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Predicting Physiological Disorders of Stored Apples

R. Ben Arie, S. Lurie, W.J. Bramlage

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PREDICTING PHYSIOLOGICAL DISORDERS OF STORED APPLES

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ABSTRACT

The aim of this project was to develop relatively simple, rapid diagnostic methods for predicting at or before harvest, the susceptibility of apple fruits to the possible development of three storage disorders: senescent breakdown (SB), superficial scald (SS) and core flush (CF) in regular atmosphere (RA) and controlled atmosphere (CA) at 0°C.

Prediction formulae for SB were developed based on mineral composition of the fruit prior to harvest and a maturity parameter at harvest. The data bases used for these formulae were collected for 'McIntosh' in Massachusetts, 'Cox's Orange Pippin' and 'Bramley's Seedling' in the U.K. and 'Jonathan' in Israel. It was found that not only do the formulae differ for each cultivar but probably also for different regions. In certain instances, where the predominant factor was Ca concentration, this method had an even broader applicability, as a predictive tool also for bitter bit and decay. However, for SB prediction on 'Jonathan' in Israel, Ca alone was insufficient and other minerals had to be taken into account. The formulae could be further improved by including certain organic acid levels at harvest, but this makes it rather cumbersome and time-consuming, in spite of the fact that simple and rapid methods were developed for both mineral and organic acid assays.

A spot test, using α -farnesol, was developed for predicting SS potential. The test requires only 24 hours, but its reliability and universality still need to be established. In the course of the search for diagnostic parameters, the accepted mode of SS development was questioned.

No predictive method for CF could be developed on the basis of the data collected in this study.

OBJECTIVES OF THE RESEARCH

The objective of this project was to develop a series of fairly simple tests or assays which could be conducted in a regional or packing-house laboratory prior to, or at harvest, and which would indicate the latent susceptibility of the fruit samples to the development of certain physiological disorders during storage. The disorders chosen for study were superficial scald and internal breakdown, but other disorders which happened to develop on the fruit were not to be ignored. The data obtained from these tests were intended to enable cold storage operators to determine:

- (a) whether post-harvest treatments should be applied to the fruit prior to storage.
- (b) what are the most appropriate storage conditions; and
- (c) how long should the fruit be stored under the above conditions with minimal losses.

INTRODUCTION

Apple fruits are prone to a fairly large number of physiological disorders, which develop during the extended postharvest life of the fruit. Various methods of refrigeration and controlled atmospheric conditions have enabled very considerable extension of the postharvest life of many apple cultivars, and the limitations set are generally of a physiological nature, the result of various imbalances in the chemistry of the fruit, caused by the unnatural environment in which it is held. Different cultivars are susceptible to different disorders, which are incurred by different sets of environmental conditions, both before and after harvest. Within the same cultivar the susceptibility of the fruit to development of the disorders can vary greatly from one year to the next, from one region to another, from orchard to orchard and possibly even from tree to tree. Our understanding of the causes of these disorders on a cellular or molecular level is very incomplete, but the little we do know may be utilised at or before harvest as a tool in predicting the predisposition of the fruit for subsequent disease development.

Many observations have pointed to the effect of time of harvest or maturity at harvest on the susceptibility of apples to a number of storage disorders (Wilkinson and Fidler, 1973). Delaying harvest has been shown to reduce the incidence of bitter pit, Jonathan spot and scald. On the other hand various types of internal breakdown are known to be enhanced by late harvests. Is there a parameter, a set of parameters, closely related to fruit maturity, which correlate so well with some or all of these disorders, that the susceptibility of the fruit can be assessed before the fruit is stored?

Various symptoms of tissue breakdown have been attributed to an imbalance in the mineral composition of the fruit, with special emphasis on the calcium content (Sheor, 1975). Attempts have been made to predict both bitter pit and internal breakdown on the basis of the mineral composition of the fruit prior to harvest (Ferguson, et al. 1979; Holland, 1980). It appears however that the equations formulated are at the best, of regional significance only (Waller, 1980). This means that each apple growing country or district is required to develop its own specific prediction formula.

Other mechanisms have also been suggested for internal breakdown development, namely carbohydrate metabolism (Faust et al., 1969). The disorder has been related to acetaldehyde accumulation instead of ethanol production in healthy fruit, higher acid content and accumulation of sorbitol. These findings point to a possible imbalance between glycolysis and the TCA cycle, the fulcrum of which is pyruvic acid. Could the level of pyruvic acid and its metabolism, or the volatiles produced by the fruit, be early indications of its susceptibility to internal breakdown?

It has been suggested that superficial scald development on apple peel is the result of the oxidation of α -farnesene in the cuticle to conjugated trienes (Huelin and Coggiola, 1970). A direct correlation between the level of α -farnesene and scald severity has not always been observed, though more was found in susceptible cultivars than in resistant cultivars, and also in earlier picked fruit, which is liable to be more susceptible (Anet and Coggiola, 1974). Anet (1974) suggested that the amount of natural anti-oxidant in the apple cuticle might be better related to scald development and he found that the disorder did not occur during storage, if the natural content remained

adequate to prevent, or sufficiently limit, the extent of α -farnesene autoxidation. These findings suggest that a good correlation might be found between the anti-oxidant level or the ratio of anti-oxidant to α -farnesene in pre-harvest fruit and the development of superficial scald during storage, thus enabling a prediction formula to be modeled.

The above-mentioned questions served as the basis for our endeavour to compile formulae or criteria for senescent breakdown and superficial scald prediction. At the same time an attempt was also made to obtain a better understanding of some of the chemical changes involved in the development of these disorders by characterisation of the diseased state versus that of healthy fruit.

MATERIALS AND METHODS

ISRAEL

1. Plant Material and Storage Conditions

The main apple cultivar chosen for study in Israel was "Jonathan", as it is susceptible to most of the physiological disorders known to develop in apples during cold storage. For the study of superficial scald, Granny Smith - a cv. very susceptible to this disorder, was also examined.

1.1 "Jonathan"

In 1984, 5 orchards representing 5 different growing regions were selected for study, the regions being: the Golan Heights, the Huleh valley, the Upper Gallil, the valley of Jezreel and the Coastal Plain. Five trees were randomly chosen for sampling in each orchard. Fruit was first sampled 10-14 days prior to the beginning of the commercial harvest, for prediction assays. Additional prediction assays were conducted on fruit at the beginning of the commercial harvest, when fruit was picked for storage. These assays were intended for prediction of disease potential of fruit harvested 7-10 days later at the end of the season. At each harvest date two samples of 50 fruits were harvested from each tree - one for storage in regular air (RA) at 0°C and the other for controlled atmosphere storage (CA). Fruit in RA was examined for physiological disorders after 3 and 5 months' storage and fruit in CA - after 7 months, both upon removal from storage and following one week at 20°C.

In 1985, fruit was sampled from the same orchards as above, at similar timings, but the number of replicates was

increased to 7 trees per orchard. Moreover, an orchard with known annual susceptibility to breakdown in a region with generally low susceptibility was added to the survey. In each orchard uniformly sized fruit, representative of the predominant size in the orchard, was harvested. The fruit was stored for 5 months in RA and 9 months in CA.

In 1986 samples were taken from 40 plots in 20 orchards (5 in the Golan Heights, 9 in the Huleh valley, 5 in the Gallil and 1 in the valley of Jezreel). Prediction analyses were conducted on preharvest samples of 50 fruits which were collected 7-10 days prior to harvest, from 25 trees in each plot. At the beginning of the commercial harvest, 4 samples of 50 uniformly sized fruits were taken at random from the bulk bins arriving in the packing house from each plot. One sample was used for analysis, 2 samples were stored in RA (after one had been dipped in 0.2% DPA) and one sample in CA at 0°C. The fruit was stored for 5 months in RA and 8 months in CA and examined after one week at 20°C for development of physiological disorders.

1.2 "Granny Smith"

In order to ascertain that "Granny Smith" apples with different superficial scald potentials would be obtained, trees were sprayed with 500 ppm ethephon at different times prior to harvest. Moreover, the fruit was harvested on two or three occasions and fruit from the interior and exterior parts of the trees was picked separately.

In 1984 the experiment was conducted in an orchard in the coastal plain. Four groups of 4 trees were sprayed 10 days prior to the beginning of the commercial harvest. At the first harvest fruit was picked from the interior and exterior parts of these and unsprayed control trees in the same blocks. One week later fruit was picked only from the

non-sprayed controls. The fruit was stored in RA at 0°C and examined after 1 week at 20°C following 3 and 5 months' storage.

In 1985 an experiment was conducted in the same orchard, with varying times of ethephon (500 ppm) application as follows:

- (a) 10 weeks prior to estimated harvest date.
- (b) 6 weeks prior to estimated harvest date.
- (c) two sprays at 10 and 6 weeks prior to estimated harvest date.

Fruit was harvested from the exterior of sprayed and non-sprayed trees on 3 occasions, with intervals of 2 weeks between harvests. Each treatment was applied to 5 replicates of 2 trees. The fruit was stored in RA at 0°C for 3 and 5 months and examined for superficial scald after 1 week at 20°C.

In 1986, an orchard in the Golan Heights was selected, in which a row of trees was sprayed with 500 ppm ethephon, using a commercial sprayer. Three blocks of 3 trees along the row were tagged and fruit was harvested from one tree in each block, on three consecutive harvest dates, with intervals of 2 weeks between harvests. Control fruit was harvested in a similar manner from non-sprayed trees, 5 rows distant from the treated row. Two samples of 50 fruit each were harvested from each tree, one of which was dipped in 3000 ppm DPA. The fruit was stored in RA for 5 months and examined for superficial scald 1 week after removal from storage.

2. Maturation Assessment

Maturation of the fruit at harvest was determined by assessment of red coloration, fruit firmness, total soluble

solids, pH, acidity and starch. Each replicate consisted of 10 fruits which were used for assessment of all parameters.

(a) Red coloration - by visual estimation of the percentage of red coloured peel.

(b) Fruit firmness - with a Hunter Spring penetrometer equipped with an 11 mm tip, on two pared cheeks of each fruit.

(c) T.S.S., pH and acidity - on the juice extracted from peeled and cored longitudinal segments cut from each of the fruit in the sample; T.S.S. with a Hitachi hand refractometer and acidity by titration of 2 ml juice with 0.1 N NaOH till pH 8.2.

(d) Starch - an equatorial slice from each fruit was dipped in an IKI solution. Maturation was assessed according to the extent of the starch response to iodine from 0 - the entire surface blackened, to 5 - no blackening of the tissue.

3. Quantification of minerals

Stem-to-calyx crescents were sliced from samples of 10 fruit, peeled and cored; 20 g were homogenized for 1 min in 40 ml of deionized water, this dilution being employed to avoid gelling of the homogenate. The homogenate was then centrifuged at 30,000xg for 10 min in order to pelletize the cell wall, mitochondria and a large part of the cell membranes. The supernatant obtained was filtered through Miracloth and the pellet was resuspended in 20 ml distilled water and centrifuged again as described above. The volume of the combined supernatants was measured and an aliquot was taken for determination of water soluble Ca, Mg and K. The concentrations of insoluble minerals were obtained by measuring the amount remaining in the pellet. The pellet was freeze-dried and weighed and 100 mg was digested overnight in 4% H_2SO_4 . Wet digestion was completed within 1 hr on a hot plate with repeated additions of H_2O_2 . After appropriate

dilution with distilled water, the mineral content of the fraction was determined. The total Ca, Mg and K concentrations in the tissue were calculated from the content in the water soluble and insoluble fractions and expressed as mg/100g fresh weight. To establish the reproducibility of the method, 10 replicates of the same pulp (pooled from several apples) were processed and the coefficient of variance (CV%) was calculated for the extraction and assay of each of the minerals.

The total levels of the investigated minerals were also determined in a freeze-dried sample, from the same fruit, by the acid digestion method described for the pellet, and the values obtained by the 2 methods were compared. K was quantified with a flame photometer (Corning 4100) and Ca (in the presence of 1% La_2O_3) and Mg by atomic absorption (Perkin Elmer). (For more detailed description of method and results see Appendix 1).

4. Organic Acids - Extraction & Quantification.

Prediction of physiological storage disorders in fruit from their organic acid content prior to storage, requires a rapid method for acid quantification in fruit at harvest. Rapid extraction followed by HPLC separation and quantification enabled the content of eight organic acids to be determined in a very short time.

The orchards were sampled for organic acid analysis in the way described above for other fruit quality parameters. After thorough washing, the peel and the pulp were pooled separately and the fruit core was disposed of. The weighed diced tissue (peel or pulp) was boiled in KH_2PO_4 buffer (0.1mM, pH 2.4). To assure good homogenization the pulp was mixed with buffer a in ratio 1:4 (w/v) and the peel 1:2 (w/v). The homogenate was centrifuged at 13000 rpm for 10 min. The supernatant was filtered through miracloth,

purified via Water's Sep-Pak (1) and filtered again through a 0.22 u millipore filter. As a result of the described procedure the tissue extract was diluted 27 and 34 times in the peel and pulp respectively. At this stage the extract was left at room temperature overnight to allow the ascorbic acid, which cochromatographed with quinic acid, to convert to dehydro - ascorbic acid which didn't interfere with relevant separation profile. Eight organic acids were separated with a Varian HPLC on the solid phase of RPC_{18} , μ licrosphere 4u in a prepacked column 250x4 (Merck) with an isocratic mobile phase of KH_2PO_4 buffer, 0.1mM pH 2.4, at 0.7cc/ml rate flow, without temperature control. Peaks were detected by UV at 214nm. Peak identification and quantification were obtained by running a standard of a mixture of the eight identified organic acids: oxalic, quinic, malic, shikimic, acetic, citric, succinic and fumaric.

As pyruvic acid could not be determined by this method due its low level and a RT close to malic acid an alternative method was adopted.

(1) Waters technical bulletin-Analysis of organic acids.

4.1 Pyruvate quantification in apple pulp.

Pyruvate content in apple pulp was determined according to the method described by Lamprecht and Heinz (1984), based on the principle that the decrease in NADH concentration measured by the change in absorbance at 339 nm is proportional to the amount of pyruvate reduced.

Treatment of the pulp prior to measurement was based on the recommendations for pyruvate determination in blood and animal tissue: 2 gr of apple pulp were ground in 9 ml of ice-cold 1M perchloric acid for 2 min in an ice-bath. The homogenate was centrifuged in the cold, filtered through Whatman #1 paper. An aliquot of known volume was brought to pH 6.8-7.0 with NaOH and the volume of NaOH required for naturalization recorded. After 15 min on ice followed by filtration, and equilibration at 25°C, the pyruvate content was determined in the filtrate, according to the method described by Lamprecht and Heinz (1984).

5. Volatile emanation and content.

Three different methods were employed for determining volatiles produced by Jonathan apples after harvest and after storage.

a) Volatile emanation by the fruit was assessed by enclosing the fruit individually in 500 ml hermetically sealed jars for 2 hours. The head space was sampled with a gas-tight syringe and 100 ul aliquots were injected into a Hewlett-Packard gas chromatograph equipped with a 6ft glass 2mm 1D carbowax 20M-TPA column and FID. The volatiles identified in order of retention times were:

acetaldehyde	- 48"
methyl acetate	- 67"
ethyl propionate	- 80"
ethanol	- 100"

iso-amyl acetate	- 123"
n-butyl acetate	- 154"
hexanal	- 167"
amyl alcohol	- 210"
n-butanol	- 260"
iso-amyl-alcohol	- 350"

Not all volatiles were present in all samples. Acetaldehyde was not normally found in the head space from whole apples. Therefore two other methods were also examined.

b) Volatile accumulation in the head space above apple pulp was assayed after grinding 5g pulp tissue at 4°C in 10 ml perchloric acid in water (1:10). The slurry was filtered through cheese cloth and the filtrate was brought to pH 6.0 with cold 1M KOH, in a 50 ml flask, which was then sealed with a rubber septum and incubated for 30 min at 30°C. One ml aliquots of head space were drawn for analysis.

Acid extraction was compared to aqueous extraction, which was boiled for 5 min and cooled before incubating and sampling as above.

c) The intercellular volatiles were collected by a rapid evacuation method adapted from Klein and Faust (1978) and Blanpied (1971). The equipment used is shown in Fig. 1. A 20 ml glass test tube is fitted with a rubber serum cap, through which a hypodermic needle connects the atmosphere within the test-tube to two 35 ml gas-tight syringes, via a three-way stop-cock. One syringe is used to create a vacuum of 500mm Hg by withdrawing 35 ml air from the test tube containing a weighed 0.6x12.5 cm cylinder of pulp tissue. The vacuum is maintained for a measured period of time (usually 2 min) by fixing the position of the plunger, with the aid of a plastic prop. With the second syringe the evacuated air is sampled for injection into the gas chromatograph, as described above.

5.1 Determination of the rate of acetaldehyde and ethanol production by apple pulp.

Apple fruit were cut into 0.5 cm thick slices. Discs, 1 cm in diameter, were punched from the slices with a corkborer. The discs were pooled from 5 healthy or disordered fruit. Ten discs, randomly chosen, weighing a total of 4gr were placed in 100 ml flasks with 5 ml 50 mM KH_2PO_4 buffer pH 6.2 without or with 2.5 mM pyruvate. The flasks were sealed with rubber serum caps incubated at 30°C and shaken at 90 stroke/min. Acetaldehyde and ethanol accumulated in the flask head space were assayed periodically during four hours by gas chromatograph as above. All measurements were performed in triplicates.

6. α -farnesene and conjugated trienes (CT) - see Materials and Methods in Appendix 3.

7. Anti-oxidants

Apple peel was ground in 19ml chloroform: methanol: water at a ratio of 5:10:4, clarified by adding 1.5 ml of chloroform and water and centrifuged. The supernatant was partitioned with 0.7% NaCl to remove non-lipid matter and the remainder was dried under nitrogen and resuspended in ethanol. The reaction mixture contained 0.2 ml 200 mM linoleic acid, 0.1 ml of apple peel extract, or ethanol as blank, 3 ml 10 mM KH_2PO_4 , pH 6.8. Reaction was initiated by placing test tubes in a 37°C water bath and adding 1.5 ml 0.2mM FeSO_4 . Aliquots (0.5 ml) were taken at the beginning and after 90 min, added to 2 ml 0.01N NaOH and read at 232nm. Standard for inhibition was various concentrations of α -tocopherol (0.1-10ug) added instead of the apple peel extract.

U.S.

1984. Research consisted of statistical analyses of data that had been collected in orchard studies in previous years. Two pools of data were available. First, a 4-year survey of commercial orchards in Massachusetts had been conducted to relate fruit mineral composition of McIntosh apples at harvest with keeping quality during and following storage. From these studies, predictive equations for keeping quality were developed and tested.

The second pool was data obtained at the Fruit Storage Laboratory at the East Malling Research Station, Kent, England. Over some 15 years of time a number of surveys of commercial orchards had been made to relate mineral composition to keeping quality of Cox's Orange Pippin and Bramley's Seedling apples. These data were made available to the authors and some were suitable for statistical analysis comparable to those used for the U.S. McIntosh data.

These statistical studies produced two scientific publications.

1985. Cortland apple trees at the Horticultural Research Center, Belchertown, Mass. were used for an intensive study of scald development and the possibility of predicting its occurrence. Details are described in the appended manuscript that has been submitted for publication in the Journal of the American Society for Horticultural Science.

1986. A series of experiments were conducted using apples from trees growing at the Horticultural Research Center, Belchertown. Fruit were stored in the research facilities at the Center.

1.1 Ten different apple varieties were each harvested at two maturities. Seven varieties were replicated 4 times, a tree serving as a replication. Three of the varieties (Jonathan, Red Rome, and Red York) were replicated only twice due to limited numbers of trees. Tree age, rootstock, and size varied among varieties, but all were grown under approximately the same cultural conditions.

At harvest, 10 fruit per replication were evaluated for maturity, using internal ethylene concentrations and starch concentrations as criteria. Ethylene was measured in a 1 ml sample of internal atmosphere, obtained with a syringe, using gas chromatography. Data are reported as percent of fruit containing concentrations of greater than 1 ppm ethylene. Starch was assessed using the starch test guides prepared in British Columbia, Canada. Fruit were cut across the equatorial plane and an iodine-potassium iodide solution was applied to the cut surface. After approximately 1 minute, the staining pattern was evaluated by comparison to the photographs on the guide. The "McIntosh Guide" was used for McIntosh, Jonathan, and Empire, the "Golden Delicious Guide" was used for Golden Delicious and Spencer, the "Spartan Guide" was used for Spartan and Cortland, and the "Red Delicious Guide" was used for Red Prince Delicious, Red Rome, and Red York.

These evaluations showed that all varieties matured to some extent between harvests (Table 1). However, Red Prince Delicious and Spencer were commercially mature at both harvests, and Red York was immature at both harvests.

Approximately 2 bushels of fruit from each replicate and each harvest were stored at 0°C in air. After 3 1/2 months one bushel was removed from storage for evaluation, and after 5 1/2 months of storage the second bushel was

removed and evaluated. Evaluation procedures will be described in later sections of this report.

1.2. McIntosh apples were harvested at commercial maturity, 8 bushels per tree from 6 trees. Each tree served as a replication.

At harvest, maturity was evaluated by internal ethylene and starch measurements. Starch score averaged 7.5, and 20% of the fruit contained more than 1 ppm ethylene. Thus, fruit were commercially mature.

From each replication, 4 boxes of fruit were dipped in each of the following solutions:

A: a mixture of 0.5 g/l of 50% WP Benlate, 1 g/l 50% WP Captan, and 0.1 ml/l of X 77 surfactant.

B: a mixture of the above materials plus 2% Briner's Grade calcium chloride, 4 g/l ascorbic acid, and a saturating amount of alpha-tocopherol (Vitamin E) in ethanol.

Boxes of fruit were dipped for 1 minute and then cooled in 0°C air before storage.

Of the 4 boxes of fruit per replicate per dipping solution, 2 were stored in air at 0°C (1 for 3 1/2 months and 1 for 6 months); 1 was kept in 0°C air for 3 weeks and then stored in controlled atmosphere (CA) at 3% O₂, 5% CO₂, and 3.3°C for 5 1/2 months; and 1 was kept in 0°C air for 5 weeks, then stored in CA at 3% O₂ and 3% CO₂ at 0°C for 3 months and then kept in 0°C air for 6 weeks. Details of the evaluations following storage will be described later.

1.3. Cortland apples from a block of 18 mature, seedling-rooted trees were used for an intensive study of scald and senescent breakdown development. The purpose of this experiment was to create many variables so that chemical factors might be correlated with occurrence of physiological disorders. Nine of these trees were sprayed with 500 ppm ethephon 10 days before harvest. At harvest, samples of fruit were taken from both the exterior and the interior of trees. Percent red surface was visually estimated for 10 fruit from each sample, and these fruit were evaluated for maturity using internal ethylene and starch score, as described previously. Results (Table 2) show that ethephon advanced maturity but not red coloration, using ethylene as a criterion. Interior controls were less mature than exterior controls, both of which were less mature than ethephon-treated fruit. However, both interior and exterior controls had the same starch score, suggesting that differences in maturity between samples were not very large. Interior fruit had much less red color than exterior fruit.

Harvested samples were consolidated into lots of about 650 per position and treatment. There were sufficient fruit for 4 replications of interior lots and 5 replications of exterior lots. These lots each consisted of 4 subsamples. Two of these subsamples were dipped in a solution of Benlate, Captan, and surfactant, and the other two were dipped in a solution of Benlate, Captan, surfactant, ascorbic acid, Vitamin E, and calcium chloride. These solutions were the same concentrations as described previously for McIntosh. Of the 2 subsamples that were dipped in each solution, one was stored in 0°C air for 3 1/2 and 5 months, and the other was stored in CA at 3% O₂, 3% CO₂, and 0°C for 5 months. Evaluation following storage will be described later.

A separate set of samples of exterior fruit, with and without ethephon treatment and replicated 5 times, was dipped in a solution containing Benlate, Captan, surfactant, and 1000 ppm of PennWalt No-Scald diphenylamine (DPA). These samples were stored in 0°C air for 3 1/2 and 5 months before evaluation.

For analytical methods see Appendices.

RESULTS

1. Senescent Breakdown (SB)

1.1 Prediction - Israel

1.1.1 Maturation

SB was significantly more prevalent in Jonathan apples harvested towards the end of the harvest season in 1984 and 1985 (Table 3). In 1984 no SB was observed in fruit picked at the beginning of the harvest season and stored either in RA (5 months) or CA (7 months), but it was considerable in fruit harvested 10-14 days later. In 1985, the fruit was more sensitive to this disorder and it occurred even in early harvested fruit, but was again more severe in the late-harvested fruit. In 1986, the experimental fruit was only picked at the beginning of the harvest season and though SB development was prevalent in RA, it was very low after 8 months in CA ($2.5 \pm 6.8\%$). Fruit that was harvested and stored commercially in CA, approximately 2 weeks after the experimental fruit, showed a high incidence of SB.

It therefore seems quite apparent that the susceptibility of Jonathan apples to this type of breakdown is dependent to some extent on the stage of maturity at harvest. However, it was difficult to find a consistently high correlation between any of the maturity parameters examined at harvest and disease potential. Two parameters, fruit firmness and the iodine test for starch, gave significantly high negative correlations with SB development in RA during two seasons. In CA the disease occurred only in one of these 2 seasons, and the correlation was less uniform. In 1986, when the correlations were examined on a regional basis, they were strengthened, as there was very little disease in the fruit from the Golan Heights (Table

4). This indicates that the regional effect may dominate the effect of maturation.

1.1.2. Mineral Composition

The mineral content of Jonathan fruit pulp was determined at the beginning of the commercial harvest in all three years and, in 1985, also 7-10 days prior to harvest (pre-harvest). In 1984 and 1985 fruit was also sampled towards the end of the harvest season, and this was the fruit that showed SB development. The average data obtained for each sampling period are presented in Table 5, and show some annual fluctuations in soluble Ca^{2+} , Mg^{2+} and Na^{+} and total K^{+} . Total Mg^{2+} and Ca^{2+} were fairly constant. For all minerals the variation between trees and orchards was high. However, in spite of this, the expected correlations between mineral content at harvest and SB development during storage were not found (Table 6). In regular storage and in CA storage in 1986 no correlations could be discerned and there was very little consistency between 1984 and 1985, with regard to CA storage. Calcium levels were high, above the generally reported threshold for development of internal breakdown, but the SB disorder developed, without correlation to Ca^{2+} . However, in 1985 in CA the disorder appeared to correlate negatively with all the other minerals determined. The only consistent correlation in both years was between SB incidence and the ratio or difference between Ca^{2+} and Mg^{2+} contents of the pulp.

These findings are in contrast to the very significant body of data collected in the USA, which indicate that in many cases the calcium content alone can be used as a tool for predicting the SB potential of McIntosh apples in storage (see below).

1.1.3. Organic acids

Eight of the 13 organic acids separated by the method described were identified and quantified by comparison with known standards. All these acids have been reported in either the peel or the pulp of various apples cvs. (Hulme, 1971) in similar orders of magnitude (Table 7). Annual fluctuations in organic acid levels were quite marked, but the variability between orchards was also very high. In 1986 regional differences were noticable in oxalic, quinic, shikimic and acetic acids (Table 8). The only acid level which showed consistent correlation with SB was quinic acid, but only for fruit stored in CA. This might indicate a different disease metabolism under different storage conditions. There was a less significant correlation between SB incidence under both storage conditions and shikimic acid content in 1985 and a more significant correlation with succinic acid when the fruit was stored in RA, in two years out of three (Table 9).

1.1.4. Stepwise Regression

As none of the correlation coefficients for any single parameter were very high or highly significant, a stepwise regression analysis was attempted, sequentially taking into account all of the variables assessed, and choosing the best possible correlation between disease incidence and harvest parameter, at each step. A R^2 value of 1.0 was obtained after 17 variables had been examined. This of course would be of no practical value, so R^2 values and probabilities for 7 variables are presented (Table 10). The predominant variable was related to maturity - the starch index. The correlation coefficient could be improved by taking into account various ratios between soluble and/or total cation levels at harvest. Additional information concerning the amount of shikimic and malic acid enabled a more reliable

prediction factor ($r = 0.78$, $p = 0.001$), but determination of so many variables would be impractical.

1.2 Prediction - U.S.

1.2.1. J. Amer. Soc. Hort. Sci. 111(5): 738-742. 1986.

Predicting Poststorage Disorders of 'Cox's Orange Pippin' and 'Bramley's Seedling' Apples by Regression Equations.

Wesley R. Autio, William J. Bramlage, and Sarah A. Weis.

Abstract. Equations were developed that could predict the incidence of senescent breakdown, bitter pit, and decay in 'Cox's Orange Pippin' apples and senescent breakdown and bitter pit in 'Bramley's Seedling' apples. The parameters used to predict the incidence of disorders included fruit Ca, P, and K concentrations; fruit weight; respiration rate; and fruit maturity. Each disorder and each cultivar had a unique prediction equation. Such equations must be established individually for a disorder, cultivar, and, probably, growing region. Given an appropriate data base, this method seems to have broad applicability as a predictive tool for these disorders. However, core flush and low temperature breakdown could not be predicted using the parameters measured in this study.

Note: The full publication is appended.

1.2.1. HortScience 21(3): 474-475. 1986.

Development of Forecasting Equations for Apple Storage Disorders: The Tobit Model Versus Linear Regression.

Wesley R. Autio, Sarah A. Weis, and William J. Bramlage.

Abstract. Forecasting equations for predicting poststorage senescent breakdown from prestorage fruit Ca concentrations were developed for 'McIntosh' and 'Cox's Orange Pippin' apples using classical linear regression and the Tobit model. A comparison of the 2 regression methods was also made using 2 hypothetical data sets. Where the dependent variable was limited and a significant portion of the data was at the limit, as with 'McIntosh' apples, the Tobit model provided a superior forecasting equation. However, in cases where the dependent variable was not limited or it was limited and a significant portion of the data was not at the limit, as with 'Cox's Orange Pippin' apples, classical linear regression and the Tobit model produced similar forecasting equations.

Note: The full publication is appended.

1.3 SB Characterization - ISRAEL

1.3.1. Mineral content

The total mineral (Ca^{2+} , Mg^{2+} and K^+) content of the pulp tissue of Jonathan apples did not alter during storage, but there were noticable changes in the solubility of the two divalent cations, especially of Ca^{2+} (Table 11). The time of harvest did not appear to affect the change, but there were marked differences between the two seasons. Correlations between total content of cations in the pulp of disordered fruit and the disorder after storage were inconsistent and not very significant. However, correlations with soluble cation fractions, especially Ca^{2+} were much higher and more significant and consistent (Table 12)

(For further analysis and discussion of these findings, see Appendix 2).

1.3.2. Membrane Permeability

Two measurements were made for estimation of membrane permeability. Needle probes were inserted into whole fruits and conductivity of the whole apple measured. Apple discs were prepared from the same apples and measured in isotonic medium for leakage. These measurements were made at harvest and upon removal from storage and compared to SB after storage. (Table 13).

There was no correlation between leakage at harvest and the amount of SB that was found after storage, but a high correlation occurred concomitant with disorder development. The electrical conductivity measurements also showed no correlation at harvest, but some correlation after storage.

1.3.3. Organic acids

The decline in titratable acid content in stored apples was due mainly to a 60% decrease in malic acid, which was ca. 85% of the total organic acid content (Table 14). Other acids which also decreased during storage were citric and quinic. On the other hand there was a 3-5 fold increase in the shikimic and acetic acid contents.

The development of SB correlated very significantly with both the change in fumaric acid content and its absolute level. In other words, there was less likelihood of SB development during storage when the decline in fumaric acid from its harvest level was considerable. Correlation between SB and other organic acid contents or changes were either non-significant (acetic, citric and quinic) or only of 95% probability (oxalic, malic and shikimic). Since malic is the predominant organic acid, one would expect to find a negative correlation between SB incidence and titratable acidity in the fruit juice upon removal from storage. However, this parameter was not measured.

1.3.3. Volatiles

1.3.3.1. Effect of RH on volatile emission

Apples were held in saturated atmosphere (100% RH) or in low RH at 0°C air storage for 3 months and then removed to shelf life and their volatile emissions monitored. Scott and Roberts (1967) reported that low humidity decreases storage disorders by encouraging the dispersion of volatiles. We found that ethylene production was similar from apples held at high or low humidity, but that other volatiles were markedly lower in apples held in low humidity except for acetaldehyde and methyl acetate (Fig. 2).

1.3.3.2. Volatiles from Jonathan apples from different orchards.

Apples were removed from air storage after 3 months and 6 months and from CA after 7 months. Three replicates of 10 apples each from three orchards were placed in jars at 20°C. On the first and 6th day after removal from storage, the jars were closed for 2 h and the volatile content of the head space was measured. Each orchard showed a distinctive "fingerprint" of volatiles. The orchards from the hilly regions of the country, Iftah and Merom Golan, showed higher volatile emission than the fruit from orchards in the valley or coastal plain. The same peaks appeared but they were higher. Fruit upon removal from 3 months storage (Fig. 3) showed high ethanol content which generally disappeared during shelf life. The other volatiles tended to increase during shelf life, particularly the longer chain alcohols. Between 3 and 6 months of storage the profile changed somewhat (Fig. 3 and Fig. 4). Ethanol was still high at removal and did not always decrease during shelf life. However, hexanal was not present after six months storage, and butanal was generally higher and the amyl alcohol peaks lower. In fruit from CA (Fig. 5) the major volatile was

ethanol. Volatile emissions were generally ten times lower than from air storage, and remained so even during shelf life. Apples from CA storage showed very few volatile peaks. The only orchards retaining complex profiles were those from the hilly regions, Iftah and Merom Golan. The ethanol levels did not decrease much during shelf life.

There was, however, no apparent correlation between the profile of volatile emissions and the susceptibility of apples from a particular orchard to storage disorders. The values for SB from these apples were: 38%, 0%, 5%, 16% and 6% for Alonim, Givat Ada, Kfar Blum, Iftah and Merom Golan, respectively.

Givat Ada showed very high ethanol levels both at 3 and 6 months of storage and yet showed no senescent breakdown. Iftah and Alonim which had the highest SB incidence, showed the 2nd and 3rd highest ethanol levels, but had not much else in common.

1.3.3.3. Changes in apple volatiles during ripening

It was of interest to see if some of the variation in volatile level among the different orchards was due to differences in fruit maturity. Consequently, we took individual apples from one orchard, placed them at 20°C and daily measured their ethylene and other volatile production. A representative apple is shown in Figure 6. The total peak area, discounting ethylene didn't change appreciably as the fruit approached the climacteric, and after the climacteric it began to decline. The profile of the peaks remained similar for the apple as it passed through its climacteric.

1.3.3.4. Volatile accumulation in disordered fruit

Samples of 9 fruits per orchard were chosen randomly upon removal from storage and divided into 3 replicates of 3 fruit. A cylinder was removed with a corkborer from each

fruit and the intercellular atmosphere was sampled under vacuum as described above. Each fruit was then cut in half and graded from 0-3 for SB severity. Index values ranging from 0 to 2.2 were obtained for 25 samples. The intercellular atmosphere contained acetaldehyde in the range of 7 to 990 ng/100g fresh wt. and ethanol from 30 to 1880 ng/100g fresh wt. Good correlations were found between both of these volatiles, separately and together and the severity of the disorder (Table 15).

1.3.3.5. Pyruvate metabolism

The increase in oxalate and acetate on the one hand and the accumulation of acetaldehyde and ethanol on the other, strongly indicated that pyruvate metabolism might be closely related to the development of SB in stored Jonathan apples. Healthy and SB disordered fruit were selected from two susceptible orchards and healthy fruit from an orchard without any SB and analysed for their pyruvic acid content. (Table 16).

The highest pyruvate content was found in fruit from an orchard, which showed no disease potential and the lowest levels were obtained in diseased fruits. This was the opposite of what we had expected and suggested that possibly an increased pyruvate decarboxylase activity was involved in the development of senescent breakdown. An experiment was therefore conducted to examine this hypothesis.

The natural production of acetaldehyde and ethanol by apple flesh discs removed from healthy and SB fruit after 4 months RA storage was compared (Table 17).

The SB disordered fruit produced higher ethanol levels than healthy fruit, but the lowest acetaldehyde level was produced by the most severely disordered fruit. This would

indicate greater alcohol dehydrogenase activity in disordered fruit, as indicated by the AA/ETOH ratio in disordered fruit compared to healthy pulp, and also necessitate greater glycolytic activity to supply NADH, required for the reaction. However, the sum of AA+ETOH in the disordered fruit also indicates an increased flux of pyruvate through this pathway. This possibility was examined by incubating apple discs from the same fruits used above in 2.5 mM pyruvic acid and measuring AA and ETOH production. The difference in the rates of production with and without pyruvic acid "the net pyruvic acid effect", is described in Table 18.

In the presence of additional pyruvic acid, all tissues increased their AA and ETOH production, but in SB disordered fruit or those with a SB potential the increase was approximately 4-fold. The much greater effect produced by pyruvic acid in fruit with SB potential (orchard B), than in severely disordered fruit (orchard A), might be an indication that an increase in pyruvate decarboxylase activity is involved in SB development. As the disorder develops and the tissue becomes disorganized, the enzyme might lose some of its activity but it still remains greater than that of healthy tissue without SB potential. Direct assays of pyruvate decarboxylase and alcohol dehydrogenase in healthy and disordered and in potentially susceptible fruit, should help to clarify the picture.

1.5 Characterization of senescent breakdown - U.S.

1.5.1 Volatile production in relation to senescent breakdown among different varieties.

Ten apple varieties, each harvested at two maturities, were stored at 0°C in air for 3.5 and 5.5 months. At removal from storage, 9 to 12 fruit were placed in 8.75 l plastic

buckets at 21°C. At 2, 4, and 7 days after removal from 0°C the buckets were sealed for 3 hours, after which two 1-ml samples of head space gases were taken for gas chromatographic (GC) analysis. All samples were injected within 1.5 hrs after being taken. (Preliminary analyses showed that acetaldehyde and ethanol were at equilibrium concentrations within 3 hours). Total headspace volume was measured by subtracting fruit volume from container volume. GC analysis was essentially according to Lidster et al. (1983). A 3.2 m x 1/8 cm stainless steel column packed with 20% Hallcomid M 18 on 60/80 mesh Chromosorb W (AW/DMCS treated) was used in a Varian Series 2700 GC. Instrument temperatures were maintained as follows: oven, 85°C; injector, 145°C; detector, 140°C. Nitrogen flow was at 70 cc/minute. Volatiles were tentatively identified by retention times of authentic standards. Using GC-mass spectrometry Lidster et al. (1983) identified these same volatiles from McIntosh apples on this column. Standards of authentic volatiles were prepared at 1000 ppm. The standards were measured only once, and corrections for any operating variables were made by using a 5 ppm ethylene standard.

After storage, seven major volatiles were tentatively identified: ethylene, acetaldehyde, ethanol, ethyl propionate, ethyl butyrate, and hexanal. Besides corresponding to retention times of authentic compounds, their appearances and relative retention sequence were similar to results of Lidster et al. (1983). In Table 19, concentrations of these volatiles in headspace over Red Prince Delicious apples are shown. Except for ethylene, the volatile production tended to increase with time at 21°C, and to be higher for fruit from the second harvest than for ones from the first harvest. Other than ethylene, the volatile with the highest concentration was acetaldehyde, and the one with the lowest concentration was hexanal.

These results generally represent the data for all 10 varieties, except that most other varieties produced lower concentrations of ethyl propionate, ethyl butyrate, and hexanal, which sometimes were not measurable until the seventh day. Thus, it appears that volatile production, except for ethylene which peaks or plateaus at the respiratory climacteric, undergoes a general increase with ripening, and that volatile production is enhanced by later maturity.

In nearly all cultivars, acetaldehyde and ethanol were produced abundantly. Since these compounds have recognized physiological significance, their relative production by 10 cultivars is shown in Tables 21 and 22. Relative production rates for ethylene are shown also in Table 20.

Ethylene production rates among cultivars were quite variable (Table 20). Spencer produced very low concentrations and Empire also produced relatively low rates. In contrast, Cortland and Golden Delicious produced extremely high rates of ethylene. These differences would be of importance in attempting to control ethylene production during apple storage, but since ethylene is physiologically active at extremely low concentrations, physiological significances of these differences do not seem likely.

Ethanol production varied greatly among cultivars (Table 21). Golden Delicious, Red Rome, and Red York produced only small amounts regardless of maturity, storage time, or time at 21°C, while McIntosh, Red Prince Delicious, and Spencer produced large quantities at nearly all measurements. Jonathan produced little after the first harvest but much more after the second harvest; this was probably the result of watercore development in the fruit by the second harvest.

Production of acetaldehyde varied more than that of any other volatile (Table 22), but differences among cultivars generally paralleled those of ethanol. Golden Delicious, Red Rome, and Red York produced very little acetaldehyde, while McIntosh, Red Prince Delicious, and Spencer produced very high concentrations. Jonathan produced much more after the second harvest than after the first harvest, probably as a result of watercore formation.

Ethanol and acetaldehyde accumulation have been related often to the development of senescent breakdown during and following storage. In this experiment the occurrence of breakdown was recorded both for the fruit used to measure volatiles (at the end of the measurement period) and for a separate lot of approximately forty fruit kept 1 wk at 21°C. Data in Table 23 show the relative occurrences of breakdown among the 10 cultivars in the 40 fruit kept 1 wk at 21°C; however, breakdown in the samples used for volatile production paralleled these differences. Spencer were extremely susceptible to breakdown, the fruit being completely lost to it after 5 1/2 months of storage. Cortland also developed much breakdown. Nearly all of the Jonathan apples developed breakdown after the second harvest, but this was watercore breakdown rather than senescent breakdown. McIntosh, Red Rome and Spartan were the only other cultivars with significant amounts of breakdown.

There was no overall relationship of ethanol or acetaldehyde accumulation to breakdown development. Spencer, McIntosh, and Cortland accumulated relatively high amounts of the volatiles and developed large amounts of breakdown. In contrast, Red Prince Delicious produced large concentrations of volatiles but developed essentially no breakdown, and Red Rome produced low concentrations of volatiles but developed significant amounts of breakdown.

These results do not preclude the use of volatile measurements in detecting susceptibility of apples to senescent breakdown, but they show that any such technique must be developed specifically for a cultivar. For example, it may be possible to detect susceptibility of Delicious and McIntosh to breakdown by monitoring accumulation of ethanol or acetaldehyde in the atmosphere of a storage, but the threshold concentrations would apparently be much higher for Delicious than they would be for McIntosh.

1.5.2. Postharvest variables affecting volatile production and senescent breakdown after storage of McIntosh apples.

A series of postharvest variables were applied to McIntosh apples, as described in the Materials and Methods section and summarized in Table 24. After removal from storage a 10-fruit sample was used for measuring volatile production at 20°C, as described in Section 1.5.1. After 7 days these fruit were cut and assessed for physiological disorders. The remainder of the fruit that were taken from storage were also kept at 20°C for 7 days and then evaluated for occurrence of senescent breakdown.

Senescent breakdown varied significantly among treatments (Table 25). Ethylene production tended to be low in the samples with significant amounts of breakdown (Table 26), probably indicating their senescence. However, some treatments (e.g., Treatments 2 and 5) also had low ethylene production but little breakdown. Samples with the highest acetaldehyde production were samples with significant breakdown (Treatment 3 and 4), but some samples with substantial acetaldehyde production developed little or no breakdown (e.g., Treatments 5 and 7). Ethanol production increased with time at 20°C regardless of treatment, but the mean ethanol production rates paralleled the mean

acetaldehyde production rates although mean ethanol rates were always lower than the mean acetaldehyde rates. Thus, there was no consistent relationship of ethanol production to development of senescent breakdown.

Among the fruit actually used for volatile production, occurrences of other disorders (brown core and what appeared to be low-temperature breakdown) were detected and recorded (Table 25). The only lots in which hardly any internal disorders occurred were Treatments 2, 5 and 7. These samples had the lowest acetaldehyde and ethanol production rates (Table 26). Thus, it appears that any of these internal disorders may be associated with increased production of these volatiles, and they may be a general consequence of collapse of normal cellular integrity and physiological functioning.

1.5.3. Preharvest and postharvest variables affecting volatile production and senescent breakdown after storage of Cortland apples.

The design of this experiment was described in Materials and Methods. For evaluating volatile production and senescent breakdown, only treatments using fruit from the exteriors of the trees were used. Thus, 5 treatments (Control, Ethephon-sprayed, Calcium-and-vitamin-treated, Ethephon sprayed and calcium vitamin-treated, and DPA-treated) were used and they were stored in both air and CA. Following removal from storage, 10 fruits were used for volatile production and measurements as described previously in section 1.5.1., and the remaining fruit were kept at 20°C for 7 days before assessment for senescent breakdown.

Significant differences in senescent breakdown existed among treatments (Table 27). Following air storage, control

and ethephon-sprayed fruit had the greatest amount of breakdown. Calcium-plus-vitamin treatment and DPA treatment reduced the amount of disorder. However, the least amount of breakdown occurred following CA storage, regardless of previous treatment. Thus, three levels of breakdown existed among treatments.

Production of ethylene, acetaldehyde, ethanol, ethyl butyrate, ethyl propionate, and hexanal by samples of these fruit is shown in Figure 7 and statistical significance of factors on these volatiles, determined by analysis of variance, is shown in Table 28.

The factors most affecting volatile production were storage type and days at 20°C after storage. Except for ethylene, CA storage generally suppressed volatile production during the first 4 days at 20°C. However, on the seventh day CA stored fruit were producing all volatiles abundantly. DPA dips and Ca/vitamin dips, which reduced breakdown in air-stored fruit (Table 27), did not reduce volatile production by these fruit (Table 28, Fig. 7). CA storage, which reduced breakdown more than any other factor (Table 11), suppressed production of all volatiles except ethylene shortly after removal from storage, and resulted in higher ethylene production (Fig. 7). These results suggest that CA storage simply delayed senescence of the fruit rather than affecting production of any specific volatile. Thus, these results give no indication that production of any of these volatiles has a causal relationship to occurrence of senescent breakdown in Cortland apples.

1.5.4. Peroxide levels at harvest in relationship to breakdown potential in Cortland apples during storage.

Many studies have shown an association of oxidative products such as peroxides to senescence in plant organs (Brennan and Frenkel, 1977). To test for a possible association to senescent breakdown in Cortland apples, fruit from the experiment described in Section 1.5.3. and the one to be described more fully in Section 2.4.2, were analyzed at harvest and after 2 or 4 weeks at 0°C for malonaldehyde by the TBA test, and for total peroxides. These values were then compared with senescent breakdown incidence in lots stored in air or CA for 3.5 or 5.5 months and then kept at 20°C for 7 days.

Samples were prepared by blending 25 g of frozen apple peel (a composite sample of tissue from 10 fruit) in 100 ml of cold acetone, filtering the blend through Whatman No. 4 paper, and bringing the filtrate to 150 ml with water.

The TBA test was essentially according to the method of Wills (1966). To a 2 ml aliquot of extract was added 2 ml of 20% trichloroacetic acid aqueous solution, and 1 ml of 0.67% aqueous solution of thiobarbituric acid (TBA).

The mixture was boiled for 10 min., cooled, and centrifuged at 5000 rpm for 10 min. The clear supernatant was brought to 10 ml with water and its absorbance was measured at 532 nm. An extinction coefficient of 1.56×10^5 was used to calculate malonaldehyde values.

Total peroxides were measured by a modification of the method of Brennan and Frenkel (1977). To 5 ml aliquots of extract were added 15 ml of water and 2 ml of titanium reagent. A blank contained 2 ml of water instead of the titanium reagent. These samples were centrifuged for 15 min

at 15000 x g and OD was measured at 415 nm against the OD of water. Peroxide values were determined by comparison with a standard curve representing 0.1 to 1 nM concentration of a titanium - H_2O_2 complex.

Both malonaldehyde and total peroxide concentrations were much higher in exterior fruit than in interior fruit at harvest, and these differences persisted through 4 wks at 0°C (Table 29). Analysis of variance showed that no other factor significantly affected either of these values (data not shown). Senescent breakdown after air storage was significantly greater in exterior fruit than in interior fruit. CA storage for 5.5 months resulted in little breakdown regardless of treatment. While these results are strictly preliminary, they suggest that the level of oxidation products at harvest may have a relationship to the potential for senescent breakdown after storage. It may also be physiologically significant that the exterior fruit, more exposed to sunlight and high temperatures, had higher levels of these oxidation products. The difference was not due to ripeness of fruit since ethephon increased ripeness (Table 2) but did not increase the activity of oxidation products (Table 29).

2. Superficial Scald (SS)

2.1 Prediction - Israel.

2.1.2. Maturation

2.1.2.1. Jonathan

Though SS is generally considered to be a disorder which can be somewhat reduced by delaying harvest, this was only achieved with Jonathan fruits in one out of two seasons. In the first season, there was even more SS development in late harvested fruit in some of the orchards,

though the overall increase in disease indicated was not statistically significant. It is therefore not surprising that in this season almost no significant correlations were found between maturity parameters at harvest and disease development in RA (Table 30) (In CA the amount of disease was negligible).

In 1985, where SS incidence was significantly affected by harvest date, the maturity parameter which correlated most consistently with disease development was acid content, though the correlation was not very high. On occasion there were higher and more significant correlations with one or two other maturity parameters (firmness, starch, red colouration), but none of them could be considered satisfactory for predicting disease potential.

In 1986, pooling of all data showed no tendency to relate disease incidence to disease potential. However, on a regional basis, in the two areas which showed a high disease incidence, the correlation between fruit firmness and SS was high and very significant (Table 31).

2.1.2.2. Granny Smith

Scald which developed on Granny Smith apples was well correlated with most of the ripeness parameters measured at harvest (Table 32)

Treatments which affected fruit maturity such as ethephon sprays, emphasized the correlation between maturity and scald development (See Appendix 3).

2.1.3. Conjugated Trienes (CT), α -farnesene and anti-oxidants.

The level of CT at harvest correlated with the scald developing after storage. A covariance analysis comparing CT level in Granny Smith apples at harvest to scald development

after 3 months showed a correlation coefficient of 0.617, significant at the 0.001 level (See Appendix 3). Covariance analysis run on Jonathan apples, comparing CT levels at harvest to scald development after 5 months of storage gave a correlation coefficient of 0.565, significant at 0.001. There was also a weak correlation with scald which developed on DPA dipped Jonathan apples ($r=0.385$, $p=0.02$).

Peel anti-oxidant content was measured by two methods, absorption at 200 nm, and amount of inhibition by peel extract of linoleic acid oxidation. The inhibition was compared to that caused by α -tocopherol. OD_{200} was thought to reflect antioxidants. However, it is obviously a mixture of compounds and in the case of Jonathan apples the peak height of OD_{200} correlates positively with the peak height of CT, whereas the reverse should be the case if the absorption at 200 nm was due to antioxidants alone. Nonetheless, correlations were run between either OD_{200} or α -tocopherol equivalents in the peel at harvest and scald development. No correlation was found.

2.1.4. Organic acid

Organic acid content of the peel was compared to scald development each year. In 1986 when 40 orchards were sampled there was no correlation. During the first two years there was a positive correlation between the amount of organic acids at harvest and scald (Table 33).

It is interesting that total titratable acidity correlated differently with scald during these two years, since malic acid is considered to be 85% of the organic acid content and it contributes significantly to the acidity measurement.

2.1.5. Early Induction of Scald

In the first year a series of temperature treatments were tried with Granny Smith apples during the first month of storage to see if scald development could be induced earlier than the normal 2-3 month storage period necessary. The treatments which were conducted on apples from two harvests were:

1. 30° for 1 month.
2. 1 week 30°, 2 weeks 0°C, 1 week 30°.
3. 3 weeks 10°C, 1 week 30°C.
- 4. 0° $\frac{3}{4}$ weeks, 1 week 30°C.

The results were negative in that no scald developed in any of the treatments.

2.1.6. Spot test

A spot test was developed with α -farnesol to predict susceptibility to disease development in storage. Aliquots of α -farnesol solutions, at a range of concentrations, were placed on a 10-fruit sample at harvest. On the following day, the diameters of the brown spots which developed were measured and correlations were drawn with the extent of disease development on large fruit samples after 3 and 5 months regular cold storage for both Jonathan and Granny Smith.

The results of the spot test on Granny Smith correlated well with scald development after 3 months storage at all concentrations of α -farnesol tried. However, the best correlation was obtained with^r the sum of spot diameters ($r=0.94$, $p=0.001$). The severity of the disease was too high after 5 months storage to obtain a good correlation ($r=0.57$, $p=0.1$).

On Jonathan there was no response to α -farnesol at concentrations below 4% and there was little difference in the response to 4% and 5% α -farnesol. A fairly good correlation between the size of the response to .4% α -farnesol and scald development after 5 months in RA, was obtained ($r = 0.761$, $p \leq 0.01$).

2.2 Prediction - U.S.

2.2.1. Antioxidant Activity in 'Cortland' Apple Peel in Relation to Superficial Scald Susceptibility after Storage.

Shimon Meir and W.J. Bramlage (J. Amer. Soc. Hort. Sci. Submitted for publication).

Abstract. 'Cortland' apples from both exterior and interior of large trees were harvested over a 25-day period, and samples were stored for 0 to 5.5 months in 0°C air. Antioxidant activity of peel at harvest was assayed. Hexane extracts of whole fruit were used to estimate alpha farnesene and conjugated trienes after 1 to 4 months of storage, and these values were correlated with scald development after 3 to 5.5 months of storage. Alpha farnesene increased during the first 2 months of storage and then decreased, while conjugated trienes increased progressively with storage time. Alpha farnesene was not affected by harvest date but conjugated trienes were decreased by later harvest. Conjugated trienes were negatively correlated more strongly with scald than was alpha farnesene.

Antioxidant activity increased with later harvest in both exterior and interior fruit, even though exterior fruit ripened during this time while interior fruit did not. Antioxidant activity at harvest was negatively correlated

more strongly with scald development than was either alpha farnesene or conjugated trienes, with r values as high as -0.83. A large OD peak at about 200 nm was detected in the hexane extracts of apples, and it correlated with antioxidant activity ($r = +0.63$). OD 200 values for harvest extracts were as strongly correlated with scald development after storage as were antioxidant assays. A large number of compounds absorbed at 200 nm, including many with antioxidant activity. We propose that OD 200 of hexane extracts is an estimate of antioxidant activity, and may represent a convenient and effective chemical index of scald susceptibility of apples after harvest.

Note: The full text is appended (Appendix 4).

2.2.2 Differences among varieties in potential prediction characteristics.

Fruit from the experiment using 10 apple varieties, described in Materials and Methods, were used to examine differences among varieties in antioxidant levels at harvest, OD 200 values, alpha farnesene and conjugated triene concentrations, and scald development after air storage.

Fruit at harvest were extracted with hexane and absorbance of the hexane was determined, as described in the appended manuscript (Appendix 4). After removal from storage, 10-fruit samples were extracted with hexane and its absorbance was measured. The remainder of the samples were kept at 20°C for 7 days, and scald was determined as percent fruit affected and as intensity of disorder, as described in Table 34.

Scald incidence increased with storage time, and tended to be less with the second harvest than with the first

harvest on varieties that developed substantial amounts of scald (Table 34). An exception was Red York, which developed scald on nearly all fruit regardless of harvest or storage time; this variety was still immature at both harvests (Table 1). Incidence varied greatly among varieties, exceeding 50% for McIntosh, Spartan, Cortland, Red Rome, and Red York, but being virtually nil on Red Prince Delicious and Golden Delicious.

Antioxidant activity at harvest also varied greatly among varieties (Table 35). McIntosh, Red Rome, Golden Delicious and Cortland had the highest mean values, whereas Spartan, Spencer, Red Prince Delicious, and Jonathan had the lowest mean values. No relationship of antioxidant activity to either harvest date or maturity (Table 1) was evident. Mean values for the two harvests were the same, but some varieties had very different values for the two harvests: Empire and Golden Delicious had much lower values at the second harvest than at the first, while Cortland and Red York had much higher values at the second than at the first harvest. Thus, it appears that antioxidant activity was a characteristic unique to each variety. It should be noted that antioxidant levels were lower in Cortland than they were the previous year (appended manuscript).

In 1985, we found that OD 200 values of hexane extracts of whole apples were representative of antioxidant activity at harvest (appended manuscript). In 1986, as with scald development and antioxidant activity, OD 200 values varied greatly among cultivars (Table 36). However, OD 200 values were not representative of antioxidant activities. McIntosh and Red Rome, which had high antioxidant levels, had among the lowest OD 200 values. Furthermore, whereas the mean antioxidant level was the same at the second harvest as at the first one, the mean OD 200 value was almost twice as

high at the second harvest as at the first one. We found previously that the OD 200 peak represented many compounds (manuscript), and the present data suggest that this composition varies greatly among varieties. There was no significant correlation across varieties and harvests between OD 200 at harvest and antioxidant levels at harvest (Table 39). Thus, any relationship between these factors must be developed within a specific variety.

Only 3 varieties contained measurable alpha farnesene at the first harvest, but by the second harvest 7 varieties had measurable concentrations (Table 37). After 3.5 months of storage high concentrations existed, and in most varieties slightly higher concentrations were found in the fruit from the second than in those from the first harvest. After 5.5 months of storage concentrations usually had fallen somewhat below those at the 3.5 month interval. Cortland and Red York had the highest levels of alpha farnesene, and both developed significant amounts of scald. However, McIntosh and Spartan had the lowest concentrations and they also developed substantial amounts of scald. The significant negative correlations between alpha farnesene concentrations at 3.5 months with scald development after 5.5 months of storage (Table 39) are contrary to frequently observed positive correlations, and probably are coincidental.

Cortland was the only variety that contained conjugated trienes at harvest, but all varieties accumulated the compounds, oxidation products of alpha farnesene, during storage (Table 38). Harvest dates had only small effects on these values. Secondary conjugated triene peaks at OD 258 and 269 were also measured and were highly correlated ($r = +0.67$ to $+0.92$) with the values shown in Table 38 (data not shown). Varieties that accumulated high concentrations

usually developed significant scald, but an exception was Red Prince Delicious. Some varieties that developed much scald, e.g. McIntosh and Red Rome, accumulated relatively low levels of conjugated trienes. Consequently, overall there was no correlation between conjugated triene concentrations and scald development across varieties (Table 39).

The majority of significant correlations among parameters across varieties showed that varieties were consistent in their production of these compounds, i.e. relative production of a compound by a variety at one time was consistent with the relative production at another time interval. This indicated significant differences in metabolic activities of the synthetic pathways among varieties. Clearly, however, sensitivity to induction of scald in relation to a given level of alpha farnesene, conjugated trienes, or antioxidants varied greatly among varieties.

Alpha farnesene and conjugated trienes are volatile compounds, and it was observed that varieties accumulating high concentrations of these compounds were generally ones that produced relative high concentrations of volatiles (Tables 20, 21, and 22). Correlations showed that conjugated trienes were often positively related to acetaldehyde and ethanol production (Table 40). The secondary peaks at OD 258 and OD 269 were also usually positively correlated with acetaldehyde and ethanol (data not shown). Indeed, scald development was also sometimes positively correlated with acetaldehyde and ethanol production after storage (Table 40). Thus, actual production of scald-inducing volatiles may be linked to the general metabolism of volatile compounds by a particular variety, whereas sensitivity to these compounds

may be due to conditions which are specific to each variety.

2.3 Superficial Scald characterisation - Israel.

2.3.1. Jonathan The five orchards showed varying susceptibility to scald. The scald level was not consistently affected by the stage of maturity at which this cultivar was harvested, with some orchards showing more scald susceptibility in the second harvest. The level of scald from the different orchards after 6 months air storage was quite similar during the two years examined, as was the level of CT in the apple cuticle after 3 months storage. (Table 41).

The level of scald which developed at the end of air storage tended to reflect the level of CT found in the middle of the storage period, except in the case of Merom Golan at both harvests and Menara at the second harvest. In both cases the CT levels were high while scald levels were low.

Taking the data from the 1984 season without Merom Golan there was a strong correlation found between the incidence of scald which developed after 6 months storage and CT level which accumulated during 3 months storage ($r = 0.62$; $p = 0.001$).

Jonathan apples showed much reduced scald levels when stored in CA (Table 42). In contrast their CT and Δ -farnesene levels were similar to those from air storage. The air storage measurements were taken after three months, while those from CA were taken after 6 months. Nonetheless, the similarities are striking, while the differences in scald level are also striking. It appears that 2.5% oxygen does not prevent the oxidation of Δ -farnesene to CT, while

it does inhibit the development of scald. If the CT are the precursors of the further reactions which lead to the brown skin discoloration, then it is one of these further steps which is inhibited by CA. It is also possible that accumulation of CT is not causally related to scald development, but is a non-related process which is affected by various conditions similarly to the scald process. In this case CA is a means to separate these two processes since it decreases scald without decreasing CT levels.

It was thought that since exogenous antioxidants can inhibit the development of scald, that the natural antioxidants in the apple peel might play a role as well in preventing scald. The level of antioxidants in the apple peel was measured by the inhibition of the oxidation of linoleic acid caused by the presence of peel extract.

The antioxidant level in apple peel was measured after 3 and 4 months of air storage and 5 days shelf life and compared to scald which developed after 5 months of storage. (Table 43). The antioxidant level decreased as storage proceeded and decreased further during shelf life. There was a tendency for the antioxidant level to be lower in orchards which showed higher scald. Two orchards showing 47-50% scald had antioxidant levels at 3 months of 65-70% inhibition of linoleic acid oxidation. The other orchards showed scald incidence of 23-33% and their antioxidant levels were 80-90% inhibition of linoleic acid oxidation. After 4 months the tendency was less pronounced but still there - 60-62% inhibition for the 2 high scald orchards and 65-75% inhibition for the other orchards. The same was true in shelf life, the high scald orchards showed 43-45% inhibition of linoleic acid oxidation by apple peel extract and the orchard with 33% scald showed 56% inhibition.

The reports in the literature indicate that α -farnesene is at very low levels and CT non-existent in apples at harvest, and that accumulation begins only during storage. We measured α -farnesene and CT in the apple cuticle at harvest and monthly for 5 months, at which time apples were removed from storage to examine scald development. Both α -farnesene and CT were present in apples at harvest. There was a wide variation of CT levels among the orchards at harvest, ranging from 0.2 to 1.2 $\mu\text{moles}/\text{cm}^2$ peel (Fig. 8). The level of both CT and α -farnesene increased at varying rates in the different orchards during storage. In some orchards, the peak level was reached after 2 months and then declined, in others after three months, and in some cases levels continued to increase throughout storage.

Covariance analyses run on Jonathan apples, comparing CT levels at harvest to scald development after 5 months of storage gave a correlation coefficient of 0.565, significant at 0.001 probability.

2.3.2. Granny Smith

This cultivar is very scald susceptible. Much more scald developed on these apples than on the Jonathan and this was reflected in the α -farnesene and CT levels, which were 6-10 times higher than in Jonathan. Scald levels in Jonathan ranged from 23-73% after 5 months of storage. These values are similar to the scald values obtained in Granny Smith after 3 months of storage. It appears that higher levels of CT are needed in Granny Smith apples to elicit scald than are required in Jonathan apples.

Most of the experiments with Granny Smith are described in the manuscript in Appendix 3. There was a clear cut correlation between the stage of maturity of the fruit at harvest and the incidence of scald development during

regular storage and subsequent shelf-life. Most susceptible to the disorder was fruit harvested from the interior region of non-ethephon sprayed trees. This was the least mature fruit. Fruit harvested from the exterior part of ethephon - sprayed trees at the early harvest or of non-sprayed fruit at a later harvest data was much less susceptible and responded better to postharvest DPA dips than did the former category of fruit. The stage of maturity of the fruit was well defined by its TSS content and a significant correlation was found between TSS at harvest and scald incidence after storage ($r = 0.76$, $p = 0.001$). There was no correlation between Δ -farnesene cuticle content at different times of storage and scald development. However, the scald index after 3 months of storage correlated well with the amount of CT present after 1.5 months of storage ($r = 0.9$, $p = 0.001$).

Unlike the CA storage which reduced scald without reducing CT levels, DPA dips reduced both (Table 44). Δ -farnesene levels were not affected by DPA dips, although occasionally they were higher than non-treated fruit, probably because the oxidation of Δ -farnesene to CT was inhibited. The levels of CT did not change during shelf-life.

Although scald symptoms developed most rapidly during shelf-life at 20°, subsequent to cold storage, there was no increase in the amount of CT during this period. It was therefore considered whether the oxidation of Δ -farnesene to CT was required for symptom development. Granny Smith apples which showed none to slight symptoms upon removal were treated with various antioxidants. Scald development during shelf-life was significantly arrested by such treatments only on symptom-free fruit. Fruit that showed

slight scald development upon removal from storage was unaffected by the antioxidants and scald developed freely.

Since there was such a clear-cut relationship between fruit maturity and scald development in this cultivar, a regime of ethephon sprays was given to obtain a broader range of maturities. (For experimental details and results see Appendix 3).

Apples have been thought to accumulate α -farnesene and CT in storage. We found that there was some α -farnesene and CT in the apples before harvest, that these levels declined as harvest was delayed and then began to rise again during storage. It was interesting to see what happened if the harvest was delayed indefinitely. Consequently, we harvested in January apples which had been left on the trees in an orchard in the Golan, and compared their CT and α -farnesene levels to apples harvested in October and placed in 0°C air storage (Table 45).

As can be seen these apples accumulated both volatiles even when not in storage, but the levels are much lower than those which developed in stored apples - 2.5 times lower for α -farnesene and 7 times lower for CT. The α -farnesene and CT content was monitored bi-weekly for the first month in the apples harvested in January and showed no change. The apples were stored for 4 months and developed no scald. Apples harvested in October developed 70% scald after 4 months of storage.

2.4 Characterization - U.S.

2.4.1. Postharvest variables affecting factors related to scald development in McIntosh apples.

In the experiment described in Section 1.5.2. and summarized in Table 24, 5 apples were extracted with hexane

at removal from storage and the extract was used to measure OD 200 values, alpha farnesene, and conjugated trienes. The remaining fruit were kept at 20°C for 7 days and assessed for scald as described in Section 2.2.

Storage in air for 6 months (Treatments 3 and 4) produced intense scald development, whether or not the fruit were dipped in calcium and vitamins (Table 46). CA storage greatly reduced scald, but only when delay before CA was not too great (Treatments 5 and 7).

Most importantly for the purpose of this study, 3 distinct levels of scald development were established: Treatments 1, 2, 5 and 7 with less than 12% scald; treatments 6 and 8 with 53 and 70% scald; and treatments 3 and 4 with 99 to 100% scald. None of the parameters supposedly related to scald development (OD 200, alpha farnesene, and conjugated trienes) was associated with these levels of scald development. This is similar to the data in the variety experiment, where McIntosh developed extensive scald, but its occurrence had no relationship to relative levels of alpha farnesene, conjugated trienes, and OD 200 values (Tables 34 to 37). It should be noted that the appearance of scald on McIntosh is different from that on any other of the varieties being tested. It produces a gray discoloration of the skin but does not cause sunken, dessiccated, dead lesions to develop on the fruit surface. We believe that scald on McIntosh is a different disorder, possibly chilling injury, than the scald that develops on the other varieties under test here. It showed no indication of being caused by oxidation products of alpha farnesene.

2.4.2. Preharvest and postharvest factors affecting scald development on Cortland apples.

In the experiment described in Section 1.5.3., 10-fruit samples were taken at removal from storage and extracted in hexane as described in the appended manuscript. The extract was then measured for OD 200 values, alpha farnesene, and conjugated trienes as described previously. The remaining fruit were kept at 20°C for 7 days and then were assessed for scald as previously described.

There was considerable variation in scald development among treatments (Table 47) but much of it was due to experimental difficulties. Much more scald developed during the 7 days following 3.5 rather than 5.5 months of air storage. This is contrary to expectations (e.g., Table 34) and was probably the result of conditions existing during the 7 days at 20°C; after 3.5 months the fruit were kept under a polyethylene sheet and hence at high humidity, whereas after 5.5 months the polyethylene was inadvertently omitted and fruit visibly desiccated due to low relative humidity. Also, the ethephon-plus-Ca- and vitamin treatment usually showed highest scald development but this may have been an artifact. The vitamin treatment caused substantial fruit damage that was difficult to distinguish from scald.

The only reliable difference in scald intensity among these treatments was the reduction of scald due to DPA treatment, whether or not fruit had been treated with ethephon before harvest. Thus, there were two levels of scald susceptibility among treatments: samples treated with DPA and ones not treated with it.

Fruit treated with ethephon 10 days before harvest contained more alpha farnesene at harvest than ones that had not received ethephon (Table 48). However, this difference

did not exist after storage; indeed, no consistent differences in alpha farnesene concentration among treatments existed after storage.

Ethephon also increased the concentrations of conjugated trienes in the apples at harvest, but this difference generally persisted in fruit at removal from storage (Table 48). The Ca-plus-vitamins dipping treatment at harvest also increased the conjugated triene concentrations in fruit at removal from storage. However, neither of these increases in conjugated triene concentrations was associated with higher incidence of scald development (Table 47). DPA dip markedly reduced conjugated triene concentrations (Table 48) and this reduction was associated with lower scald incidence. The lack of correlation of scald with the increased conjugated trienes in ethephon-treated and Ca-plus-vitamin treated fruit might reflect a lack of sensitivity in our scald-development technique, a saturating concentration of conjugated trienes in the control fruit, or a complex interaction in the mechanism by which conjugated trienes lead to scald development.

OD200 values were higher at harvest in ethephon-treated exterior fruit than in control exterior fruit, but this difference did not exist in the interior fruit (Table 48). There was no other consistent difference among treatments in OD200 values, and no relationship between these values and scald development (Table 48). The values increased during storage, but less in CA than in air storage (Table 47).

2.5 Stimulation of carotenoid synthesis in relation to scald susceptibility in Cortland apples - U.S.

Alpha-farnesene is a sesquiterpene, a diverse group of terpenoid compounds containing a 15-carbon skeleton.

Farnesyl pyrophosphate is the precursor of all sesquiterpenes. This compound is also the precursor of the bigger terpenoids: steroids, carotenoids and xanthophylls. No work has been published dealing with the biosynthesis of alpha farnesene from farnesyl pyrophosphate in apples; indeed, little has been published on the nature of scald since commercial control measures with DPA and ethoxyquin have been developed. The facts that it is difficult to find alpha farnesene in the apples at harvest time and that it rises during storage, lead to the suggestion that this may be a result of an inhibition of the chain of reactions leading to the bigger terpenoids. Yokoyama et al. (1984) described a series of compounds that are effective in several steps of the biosynthesis chain. The effect is believed to be caused by derepression of the genes regulating the synthesis of specific enzymes and inhibition of the cyclases in the biosynthetic pathway of the carotenoids. Our hypothesis is that, by increasing the biosynthesis of carotenoids by these substrates, the alpha farnesene accumulation during storage will decrease. If alpha farnesene is the cause of scald, less scald should develop.

To test this hypothesis, we received from Dr. Henry Yokoyama, Fruit and Vegetable Chemistry Laboratory, Pasadena, CA, a gift of 3 compounds that can stimulate carotenoid synthesis. These compounds are designated as DCPTA, MPTA, and MOPTA. They are modifications of the compounds CPTA, (2-(4-chlorophenylthio) triethylamine hydrochloride), well known to stimulate carotenoid synthesis in citrus (Poling et al., 1975).

Since the compounds were received after harvest in 1985, they were used as a postharvest dip treatment. Cortland apples were harvested on September 23, stored in

0°C air for 16 days, and then dipped in a series of solutions. All solutions contained 0.5 g/l of 50% WP Benlate, 1 g/l of 50% WP Captan, and 0.1 ml/l x 77 surfactant. Treatments consisted of no addition to this solution (control) and the following additions: MPTA, 50 or 500 ppm; DCPTA, 500 ppm; MOPTA, 500 ppm; aminotriazole, 50 or 500 ppm; or diphenylamine (Shield liquid), 1000 ppm. Aminotriazole is believed to inhibit carotenoid synthesis and DPA is a known scald inhibitor. One box of apples constituted an experimental unit, and these units were replicated 6 times, each replicate being a separate tree as source of fruit.

The fruit were then stored at 0°C in air. One and 3 months after dipping, 10 fruit per replication were taken from 6 of the treatments, extracted with hexane, and the extract was measured for alpha farnesene and conjugated trienes by optical density. After 3 and 5 months of storage, 25 fruit samples were placed at 20°C for 7 days after which they were assessed for scald and scald score, as described in Table 48.

MPTA, DCPTA, MOPTA, and DPA all reduced the concentrations of alpha farnesene after 1 and 3 months of storage (Table 49). However, aminotriazole had no effect. Only DPA reduced conjugated triene concentration, scald incidence, or scald intensity. Fruit were evaluated for yellow color using a visual color chart, but no difference was visually apparent.

These results suggest that the carotenoid-stimulating compounds modified the terpenoid pathways sufficiently to reduce significantly the accumulation of alpha farnesene, although it cannot be determined whether or not they actually stimulated carotenoid synthesis. Yet, the reduction

in alpha farnesene was not reflected in a reduction of its oxidation products, the conjugated trienes, or in scald development. It may have been that even the lowered concentration of alpha farnesene was sufficient to saturate the capacity of these fruit to form conjugated trienes. The conjugated triene concentrations recorded here were relatively low in comparison with values in a parallel experiment in 1985 (appended manuscript). Since these treatments were applied 2 1/2 weeks after harvest, their potential for modifying terpenoid synthesis may have been seriously limited.

In 1986, two of these compounds, MPTA and DCPTA, were applied to Cortland apples in a different manner. Eight days before harvest these compounds, in solutions containing 0.25 ml/l of the surfactant X-77, were painted onto fruit. Control fruit were painted with the surfactant solution. Each treatment was replicated 4 times, separate trees constituting a replication.

Fruit were harvested when 15% of them contained more than 1 ppm of ethylene. Samples of 45 fruit were stored in either 0°C air or in 2% O₂, 3% CO₂. However, the CA samples were kept in air for 3 weeks before CA conditions were established. Samples were removed from storage after 4 1/2 months at which time 10 fruit per sample were extracted with hexane and the extract was measured for alpha farnesene and conjugated triene concentrations. The rest of the fruit were kept at 20°C for 7 days and scald incidence and intensity were determined.

Neither of these compounds significantly reduced alpha farnesene concentrations in fruit after storage (Table 50). However, both of them significantly reduced conjugated triene concentrations and both reduced scald incidence on

the CA-stored fruit. No difference in yellow color was visually apparent. It should be noted that the DCPTA caused necrotic lesions to develop on the fruit surface. MPTA, applied at a lower concentrations, caused no injury.

The difference in results between the 2 seasons may be due to the time intervals used for measuring alpha farnesene and conjugated trienes. Alpha farnesene reaches maximum concentration after about 3 months in storage and then declines, presumably due to volatilization. Conjugated trienes, however, continue to accumulate with time in storage (appended manuscript). Thus, in 1986 an earlier difference in alpha farnesene concentration may have dissipated by 4.5 months, whereas the longer time may have allowed difference in potential for forming conjugated trienes to have been realized.

These results suggest that the potential for scald development may be influenced by factors that manipulate terpenoid biosynthetic pathways. It is intriguing to speculate that the means may be found to stimulate carotenoid synthesis and reduce the accumulation of alpha farnesene and ultimately conjugated trienes. In this way the vitamin content of the fruit might be enhanced while the scald potential is diminished.

3. Core flush (CF) - Israel.

The incidence of core-flush varied from one year to the next and variation between orchards was high (Table 51). CF tended to be more prevalent in CA than in RA storage (Table 52). However, the annual variation was less than the variability between orchards, and there appeared to be a greater susceptibility to the disorder in fruit from the

cooler, hilly regions - Gallil and Golan Heights (Table 52) and Iftah, Merom Golan and Manara - (Table 51).

3.1 Prediction

There was no consistent correlation between any of the maturation parameters measured and CF development in RA storage, but fruit with low titratable acidity tended to be more susceptible to the disease than high-acid fruit in CA storage (Table 53). However, the other inconsistent correlations between maturation parameters and CF development, support the conclusion that this disorder is not related to maturity of the fruit at harvest and that harvesting the fruit with a higher acid content (i.e. earlier) would not prevent its development. It appears rather to be the intrinsic characteristic of the acid content of the fruit, which is related to disorder susceptibility. Examination of the correlations between individual acids and CF development showed a significant correlation with shikimic acid ($r = 0.47$, $p = 0.008$) in CA storage in 1986 but not in RA storage. In CA, there was an increase in shikimic acid, which was negatively proportionate to the harvest level ($r = -0.59$, $p \leq 0.001$). In CA storage the disorder also correlated negatively with soluble and total Mg^{2+} ($r = -0.43$, $p = 0.006$ and $r = -0.50$ $p = 0.001$ respectively) and total K^+ ($r = 0.34$, $p = 0.036$). However, in RA storage the only single correlation was with the K^+/Na^+ ratio ($r = -0.33$, $p = 0.04$), which was similar in CA storage ($r = -0.42$, $p = 0.008$).

Stepwise regression analysis of the 1986 data accounted for 62% of the variation with 16 variables for RA storage and 75% of the variation with 14 variables (not identical) for CA storage. The most important variable for both storage conditions was fruit size. The correlation could be reasonably improved beyond this by the addition of up to 5

other variables related to mineral content and acidity (Table 54).

4. Jonathan Spot (JS)

4.1 Prediction

JS is a disease which can be virtually controlled by CA storage, as was observed in our experiments. The average disease incidence in RA storage, as related to time of harvest is shown in Table 55. There was a tendency for higher disease incidence on fruit harvested towards the end of the harvest season. Correlations between maturity parameters at harvest and disease development (Table 56) supported this tendency and indicated that fruit with low acidity and starch contents was more susceptible to the disorder. There was also some indication that fruit which is more highly coloured, showed a greater susceptibility to JS. The lack of any correlation between JS and maturity in 1986, might relate to the fact that all the fruit was harvested only at the beginning of the harvest season and the incidence of the disorder was not very high.

There were no significant correlations between JS and mineral content of the fruit peel, but for the organic acid peel content, there was a weak correlation with shikimic acid ($r = 0.35$, $p \leq 0.05$) in two out of three years.

With stepwise regression analysis 96% of the variation could be accounted for by taking into account 16 harvest parameters. The most closely related variables are 3 of the organic acids and by the addition of harvest firmness, a model R^2 of 0.372 was obtained (Table 57).

DISCUSSION

Senescent Breakdown

Though the predominant factor which has been negatively related to SB development in storage has been total Ca (Bramlage et al. 1983. Martin et al. 1975, Perring, 1976, Sharples, 1980), other minerals have also been implicated in disease occurrence, such as Mg (Sharples, 1968), N (Perring, 1976, Wills and Scott, 1976), and P (Sharples, 1968, Sharples, 1980, Wills and Scott, 1976). However, mineral content alone could not be used to predict SB development with sufficient certainty and other factors such as maturity, fruit size and organic acid levels were shown to improve the predictability of the disease. On the basis of these data collected prior to harvest (minerals) and at harvest (maturity, size and organic acids) prediction equations could be formed. However, a comparison of data for McIntosh from Massachusetts, for Cox's Orange Pippin from England and for Jonathan from Israel showed very different equations for each and the relative importance of the components varied greatly. Thus, in Israel Ca was of much less weight than in either England or the U.S. Therefore, unique equations have to be established for each cultivar and probably for each growing region, as indicated by the comparison drawn in one year between 3 growing regions in Israel.

The prediction formulae which could be compiled for each cultivar and region using the parameters described, would require a considerable amount of labour during the harvest season and might appear impractical. A single parameter, if possible, would be much more effective. A fuller and deeper understanding of the mechanism of SB development should indicate a preharvest parameter that would be of predictive value. Characterisation of diseased

tissue showed increased membrane leakage, an increased solubility of cations, especially Ca, a greater decrease in the fumaric acid content, reduced pyruvate and enhanced accumulation and production of acetaldehyde and ethanol. Assay at harvest of membrane leakage, solubility of cations, fumaric acid content or production of ethanol and acetaldehyde did not indicate that any of these parameters could be used singly as a predictive tool. Pyruvic acid at harvest was not assayed, but its involvement in the mechanism of breakdown development seems quite probable, as it is the precursor to acetaldehyde and ethanol. Though the data suggest that the production of these two metabolites might not be specific to senescent breakdown development, but rather a general consequence of tissue collapse, this might be used to advantage. Assay at harvest of the pyruvate content and/or the enzymes directly involved in its production and metabolism, might indicate the propensity of the fruit to various types of breakdown during storage. As pyruvate is the fulcrum of carbohydrate metabolism, being produced via the glycolytic pathway or by decarboxylation of malate and having three alternative outlets: oxidative decarboxylation to acetyl CoA, decarboxylation to acetaldehyde or transamination to amino acids, this complex should be worth studying with regard to prediction and characterization of SB (Clijsters, 1965, Faust *et al.* 1969, Bufler and Bangerth, 1982). One other promising avenue for a possible single parameter to determine the potential for SB has been opened for further investigation, i.e. the level of lipid oxidation products at harvest.

Superficial Scald

The correlation of superficial scald development in storage and the maturity of the fruit at harvest, as well as the involvement of alpha-farnesene and its oxidation products - the conjugated trienes, have been well documented

(See references in Appendices 3 and 4). Anet and Coggiola (1974) also suggested that the auto-oxidation of alpha-farnesene is controlled by endogenous peel anti-oxidants. It therefore seemed reasonable that seasonal variation in susceptibility to SS could be detected by determining the anti-oxidative activity of the apple peel either as a sole parameter or in relation to the alpha-farnesene and/or conjugated triene levels. Parallel studies on different cvs. in the US and Israel, have shown however that we are perhaps further away from a comprehensive understanding of the development of superficial scald than we were at the outset of this project. It can no longer be said with any certainty that procrastinating harvest will ensure less SS, though the general tendency in most cvs. was apparent. In comparing cvs. there was no consistent correlation between susceptibility of a cv. to SS and the characteristic levels of alpha-farnesene, conjugated trienes or anti-oxidants at the time of harvest. Clearly, the sensitivity of cultivars to induction of scald varied greatly in relation to levels of these compounds at harvest.

Within a cv. the most consistent and significant correlation was found between conjugated triene level at harvest and disease potential. However, these correlations might be purely coincidental for the following reasons: a) no correlations could be found between cultivar susceptibility and alpha-farnesene, CT and anti-oxidant levels. b) CA storage, which reduces scald incidence has no effect on alpha farnesene, conjugated trienes or anti-oxidant levels. c) there is no correlation between SS development during shelf-life and changes in levels of alpha-farnesene and conjugated trienes. d) treatments which inhibited alpha-farnesene biosynthesis had no effect on disease incidence.

or hardly any effect when conjugated 'triene' levels were reduced.

In the light of these data, the assumption that oxidation products of alpha-farnesene are the cause of superficial scald development should maybe reconsidered and other oxidative processes occurring in the apple peel should be examined as possible causes of the disease.

The limited data obtained with the spot-test, in which the immediate (24 hours after harvest) response of the fruit peel to alpha-farnesol, correlated well with the post storage disease incidence, holds promise for developing a predictive method for SS. The tests need to be extended to other cvs. and re-examined during years of low disease potential to determine the reliability and universality of the method.

Core-Flush

Core flush was more prevalent in CA storage than in regular air storage, in agreement with the early findings of Fidler and North (1963) and more recent work in Australia (Scott and Wills, 1976, and Little and Taylor, 1981). There was no effect of the stage of maturity of the fruit at harvest on disease incidence, though this point has been controversial. Organic acid metabolism appears to be related to disease development in that the disease potential was greater in low acid fruit and that a significant correlation ($p < 0.01$) was found between shikimic acid content and CF incidence in CA storage. Stepwise regression analysis for one year indicated that a prediction formula could be compiled on the basis of fruit size, shikimic acid, K and Mg contents. However, regional effects seem to predominate and more data need to be collected according to the 1986 model, to see if it is possible to develop formula.

In the work in the US using data gathered from the fruit storage laboratory in England, core flush in Cox's Orange Pippin was correlated with high phosphorus and low calcium. However, its occurrence after harvest could not be predicted from preharvest mineral analysis. It appears that senescent breakdown, bitter pit and superficial scald are largely influenced by preharvest conditions - and therefore are predictable at harvest time - while core flush, brown core and low temperature breakdown are primarily the consequences of postharvest conditions and thus are not predictable at harvest time.

Brown Core

Brown core is very similar to core flush in its etiology. In the experiments involving McIntosh apples stored 6 months at 0°C all developed brown core (section 1.5.2. Table 25). These samples produced larger quantities of acetaldehyde and ethanol than other healthy fruit, presumably because of cellular collapse in the disordered fruit. However, in another experiment with Red York apples, all developed brown core after 5.5 months at 0°C. In this case neither ethanol or acetaldehyde production was very high in this variety compared to production rates in varieties which did not develop brown core. Thus, there appears to be no relationship between brown core and volatile production.

Low Temperature Breakdown

Low temperature breakdown is another disorder which results from storage of certain apple varieties at near 0°C. Both Cox's Orange Pippin and Bramley's Seedling apples developed low temperature breakdown and in both varieties it was correlated with low phosphorus concentration. In Cox's it was also associated with low magnesium concentrations. However, in neither case was this disorder predictable from

preharvest mineral analysis, suggesting that it is predominantly a function of postharvest conditions (Autio et al., 1986).

This disorder is not normally seen in McIntosh or Cortland, but in one experiment a disorder occurred in McIntosh which appeared to low temperature breakdown (Table 25). It developed in samples stored six months in a combination of air-storage and CA-storage regimes at 0°C, but it did not occur in samples stored in either air at 0°C for 6 months, or air- and CA - regimes at 3.3°C. Thus, the disorder appeared to be induced by the CA atmosphere interacting with the low storage temperature.

Jonathan Spot

It was not our intention to predict the incidence of Jonathan spot, as this is not a disease of any importance in CA storage. However, as it occurred profusely in RA storage, its incidence was recorded and related to the various parameters measured. The data supported previous reports that this is a maturity related disorder, which can be controlled by CA storage or by early harvest for RA storage (Richmond et al., 1964). Moreover, the involvement of organic acid metabolism in disease development was substantiated and the best correlation was found with shikimic acid.

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Table 1. Harvest dates, starch scores, and internal ethylene concentrations for 10 varieties of apples harvested from the Horticultural Research Center, Belchertown, Mass. 1986.

Variety	Harvest I			Harvest II		
	Date	Starch ($\pm$ S.E.)	Pct $C_2H_4 > 1$ ppm ($\pm$ S.E.)	Date	Starch ($\pm$ S.E.)	Pct $C_2H_4 > 1$ ppm ($\pm$ S.E.)
McIntosh	9/8	3.9 $\pm$.2	10 $\pm$ 4	9/17	6.1 $\pm$.1	43 $\pm$ 7
Jonathan	9/17	3.2 $\pm$.1	5 $\pm$ 5	9/29	8.9 $\pm$.1	55 $\pm$ 25
Empire	9/17	1.4 $\pm$.1	0 $\pm$ 0	9/29	3.5 $\pm$.2	3 $\pm$ 3
Spartan	9/17	2.1 $\pm$.0	33 $\pm$ 3	9/29	4.0 $\pm$.3	70 $\pm$ 5
Cortland	9/17	1.4 $\pm$.2	3 $\pm$ 3	9/29	5.9 $\pm$.3	50 $\pm$ 9
Red Prince						
Delicious	10/1	2.6 $\pm$.2	70 $\pm$ 9	10/8	3.9 $\pm$.4	78 $\pm$ 8
Spencer	10/1	7.8 $\pm$.0	70 $\pm$ 12	10/8	8.4 $\pm$.1	80 $\pm$ 8
Red Rome	10/1	2.5 $\pm$.4	5 $\pm$ 5	10/15	3.8 $\pm$.9	85 $\pm$ 15
Red York	10/1	1.0 $\pm$.0	0 $\pm$ 1	10/15	1.7 $\pm$.2	0 $\pm$ 0
Golden						
Delicious	10/1	7.4 $\pm$.3	0 $\pm$ 1	10/15	8.2 $\pm$.1	28 $\pm$ 28

Table 2. Maturity indices and red coloration of Cortland apples at harvest. 1986.

Position in tree	Treatment	Pct. $C_2H_4 > 1$ ppm	Starch score	Pct. surface red
Interior	Control	5 c ^z	3.3 c	35 b
Interior	Ethephon	100 a	6.2 a	33 b
Exterior	Control	24 b	3.1 c	72 a
Exterior	Ethephon	94 a	4.4 b	69 a

^zMeans in a column not followed by the same letter are significantly different at the 5% level.

Table 3 - Correlations (r) between maturity parameters and senescent breakdown (SB) after storage in regular air (RA) or in controlled atmosphere (CA) plus shelf-life.

Parameter	1984			1985			1986		
	RA		CA	RA		CA	RA		CA
	2nd harvest	2nd harvest	1st harvest	2nd harvest	both harvests	1st harvest	2nd harvest	both harvests	
Firmness	NS	0.368*	-0.455***	NS	-0.429***	-0.385*	-0.617***	-0.537***	-0.381*
TSS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Acid	NS	NS	NS	NS	NS	-0.309*	-0.521***	-0.351***	NS
pH	NS	NS	-	-	-	-	-	-	-
Starch	NS	NS	-0.580***	-0.438***	-0.568***	NS	-0.531***	NS	-0.530***
Ground colour	-	-	-	-	-	-	-	-	-
Red Colour	NS	NS	NS	NS	NS	NS	-0.390*	-0.270	NS
DF	28	28	40	40	82	40	40	82	38
Disease (%±SD)	8.6 ±16.2	9.2 ±13.2	13.5 ±12.5	22.9 ±14.7	8.1 ±11.0	12.8 ±11.3	18.5 ±18.7		

* p<0.05
 ** p<0.01
 *** p<0.001
 NS - Non-significant.

Table 4 - Correlations between harvest firmness and starch content of Jonathan apples from different regions and SB development during RA storage.

Region	Disease incidence ±SD	Correlation coefficient		DF
		Firmness	Starch	
Hula	21.1±22.0	-0.665**	0.671**	17
Gallil	24.4±17.3	NS	0.804**	8
Golan	7.54±2.3	NS	NS	8

** $p \leq 0.01$

NS - Non-significant.

Table 5 - Mineral content in the pulp of Jonathan apples at harvest.

		mg/ 100 g. f.w. ($\pm$ SD)					
Mineral	Fraction	1984	1984	1985	1985	1985	1986
		1st harvest	2nd harvest	preharvest	1st harvest	2nd harvest	
Ca	soluble	2.9 $\pm$ 0.6	2.4 $\pm$ 0.5	2.1 $\pm$ 0.1	1.4 $\pm$ 0.4	1.4 $\pm$ 0.4	2.8 $\pm$ 0.5
	total	4.5 $\pm$ 0.7	4.2 $\pm$ 0.6	3.6 $\pm$ 0.6	4.1 $\pm$ 0.5	4.1 $\pm$ 0.5	4.7 $\pm$ 0.6
Mg	soluble	3.6 $\pm$ 0.6	3.4 $\pm$ 0.7	3.2 $\pm$ 0.5	2.7 $\pm$ 0.7	2.5 $\pm$ 0.7	3.2 $\pm$ 0.3
	total	4.4 $\pm$ 0.6	4.3 $\pm$ 0.7	4.0 $\pm$ 0.6	4.2 $\pm$ 0.8	4.2 $\pm$ 0.6	4.0 $\pm$ 0.4
K	soluble	103.9 $\pm$ 18.9	103.3 $\pm$ 24.1	77.3 $\pm$ 12.3	86.5 $\pm$ 15.5	85.2 $\pm$ 20.3	90.0 $\pm$ 10.8
	total	107.5 $\pm$ 19.7	106.9 $\pm$ 24.9	83.9 $\pm$ 13.3	92.3 $\pm$ 16.2	93.8 $\pm$ 16.2	95.5 $\pm$ 11.7
Na	soluble	8.1 $\pm$ 2.3	6.5 $\pm$ 1.9	1.2 $\pm$ 0.7	1.7 $\pm$ 1.1	1.2 $\pm$ 0.6	4.9 $\pm$ 4.6
P	soluble	-	-	4.6 $\pm$ 1.5	4.5 $\pm$ 1.3	5.0 $\pm$ 1.6	-
n		30	30	42	42	42	40

Table 6 - Correlations between soluble and total mineral content of Jonathan apple fruit pulp 1-2 weeks before harvest and the incidence of senescent breakdown after 8 months' CA storage + 8 days shelf-life. (SB - incidence in late-harvested fruit).

Mineral	Fraction	1984		1985	
		1st harvest	2nd harvest	Preharvest	1st harvest
Ca	soluble	NS	NS	NS	NS
	total	NS	NS	NS	NS
Mg	soluble	NS	NS	-0.406**	-0.431**
	total	NS	NS	-0.435**	-0.362*
K	soluble	NS	NS	-0.463**	-0.448**
	total	NS	NS	-0.505***	-0.443**
Na	soluble	-0.346*	NS	-0.390*	-0.318*
P	soluble	-	-	-0.444**	-0.416**
Mg-Ca	soluble	NS	-0.471**	-0.387*	-0.345*
	total	NS	-0.463**	-0.341*	-0.395**
Ca/Mg	soluble	NS	-0.447*	0.383*	
	total	NS	-0.428*	0.383*	0.490**
K/Ca	soluble	NS	0.440*	NS	
	total	0.366*	0.404*	NS	-0.367*
K/Na	soluble	0.408*		0.330*	0.410**
%SB $\pm$ SD		9.2 $\pm$ 13.2		12.8 $\pm$ 11.3	
DF		28		40	

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

NS - Non-significant.

Table 7 - Organic acid content in the peel of Jonathan apple at harvest.

Organic Acid	mg/100 g f.w. ($\pm$ SD)			
	1984 2nd harvest	1985 1st harvest	1985 2nd harvest	1986
Oxalic	25.4 $\pm$ 7.8	27.7 $\pm$ 9.5	37.9 $\pm$ 14.4	22.3 $\pm$ 9.8
Quinic	41.0 $\pm$ 26.2	39.1 $\pm$ 18.5	30.0 $\pm$ 15.4	36.8 $\pm$ 15.0
Malic	1117.8 $\pm$ 265.4	960.3 $\pm$ 222.5	1067.5 $\pm$ 308.3	963.9 $\pm$ 169.8
Shikimic	3.0 $\pm$ 0.7	3.0 $\pm$ 0.8	2.9 $\pm$ 0.9	2.9 $\pm$ 0.8
Acetic	1.0 $\pm$ 1.7	2.2 $\pm$ 3.7	1.7 $\pm$ 3.5	3.5 $\pm$ 5.0
Citric	7.8 $\pm$ 4.9	11.2 $\pm$ 4.1	8.9 $\pm$ 3.9	9.9 $\pm$ 5.0
Succinic	15.9 $\pm$ 19.9	2.2 $\pm$ 3.6	62.7 $\pm$ 55.6	11.3 $\pm$ 28.5
Fumaric	19.8 $\pm$ 3.8	11.0 $\pm$ 2.9	13.5 $\pm$ 3.3	13.1 $\pm$ 3.2

Table 8 - Organic acid content in apple peel of fruit from orchards in three regions (1986).

Organic Acid Region	mg/100 g f.w.							
	Oxalic	Quinic	Malic	Shikimic	Acetic	Citric	Succinic	Fumaric
Hula	32.0a	30.7b	931.4a	2.5b	1.6b	9.7a	13.2a	13.6a
Gallil	22.2b	44.3a	1002.0a	2.7b	4.3ab	9.5a	8.6a	12.3a
Golan	26.3ab	42.5ab	965.0a	3.9a	6.9a	9.4a	5.6a	12.3a

a, b = Mean separation within columns according to Duncan's multiple range test ($p = 0.05$).

Table 9 - Correlations between organic acid content in Jonathan apple peel at harvest and SB development during regular (RA) and controlled atmosphere (CA) storage.

Organic Acid	RA			CA		
	1984	1985	1986	1984	1985	1986
Oxalic	NS	NS	NS	NS	NS	NS
Quinic	NS	NS	NS	-0.405**	-0.425***	-0.440**
Malic	NS	NS	NS	NS	NS	NS
Shikimic	NS	-0.352*	NS	NS	-0.322*	NS
Acetic	NS	NS	NS	NS	NS	NS
Citric	NS	NS	NS	NS	NS	NS
Succinic	NS	0.384*	0.623***	NS	NS	NS
Fumaric	NS	NS	NS	NS	NS	NS

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

NS = Non-significant.

Table 10 - Stepwise regression procedure for dependent harvest variables and SB incidence after 5 months RA storage.

(n=39)

No. of variables	Variables	R ²	P
1	Starch Index (SI)	0.211	0.003
2	SI + Mg _s	0.288	0.002
3	SI + K/Ca _t + Na _s	0.342	0.002
4	SI + K/Ca _t + K/Ca _s + P/Ca	0.412	0.002
5	K/Ca _t +Shik ^s +K/Ca _s +P/Ca+mal ^s	0.5107	0.001
7	SI+K/Ca-T+mal ^s +K/Na-S+Shik. +K/Ca _s + P/Ca + mal.	0.609	0.001

1. s = soluble.

2. t = Total.

3. Shik = Shikimic acid.

4. Mal = malic acid.

Table 11 - Changes in the solubility of Ca^{2+} , Mg^{2+} and K^{+} in the pulp of Jonathan apples during storage, expressed at percentage of the level at harvest ($\pm\text{SD}$).

Year	Harvest	Ca^{2+}	Mg^{2+}	K^{+}
1984	early	52.9 $\pm$ 6.4	74.5 $\pm$ 6.3	80.9 $\pm$ 3.8
	late	58.6 $\pm$ 6.5	78.6 $\pm$ 6.9	94.7 $\pm$ 3.8
1985	early	71.4 $\pm$ 6.0	92.7 $\pm$ 5.1	113.3 $\pm$ 4.9
	late	73.9 $\pm$ 5.5	85.5 $\pm$ 4.4	111.4 $\pm$ 4.2

Table 12 - Correlations between SB incidence and various parameters relative to soluble mineral content after storage.

Parameter	1984	1985
Ca ²⁺	-0.492**	-0.660***
Mg ²⁺	NS	-0.449**
K ⁺	NS	-0.315*
K ⁺ /Ca ²⁺	0.555**	0.510**
Ca ²⁺ /Mg ²⁺	-0.346*	-0.399*
Δ Ca ²⁺ (1)	-0.420**	-0.555***
Δ Mg ²⁺ (1)	-0.465**	-0.402**
Δ K ⁺ (1)	-0.616***	-0.355*

(1) % change in soluble cation content of pulp during storage.

* p ≤ 0.5

** p ≤ 0.01

*** p ≤ 0.001

NS = Non-significant.

Table 13 - Correlations between parameters of membrane permeability and SB.

	r	p
conductivity at harvest	.234	NS
conductivity after storage	.362	.02
leakage at harvest	.105	NS
leakage after storage	.577	.001

Table 14 - The changes in organic acid content of Jonathan apple pulp during 5 months RA storage and their correlation to SB development.

Organic acid	Content as % of harvest value ($\pm$ SE)	Correlation (r) of SB to acid content	% change from harvest
Oxalic	87.7 $\pm$ 24.2	0.323*	NS
Malic	41.5 $\pm$ 2.53	-0.338*	-0.375*
Shikimic	360 $\pm$ 147	-0.326*	0.430*
Fumaric	84.2 $\pm$ 6.49	0.548***	0.483**
Acetic	542 $\pm$ 137	NS	NS
Citric	25.1 $\pm$ 9.7	NS	NS
Quinic	15.0 $\pm$ 3.8	NS	NS

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

NS = Non-significant.

Table 15 - Correlation (r) between volatile content of Jonathan pulp tissue after CA storage and the severity of SB.

Volatile	r	p
Acetaldehyde	0.527	0.01
Ethanol	0.628	0.001
Acetaldehyde + Ethanol	0.576	0.01

Table 16 - Pyruvate content of healthy and SB disordered Jonathan apple fruit pulp.

Orchard	Pyruvate (ug/100g f. w.)	
	Healthy tissue	SB tissue
Alonim	1.89 $\pm$ 0.04	1.39 $\pm$ 0.10
Sassa	2.13 $\pm$ 0.11	1.54 $\pm$ 0.13
Ortal	2.22 $\pm$ 0.12	-

Table 17 - Production of acetaldehyde (AA) and ethanol (ETOH) by healthy and SB disordered apple pulp discs with varying susceptibility to SB.

Orchard	SB (%)	pulp tissue	Volatile production (nmol/g f.w./h)			
			AA	ETOH	AA+ETOH	AA/ETOH
A	55	healthy	17.9bc	12.8c	30.6c	1.4bc
		disordered	9.7c	51.3b	61.3b	0.2d
B	15	healthy	20.2b	16.0c	36.2c	1.3c
		disordered	32.3a	121.2a	153.5a	0.3d
C	0	healthy	23.2b	13.1c	36.3c	1.8ab
D	0	healthy	17.3bc	9.5c	26.7c	1.9a

a, b, c - Mean separation within columns according to Duncan's multiple range test ($p = 0.05$).

Table 18 - "Net pyruvic acid effect" obtained from healthy and disordered Jonathan apple discs from fruit of varying susceptibility to SB.

Orchard	SB (%)	pulp tissue	Net volatile production (nmol/g f.w./h)			
			AA	ETOH	AA+ETOH	AA/ETOH
A	55	healthy	6.6	4.2	10.8	1.6
		disordered	27.8	17.6	45.4	1.6
B	15	healthy	86.7	13.3	100.0	6.5
		disordered	73.6	34.8	108.4	2.2
C	0	healthy	16.9	5.5	22.4	3.0
D	0	healthy	19.4	4.8	24.2	4.1

Table 19. Concentrations^z (nl · kg⁻¹ · 3 hr⁻¹) of certain volatile compounds in the headspace above Red Prince Delicious apples after storage for 3.5 months in 0°C air and then being kept at 20°C for 2, 4, and 7 days. 1986.

Volatile ^y	Harvest I			Harvest II		
	2 days	4 days	7 days	2 days	4 days	7 days
Ethylene	185 ± 8	208 ± 22	208 ± 35	364 ± 39	185 ± 40	202 ± 50
Acetaldehyde	50 ± 15	54 ± 15	183 ± 61	75 ± 22	226 ± 54	284 ± 71
Ethanol	20 ± 5	41 ± 9	117 ± 24	43 ± 8	112 ± 28	177 ± 56
Ethyl propionate	3 ± 1	14 ± 4	62 ± 18	15 ± 6	57 ± 27	85 ± 39
Ethyl butyrate	7 ± 3	25 ± 8	25 ± 5	31 ± 10	56 ± 30	62 ± 44
Hexanal	3 ± 2	21 ± 7	20 ± 3	18 ± 3	33 ± 13	41 ± 23

^zPlus or minus standard errors

^yCompounds were tentatively identified by comparison with retention times for authentic compounds.

Table 20. Ethylene production² (nl · kg⁻¹ · 3 hr⁻¹) by 10 apple varieties after storage for 3.5 and 5.5 months in 0°C air and then being kept at 20°C for 2, 4, and 7 days. 1986.

Variety	Harvest I						Harvest II					
	3.5 months			5.5 months			3.5 months			5.5 months		
	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days
McIntosh	292 + 5	301 + 9	220 + 9	186 + 28	298 + 9	236 + 30	269 + 10	278 + 20	199 + 3	298 + 9		
Jonathan	134 + 21	158 + 6	137 + 10	154 + 17	245 + 5	78 + 31	89 + 1	160 + 45	255 + 5	209 + 24		
Empire	85 + 6	152 + 12	138 + 21	98 + 5	202 + 2	121 + 11	135 + 7	143 + 8	159 + 7	171 + 3		
Spartan	188 + 8	182 + 13	185 + 11	171 + 26	292 + 13	225 + 17	236 + 7	205 + 13	273 + 9	223 + 9		
Cortland	328 + 36	409 + 24	343 + 24	321 + 20	442 + 19	419 + 34	500 + 13	439 + 46	581 + 36	406 + 24		
Red Prince												
Delicious	185 + 8	208 + 22	208 + 35	225 + 25	237 + 16	364 + 39	185 + 40	202 + 50	237 + 9	158 + 21		
Spencer	89 + 11	66 + 6	84 + 16	---	---	72 + 9	49 + 6	63 + 9	---	---		
Red Rome	138 + 3	179 + 4	204 + 4	233 + 10	208 + 3	250 + 31	159 + 1	171 + 9	261 + 23	205 + 2		
Golden Delicious	153 + 11	153 + 28	301 + 10	195 + 29	188 + 19	197 + 5	160 + 5	338 + 13	155 + 3	168 + 10		
	306 + 31	375 + 34	438 + 39	342 + 26	427 + 36	528 + 34	392 + 23	400 + 29	509 + 24	437 + 29		

²Plus or minus standard errors.

Table 21. Ethanol production² (ml · kg⁻¹ · 3 hr⁻¹) by 10 apple varieties after storage for 3.5 and 5.5 months in 0°C air and then being kept at 20°C for 2, 4, and 7 days. 1986.

Variety	Harvest I						Harvest II					
	3.5 months			5.5 months			3.5 months			5.5 months		
	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days
McIntosh	13 + 2	43 + 8	56 + 5	29 + 3	103 + 5	41 + 8	92 + 10	147 + 21	30 + 4	123 + 28		
Jonathan	6 + 3	0	11 + 8	0	0	44 + 9	35 + 5	30 + 20	29 + 12	5 + 1		
Empire	2 + 1	8 + 3	14 + 1	4 + 2	20 + 2	1 + 0	4 + 2	5 + 2	47 + 11	39 + 7		
Spartan	5 + 1	9 + 4	19 + 8	10 + 0	32 + 4	20 + 12	23 + 12	50 + 14	104 + 20	93 + 14		
Cortland	7 + 1	18 + 7	44 + 8	10 + 1	31 + 7	9 + 1	24 + 2	38 + 1	59 + 8	65 + 16		
Red Prince												
Delicious	20 + 5	41 + 9	117 + 24	48 + 3	68 + 7	43 + 8	112 + 28	178 + 56	105 + 22	83 + 8		
Spencer	18 + 3	64 + 17	156 + 30	---	---	72 + 13	91 + 18	205 + 17	---	---		
Red Rome	7 + 1	3 + 1	7 + 1	4 + 0	4 + 1	10 + 1	8 + 0	25 + 6	14 + 5	16 + 7		
Red York	6 + 1	7 + 0	19 + 4	10 + 1	10 + 0	18 + 5	11 + 0	49 + 3	11 + 6	15 + 7		
Golden Delicious	7 + 3	1 + 0	2 + 0	1 + 1	0	10 + 3	4 + 1	30 + 8	3 + 1	1 + 1		

± Plus or minus standard errors.

Table 22. Acetaldehyde production² (nl · kg⁻¹ · 3 hr⁻¹) by 10 apple varieties after storage for 3.5 and 5.5 months in 0°C air and then being kept at 20°C for 2, 4, and 7 days. 1986

Variety	Harvest I						Harvest II					
	3.5 months			5.5 months			3.5 months			5.5 months		
	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days	2 days	4 days	7 days
McIntosh	20 + 3	31 + 3	69 + 4	33 + 2	264 + 16	53 + 15	107 + 16	147 + 22	35 + 4	347 + 55		
Jonathan	0	0	7 + 3	0	0	21 + 1	11 + 0	10 + 2	21 + 14	3 + 0		
Empire	0	8 + 2	7 + 1	6 + 2	115 + 5	0	1 + 1	1 + 1	26 + 5	23 + 18		
Spartan	0	9 + 4	7 + 2	15 + 2	176 + 21	18 + 14	20 + 7	46 + 16	80 + 16	123 + 9		
Cortland	7 + 2	21 + 5	37 + 6	9 + 2	32 + 5	18 + 4	26 + 5	51 + 6	47 + 7	64 + 8		
Red Prince												
Delicious	50 + 15	54 + 15	183 + 61	62 + 4	68 + 10	75 + 22	226 + 54	284 + 71	105 + 11	146 + 19		
Spencer	27 + 7	88 + 37	162 + 44	---	---	49 + 5	109 + 46	266 + 4	---	---		
Red Rome	0	0	0	1 + 0	3 + 0	0	17 + 10	10 + 1	9 + 0	6 + 2		
Red York	0	8 + 0	21 + 0	9 + 1	11 + 2	0	37 + 23	33 + 8	13 + 2	11 + 0		
Golden Delicious	2 + 0	1 + 0	7 + 2	0	0	0	0	2 + 1	8 + 2	0		

²Plus or minus standard errors.

Table 23. Occurrence of senescent breakdown² in 10 apple varieties after being stored for 3.5 and 5.5 months in 0°C air, and then being kept for 7 days at 20°C.

Variety	Harvest I		Harvest II	
	3.5 months	5.5 months	3.5 months	5.5 months
McIntosh	6 ± 2	12 ± 2	14 ± 3	25 ± 5
Jonathan ^Y	8 ± 3	4 ± 3	73 ± 8	---
Empire	2 ± 1	1 ± 0	0	0
Spartan	15 ± 2	6 ± 3	10 ± 3	1 ± 4
Cortland	48 ± 4	28 ± 2	49 ± 4	59 ± 2
Red Prince Delicious	2 ± 1	2 ± 1	1 ± 1	2 ± 1
Spencer	93 ± 3	---	96 ± 3	---
Red Rome	6 ± 4	10 ± 4	14 ± 1	16 ± 2
Red York ^X	0	0	0	6 ± 1
Golden Delicious	2 ± 1	1 ± 1	9 ± 3	0

²Percent incidence ± standard error.

^YAt the second harvest most Jonathan apples had watercore, and after storage they developed watercore breakdown.

^XAfter 5.5 months of storage all Red York apples had browncore.

Table 24. Postharvest treatments applied to McIntosh apples for assessment of relationships of volatile production and senescent breakdown.

Treatment number	Experimental conditions	Storage time (months)
1.	Dipped in fungicides; stored in 0°C air	3.5
2.	Dipped in fungicides, vitamins and calcium chloride; stored in 0°C air	3.5
3.	Same as Treatment 1	6
4.	Same as Treatment 2	6
5.	Dipped in fungicides, stored in air for 3 wks and then in CA at 33°C	6
6.	Dipped in fungicides, stored in air for 5 wks, CA (3% O ₂ , 3% CO ₂ , 0°C) for 3 months, and then air for 6 wks	6
7.	Same as Treatment 2 except for storage in air for 3 wks and then in CA at 3.3°C	6
8.	Same as Treatment 2 except for storage in air for 5 wks, CA (3% O ₂ , 3% CO ₂ , 0°C) for 3 months, and then air for 6 wks	6

Table 25 - Occurrence of disorders in McIntosh apples after storage.

Tree treatments*	Large storage sample	10-fruit sample used for volatiles		
	Pct. senescent breakdown	Senescent breakdown(%)	Low-temp breakdown(%)	Brown Core(%)
1	18 b ^y	28	0	0
2	5 c	7	0	0
3	38 a ^y	63	0	100
4	14 b	27	7	100
5	2 c	0	0	0
6	1 c	10	100	0
7	0 c	3	0	0
8	0 c	7	97	0

* See Table 8.

^y Means not followed by the same letter are significantly different at the 1% level.

Table . Ethylene, acetaldehyde, and ethanol production (nl · kg⁻¹ · 3 hr⁻¹) by McIntosh apples after various postharvest treatments plus 2 to 7 days at 20°C.

Treatment	Ethylene				Acetaldehyde				Ethanol			
	2 days	4 days	7 days	Mean	2 days	4 days	7 days	Mean	2 days	4 days	7 days	Mean
1.	402 ± 31	392 ± 30	246 ± 10	347	76 ± 5	129 ± 6	246 ± 38	150	57 ± 6	86 ± 11	172 ± 9	105
2.	374 ± 24	373 ± 17	232 ± 36	326	43 ± 3	49 ± 7	93 ± 8	62	29 ± 4	47 ± 1	83 ± 8	53
3.	356 ± 24	268 ± 12	195 ± 23	273	331 ± 12	436 ± 10	190 ± 20	319	172 ± 9	273 ± 21	322 ± 14	255
4.	383 ± 10	291 ± 17	275 ± 20	315	316 ± 16	405 ± 25	368 ± 36	363	163 ± 10	229 ± 3	338 ± 42	243
5.	419 ± 40	256 ± 21	234 ± 22	303	58 ± 11	307 ± 22	299 ± 15	221	42 ± 8	121 ± 24	205 ± 20	123
6.	551 ± 7	498 ± 11	406 ± 24	485	21 ± 4	47 ± 7	102 ± 10	57	11 ± 4	34 ± 5	92 ± 10	46
7.	433 ± 20	263 ± 20	291 ± 16	329	53 ± 10	243 ± 27	302 ± 17	203	33 ± 7	119 ± 5	178 ± 16	110
8.	592 ± 24	521 ± 23	426 ± 10	513	17 ± 2	49 ± 6	103 ± 5	56	7 ± 1	40 ± 11	90 ± 5	46

Table 27 . Senescent breakdown (percent) of Cortland apples following storage in air for 3.5 months and CA for 5 months, plus 7 days at 20°C.

Treatment	0°C air storage	0°C CA storage
Control	68 a ²	6 a
Ethephon	54 ab	4 a
DPA	43 bc	1 a
Ca + vit. E + vit. C	26 c	2 a
Ethephon + Ca + vit. E + vit. C	21 c	1 a

²Means in a column not followed by the same letter are significantly different.

Table 28 . Significance of factors affecting production of 6 volatiles by Cortland apples following storage. 1986.

Factor	Ethylene	Acetaldehyde	Ethanol	Ethyl propionate	Ethyl butyrate	Hexanal
Storage type (S)	NS ^z	**	***	*	NS	***
Ethephon spray (E)	NS	NS	NS	NS	NS	NS
DPA dip (DPA)	**	NS	NS	NS	NS	NS
Ca/vit. dip (vit.)	NS	NS	NS	NS	NS	NS
Days at 20° (days)	NS	***	***	***	***	***
S x E	NS	NS	**	NS	NS	NS
S x days	**	***	**	NS	NS	NS
E x vit.	NS	*	*	NS	NS	NS
DPA x days	NS	NS	NS	NS	NS	*
vit. x days	*	NS	NS	NS	NS	NS

8

NS = No significance; * = significance at the 5% level; ** = significance at the 1% level;
*** = significance at the 0.1% level.

Table 30 - Correlation (r) between maturity parameters and superficial scald (SS) development on Jonathan apples after RA and CA storage.

Maturity Parameter	1984	1985		1986
	RA	RA	CA	RA
Firmness	NS	NS	0.318**	NS
T.S.S.	NS	NS	NS	NS
Acid	NS	-0.393**	-0.576***	NS
Starch	NS	NS	0.305**	NS
Ground colour	NS	NS	NS	NS
Red colour	NS	-0.413***	NS	-
DF	58 ¹	82 ¹	82 ¹	38
Disease incidence (%±SD)	29.5±19.8	25.2±14.4	25.0±15.0	19.4±13.8

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.001$

NS - Non-significant.

¹ - Data from two harvests.

Table 31 - Correlations between firmness of Jonathan apples at harvest from different regions and SS development during RA storage.

Region	Disease (%±SD)	Correlation coefficient		DF
		r	P	
Hula	19.3±11.7	0.212	NS	18
Gallil	18.2±17.2	-0.757	0.01	8
Golan	22.3±15.9	0.290	NS	8

NS - Non-significant.

Table 32 - Correlations (r) between ripeness parameters measured at harvest on Granny Smith apples and SS which developed after 3 months storage and shelf-life.

Parameter	r	p
firmness	0.589	0.001
T.S.S.	-0.408	0.001
acidity	0.553	0.001
starch	0.203	NS

NS - Non-significant.

Table 33 - Correlations (r) between organic acid contents of Jonathan apple peel at harvest and SS development in RA..

Organic acid	1984		1985	
	r	p	r	p
Oxalic	0.490	0.01	0.480	0.01
Malic	0.528	0.01	0.334	0.05
Fumaric	0.546	0.01	0.429	0.01

Table 34. Scald development on 10 varieties of apples after 3 1/2 or 5 1/2 months of storage in 0°C air plus 7 days at 20°C. 1986.

Variety	Percent scald ^z				Scald score ^y			
	Harvest I		Harvest II		Harvest I		Harvest II	
	3.5	5.5	3.5	5.5	3.5	5.5	3.5	5.5
McIntosh	22 $\pm$ 7	98 $\pm$ 2	20 $\pm$ 7	90 $\pm$ 6	0.3 $\pm$.1	3.4 $\pm$.1	0.2 $\pm$.1	2.5 $\pm$.4
Jonathan	1 $\pm$ 1	48 $\pm$ 3	9 $\pm$ 9	14 $\pm$ 4	0.2 $\pm$ 0	0.8 $\pm$.1	0.1 $\pm$.1	0.2 $\pm$.1
Empire	0	14 $\pm$ 3	0	3 $\pm$ 1	0	0.2 $\pm$.1	0	0
Spartan	8 $\pm$ 3	78 $\pm$ 4	3 $\pm$ 1	65 $\pm$ 6	0.1 $\pm$ 0	1.7 $\pm$.1	0	1.3 $\pm$.2
Cortland	3 $\pm$ 1	51 $\pm$ 4	5 $\pm$ 3	12 $\pm$ 2	0.1 $\pm$ 0	0.7 $\pm$.1	0.1 $\pm$.1	0.2 $\pm$.1
Red Prince								
Delicious	1 $\pm$ 1	0	0	0	0	0	0	0
Spencer	48 $\pm$ 7	---	23 $\pm$ 8	---	0.7 $\pm$.1	---	0.4 $\pm$.2	---
Red Rome	65 $\pm$ 10	93 $\pm$ 1	38 $\pm$ 15	58 $\pm$ 1	0.9 $\pm$.1	2.1 $\pm$.3	0.4 $\pm$.2	0.9 $\pm$.1
Red York	84 $\pm$ 4	96 $\pm$ 1	96 $\pm$ 4	100 $\pm$ 0	1.0 $\pm$.1	1.4 $\pm$.1	1.1 $\pm$.1	1.8 $\pm$.2
Golden Delicious	1 $\pm$ 1	1 $\pm$ 1	0	0	0	0	0	0

^zMean $\pm$ standard error

^yScore: 1 = 1 to 10%; 2 = 11 to 33%; 3 = 34 to 66%; 4 = 67 to 100% of surface affected.

Table 35. Antioxidant concentration (alpha tocopherol equivalents) (mg : g⁻¹ dry wt) in peel of 10 varieties of apples at harvest. 1986

Variety	Harvest I	Harvest II	Mean
McIntosh	5.45 ± .25 ^z	5.29 ± .49	5.37
Jonathan	2.70 ± 0	1.80 ± .20	2.25
Empire	4.46 ± .74	1.34 ± .11	2.90
Spartan	1.11 ± .18	1.22 ± .17	1.17
Cortland	1.61 ± .23	5.26 ± .73	3.44
Red Prince Delicious	2.10 ± .31	1.95 ± .23	2.03
Spencer	1.65 ± .31	1.67 ± .31	1.66
Red Rome	4.37 ± .32	4.80 ± .60	4.58
Red York	1.25 ± .15	4.75 ± .85	3.00
Golden Delicious	4.95 ± .54	3.20 ± .54	4.08
Mean	2.97	3.13	

^zMean ± standard error.

Table 36 . OD 200 values for hexane extracts of apples (100 ml extract . (1000 cm²)⁻¹) of 10 varieties at harvest and after 3.5 and 5.5 months of storage in air at 0°C. 1986.

Variety	At harvest		3.5 months stg.		5.5 months stg.	
	Harv. I	Harv. II	Harv. I	Harv. II	Harv. I	Harv. II
McIntosh	1.3 + 0.9 ^z	5.0 + 0.4	23.4 + 1.3	21.3 + 0.9	27.1 + 0.5	27.3 + 1.1
Jonathan	5.4 + 0.5	15.3 + 1.4	25.5 + 0.7	38.2 + 1.0	31.3 + 2.7	34.3 + 0.6
Empire	6.0 + 0.4	14.6 + 0.1	26.9 + 1.3	42.0 + 0.9	29.1 + 0.7	40.2 + 0.8
Spartan	5.9 + 0.8	14.1 + 1.6	23.5 + 1.3	30.2 + 0.7	26.5 + 1.0	29.9 + 1.2
Cortland	14.4 + 2.2	31.7 + 0.8	37.4 + 1.6	43.0 + 0.4	41.0 + 1.0	49.4 + 0.8
Red Prince Delicious	16.2 + 1.0	17.4 + 1.3	38.3 + 0.9	43.8 + 1.5	39.5 + 1.3	40.2 + 1.5
Spencer	10.4 + 1.1	9.5 + 0.4	37.9 + 0.4	40.2 + 0.7	---	---
Red Rome	6.3 + 0.4	10.4 + 0.4	28.1 + 0.5	19.3 + 0.3	15.0 + 3.6	19.0 + 7.9
Red York	11.2 + 0.6	14.6 + 0.2	44.7 + 5.1	44.8 + 2.2	51.1 + 1.6	48.0 + 0.7
Golden Delicious	7.2 + 1.1	14.9 + 1.1	36.7 + 1.3	42.2 + 1.4	33.3 + 1.0	35.7 + 1.7
Mean	8.4	14.8	32.2	36.5	32.7	36.0

^zMean = standard error.

Table 37 . Alpha farnesene concentration (n moles · (cm²)⁻¹) in peel of 10 varieties of apples at harvest and after 3.5 and 5.5 months of storage in air at 0°C.

Variety	At harvest		3.5 months		5.5 months	
	Harv. I	Harv. II	Harv. I	Harv. II	Harv. I	Harv. II
McIntosh	0	6.2 ± 1.8 ^z	35.2 ± 1.5	47.6 ± 2.8	32.0 ± 2.1	37.0 ± 2.2
Jonathan	0	0	66.1 ± 2.4	68.4 ± 2.7	54.0 ± 1.0	39.5 ± 0.2
Empire	0	0	58.8 ± 4.3	72.7 ± 2.1	40.7 ± 3.3	32.4 ± 2.9
Spartan	0	0	51.6 ± 2.6	56.7 ± 3.4	37.1 ± 2.6	39.0 ± 1.4
Cortland	22.3 ± 3.0	47.0 ± 6.7	89.1 ± 7.6	101.5 ± 5.5	69.2 ± 1.2	58.2 ± 2.1
Red Prince Delicious	6.7 ± 1.8	9.6 ± 0.8	78.1 ± 3.1	84.7 ± 4.3	55.3 ± 2.7	44.9 ± 2.2
Spencer	8.1 ± 1.4	5.2 ± 0.8	65.6 ± 0.6	71.1 ± 3.9	---	---
Red Rome	0	7.5 ± 1.2	71.1 ± 1.2	69.6 ± 1.2	57.3 ± 20.0	58.8 ± 21.4
Red York	0	6.2 ± 0.4	93.5 ± 16.1	107.2 ± 16.7	96.4 ± 2.5	74.9 ± 0.7
Golden Delicious	0	9.1 ± 1.1	70.0 ± 3.3	79.0 ± 4.0	38.8 ± 2.0	35.1 ± 1.9

^zMean ± Standard error.

Table 38. Conjugated triene concentrations (n moles $\cdot$ (cm²)⁻¹) in 10 varieties of apples after storage in air at 0°C for 3.5 and 5.5 months. 1986.

Variety	3.5 months		5.5 months	
	Harv. I	Harv. II	Harv. I	Harv. II
McIntosh	3.8 $\pm$.5 ^z	3.7 $\pm$ 0.2	5.8 $\pm$ 0.1	6.4 $\pm$ 0.3
Jonathan	1.9 $\pm$.0	4.0 $\pm$ 0.5	6.1 $\pm$ 0.1	7.8 $\pm$ 0.8
Empire	3.1 $\pm$.2	3.5 $\pm$ 0.3	6.5 $\pm$ 0.8	5.8 $\pm$ 0.9
Spartan	5.8 $\pm$.3	5.7 $\pm$ 0.3	10.5 $\pm$ 1.1	12.0 $\pm$ 1.0
Cortland ^y	5.7 $\pm$.5	7.3 $\pm$ 0.5	10.9 $\pm$ 1.3	11.0 $\pm$ 1.0
Red Prince Delicious	7.7 $\pm$.2	11.2 $\pm$ 0.4	12.4 $\pm$ 0.9	12.4 $\pm$ 0.8
Spencer	6.4 $\pm$.4	5.0 $\pm$ 0.4	---	---
Red Rome	3.6 $\pm$.2	3.5 $\pm$ 1.2	6.3 $\pm$ 1.1	4.9 $\pm$ 0.1
Red York	6.8 $\pm$.7	7.3 $\pm$ 1.5	8.8 $\pm$ 0.8	9.4 $\pm$ 1.9
Golden Delicious	4.0 $\pm$.4	4.2 $\pm$ 0.2	3.1 $\pm$ 0.5	3.7 $\pm$ 0.2
Mean	4.9	5.5	7.8	8.2

^zMean $\pm$ standard error.

^yCortland was the only variety with measurable conjugated trienes at harvest. Values were: Harv. I, 3.6 $\pm$ 2.5; Harv. II, 3.5 $\pm$.6.

Table 39. Correlation coefficients among factors related to scald development in 10 varieties of apples. 1986.

	OD 200		Alpha farnesene		Conjugated trienes		Pct. scald		Scald score	
	Harv.	3.5 mo	5.5 mo	3.5 mo	5.5 mo	3.5 mo	5.5 mo	3.5 mo	5.5 mo	
Antioxidants, harvest	NS ²	-0.3*	NS	NS	NS	-0.3*	-0.4**	NS	NS	+0.3*
OD 200:										
Harvest	---	+0.6***	+0.7***	+0.7***	NS	+0.5***	+0.4***	NS	-0.5***	-0.6***
3.5 mo	---	---	+0.8***	+0.8***	+0.3**	+0.5***	NS	NS	-0.6***	-0.6***
5.5 mo	---	---	---	+0.3**	+0.4**	+0.5***	+0.3**	NS	-0.4**	-0.4***
Alpha farnesene:										
3.5 mo	---	---	---	---	+0.6***	+0.3*	+0.3*	NS	-0.4**	-0.6***
5.5 mo	---	---	---	---	---	+0.3*	+0.3*	NS	NS	NS
Conjugated trienes:										
3.5 mo	---	---	---	---	---	---	+0.7***	NS	NS	NS
5.5 mo	---	---	---	---	---	---	---	NS	NS	NS

2NS = Not significant; * = Significant at 5% level; ** = Significant at 1% level; *** = Significant at 0.1% level.

Table 40. Correlation coefficients among volatile compounds and scald development in 10 varieties of apples. 1986.

	Ethylene		Acetaldehyde		Ethanol	
	3.5 mo	5.5 mo	3.5 mo	5.5 mo	3.5 mo	5.5 mo
Antioxidants, harv.	+0.4**z	+0.3*	NS	NS	NS	NS
OD 200:						
Harv.	+0.4**	NS	NS	NS	NS	NS
3.5 mo	NS	NS	NS	-0.5***	NS	NS
5.5 mo	NS	NS	NS	-0.3*	NS	NS
Alpha farnesene:						
3.5 mo	NS	NS	NS	-0.6***	NS	-0.3*
5.5 mo	NS	NS	NS	-0.3*	NS	NS
Conj. trienes:						
3.5 mo	NS	NS	+0.5***	+0.4**	NS	+0.3*
5.5 mo	NS	NS	+0.3*	NS	NS	+0.4**
Pct. scald:						
3.5 mo	-0.3*	NS	NS	NS	NS	NS
5.5 mo	NS	NS	NS	0.4**	NS	NS
Scald score:						
3.5 mo	-0.4**	NS	NS	NS	NS	NS
5.5 mo	NS	NS	NS	+0.6***	NS	+0.4**

zNS = Not significant; * = Significant at 5% level; ** = Significant at 1% level; *** = Significant at 0.1% level.

Table 41 - The effect of harvest time on the post-storage (RA for 5 months) incidence of SS on Jonathan apples from different orchards in relation to the level of conjugated trienes in the peel after 3 months.

	scald (%)		conjugated trienes (umole/cm ²)	
	1984	1985	1984	1985
Harvest I				
1. Alonim	30	56	0.48	0.45
2. Givat Ada	26	25	0.29	0.11
3. Kfar Blum	28	30	0.66	0.56
4. Iftah	56	56	1.09	1.11
5. Merom Golan	13	37	1.73	0.57
6. Manara	-	74	-	1.08
Harvest II				
1. Alonim	35	33	0.53	0.37
2. Givat Ada	65	47	1.12	0.68
3. Kfar Blum	33	32	0.85	0.35
4. Iftah	68	50	0.96	0.61
5. Merom Golan	33	23	1.65	0.73
6. Manara	-	23	-	1.68

Table 42 - Levels of scald, CT and α -farnesene from Jonathan apple peel in RA or CA storage.

Orchard Location	Scald (%)			CT ($\mu\text{m}/\text{cm}^2$)		α -farnesene	
	RA		CA	RA	CA	RA	CA
	3 mos	5 mos	5 mos	5mos	5mos	3 mos	5 mos
Harvest I							
1. Alonim	0	30	5	0.48	0.50	4.92	5.00
2. Givat Ada	0	26	5	0.29	0.26	1.13	2.61
3. Kfar Blum	6	28	2	0.66	0.57	7.14	5.69
4. Iftah	10	56	8	1.09	1.49	22.00	14.93
5. Merom Golan	0	13	0	1.73	0.69	30.00	9.79
Harvest II							
1. Alonim	10	35	0	0.53	0.47	2.49	4.00
2. Givat Ada	44	65	7	1.12	0.60	8.22	6.23
3. Kfar Blum	2	33	5	0.85	0.39	9.57	3.64
4. Iftah	24	68	0	0.96	1.03	23.00	8.89
5. Merom Golan	2	33	-	1.65	-	31.00	-

Table 43 - Presence of antioxidants in apple peel of Jonathan from different orchards after 3 and 4 months of air storage and shelf-life in relation to SS after 5 months in RA storage.

Orchard location	% inhibition of linoleic acid oxidation			
	3 mos	4 mos	4 mos+ shelf-life	SS (%)

1. Alonim	90	75	56	33
2. Givat Ada	65	62	43	47
3. Kfar Blum	83	65	-	32
4. Iftah	70	60	45	50
5. Manara	85	69	-	23
6. Merom Golan	80	65	-	23

Table 44 - The effect of maturity at harvest and post harvest DPA dip on scald α -farnesene and CT levels on Granny Smith apples from Kvutzat Shiller after removal from 3 months RA storage and shelf-life (SL).

Fruit location on tree	Ethephon	DPA	Scald (%)		CT umoles/m ²		α-farnesene	
			RA	SL	RA	SL	RA	SL
Harvest I								
Exterior	-	-	8	48	100	-	625	-
	-	+	0	8	42	-	705	-
	+	-	0	23	60	54	844	-
	+	+	0	0	18	-	868	-
Interior	-	-	28	90	110	103	550	390
	-	+	0	38	74	73	632	-
	+	-	0	70	110	-	774	-
	+	+	0	18	41	-	714	-
Harvest II								
Exterior	-	-	3	53	105	-	999	-
	-	+	0	0	27	-	720	-
Interior	-	-	3	70	115	96	770	208
	-	+	0	0	30	40	696	-

Table 45 - α -farnesene and CT levels in Granny Smith.

	α -farnesene umoles/cm ² peel	CT
Apples harvested in January	25.7	2.8
Apples harvested in October + 3 mos storage	62.6	18.9

Table 46. Effects of postharvest conditions on factors related to scald development and on incidence of scald. McIntosh apples. 1986.

Treatment ^z	OD 200 (100 ml extract • 1000 (cm ²)-1)	Alpha farnesene (n moles • (cm ²)-1)	Conj. trienes (n moles • (cm ²)-1)	Scald	
				Pct.	Score
1	26.4	40.6	4.56	11	0.1
2	24.8	33.5	5.36	8	0.1
3	28.0	30.4	7.80	99	3.7
4	27.8	33.4	8.65	100	3.6
5	15.3	36.0	8.57	7	0.1
6	21.1	34.1	12.74	53	1.0
7	16.6	31.3	9.75	6	0.1
8	22.3	34.6	12.30	70	1.6

^zSee Table 24 for description of treatments.

Table 47. Effects of treatments on scald development on Cortland apples following storage in air at 0°C and in CA at 0°C and 3% O₂ and 3% CO₂. 1986.

Treatment	Percent scald			Scald score		
	Air		CA	Air		CA
	3.5 mo	5.5 mo	5.5 mo	3.5 mo	5.5 mo	5.5 mo
Interior:						
Control	52 ± 3 ^z	25 ± 3	29 ± 4	0.52 ± .03	0.25 ± .03	0.36 ± .07
Ethephon (eth)	55 ± 6	36 ± 1	36 ± 3	0.55 ± .06	0.36 ± .01	0.38 ± .07
Ca + vitamins (vit)	39 ± 10	25 ± 5	11 ± 3	0.55 ± .10	0.30 ± .06	0.12 ± .03
Eth + Ca + vit	42 ± 10	54 ± 10	43 ± 8	0.46 ± .10	0.69 ± .18	0.51 ± .12
Exterior:						
Control	53 ± 5	28 ± 4	29 ± 4	0.53 ± .05	0.30 ± .04	0.31 ± .04
Ethephon	37 ± 5	28 ± 5	31 ± 6	0.37 ± .04	0.28 ± .05	0.35 ± .04
Ca + vitamins	18 ± 8	28 ± 3	23 ± 4	0.23 ± .08	0.30 ± .04	0.27 ± .04
Eth + Ca + vit	48 ± 10	49 ± 5	76 ± 12	0.49 ± .10	0.51 ± .05	0.86 ± .12
DPA	24 ± 4	1 ± 1	2 ± 1	0.23 ± .04	0.01 ± .01	0.02 ± .00
Eth + DPA	7 ± 2	3 ± 1	1 ± 1	0.07 ± .01	0.03 ± .01	0.01 ± .00

^zMean ± standard error.

Table 48. Alpha farnesene and conjugated triene concentrations, and OD 200 values, in hexane extracts of Cortland apples. 1986.

Treatment	Alpha farnesene (n moles · (cm ²) ⁻¹)				Conjugated trienes n moles · (cm ²) ⁻¹				OD 200 (100 ml extract · (1000 cm ²) ⁻¹)			
	Harvest	Air stg	5.5 mo	CA	Harvest	Air stg	5.5 mo	CA	Harvest	Air stg	5.5 mo	CA
	3.5 mo	5.5 mo	5.5 mo	5.5 mo	3.5 mo	5.5 mo	5.5 mo	5.5 mo	3.5 mo	5.5 mo	5.5 mo	5.5 mo
Interior:												
Control	75 ± 4 ²	89 ± 4	55 ± 7	64 ± 9	1.0 ± .0	5.8 ± 1.2	6.0 ± 0.3	12.5 ± 1.5	35.6 ± 0.6	44.8 ± 2.2	43.5 ± 2.0	34.7 ± 3.0
Echephon	114 ± 11	75 ± 3	55 ± 7	57 ± 3	3.4 ± .6	8.8 ± 0.1	9.1 ± 0.3	11.6 ± 0.6	32.6 ± 3.2	45.3 ± 2.2	43.9 ± 1.8	40.0 ± 0.8
Ca + vit	—	66 ± 4	50 ± 2	76 ± 5	—	10.9 ± 0.7	13.2 ± 0.4	15.5 ± 1.1	—	39.8 ± 0.6	44.3 ± 0.6	37.5 ± 0.9
Ech + Ca + vit	—	66 ± 5	50 ± 3	55 ± 2	—	20.9 ± 1.8	23.0 ± 2.5	20.8 ± 1.8	—	41.7 ± 2.5	45.3 ± 1.6	38.1 ± 1.3
Exterior:												
Control	34 ± 3	72 ± 7	70 ± 4	74 ± 6	1.0 ± .2	5.5 ± 0.7	7.4 ± 0.7	11.1 ± 2.4	9.3 ± 0.6	44.0 ± 1.4	43.4 ± 1.3	37.5 ± 0.5
Echephon	132 ± 8	77 ± 4	64 ± 5	73 ± 5	3.4 ± .5	6.0 ± 0.4	6.8 ± 0.3	11.1 ± 1.4	40.9 ± 1.1	45.6 ± 0.5	44.8 ± 0.7	41.5 ± 1.2
Ca + vit	—	71 ± 4	58 ± 1	66 ± 6	—	8.9 ± 0.8	11.2 ± 1.1	11.6 ± 1.2	—	42.8 ± 0.5	43.6 ± 1.2	38.9 ± 0.6
Ech + Ca + vit	—	70 ± 6	63 ± 3	67 ± 3	—	14.9 ± 0.9	15.9 ± 1.7	24.0 ± 0.3	—	43.3 ± 0.4	47.5 ± 0.6	43.6 ± 0.8
DPA	—	71 ± 6	59 ± 3	65 ± 4	—	2.5 ± 0.2	3.6 ± 0.4	3.0 ± 0.4	—	45.1 ± 0.6	44.5 ± 1.4	37.5 ± 1.0
Ech + DPA	—	73 ± 6	68 ± 4	60 ± 6	—	3.8 ± 0.2	4.8 ± 0.2	3.0 ± 0.4	—	44.3 ± 1.1	48.2 ± 1.1	40.9 ± 2.7

Mean ± standard error.

Table 4g. Effects of postharvest dip treatments on alpha farnesene and conjugated triene concentrations in hexane extracts of whole apples, and on scald development following storage of Cortland apples. 1985.

Treatment	Alpha farnesene (n moles (cm ²) ⁻¹)		Conjugated trienes (n moles (cm ²) ⁻¹)		Scald incidence (Pct)		Scald intensity (Scorez)	
	1 mo	2 mo	1 mo	3 mo	3 mo	5 mo	3 mo	5 mo
Control	163 c ^y	96 b	4.7 b	7.9 b	70 b	85 b	19 b	31 b
MPTA, 50 ppm	---	---	---	---	57 b	86 b	13 b	30 b
MPTA, 500 ppm	145 ab	77 a	5.2 b	7.4 b	73 b	85 b	12 b	27 b
DCPTA, 500 ppm	141 a	78 a	5.7 b	9.5 b	76 b	95 b	18 b	38 b
MOPTA, 500 ppm	143 a	77 a	4.4 b	7.8 b	64 b	82 b	16 b	25 b
Aminotriazole, 50 ppm	---	---	---	---	65 b	92 b	19 b	33 b
Aminotriazole, 500 ppm	160 bc	96 b	5.3 b	7.9 b	64 b	90 b	17 b	34 b
DPA, 1000 ppm	147 ab	80 ab	2.2 a	3.7 a	17 a	25 a	3 a	6 a

^zScald intensity rated on scale of 0 (no scald) to 4 (> 66% of surface affected). Values shown are the sum of scores for 25 apples, with maximum possible score being 100.

^yMeans in a column not followed by a common letter are significantly different at the 5% level.

Table 50. Effects of preharvest application of carotenoid-stimulating compounds to Cortland apples on alpha farnesene and conjugated trienes in hexane extracts of fruit after storage, and on scald development after storage plus 7 days at 20°C. 1986.

Treatment	Alpha farnesene (n moles · (cm ²) ⁻¹)	Conj. trienes (n moles · (cm ²) ⁻¹)	Scald	
			Pct	Score ^z
<u>Air storage 0°C, 4.5 months</u>				
Control	60 a ^y	7.1 a	21 a	0.23 a
MPTA, 2.5 g/l	63 a	6.2 b	26 a	0.29 a
DCPTA, 4 g/l	58 a	6.2 b	28 a	0.29 a
<u>CA storage, 0°C, 4.5 months</u>				
Control	72 a	11.8 a	36 a	0.48 a
MPTA, 2.5 g/l	75 a	8.2 b	14 b	0.15 a
DCPTA, 4 g/l	79 a	9.2 b	26 ab	0.27 a

^zScale as on Table 23. Values are mean score per fruit.

^yMeans in a column and storage type not followed by a common letter are significantly different at the 5% level.

Table 51 - Average incidence of core-flush (CF) development in Jonathan apples in RA and CA storage ($\pm$ SD).

Year	No. of orchards	Region	RA	CA
1984	6	country-wide	2.7 $\pm$ 1.9	17.8 $\pm$ 17.2
1985	6	country-wide	7.5 $\pm$ 7.0	13.2 $\pm$ 4.9
1986	18	Huleh	9.1 $\pm$ 9.3	3.2 $\pm$ 3.0
	10	Gallil	19.6 $\pm$ 14.3	27.5 $\pm$ 21.2
	10	Golan	24.0 $\pm$ 17.8	34.5 $\pm$ 24.3

Table 52 - Annual variation in CF development in CA in Jonathan apples from different orchards.

Orchard	% core flush		
	1984	1985	1986
Alonim	7.9	4.8	0
Givat Ada	11.8	5.4	-
Kfar Blum	3.9	3.9	10.0
Iftah	32.4	15.2	35.0
Merom Golan	33.3	2.5	30.0
Menara	-	7.8	47.5

Table 53 - Correlations between maturity parameters and CF after storage in RA and CA and shelf-life.

Parameter	1984 ^{1,2}	1985 ²		1986	
	CA	RA	CA	RA	CA
Firmness	NS	-0.434***	-0.503***	NS	NS
TSS	-0.363**	NS	NS	NS	NS
Acid	-0.475***	NS	-0.247*	NS	-0.457**
Starch	NS	-0.283**	-0.382***	NS	NS
Ground colour	NS	NS	NS	NS	NS
Red colour	NS	NS	-0.243*	-0.376*	NS
DF	58	82	82	38	38

¹ No disease in RA

² Data of two harvests pooled.

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

NS - Non-significant.

Table 54 - Stepwise Regression Analysis of CF in RA and CA storage versus harvest variables (1986).

Storage Condition	Variable added	R ²	P
RA	fruit size	0.2331	0.002
	+Mg ²⁺ /Ca ²⁺	0.2692	0.004
	+Soluble K ⁺ /Na ⁺	0.3141	0.004
	+Quinic acid	0.3494	0.005
	+Soluble Mg ²⁺	0.3863	0.005
	+Titratable acidity	0.4374	0.003
CA	fruit size	0.3335	0.0001
	+K ⁺	0.4642	0.0001
	+Shikimic acid	0.5063	0.0001
	+Mg ²⁺	0.5342	0.0001

Table 55 - JS development on Jonathan apples from
different harvests during 5 months RA storage.

Year	1st harvest ^(a)	2nd harvest ^(b)
1984	22.6 $\pm$ 13.3	34.4 $\pm$ 16.1
1985	7.0 $\pm$ 8.3	13.8 $\pm$ 11.8
1986	11.1 $\pm$ 13.8	---

(a) at the beginning of the commercial harvest.

(b) 7-10 days after the first harvest.

Table 56 - Correlations between JS development in RA storage and maturity parameters of Jonathan apples at harvest.

Parameter	1984	1985	1986
Firmness	NS	NS	NS
TSS	NS	NS	NS
Acidity	-0.419***	-0.308**	NS
Starch	-0.316*	-0.431***	NS
Ground colour	-0.331**	--	--
Red colour	NS	-0.452***	--
DF	58	82	38

* $p \leq 0.05$

** $p \leq 0.01$

*** $p \leq 0.0001$

NS - Non-significant.

Table 57 - Stepwise regression analysis of JS in RA storage versus harvest variables (1986).

Variable Added	R ²	P
Shikimic acid	0.203	0.004
+Citric acid	0.280	0.003
+Firmness	0.327	0.003
+Acetic acid	0.372	0.003

Fig.1. Apparatus for extracion of internal atmosphere.

V-Syringe in which vaccum is created.

G-Syringe in which volatiles are collected.

T-Test-tube contaning plug of fruit tissue.

T.s.-Three way stopcock.

P-Platic to hold the piston during the extraction

FIG. 2. THE EFFECT OF RELATIVE HUMIDITY IN
RA STORAGE ON SUBSEQUENT VOLATILE
EMANATIONS FROM JONATHAN APPLES AT 20C

FIG. 3 VOLATILE EMANATIONS FROM JONATHAN APPLES FROM DIFFERENT ORCHARDS AFTER 3 MONTHS RA STORAGE AND 1 WEEK AT 20C

FIG. 4 VOLATILE EMANATIONS FROM JONATHAN APPLES FROM DIFFERENT ORCHARDS AFTER 6 MONTHS RA STORAGE AND 1 WEEK AT 20C

FIG. 5 VOLATILE EMANATIONS FROM JONATHAN APPLES FROM DIFFERENT ORCHARDS AFTER 7 MONTHS CA STORAGE AND 1 WEEK AT 20C

FIG. 6 THE PATTERN OF VOLATILE EMANATION
FROM A JONATHAN APPLE DURING POST-RA-
STORAGE RIPENING AT 20C

FIG. 7 PRODUCTION OF VOLATILES BY CORTLAND APPLES DURING 2, 4 OR 6 DAYS
AT 20°C FOLLOWING AIR (OPEN BARS) OR CA (LINED BARS) STORAGE .

Treatments: 1- Control; 2- Ethephon; 3- DPA;

4- Ca+Vit E+Vit C; 5- Ethephon+Ca+Vit E+Vit.c.

FIG. 8 ALPHA-FARNESENE AND CONJUGATED TRIENE LEVELS IN JONATHAN APPLES DURING THE 1985/6 STORAGE SEASON.

HARVEST 1 CONJUGATED TRIENES

— ALONIM
 GIVAT ADA
 KFAR BLUM
 — IFTAH
 MEROM GOLAN

ALPHA-FARNESENE

— ALONIM
 GIVAT ADA
 KFAR BLUM
 — IFTAH
 MEROM GOLAN

HARVEST 2 CONJUGATED TRIENES

ALPHA FARNESENE

Description of Cooperation

Prof. Bramlage visited Israel in June 1984, just after the initiation of the project. Detailed plans were made for the first year's experiments in both countries. Shimon Meir, a post-doc, who began work on the project during the first year in Israel, continued his research in Prof. Bramlage's lab. from 1985 to 1987. Contact was maintained by correspondence and all the scientists participating in the project met at the Gordon Conference on Post-harvest Physiology, which was held in New Hampshire in 1986. Mutual plans for the final year were made during discussions at this meeting. Prof. Bramlage again visited the Israeli team in June 1987 for comparison of results and discussions pertaining to the submission of the final report.

Evaluation of Research Achievement

The prediction formulae developed in this project for senescent breakdown are based chiefly on the calcium content of the fruit determined during the two weeks prior to harvest. Addition of one other parameter, usually an indication of maturity at harvest, improves the predictability of the formula. Such a formula can be a useful predictive tool, but in some cases more than two parameters were found necessary to achieve a reliable predictive formula. Moreover, in spite of the relatively simple and rapid method suggested for assaying soluble instead of total calcium, the implementation of prediction requires considerable expenditure. The conclusions drawn from successful prediction would be the need to apply a post-harvest calcium dip and the expected length of storage duration. The calcium dip is inexpensive and generally beneficial in other respects too, such as delaying fruit softening and reducing bitter pit, when it occurs. It is therefore generally applied to those cultivars which have been shown to respond favourably. Controlling the duration

of storage is somewhat difficult to handle under current storage conditions in Israel and Massachusetts. For efficient planning of storage duration the storage facilities required are a large number of relatively small rooms and large quantities of fruit arriving at the packing house each day. Massachusetts has the small rooms but Israel has the large quantities per diem per packing house. Neither has both requirements. It therefore would seem more beneficial to convince growers to control SB by applying a post-harvest calcium dip, rapid cooling and CA pull-down and competent cold storage management. The conditions in the U.K. at present appear to lend themselves more readily to a routine mineral analysis for prediction purposes, and in such a situation the suggested method of soluble mineral analysis would certainly be less time consuming and also less expensive.

Prediction of superficial scald would be eminently more useful, if the postharvest DPA dip could be avoided during years of low susceptibility. The expected restrictions on the use of this chemical make scald prediction even more attractive. The spot test devised in this project holds promise for cultivars that do not have a very high scald potential, such as 'Jonathan' and 'Cortland'. It might not have much value for 'Granny Smith' which very seldom has a low scald incidence. In all events, further evaluation of the reliability and universality of the method needs to be conducted before it becomes commercially applicable. The advantages of the test are its simplicity and rapidity.

The project has contributed to a fuller basic understanding of the development of senescent breakdown and has opened an avenue for further investigation of the physiology and biochemistry of this disorder. With regard to superficial scald, the results of the research conducted

within the framework of a search for predictive tools, raise questions as to the validity of the accepted hypothesis pertaining to the involvement of oxidation products of Δ -farnesene in disease development.

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