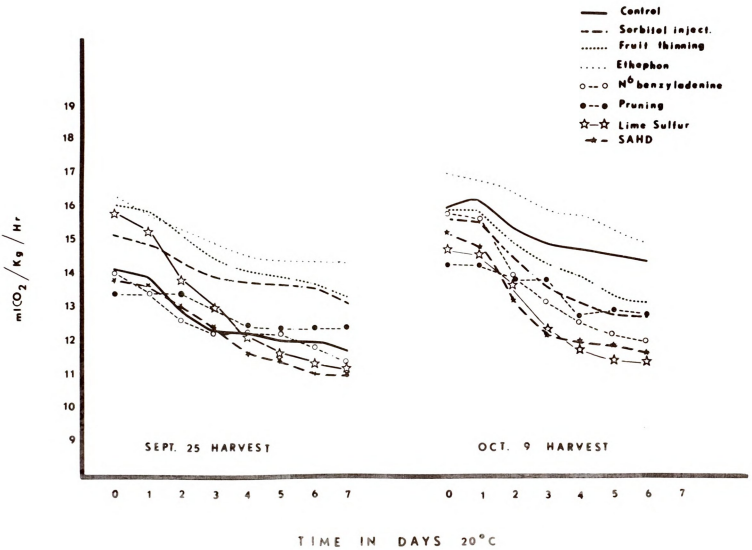

SEPT. 25 HARVEST
OCT. 9 HARVEST
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8
0 1 2 3 4 5 6 7 8
DAYS AFTER HARVEST 20° C
Control
Sorbitol inject.
Fruit thinning
Ethephon
N⁶benzyladenine
Pruning
Lime Sulfur
SADH

Fig. 13. Effect of the different treatments on the respiration rate of Jonathan apples after 3 months of air storage at 2°C.


Control
Sorbitol inject.
Fruit thinning
Ethephon
N⁶ benzyladenine
Pruning
Lime Sulfur
SAHD
ml CO2 / Kg / Hr
19
18
17
16
15
14
13
12
11
10
9
SEPT. 25 HARVEST
OCT. 9 HARVEST
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7
TIME IN DAYS 20°C

the ratio Mg/Ca (Table 7). Ca content of the fruit was negatively correlated with internal breakdown, sorbitol content and core browning. The ratios of K/Ca and (K+Mg)/Ca were positively correlated with internal breakdown, sorbitol content, and core browning in fruits harvested on October 9 and stored in Ca for 6 months (Table 8). Watercore and internal breakdown were negatively correlated with Ca content of fruits harvested October 9 and stored 3 or 6 months in air (Tables 9 and 10). Firmness was positively correlated with Ca content of fruits stored 3 months in air (Table 9).

Orchard treatments also affected other Jonathan apple disorders. N^6-benzyladenine had the lowest incidence of lenticel spot, but it was only significantly lower than ethephon (Table 11). Chemically defoliated trees produced fruits with a significantly lower amount of core browning and brown heart than fruits from trees receiving the sorbitol injection or no treatment. Ethephon fruits had a significantly higher amount of core browning than fruits from all the other treatments (Table 12). Core browning was positively correlated with watercore and internal breakdown on fruits from both harvest dates and with sorbitol content of fruits from the October 9 harvest. No significant correlation was found for lenticel spot or brown heart with watercore, sorbitol content or internal breakdown (Table 13).

Table 7. Effect of orchard treatments on mineral content of Jonathan apples, 1970

Treatment	Ca %	K %	Mg %	K/Ca	K+Mg/Ca	Mg/Ca
Ethephon spray	0.052 a	0.86 a	0.025 a	16.48 a	16.97 a	0.489 a
Control (nontreated)	0.053 a	0.82 a b	0.033 a	15.36 a b	16.00 a b	0.639 a
Fruit thinning	0.054 a	0.74 b	0.033 a	13.77 a b	14.40 a b	0.630 a
Sorbitol injection	0.055 a b	0.78 a b	0.024 a	14.24 a b	14.68 a b	0.446 a
Partial defoliation	0.057 a b	0.75 a	0.027 a	12.13 b	13.59 b	0.472 a
N^6-benzyladenine spray	0.058 a b	0.70 a b	0.032 a	13.46 b	14.01 b	0.052 a
Chemical defoliation	0.058 a b	0.84 a b	0.034 a	14.55 a b	15.14 a b	0.595 a
SADH spray	0.063 b	0.83 a b	0.027 a	13.46 b	13.81 b	0.419 a

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 8. Significant correlation coefficients for fruit mineral content with internal breakdown, core browning, and brown heart of Jonathan apples after 6 months of CA storage at 0°C + 2 weeks at room temperature, 1970.

	Early harvest Sept. 25		Middle harvest October 9		
Element	Internal Breakdown	Sorbitol Content	Internal Breakdown	Core Browning	Sorbitol Content
K	0.379 *		0.342 *		n.s.
P					
Na					
Ca		-0.361 *	-0.515 **	-0.345 *	-0.355 *
Mg					
Mn					
K/Ca			0.527 ***	0.454 **	0.345 *
Mg/Ca					
(Mg + K)/Ca			0.526 ***	0.456 **	0.346 *
(Mg + P)/Ca					
P/Ca			0.374 *	0.358 *	

*** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

Table 9. Significant correlation coefficients of fruit mineral content with watercore, firmness and internal breakdown of Jonathan apples after 3 months of storage at 2°C.

	Early harvest Sept. 25		Middle harvest October 9		
Element	Firmness	Internal Breakdown	Firmness	Internal Breakdown	Watercore
K					
P					
Na					
Ca	0.351 *	-0.441 **	0.557 ***	-0.397 *	-0.464 **
Mg					
Mn					
K/Ca			0.374 *	0.436 **	0.496 **
(Mg + K)/Ca			0.377 *	0.427 **	0.482 **
(Mg + P)/Ca					
P/Ca		0.374 *			

*** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

Table 10. Correlation coefficients of fruit mineral content with watercore and internal breakdown of Jonathan apples after 6 months of storage at 2°C.

	Early harvest Sept. 25		Middle harvest October 9	
Element	Internal Breakdown	Watercore	Internal Breakdown	Watercore
K	n.s.	n.s.	0.378 *	n.s.
P				
Na				
Ca	n.s.	n.s.	-0.505 **	-0.464 **
Mg				
Mn				
K/Ca	n.s.	n.s.	0.559 ***	0.496 **
(Mg + K)/Ca	n.s.	n.s.	0.554 ***	0.482 **
P/Ca	n.s.	n.s.	0.408 *	n.s.

*** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

Table 11. Effect of orchard treatments on lenticel spot of Jonathan apples after 6 months of air storage at 2°C and 6 months of CA storage at 0°C.

Treatment	Lenticel Spot Air (%)		CA (%)		
N^6-benzyladenine spray	1.662	a	2.17	a	
Fruit thinning	4.32	a	3.37	a	b
SADH spray	3.01	a	3.47	a	b
Sorbitol injection	4.27	a	3.63	a	b
Chemical defoliation	4.15	a	3.82	a	b
Control	3.18	a	4.57	a	b
Partial defoliation	3.60	a	4.61	a	b
Ethephon spray	4.23	a	6.65		b

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 12. Effect of orchard treatments on core browning and brown heart of Jonathan apples after 6 months CA storage at 0°C plus 2 weeks at 20°C.

Treatment	Core Browning (index)	Brown Heart (index)
Chemical defoliation	0.62 a	0.09 a
SADH spray	4.13 a b	0.77 a b c
Fruit thinning	4.43 a b	0.72 a b
N6-benzyladenine spray	5.38 a b	1.38 a b c
Partial defoliation	5.86 a b	1.19 a b c
Sorbitol injection	6.25 b	2.25 b c
Control	6.85 b	2.86 c
Ethephon spray	13.43 c	1.46 a b c

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 13. Correlation coefficients for ground color, watercore and sorbitol at harvest and internal breakdown with firmness, lenticel spot, core browning and brown heart of Jonathan apples as measured after 6 months of CA storage at 0°C.

Factor	Harvest date	Firmness	Lenticel spot	Core browning	Brown heart
Ground color	Sept.25	n.s.	n.s.	n.s.	n.s.
Ground color	Oct. 9	-0.403 *	0.372 *	0.340 *	0.422 *
Watercore	Sept.25	n.s.	n.s.	0.378 *	n.s.
Watercore	Oct. 9	n.s.	n.s.	0.678 ****	n.s.
Sorbitol	Sept.25	n.s.	n.s.	n.s.	n.s.
Sorbitol	Oct. 9	n.s.	n.s.	0.425 **	n.s.
I. Breakdown	Sept.25	n.s.	n.s.	0.706 ****	n.s.
I. Breakdown	Oct. 9	-0.408 *	n.s.	0.595 ****	n.s.

**** $P < 0.001$

** $P < 0.01$

* $P < 0.05$

SADH consistently produced the firmest fruits at harvest and after 3 and 6 months of storage (Table 14). The ground color was more yellow for control and ethephon-sprayed fruits and was greener for the N^6-benzyladenine, partial defoliation, and sorbitol injection treatments. No significant difference was found for treatment effect on fruit size (Table 15), yet fruit size was significantly related to the appearance of watercore, internal breakdown and core browning (Table 16).

The Ca and defoliation treatments applied in 1971 significantly reduced watercore in fruits of the late harvest (Table 17). $Ca(NO_3)_2$ sprays had an intermediate effect between control and the $CaCl_2$ treatments or the single application of lime sulfur. Similar trends for watercore occurred at the early harvest when it was of relatively low severity; however, the single massive application of $CaCl_2$ and hand defoliation gave significant reductions. There was no fruit remaining on the hand defoliated trees at the second harvest (October 28). Significant reductions in sorbitol were achieved by lime sulfur applied once and by $CaCl_2$ sprays, with lime sulfur being best at the second harvest. Similar differences occurred at the first harvest where hand defoliation was likewise effective (Table 17). Internal breakdown was significantly reduced, when evaluated after 6 months air storage, by the single massive application of lime sulfur, both $CaCl_2$ orchard sprays, and by the lime sulfur and $CaCl_2$ dip treatments. Internal breakdown was significantly reduced by all treatments when fruits were evaluated after 8 months of air storage at 2°C. (Table 18).

Table 14. Effect of treatments on flesh firmness of Jonathan apples at harvest, and after 3 and 6 months of storage.

Treatment	Flesh firmness at harvest	Flesh firmness after 3 months of air storage at 2°C.	Flesh firmness after 6 months of CA storage at 0°C.
Sorbitol injection	15.48 a	10.57 a	11.95 a
Fruit thinning	15.63 a b	10.80 a	11.98 a
N^6-benzyladenine spray	15.81 a b	10.86 a	12.20 a
Partial defoliation	15.81 a b	11.13 a	12.35 a b
Ethephon spray	15.86 a b	10.93 a	11.73 a
Chemical defoliation	15.87 a b	11.07 a	12.18 a
Control	16.51 a b	10.80 a	11.45 a
SADH spray	16.73 b	12.21 b	13.57 b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

Table 15. Effect of orchard treatments on ground color and fruit size of Jonathan apples.

Treatment	Ground Color	Fruit Size
Control	6.25 a	145.2 a
Ethephon spray	6.12 a b	151.0 a
Chemical defoliation	6.00 a b	138.0 a
Fruit thinning	5.87 a b	135.2 a
SADH spray	5.75 a b	139.0 a
N^6-benzyladenine spray	5.63 a b	142.7 a
Partial defoliation	5.63 a b	138.2 a
Sorbitol injection	5.50 b	135.9 a

Means followed by the same letter are not significantly different. ($P<0.05$ Tukey's test).

Table 16. Linear correlation coefficients between fruit size and incidence of watercore, internal breakdown and core browning of Jonathan apples.

Disorder	Fruit Size	
	Early harvest Sept. 25	Middle harvest October 9
Watercore	n.s.	0.434 **
Internal breakdown		
After 3 mo. in air at 2°C	n.s.	0.522 **
After 6 mo. in air at 2°C	n.s.	0.416 *
After 6 mo in CA at 0°C	n.s.	0.393 *
Core browning	n.s.	0.481 **

** $P < 0.01$

* $P < 0.05$

Table 17. Effect of orchard treatments on watercore and sorbitol content of Jonathan apples at harvest, 1971 - 1972.

Treatment	Harvest Date			
	October 10		October 28	
	Watercore (index)	Sorbitol % dry wt.	Watercore (index)	Sorbitol % dry wt.
Control	1.10 a	5.74 a	2.25 a	7.19 a
Orchard sprays				
L.Sulfur mult.applic.	0.78 ab	4.98 ab	1.15 bc	5.21 bc
L.Sulfur sing.applic.	0.84 ab	3.94 bc	1.00 b	4.25 b
$CaCl_2$ mult.applic.	1.00 ab	3.23 c	1.07 b	4.98 bc
$CaCl_2$ sing.applic.	0.65 b	4.20 bc	1.02 b	5.20 bc
$Ca(NO_3)_2$ mult.applic.	0.85 ab	5.02 ab	1.50 c	6.38 a c
$Ca(NO_3)_2$ sing.applic.	0.84 ab	4.85 ab	1.50 c	6.75 a
Hand defoliation	0.65 b	4.07 bc	-	-
Post harvest dip				
$CaCl_2$	0.95 ab	4.83 ab	-	-
Lime Sulfur	1.00 ab	4.61 ab	-	-

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Table 18. Effect of orchard treatments and post harvest dips on the incidence of internal breakdown of Jonathan apples after 6 months (A) and after 8 months (B) of air storage at 2°C plus 2 weeks at 20°C.

Treatment	(A) Internal Breakdown %		(B) Internal Breakdown %	
Control (nontreated)	29.2	a	44.00	a
Orchard sprays				
L.Sulfur mult. applic.	3.5	a b	2.05	b
L.Sulfur sing. applic.	1.5	b	1.37	b
$CaCl_2$ mult. applic.	0.0	b	0.00	b
$CaCl_2$ sing. applic.	0.1	b	0.16	b
$Ca(NO_3)_2$ mult. applic.	3.4	a b	7.47	b
$Ca(NO_3)_2$ sing. applic.	8.6	a b	5.75	b
Hand defoliation	2.8	b	-	
Post harvest dip				
$CaCl_2$	1.0	b	0.00	b
Lime Sulfur	0.4	b	3.71	b

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test).

Internal breakdown was correlated in a positive manner with sorbitol ($r = 0.513$ ***) and with watercore content at the midharvest date ($r = 0.362$ *). Sorbitol and watercore were positively correlated ($r = 0.413$ **). Fruit size (weight) was positively correlated with watercore and sorbitol content for both harvests (Table 19).

Analysis of the CO_2 evolution of apples harvested October 28 revealed that fruit from all Ca sprayed trees had a lower respiration rate than nontreated control fruit. Fruits sprayed with $CaCl_2$ several times during the growing season had the lowest rate of respiration (Fig. 14).

The effect of $CaCl_2$ and lime sulfur sprays on the internal concentration of C_2H_4 in apple fruits was periodically analyzed beginning August 15. The results presented in Fig. 15 show that C_2H_4 was below 1 ppm up to September 20. At this time the nontreated fruits increased in C_2H_4 to 9 ppm and continued to increase thereafter. Fruits sprayed several times with $CaCl_2$ or with lime sulfur were delayed in their increase of C_2H_4 concentration until 5-8 days later. Once C_2H_4 production was accelerated, it was considerably lower in Ca-sprayed fruits than in nontreated fruits.

Postharvest dips with $CaCl_2$ and lime sulfur significantly increased the incidence of lenticel spot on fruits examined after 6 months of air storage. The control fruit had the highest percentage of lenticel spot on fruits evaluated after 8 months of air storage at 2°C, but variability among all

Table 19. Correlation coefficients of fruit sorbitol content and watercore by harvest date to average fruit weight and internal breakdown after 6 months air storage at 2°C plus 2 weeks at 20°C.

Factor	Sorbitol Content		Watercore	
	October 10 Harvest	October 28 Harvest	October 10 Harvest	October 28 Harvest
Sorbitol content			0.413 **	0.568 ***
Internal Breakdown	0.513 ***	-----	0.362 *	____
Average Fruit Wt. (gm)	0.316 *	0.456 **	0.424 **	0.714 ***

*** P < 0.001

** P < 0.01

* P < 0.05

Fig. 14. Effect of the different treatments on the respiration rate of Jonathan apples.

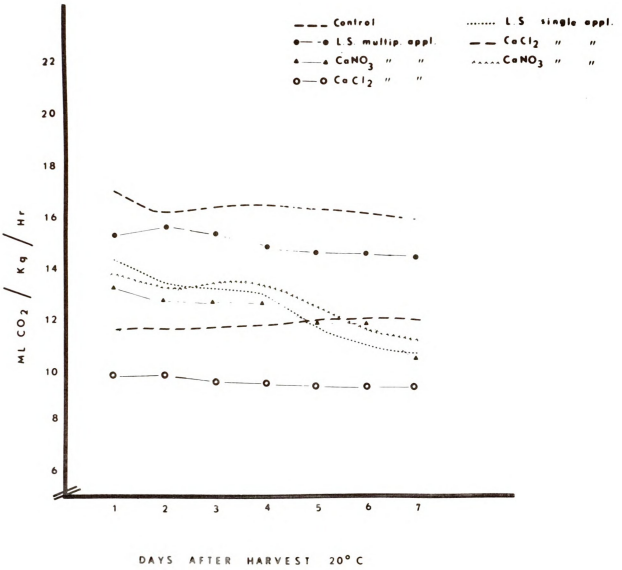
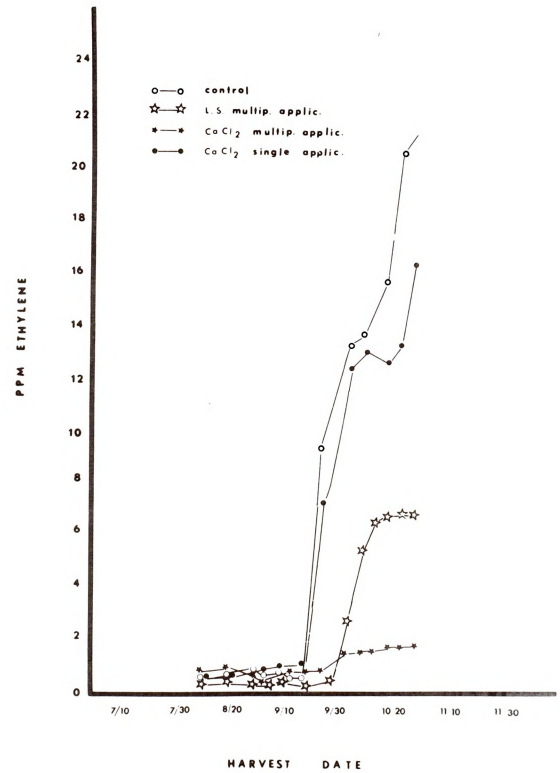

Control
L.S. multip. appl.
CaNO3 " "
CaCl2 " "
L.S. single appl.
CaCl2 " "
CaNO3 " "
ML CO2 / Kg / Hr
22
20
18
16
14
12
10
8
6
1
2
3
4
5
6
7
DAYS AFTER HARVEST 20° C

Fig. 15. Internal content of ethylene of Jonathan apples as related to treatment and time of harvest.


control
L.S. multip. applic.
$CoCl_2$ multip. applic.
$CoCl_2$ single applic.
PPM ETHYLENE
0
2
4
6
8
10
12
14
16
18
20
22
24
7/10
7/30
8/20
9/10
9/30
10 20
11 10
11 30
HARVEST DATE

samples diminished the statistical significance (Table 20). Jonathan spot was significantly reduced by $CaCl_2$ and lime sulfur applied either as sprays or dips, and by one massive orchard spray of $Ca(NO_3)_2$. Soft scald was significantly increased by the lime sulfur dip treatments (Table 21).

No significant effect of treatments on flesh firmness was noted at harvest (Table 22). After 6 months of air storage the fruits sprayed several times with $CaCl_2$ and $Ca(NO_3)_2$, or dipped in $CaCl_2$ solutions were significantly firmer than the control. Control fruits were also consistently larger than fruits from other treatments at all harvest dates (Table 23).

A summary of the most important correlations found in the orchard experiments during the years 1970-71 is presented in Table 24. Sorbitol and watercore were positively correlated both years for fruit of the middle and late harvest dates. Sorbitol and watercore were positively correlated with internal breakdown in both years at the middle harvest. Fruit from the late harvest was not stored. Fruit size, as measured by weight, was positively correlated with sorbitol and watercore for the middle and late harvests and with internal breakdown for fruits of the middle harvest in both years.

Fruit porosity measurements by analysis of the internal atmosphere of McIntosh apples at harvest time revealed there was a relatively constant percentage of CO_2 and O_2 until October 10 being approximately 1 and 19%, respectively.

Table 20. Effect of orchard treatments and postharvest dips on the incidence of lenticel spot of Jonathan apples after 6 months (A) and after 8 months (B) of air storage at 2°C plus 2 weeks at 20°C.

Treatments	(A) Lenticel Spot %		(B) Lenticel Spot %	
Control (nontreated)	0.0	a	56.60	a
Orchard sprays				
L.Sulfur mult. applic.	0.0	a	12.33	a
L.Sulfur sing. applic.	0.5	a	11.50	a
$CaCl_2$ mult. applic.	0.0	a	16.90	a
$CaCl_2$ sing. applic.	0.4	a	13.12	a
$Ca(NO_3)_2$ mult. applic.	0.0	a	10.16	a
$Ca(NO_3)_2$ sing. applic.	0.2	a	41.60	a
Postharvest dips				
$CaCl_2$	3.1	b	18.60	a
Lime Sulfur	17.7	c	12.36	a

Means followed by the same letter are not significantly different.

($P < 0.05$, Tukey's test).

Table 21. Effect of orchard treatments and postharvest treatments on Jonathan spot and soft scald of Jonathan apples after 6 months of cold storage at 2°C plus 2 weeks at room temperature.

Treatment	Jonathan Spot %	Soft Scald %
Control	49.1 a	3.9 a
Orchard sprays		
L.Sulfur mult. applic.	4.3 b	0.7 a
L.Sulfur sing. applic.	18.7 bcd	1.2 a
$CaCl_2$ mult. applic.	7.5 bc	0.0 a
$CaCl_2$ sing. applic.	9.7 bcd	0.1 a
$Ca(NO_3)_2$ mult. applic.	29.4 a cd	2.1 a
$Ca(NO_3)_2$ sing. applic.	13.0 b d	0.5 a
Hand defoliation	33.8 a d	1.1 a
Post harvest dips		
$CaCl_2$	17.5 bcd	1.0 a
Lime Sulfur	18.4 bcd	27.3 b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

Table 22. Effect of orchard and postharvest treatments on flesh firmness of Jonathan apples at harvest time and after 6 months of air storage at $2^{o}C$.

	October 10 Harvest	October 20 Harvest	October 28 Harvest	After 6 months of air storage
Control	15.97 a	15.42 a	14.25 a	12.32 a
Orchard sprays				
L.Sulfur mult. applic.	16.77 a	15.75 a	15.80 a	13.05 a b
L.Sulfur sing. applic.	16.42 a	15.15 a	15.97 a	13.27 a b
$CaCl_2$ mult. applic.	16.75 a	15.22 a	15.75 a	13.33 b
$CaCl_2$ sing. applic.	16.40 a	15.10 a	14.35 a	12.97 a b
$Ca(NO_3)_2$ mult. applic.	16.00 a	15.82 a	15.62 a	13.37 b
$Ca(NO_3)_2$ sing. applic.	15.93 a	15.80 a	16.15 a	13.27 a b
Hand defoliation	16.67 a	-	-	12.52 a b
Postharvest dips				
$CaCl_2$	16.15 a	-	-	13.37 b
Lime Sulfur	16.02 a	-	-	12.82 a b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

Table 23. Effect of orchard treatments on weight of Jonathan apples at harvest.

Treatment	October 10 Weight in gm	October 20 Weight in gm	October 28 Weight in gm
Control	128.7 a	144.0 a	142.5 a
Orchard sprays			
L.Sulfur mult. applic.	106.0 ab	120.5 ab	111.7 b
L.Sulfur sing. applic.	109.5 ab	117.2 ab	117.5 abc
$CaCl_2$ mult. applic.	96.0 b	109.7 ab	100.2 b d
$CaCl_2$ sing. applic.	107.2 ab	101.2 b	93.7 b
$Ca(NO_3)_2$ mult. applic.	119.0 ab	127.5 ab	131.0 a
$Ca(NO_3)_2$ sing. applic.	119.2 ab	121.0 ab	125.0 a cd
Hand defoliation	98.2 ab	-	-

Means followed by the same letter are not significantly different.

($P < 0.05$, Tukey's test).

Table 24. Summary of correlations from orchard experiments with Jonathan apples according to relative time of harvest, 1970 and 1971.

Factors compared	Harvest date			
	Early	Middle		Late
	9/25/70	10/9/70	10/10/71	10/28/71
Sorbitol vs watercore	n.s.	0.688 ****	0.413 **	0.568 ***
Sorbitol vs internal breakdown				
After 3 mo. in air at 2°C	n.s.	0.623 ****	-	-
After 6 mo. in air at 2°C	n.s.	0.695 ****	0.513 ***	-
After 6 mo. in CA at 0°C	n.s.	0.692 ****	-	-
After 8 mo. in air at 2°C	-	-	-	-
Watercore vs internal breakdown				
After 3 mo. in air at 2°C	n.s.	0.767 ****	-	-
After 6 mo. in air at 2°C	0.593****	0.727 ****	0.362 *	-
After 6 mo. in CA at 0°C	n.s.	0.780 ****	-	-
Weight vs watercore	n.s.	0.434 **	0.424 **	0.714 ****
Sorbitol vs weight	n.s.	n.s.	0.316 *	0.701 ****
Weight vs internal breakdown	n,s.	0.416 *	0.501 ***	-

**** $P < 0.0005$
*** $P < 0.001$
** $P < 0.01$
* $P < 0.05$

Beginning October 12 the CO_2 concentration increased reaching 4.60% on October 20 with the O_2 decreasing to 16.25%; this coincided with a progressive increase of watercore to the severe category on October 10 (Table 25).

A similar study showed no significant changes in CO_2 and O_2 for Jonathan fruits sampled on the tree, yet late harvested apples accumulated CO_2 and decreased in O_2 content when stored at 20°C for 8 days. The increase in watercore coincided with the CO_2 increase and O_2 decrease (Table 26).

Porosity measurements of severely watercored apples showed a much lower rate of outward gas flow from the pith than non-watercored fruits (Fig. 16). Porosity measurements of pith discs from watercored and non-watercored apples also showed a constant low gas flow rate for watercored tissue and a higher gas flow rate from apple discs without watercore (Fig. 17). An experiment designed to measure the effect of removing the skin and cutting away increasing amounts of flesh tissue on the porosity of Jonathan applesindicated an increase in porosity with time for non-watercored apples and a fairly constant low rate of gas flow through watercored fruits (Fig. 18). Similarly, late harvested fruits showing external symptoms of breakdown after two weeks at room temperature following harvest, were of low porosity as compared with fruits without internal breakdown (Table 27). A survey of the change in porosity of fruits from 12 Michigan orchards as the fruit

Table 25. Mean internal atmosphere and watercore development of 10 McIntosh apples by harvest date.

Harvest date	CO_2 %	O_2 %	Watercore (index)
8/30	1.19	19.76	0.0
9/10	1.25	19.51	0.0
9/20	0.98	19.90	0.4
9/25	1.05	19.32	0.8
9/30	1.12	18.97	0.8
10/5	1.25	19.23	1.6
10/10	1.03	19.97	1.0
10/12	1.90	18.34	1.5
10/15	3.90	17.00	1.6
10/17	4.25	16.48	2.4
10/20	4.60	16.25	3.2

Table 26. Mean internal atmosphere of 15 Jonathan apples from 3 trees as related to harvest date, watercore, and subsequent breakdown development after 8 days at 20°C.

Upon Harvest				Plus 8 days at 68°F			
Harvest date	CO_2 %	O_2 %	C_2H_4 ppm	CO_2 %	O_2 %	Watercore (index)	Breakdown (index)
9/20	0.95	19.5	1.24	1.24	18.7	0.0	0.0
10/1	0.92	19.7	3.28	1.18	18.9	0.5	0.0
10/5	1.02	19.4	5.65	1.07	19.4	0.5	0.0
10/10	0.86	20.5	14.30	0.76	10.9	1.0	0.0
10/15	1.01	19.5	18.71	0.96	19.3	1.2	0.0
10/20	1.11	19.6	17.63	1.23	19.1	1.2	0.0
10/25	1.14	19.3	20.14	1.09	18.9	1.7	1.0
10/30	1.03	19.4	24.25	1.18	18.7	2.0	0.5
11/3	1.18	19.2	38.26	3.85	16.9	3.4	1.75
11/5	1.28	19.0	63.35	4.10	16.2	3.2	2.3

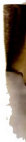


Fig. 16. Gas flow characteristics from the pith outward of watercored and non-watercored Jonathan apples.

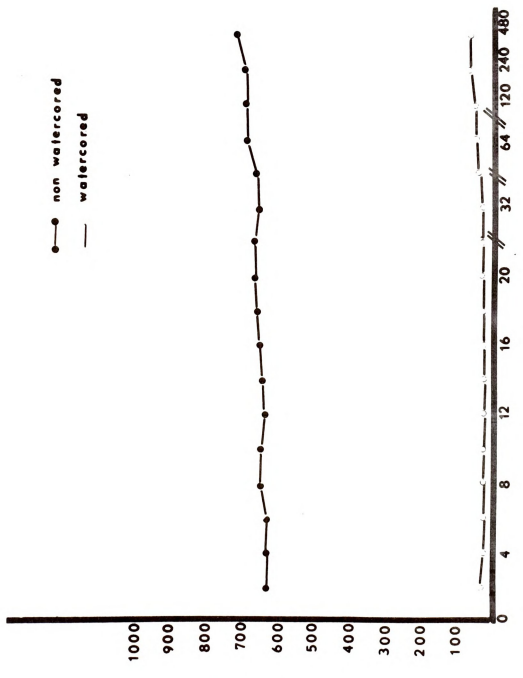

non watercored
watercored
1000
900
800
700
600
500
400
300
200
100
0
4
8
12
16
20
32
64
120
240
480
TIME IN MINUTES

Fig. 17. Gas flow through characteristics of pith discs from watercored and non-watercored Jonathan apples.

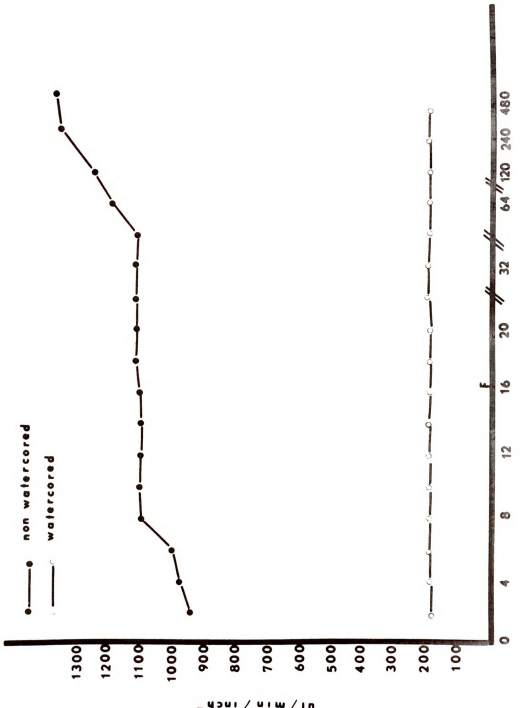

non watercored
watercored
ul/min/inch²
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
4
8
12
16
20
32
64
120
240
480
TIME IN MINUTES

Fig. 18. Effect of skin peeling and flesh removal on gas flow characteristics from the pith outward of watercored and non-watercored Jonathan apples.

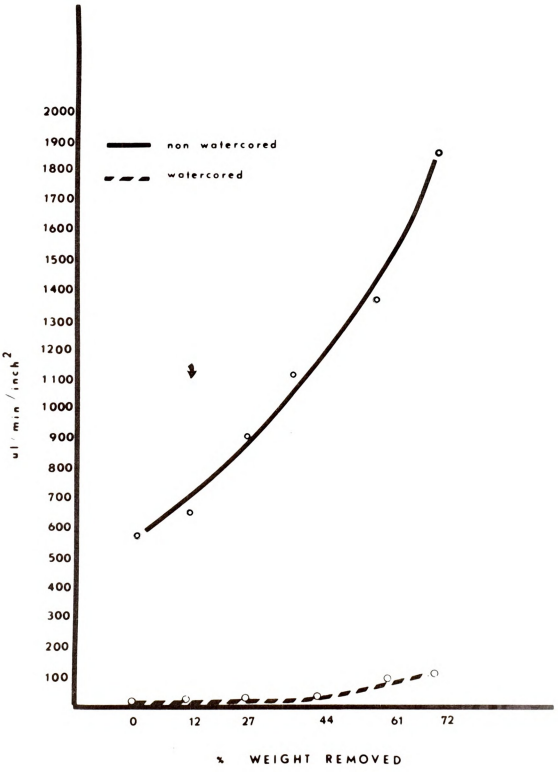

2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
non watercored
watercored
ul · min / inch²
0
12
27
44
61
72
% WEIGHT REMOVED

Table 27. Porosity of late harvested (October 28) Jonathan fruits showing distint external breakdown symptoms after being two weeks at 20°C, as compared with fruits not showing breakdown symptoms.

	Porosity ul/min/inch^2	Breakdown (index)
Fruits with external breakdown symptoms	31 a	3.4 a
Fruits w/o external breakdown symptoms	573 b	1.0 b

Means followed by the same letter are not significantly different ($P < 0.05$, Tukey's test).

approached maturity indicated a steady increase in porosity up to the harvest of October 11. Porosity increased positively with fruit size until October 4 (Tables 28 and 29). After October 11, and as the fruits developed watercore symptoms, there was a decrease in the rate of gas flow through the pith area. This resulted in a decrease of the positive correlation value of porosity to weight or size. A negative correlation between watercore and porosity developed by October 28 (Table 29).

The role of leaves on the growth, watercore development and porosity characteristics of Jonathan fruits is summarized in Table 30. Fruits from ringed and defoliated branches were significantly smaller, less porous and lower in watercore than control fruits or fruits from ringed branches with leaves. Fruits from the latter branches also were larger by weight and had significantly more watercore and less porosity than control fruits.

Late harvested fruit which received Ca orchard sprays had significantly less watercore and higher rates of gas flow through the pith than control fruit (Table 31).

Table 28. Porosity in ul/min/inch^2 of Jonathan apples from 12 orchards as related to harvest date

Harvest date	Orchard No.														
	South West			Average	South Central	South East	West Central				Average	West		Average	North West
	1	2	3		4	5	6	7	8	9		10	11		12
9/13		291													
9/20	341	357	361	353	361	243	226	146	217	250	209				
9/27	400	498	271	390	271 *	258	245	382	443 *	181 *	312	168	290	229	328
10/4	283 *	400 *	317 *	346 *	317	184 *	383 *	202 *	462	301	337	227	302	264	296 *
10/11	578	557	420	518	420	394	-	-	563	405	484	330	315	322	276
10/18												607 *	639 *	623	680

Each number represents the means of 5 observations.

* Indicates best estimated harvest time for long term storage

Table 29. Correlation coefficients of porosity to weight (fruit size) and watercore by harvest date. Jonathan apples.

Harvest date	Porosity vs. weight	Porosity vs. watercore
9/20	.413 ***	-
9/27	.522 ***	-
10/4	.613 ***	-
10/11	.414 ***	n.s.
10/18	.370 ***	n.s.
10/28	.070 n.s.	-.379 ***

*** = $P < 0.001$

Table 30. Effect of leaves on the weight, porosity and watercore development of Jonathan apples.

Treatment	Fruit Wt. gm.	Porosity ul/min/inch^2	Watercore (index)
Fruit from ringed branches with leaves removed	62.6 a	10 a	0.0 a
Fruits from ringed branches with leaves remaining	148.5 b	338 b	2.6 b
Control fruits	130.9 b	612 c	1.0 c

Means followed by the same letter are not significantly different. ($P < 0.05$, Tukey's test)

Branches ringed August 15/71

All fruits harvested October 15/71

Table 31. Effect of orchard treatment on porosity and watercore development of late harvested (Oct. 28) Jonathan apples.

Treatments	Watercore Index	Porosity ul/min/Inch^2	Weight in gms.
Control	1.95 a	140 a	130.15 a
Orchard sprays			
L.Sulfur mult. applic.	1.12 b	667 b	115.35 a b
L.Sulfur sing. applic.	1.00 b	614 b	109.87 a b
$CaCl_2$ mult. applic.	1.00 b	607 b	103.47 a b
$CaCl_2$ sing. applic.	1.00 b	459 b	96.47 b
$Ca(NO_3)_2$ mult. applic.	1.15 b	548 b	130.35 a
$Ca(NO_3)_2$ sing. applic.	1.00 b	594 b	115.20 a b

Each value represents the mean of 40 observation

Means followed by the same letter are not significantly different. ($P<0.05$, Tukey's test).

DISCUSSION

The highly significant correlations of sorbitol to watercore, sorbitol to internal breakdown and watercore to internal breakdown (Table 24) suggest that fruit sorbitol metabolism at harvest time is of primary importance on the development of internal breakdown (IB) during storage. The positive correlation of watercore to sorbitol agrees with the findings of Williams (1966) and Kollas (1968), and substantiates the hypothesis that watercore develops as the cells lose the capacity to metabolize sorbitol and/or incorporate it into storage compartments.

Evidence is presented in Tables 1-5 and Figs. 3-9 supporting the hypothesis that watercore and internal breakdown can be regulated by manipulation of sorbitol content in Jonathan apples. Reduction of both was attempted by removal of the source of sorbitol. Of the three treatments used, partial defoliation, complete hand defoliation and chemical defoliation, the latter was more effective than partial defoliation in reducing IB, sorbitol, and watercore (Tables 1-5). This was probably because chemical defoliation resulted in more leaf damage or leaf removal than partial defoliation. Chemical defoliation by lime sulfur (Tables 17-18) was as effective as complete hand defoliation in reducing watercore, sorbitol content and IB. Although a somewhat higher content of fruit Ca (60 ppm) was found after chemical defoliation than in

fruit from ethephon-sprayed or non-treated trees (Table 7), it is doubtful that Ca was the key factor in the reduction of IB. All fruits, regardless of treatment, had adequate Ca according to the results of other investigators (Sharples, 1967; Perring, 1968; Stebbins, 1970). It is indicated that the effect of defoliation in reducing IB was due to the reduction of sorbitol in the cells or its accumulation in the intercellular spaces. The fact that fruits from defoliated trees had lower respiration and ethylene evolution rates than fruit from nondefoliated trees (Figs. 11 and 12), as well as lower sorbitol and watercore than control fruits, indicates that the defoliation treatments prevented the abnormal metabolic stresses reported to be induced in fruit cells by watercore (Smagula, 1968; Williams, 1966; Bangerth, 1972).

The available data does not suggest the mode of action for N^6-benzyladenine in reducing fruit sorbitol and subsequent IB development during storage. A possible explanation is offered by Shindy and Weaver (1970). They found that grape leaves dipped in benzyladenine or gibberellic acid became strong "sinks" so as to withhold the export of photosynthates to other parts of the plant. Later Quinland and Weaver (1970) compared carbohydrate transported to grape clusters dipped in gibberellic acid from shoots with and without benzyladenine and GA sprays, and found that less photosynthates moved from the sprayed shoots. They concluded that the growth regulators caused the leaves to better compete for metabolites with the grape clusters.

N^6-benzyladenine-treated fruits had lower rates of respiration and C_2H_4 evolution than fruits from the control, ethephon, sorbitol injection, or fruit thinning treatments (Figs. 11 and 12). This is in accordance with the response to kinetin found for green leafy vegetables (Dedolph et al. 1961); broccoli (Dedolph et al. 1962), and strawberries (Dayawon and Shutak, 1967); but different from the results of Smock et al. (1962) where a stimulation of the respiration rate in preclimacteric apples was observed. Therefore, it is likely that N^6-benzyladenine reduced sorbitol and IB by reducing the flow of metabolites from the leaves to the fruits.

Another method for reducing sorbitol within fruits was by extension of the physiological age in which fruits could metabolize the sorbitol as supplied from the leaves. SADH used for this purpose reduced watercore, sorbitol and IB. This confirms earlier reports by Edjerton and Hoffman (1965); Batjer and Williams, (1966) and Lord et al. (1967). Fruits receiving SADH also had lower respiration and ethylene evolution rates at the early and midseason harvest dates than fruits from all other treatments. This is in agreement with the findings of Rhodes et al. (1969) and Miller and Lougheed (1971). Unfortunately, two of the four trees utilized had been trunk ringed at ground level by rodents and this apparently had an effect on the treatment. There were indications that flow of metabolites to the roots was impeded since the ringed

trees died the following year. Accumulation of metabolites in the above ground parts of the tree during the treatment year could have accounted for the erratic results obtained for this treatment.

Trees that were fruit thinned or injected with sorbitol solutions had fruit with higher respiration and ethylene evolution rates than fruits from the defoliation, kinetin, or SADH treatments (Fig. 11, 12 and 13). This suggests that fruits from the sorbitol injection and thinning treatments were under the abnormal stress exerted by watercore conditions reported by Smagula et al. (1968).

Treatments that hastened fruit maturation, and thereby the period in which fruits could metabolize sorbitol, caused an increase in fruit sorbitol at harvest. Ethephon-sprayed fruits had the highest amount of watercore, sorbitol, and IB of all treatments (Tables 1-5) and the highest rates of CO_2 and C_2H_4 evolution (Figs. 11, 12 and 13). Since all treatments were harvested at the same time, it is likely that ethephon caused the highest sorbitol and watercore contents because of its effect in advancing maturity. The stimulation of the respiration rate is in accordance with the results of Russo et al. (1967) with bananas. Even though the onset of the climacteric rise was not accelerated appreciably by ethephon, this effect was probably due to the short time

of fruit harvest. Testey and Shanmuganathan (1971) found similar results for Northern Spy apples sprayed with different concentrations of ethephon.

The reduction in watercore, sorbitol, and IB obtained in 1970 with lime sulfur suggested that other sources of Ca should be investigated. The reductions of watercore content at harvest attained by $Ca(NO_3)_2$ and $CaCl_2$ orchard spray applications in 1971 (Table 17) were similar to those reported by Boon et al. (1968) and Bangerth, (1972).

The effective reduction of sorbitol content by multiple orchard applications of $CaCl_2$ (Table 17) and of respiration rates by all Ca sprays (Fig. 14) suggest a dual benefit from Ca. First, calcium may facilitate metabolism of sorbitol and its incorporation into storage compartments as suggested by Bangerth et al. (1972); this concept is further supported by the highly significant negative correlation of calcium content to watercore and to sorbitol (Tables 8 and 9). Secondly, if the accumulation of toxic compounds is needed for the development of breakdown (Clijters, 1965; Wills, 1970), the lower respiration due to Ca treatment would retard or prevent a level favoring breakdown development.

The delayed and lower production of ethylene of fruits sprayed several times with $CaCl_2$ or lime sulfur (Fig. 15) offers further evidence that the metabolism was affected by Ca (Fig. 14). The role of Ca in slowing metabolism and

delaying the production of C_2H_4 by the apple fruits is not clear. A possible explanation is the known effect of Ca in maintaining the integrity of cell membranes and thereby a better compartmentalization of cell substrates (Jones and Lunt, 1967).

The presence of watercore (Figs. 16 and 17 and Tables 25, 26, 28, 29, 30 and 31) limits the free flow of gases within the apple fruit. Internal measurements of gaseous content showed McIntosh and Jonathan apples accumulated CO_2 and became lower in O_2 content in the internal atmosphere as the severity of watercore increased (Tables 25 and 26). In severely watercored apples, the core was almost impervious (Fig. 18). Cutting away the peel and flesh did not increase porosity and a puncture was required to measureably increase gas flow. Many heavily watercored fruits which developed breakdown symptoms shortly after harvest were of low porosity in comparison to apples without breakdown (Table 27).

The increase in porosity with fruit enlargement (Tables 28, 29 and 30) is likely due to the increase in volume of the intercellular spaces (Hoff and Dostal, 1968; Kerawala, 1968). As fruits mature they reach a condition, perhaps when sorbitol accumulates in the intercellular spaces, that results in a gradual decrease of the positive correlation of weight to porosity (Table 29). This is indicative of the gradual obstruction to gas flow that fruits develop as watercore forms and is in accordance with the findings of Trout et al.

(1942). They found increased resistance of the fruit to gaseous diffusion with increasing age. After removal from storage increased accumulation of CO_2 and reduction of O_2 in the internal atmosphere of the fruit was found. Ben-Yehoshua et al. (1963) also found a marked increase in the resistance of the fruit to gas diffusion associated with avocado fruit ripening and softening. He estimated a decrease in the air volume of ripe avocados, and suggested that resistance to gas flow was due to a clogging up of the air spaces. Extensive waterlogging in senescent cells of bean endocarp was also reported by Sacher (1959).

That calcium treatments prevented the accumulation of sorbitol and formation of watercore condition is evident from the gas flow characteristics of fruits sprayed with calcium (Table 31). These late harvested fruits had a significantly higher porosity and lower watercore content than nontreated fruits.

The effect of the different treatments on other storage disorders are presented in Tables 11, 12, 20 and 21. N^6-benzyladenine was the most effective treatment in reducing lenticel spot (Table 11), and chemical defoliation was the most effective in reducing brown heart and core browning (Table 12). These beneficial effects of chemical defoliation were probably due to the decreased watercore, since advanced

maturity and watercore conditions have been associated before with the development of brown heart and core browning (Chace, 1959; Kerawala, 1968; Dewey and Dilley, 1968).

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the possibilities of regulating the development of internal breakdown of Jonathan apples by manipulation of the sorbitol content of the fruit prior to harvest. Information gained would perhaps be of value in developing cultural or handling practices to reduce the incidence of internal breakdown of apples in commercial storage.

Defoliation of the trees approximately one week before fruit harvest was effective in reducing sorbitol and watercore at harvest, and subsequent development of internal breakdown. Complete defoliation, either chemically or by hand, was more effective than partial defoliation by pruning terminal growth. Since there was a significant positive correlation between sorbitol and watercore and between sorbitol and internal breakdown it is concluded that defoliation modified internal breakdown as a result of its effect on the sorbitol content of the fruit.

Fruit thinning, injection of sorbitol into the tree, and orchard sprays with ethephon increased sorbitol and watercore content at harvest and subsequent development of internal breakdown. Fruits from these treatments also had higher rates of respiration and ethylene evolution than apples from chemically defoliated or kinetin-sprayed trees. It is probable

that the significant increase in sorbitol and watercore, and therefore internal breakdown, of ethephon-sprayed trees was due to acceleration of fruit ripening.

Several applications of $CaCl_2$ and single applications of lime sulfur as orchard sprays significantly reduced the sorbitol and watercore content of the fruit at harvest, and internal breakdown during storage. The significant negative correlations of sorbitol to Ca and internal breakdown to Ca, when considered with the findings of other investigators (Bangerth et al. 1972), indicate that Ca facilitates the metabolism of sorbitol and its storage as fructose in the cells.

Fruits sprayed with Ca or lime sulfur had lower respiration rates and less C_2H_4 production than nontreated fruit of the same chronological age. This lower metabolism would decrease the possibilities for accummulation of toxic compounds that may develop as a result of watercore. These apples would be less likely to be affected by such accummulation of volatile metabolites since the fruit tissues possess better gas exchange properties. Tissue porosity, as measured by gas flow from the pith outward was negatively correlated with watercore content.

Apparently there is an important interrelationship of sorbitol metabolism and calcium content that affects the development of watercore and internal breakdown.

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