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# [C]hemical, Cultural, and Physiological [F]actors Influencing 'Stayman' [F]ruit Cracking

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# Chemical, Cultural, and Physiological Factors Influencing 'Stayman' Fruit Cracking

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# Abstract

Sprays of $GA_{4+7}$ + NAA + Vapor Gard reduced fruit cracking, reduced fruit drop, in one case reduced fruit firmness slightly, and delayed and reduced flowering the next year. Sprays of NAA or its addition to the $GA_{4+7}$ spray did not further reduce cracking. Trunk-scoring alone or in combination with spray treatments of $GA_{4+7}$ + NAA + Vapor Gard slightly reduced fruit firmness, increased red color, and reduced fruit cracking. Foliar fertilizer (Nutri Leaf, 20-20-20) applied in combination with the growth regulator sprays caused non-colored areas of the fruits to be lumpy and green (growth regulator sprays alone did not cause this problem). These areas of the fruit (mostly caylx-end and green sides) failed to develop red color, even when left on the tree for an extra week after normal harvest, thus reducing their fresh market value.

Dicamba reduced cracking from 19% to 5% in 1989, and from 60% to 40% in 1990. Ethephon increased cracking from 60% to 91%. Antitranspirants (Anti-stress 550 and Farwells grafting seal) had no effect on fruit cracking.

Apples collected from 'Stayman' trees that had a high percentage of fruit cracked seldom cracked when submerged in water for 3 days. However, when duplicated samples were submerged in non-ionic surfactant-water solutions (l.25 ml/liter X-77), water uptake and fruit cracking were greatly increased. A rapid test was developed to determine the susceptibility of fruit to cracking by submerging fruit samples in non-ionic surfactant-water solutions.

Fruit bagged in Kraft paper bags 24-51 days after full bloom (AFB) had less side and stem-end cracking, side russet, or scarf skin than did non-bagged fruit. These data indicate that fruits may be conditioned early in their development to mid-season cracking.

Soil-applied $NH_4NO_3$ increased fruit cracking of apples on 15-year-old 'Stayman'/seedling trees. Root-pruning in June reduced fruit cracking from 33% to 23% but had no effect when done in April or May.

Fruit submerged in Ethoxyquin or Diphenylamine (DPA) for 3 days caused fruit cracking and water uptake similar to that caused by X-77. Fruit dipped for 10 seconds in DPA, air dried, and placed in cold storage in plastic bags for 22 days did not crack even though water had condensed on the fruit. If these stored DPA-treated fruit were run across an apple grader and then re-bagged, no cracking occurred; but if these fruit were placed in water for a period of 3 days, 24% of the fruit cracked. Only fruit that did not go across the grader remained non-cracked. Apparently, fruits that had been across the grader brushes were more susceptible to cracking.

Laboratory data indicate that ‘Golden Delicious’ and ‘Red Delicious’ apples had lower epidermal break force and higher water absorption than ‘Stayman’ apples, suggesting that these factors were not the cause for fruit cracking. Our data indicate that ‘Stayman’ fruit cracking was caused by high internal fruit pressure that developed when fruits absorbed moisture.

# Contents

## Introduction

Side cracking of 'Stayman' fruit usually occurs during relatively long rainy periods or dewy nights after fruits have attained 50 cm or more in diameter. In addition, we have observed fruit cracking near the stem-end when fruits were 30-50 cm in diameter. Stem-end fruit cracks healed in a few weeks, and by harvest time the scarring was not very noticeable, unless the cracks had been over 1 cm in length when cracking occurred (Byers, unpublished). We believe side cracks did not heal because cell division had stopped by the time side-cracking had started. Verner (1935) reported that fruits borne on the periphery of the tree and exposed to the sun, russeted fruit, highly colored fruit, or the sides of the fruits with the greater sugar concentrations are more susceptible to cracking. Dry periods followed by rain are commonly thought to cause a great or sudden increase in water content of the fruit, thus causing fruit to crack. However, Verner (1935) was unable to demonstrate that drought followed by a rapid rise in soil moisture caused cracking or that covering of limbs during rainy periods prevented it. His data suggest that cracking occurs when the relative humidity is near 100% for 6 hours or more.

Submerging apples in a surfactant solution for 1 to 3 days increased water uptake and fruit cracking, but pesticides commonly used on apples did not increase water uptake or cracking of fruit in this laboratory test (Byers et al., 1990). The data indicate that water absorption through the epidermis might be responsible for some water uptake and cracking under field conditions.

Previous work has indicated that fruit cracking is reduced by root pruning (-6%), scoring (-11%), or four sprays of a combination of $GA_{4+7}$ + NAA + Vapor Gard + Alar (-71%) (Byers et al., 1990). Individually, the chemicals in this spray combination were ineffective or marginally effective—Alar (-6%), Vapor Gard (-3%), NAA (-9%), $GA_{4+7}$ (-15%). These data suggest combinations of materials may be much more effective than would be expected based on performance of the individual chemicals.

The objectives of the experiments reported herein were to: 1) determine if cracking of 'Stayman' fruit submerged in surfactant solutions was correlated with natural field cracking; 2) determine if bagging individual fruit early in development would affect cracking later in the season; 3) determine if soil or foliar fertilizers, root pruning, scoring, and/or chemical sprays influenced fruit cracking; and 4) determine if stop-scald materials, or placing graded or non-graded fruit in plastic bags followed by cold storage, influenced cracking.

Our rationale for testing certain cultural treatments in experiments reported here have been based on observations that fruits on vigorous trees crack more severely than do those from less vigorous trees. We suspect that heavy dormant-pruning, fertilization, weed control, and trickle-irrigation contribute to fruit cracking. In addition, low foliage-to-fruit ratios, highly colored strains, small fruit, and rough finish contribute to fruit cracking.

Certain orchard practices could be tested for their effectiveness for reducing tree vigor and fruit cracking, such as: scoring, root pruning, eliminating fertiizer, reducing herbicide strip width, and reducing dormant pruning. These practices might reduce root vigor and root absorption of water and salts, and may promote water loss from leaves, resulting in a greater top-to-root ratio.

A high top-to-root ratio reduced root pressure and increased total transpiration (Devlin and Witham, 1983); thus, severe pruning would be expected to increase cracking. Drought has been shown to increase salt concentrations in the root; and when water was re-supplied, the root pressure increased (Devlin and Witham, 1983). Fertilizer could increase salt concentrations in root or stimulate unwanted root growth.

Growth regulators (auxins and gibberellins) affected the plasticity and elasticity of pea and Avena stems (Yoda and Ashida, 1960; Adams et al., 1975) and regulated water balance (Mansfield, 1988). In apples, Ethephon, a powerful growth regulator, reduced shoot growth and sometimes fruit growth (Byers, 1993), increased fruit drop, hastened maturity (Unrath, 1972), and promoted flower bud formation (Williams, 1972); but data on its effect on fruit cracking have not been published.

Since soil-applied fertilizers theoretically could stimulate root growth and fruit cracking, the application of foliar fertilizers plus growth regulators to control cracking would be a possible cultural change that might promote good foliage condition and fruit size if soil-applied fertilizers were eliminated. In Avena hypocotyls, KCl and EDTA used in one experiment appeared to increase cell wall extensibility (Metraux, 1988).

Vapor Gard, superior oil, or a surfactant was used in some of the experiments reported here in an attempt to potentiate expensive growth regulators. Previous results indicated that X-77 increased fruit cracking of 'Stayman' in both laboratory submersion and in field tests when applied alone but Vapor Gard or superior oil did not (Byers et al., 1990); and in grapes, surfactants increased cracking under field conditions (Marois et al., 1987).

## Materials, Methods, and Results

### Experiment 1. Laboratory test for evaluation of 'Stayman' fruit cracking

***Materials and Methods.*** Five 'Stayman' apples were harvested from each of 5 trees from several blocks in Virginia where experiments were in progress in 1989. Apples were numbered on the skin with a marker, individually weighed on a top-loading balance (± 1 mg), and submerged in buckets of an aqueous solution of 1.25 ml/liter X-77. After 1 and 3 days of submersion, each apple was examined for cracks; after 3 days each apple was blotted dry with paper towels and reweighed. The percentage weight gain was calculated separately for non-cracked and cracked apples.

***Results.*** Fruit samples taken from two sections of one Winchester block (sample #G1 and #G2) were not cracked on the tree in the field in one part of the block (#G1), but 23% of the apples in another part of the same block (#G2) were cracked. In the X-77 submersion test, less water uptake and no cracking occurred with fruit from the #G1 sample when compared to fruit from the #G2 sample. Fruit from a block of '201 Stayman' trees/ M.9 at Timberville absorbed more water than those at other '201 Stayman' trees at other locations, but they did not crack as badly in the field or in the X-77 submersion test as did the '201' sample from Massies Mill (#S5). The 'Staybrite' strain from Massies Mill (#S5) appeared to crack more than did the '201' strain from Massies Mill in both the field and the X-77 submersion tests, but water absorption of the Staybrite strain was lower. The 'Stayman Supreme' (#S5) at the Massies Mill location did not crack in the field, and cracked only slightly in the X-77 laboratory test. (This strain seldom cracks on the tree, is not as highly colored, and some growers say it has other qualities inferior to the '201 Stayman' strain.) These data indicate that fruit samples collected from trees with a high degree of field-cracking also cracked when submerged in X-77 surfactant solutions.

### Experiment 2. Effect of enclosing 'Stayman' fruit in Kraft paper bags

***Materials and Methods.*** In 1989, 25 16-year-old '201 Stayman'/ seedling trees were selected for uniform crop load, and 4 fruits on each tree were covered with a Kraft paper bag for various periods: 16-24 days after full bloom (AFB), 24-51 days AFB, 38-65 days AFB, 65-97 days AFB, 80-111 days AFB, and 111-121 days AFB; or were tagged as controls at 24, 44, or 87 days AFB. Each treatment represented a 100-fruit sample.

Stem-end cracks longer than 0.5 cm were recorded 51 to 129 days AFB. Since stem-end cracks had occurred by 65 days AFB and had healed by 111 days AFB, healed cracks were not counted at 111, 120, or 129 days AFB. Side cracks longer than 0.5 cm were recorded from 97 to 168 days AFB.

Side russet was rated from 0 to 5 at harvest and scarf skin from 0 to 10. Side russet ratings were: 0 = lenticel enlargement; 2 = lenticels enlarged and some russet between lenticels; 3 = lenticels enlarged and slightly raised to touch, moderate to heavy russet between lenticels; 4 = lenticels enlarged and moderately raised to touch and moderate to heavy russet between lenticels; 5 = lenticels enlarged and heavily raised to touch and heavy russet between lenticels. Scarf skin: 1 = light and 10% affected; 3 = moderate and 30% affected; 5 = severe and 50% affected. No ratings for scarf skin were over 5.

***Results.*** Fruit enclosed in Kraft paper bags from 16 to 44, 24 to 51, and 38 to 65 days AFB had fewer stem-end cracked fruits 65 days AFB than the controls had (Table 2). Stem-end cracks healed by 111 days AFB; thus, they were recorded as no longer present, but fruit were examined for any new stem-end cracks on each subsequent date. Side-cracking began by 97 days AFB. Some side cracking was associated with the stem-end cracking, but most was not associated with the healed stem-end crack.

All bagging treatments suppressed side cracking in the period 120 to 168 days AFB. Side russet was reduced by bagging 16 to 44, 24 to 51, and 38 to 65 days AFB. Scarf skin was reduced by bagging 16 to 44, 24 to 51 days, and 38 to 56 days AFB. These data indicate that fruit cracking, scarf skin, and russet may be influenced by similar environmental conditions in the 60-day period after bloom.

At harvest, fruits in the paper bags were very wet early in the morning after heavy dew, light rain, or high humidity during the night. The fruit and the bag dried out during the day. We believe that the moisture on the fruit in the bag was due to condensation of water vapor on the cold fruit at night. Further study should be made regarding the bagging technique for keeping fruit dry; apparently the technique did not keep the fruit dry when humidity was high.

## Experiment 3. Soil-applied fertilizers on 'Stayman' fruit cracking

***Materials and Methods.*** In 1989, 50 16-year-old '201 Stayman'/seedling trees were selected for uniform crop load. Ten single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The following 5 treatments were applied: 1) control--no fertilizer, 2) 2.27 kg/tree of $NH_4N0_3$ (33% N), 3) 2.27 kg/tree of KCl (50% K), 4) 2.27 kg/tree of super phosphate (48% P), and 5) 36.3 kg/tree of $CaSO_4$ (20% Ca). Treatments 2, 3, and 4 were applied as a split application May 2 and May 16 in 3.8 liter of water, and treatment 5 was applied to the soil May 9 and was spread within 1 meter of each tree trunk. Five limbs with an average of 16 fruits/limb were selected and tagged on each of 10 trees. These fruits were monitored for cracking from 26 June to 6 October (about 800 fruits/treatment). The number of cracked fruits on the tagged limbs were counted and removed, and the percentage of cracked fruit was calculated for each date. Because the growers had treated the experimental area with fertilizer in 1990, only cracking of the $CaSO_4$ treatment was monitored in 1990.

***Results.*** Soil-applied $NH_4NO_3$ increased fruit cracking of 'Stayman' apples on 15-year-old 'Stayman'/seedling trees in 1989 (Table 3). Since the grower accidentally fertilized the plots in 1990, only the Ca $SO_4$ and the control were followed. In 1990 both treatments had 28% cracked fruit.

**Experiment 4. Root pruning effects on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1990, 160 17-year-old '201 Stayman'/seedling trees were selected for uniform crop load and terrain in an orchard having 16 rows. Four rows of each of the following treatments were applied in a randomized complete block design: 1) control, 2) root-pruned 20 April, 3) root-pruned 22 May, and 4) root-pruned 22 June. Five limbs with an average of 3.5 fruits/limb were selected and tagged on each of 10 trees in each of the replicates. These fruits were monitored for cracking from 30 May to 1 Oct (about 700 fruit/treatment). Stem-end and side-cracked fruit on the tagged limbs were counted, side cracked fruits were removed, and the percentage of fruits cracked was calculated for each date.

***Results.*** Side-cracking of fruit was reduced from 33% to 23% by root pruning in June 1990 (Table 4). Some reduction may have occurred by the April and May root pruning, but the data are for the most part not significantly different from those of the control. Stem-end cracks were very evident by 30 May but they healed over by 16 July.

**Experiment 5. Scoring and multiple growth regulator sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1989, 16 16-year-old '201 Stayman'/seedling trees were selected for uniform crop load. Four single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The following 4 treatments were applied: 1) control--no treatment, 2) trunk scored 12 June + $GA_{4+7}$ + NAA + Vapor Gard 14 Jun, 3) trunk scored 12 Jun and 28 Jun + $GA_{4+7}$ + NAA + Vapor Gard 14 Jun and 30 Jun, and 4) trunk scored 12 June and 30 Jun

+ $GA_{4+7}$ + NAA + Vapor Gard 14 June, 30 June, and 18 July. The chemical spray rates that were applied are listed in Table 5. The trees were approximately 5 meters high and 5 meters wide, planted in rows 8 meters apart. Five limbs with an average of 20 fruits/limb were selected and tagged on each of 4 trees. These fruits were monitored for cracking from 16 Aug to 13 Oct (about 400 fruits/treatment). Side-cracked fruit on the tagged limbs were counted and removed, and the percentage of cracked fruit was calculated for each date. In addition, the number of non-cracked fruit that dropped in the period from 14 Sep to 13 Oct was tabulated.

***Results.*** Grower-applied treatments of scoring + spraying trees with $GA_4$+$_7$ + NAA + Vapor Gard were evaluated for cracking (Table 5). Spray treatments were applied 2 days after scoring. Trees were scored no more than twice, since some trees showed a yellowish cast after 2 scorings. Cracking was reduced from 72% to 32% by 2 scorings and 3 chemical applications. These treatments also reduced fruit drop of non-cracked apples from 58% to 24% in the 14 Sep to 13 Oct period. We suspect the NAA applied in the summer period reduced fruit drop.

**Experiment 6. Scoring, growth regulator, and foliar fertilizers on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1989, 102 15-year-old '201 Stayman'/seedling trees were selected for uniform crop load. Six single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The 17 spray and scoring treatments were applied at the dates indicated as listed in Table 6. Five limbs with an average of 13 fruits/limb were selected and tagged on each of 6 trees. These fruit were monitored for cracking from 4 Jul to 5 Oct (about 400 fruits/treatment). The number of side-cracked-fruits on the tagged limbs were counted and removed, and the percentage cracked fruit was calculated for each date.

In addition, 10 fruits were sized with a band caliper, rated for percentage of red color; and, on two sides of each fruit, firmness was determined with an Effigi fruit tester fitted with a 11.1-mm tip. Return bloom was rated from 0 to 10 (a rating of 4 would be adequate bloom for a full crop), and on 15 Apr 90 the percent of flowers that had opened on each limb was recorded.

***Results.*** Fruit cracking in 1989 was not as serious as in 1987 or 1988. For this reason, differences expected among several treatments could not be determined (Table 6). None of the treatments suppressed cracking more than 5 mg/liter GA. Treatments that contained GA in the spray combination also reduced cracking. Scoring alone or in combination with spray treatments reduced fruit firmness slightly, increased red color, and reduced fruit cracking.

Return bloom was reduced to less than half that of the control by several of the treatments; however, most of the same treatments delayed flower opening (Table 6).

**Experiment 7. Scoring, growth regulator, and foliar fertilizer on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1989, 90 6-year-old '201 Stayman'/ M.26 trees on a three-wire trellis were selected for uniform crop load. Five 6-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The 3 treatments were applied on the dates indicated in Table 7. Each tree was tagged on the trunk about 1.3 meters from the soil. About 20 fruits from each tree were monitored for cracking from 4 Jul to 5 Oct (about 600 fruits/treatment). Cracked fruits on the tagged limbs were counted and removed, and the percentage of cracked fruit was calculated for each date.

In addition, 10 fruits were sized with a band caliper, rated for percentage of fruit showing red; and firmness was determined on two sides of each fruit at harvest and again after cold storage on 14 Dec 89 with an Effigi fruit tester fitted with a 11.1-mm tip. The delayed bloom was expressed as the percent of clusters that had separated on 19 Apr 90 and the percent of flowers that had opened 25 Apr 90. Fruit/ $cm^2$ cross-sectional area of limb was recorded on 15 May 90 on one limb/tree as a measure of fruit density.

***Results.*** 'Stayman'/M.9 trees, scored 4 times with a carpet knife, had numbers of fruit cracked similar to those of the untreated control trees (Table 7). Scoring 4 times + 5 mg/l $GA_{4+7}$ + 2.5 ml/l superior oil + 20 mg/ l NAA + 6 g/l 20-20-20 fertilizer (Nutri Leaf) reduced fruit cracking from 15% to 1%. Fruit diameter and red color were not affected by the treatment, but firmness was reduced slightly at harvest and after cold storage.

The spray treatments delayed flower opening, as indicated by the percent of clusters separated 19 Apr 90 and the percent of flowers that had opened by 25 Apr 90; however, the number of fruits/$cm^2$ cross sectional area of limb on 15 May 90 indicated that the number of fruits per tree was inadequate for a full crop. These trees appeared to be more affected than were the 'Stayman'/seedling trees in Experiment 6. The delayed flowering appeared to be a benefit, but was offset by the reduced numbers of flowers.

**Experiment 8. Low rate herbicide sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1989, 30 15-year-old '201 Stayman'/ seedling trees were selected for uniform crop load. Six single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The 5 treatments listed in Table 8 were applied at the dates indicated. Four limbs with an average of 16 fruits/limb were selected and tagged on each of 6 trees. These fruit were monitored for cracking from 13 Jun to 16 Oct (about 400 fruit/treatment). Side-cracked fruit on the tagged limbs were counted and removed, and the percentage of cracked fruit was calculated for each date. At harvest, fruit diameter was determined as in Experiment 6.

Near harvest the skin puncture firmness was tested on 4 sides of one apple from each replicate of the control and the Dicamba-treated trees using a Wagner (500 g) dynamometer (Greenwich, Conn.) fitted with a small point-type plunger.

***Results.*** Dicamba (20 mg/l) applied 6 Jul 89 inhibited fruit cracking of 14-year-old 'Stayman'/seedling trees, particularly in July and August (Table 8). Fruit skin resistance in the puncture test indicated that Dicamba-treated fruits were less resistant in puncture than the controls were (Table 8).

Triclopyr applied 27 Apr 89 appeared to increase fruit cracking, but an application made on 6 July inhibited fruit cracking (Table 8).

**Experiment 9. Growth regulator and anti-transpirant sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1990, 56 17-year-old '201 Stayman'/ seedling trees were selected for uniform crop load. Eight single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The 7 treatments listed in Table 9 were applied on the dates indicated. Eight limbs with an average of 4 fruits/ limb were selected and tagged on each tree. These fruits were monitored for cracking from 17 Jul to 29 Sep (about 400 fruits/treatment). Cracked fruits on the tagged limbs were counted and removed, and the percentage of cracked fruit was calculated for each date.

In addition, 10 fruits were rated for percentage of red color, and on two sides of each fruit, firmness was determined at harvest with an Effigi fruit tester fitted with a 11.1-mm tip.

***Results.*** In 1990, multiple applications of the combination of GA + NAA + Vapor Gard reduced fruit cracking from 60% to 33% at harvest (Table 9). No loss of firmness or red color (10% non-statistical increase, data not shown) was detected. Multiple Dicamba applications alone or in combination with GA + NAA + Vapor Gard reduced fruit cracking to an extent similar to the reduction caused by GA + NAA + Vapor Gard. Ethephon increased cracking from 60% to 91%. The Anti-stress 550 or the Farwells grafting seal had no effect on fruit cracking.

**Experiment 10. Growth regulators and adjuvant sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1991, 50 5-year-old '201 'Stayman'/ Mark trees on a two-wire trellis were selected for uniform crop load. Ten single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The treatments listed in Table 10 were applied on the dates indicated. An average of 120 apples per tree were monitored for cracking from 17 Jul to 9 Oct (about 1200 apples per treatment). The number of cracked fruits on each tree was counted and removed, and the percentage of cracked fruit was calculated for each date.

***Results.*** In 1991, 8 applications of $GA_{4+7}$+ NAA reduced fruit cracking from 31.8% to 10.5% (Table 10). The addition of LI 700 surfactant at two rates or Vapor Gard did improve the growth regulator results, if single-degree-of-freedom comparison contrasts were used instead of the Duncan's multiple range test.

**Experiment 11. Growth regulators and copper sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1991, 45 5-year-old '201 'Stayman'/M.7 trees were selected for uniform crop load. Nine single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The treatments listed in Table 11 were applied on the dates indicated. An average of 120 apples per tree were monitored for cracking from 17 Jul to 9 Oct (about 1080 apples per treatment). The number of cracked fruits on each tree were counted and removed, and the percentage of cracked fruit was calculated for each date.

Results. In 1991, 6 applications of a COCS copper at two rates did not reduce fruit cracking and did not affect the results of the growth regulator sprays when COCS was tank mixed with $GA_{4+7}$ and NAA (Table 11).

**Experiment 12. Growth regulators and adjuvant sprays on 'Stayman' fruit cracking**

***Materials and Methods.*** In 1992, 130 six-year-old 'Staybrite Stayman'/M.7A trees were selected for uniform crop load. Ten single-tree replicates per treatment in a randomized complete block design were blocked according to row and terrain. The treatments listed in Table 12 were applied on the dates indicated. An average of 50 apples per tree were monitored for cracking from 17 Jul to 9 Oct (about 50 apples per treatment). The number of cracked fruits on each tree were counted and removed, and the percentage of cracked fruit was calculated for each date.

***Results.*** In 1992, $GA_{4+7}$ at 5 or 20 ppm greatly reduced fruit cracking; however, there appeared to be no benefit from 20 ppm $GA_{4+7}$ or the addition of NAA to the $GA_{4+7}$ sprays or of NAA alone. A new growth regulator XYZ, currently under a secrecy agreement, appeared to have no effect alone or in combination with $GA_{4+7}$ or NAA. The addition of Regulaid, Li 700, Oil, or Vapor Gard did not improve the effectiveness of the growth regulator mixture (Table 12).

**Experiment 13. Effect of submerging 'Stayman' apples in a surfactant or apple scald inhibitors**

***Materials and Methods.*** In 1989, 50 'Staybrite' apples from Massies Mill, Va., were harvested on 7 Sep and on 8 Sep were weighed and submerged in Diphenylamine, Ethoxyquin, or X-77 for 3 days as listed in Table 13. After 1 or 3 days of submersion, each individual apple was blotted dry with a paper towel, examined for cracks, and reweighed at 3 days. The percentage weight gain was determined for non-cracked and cracked apples.

***Results.*** In February 1989, one grower in the Winchester area lost, due to fruit cracking, more than 300 bushels of 'Stayman' fruit that had been packaged in 2.3 kg plastic bags in January 1989 and placed in cold storage for a period of 4-5 weeks. These fruits were not treated with stop-scald materials as is usually done at cold storages in this area.

'Staybrite Stayman' fruit from Massies Mill submerged in Ethoxyquin or DPA solutions for 1- and 3-day periods exhibited fruit cracking and water uptake similar to X-77 (Table 13). Previous tests indicated that fruit submerged in typical pesticide concentrations used in the summer period did not increase cracking or water uptake (Byers et al., 1990).

**Experiment 14. Effect of dipping 'Stayman' apples in an apple scald inhibitor, subsequent cold storage, and water submersion**

***Materials and Methods.*** Fifty 'Staybright' apples from Massies Mill, Va., were harvested on 7 Sep and held in cold storage. On 19 Sep each fruit was weighed and submerged in Diphenylamine for 10 seconds, air dried, and placed in cold storage for 8 days (Table 14). Fruits were then removed from cold storage and divided into two groups. One group was placed directly in 5-lb polyethylene bags, and the other group was run across a commercial apple grader (washed and dried with a brush-type drying roll, without wax). Fruits were stored in bags and then removed from storage twice and allowed to warm at room temperature to induce condensation on the fruit in the bags (6 hours and 24 hours on days 6 and 13, respectively). Water condensed on the fruits in cold storage, even on the first day fruits were in the bags. Fruits were held in bags for a total of 22 days in cold storage.

Since none of the 50 fruits cracked in cold storage, fruits from both groups then were submerged for 3 days in water only. After 1 or 3 days of submersion, each apple was blotted dry with a paper towel, examined for cracks, and reweighed at 3 days. The percentage weight gain was determined for non-cracked and cracked apples.

***Results.*** 'Staybrite Stayman' apples from Massies Mill submerged in DPA for 10 seconds, air dried, and placed in plastic bags in cold storage for 22 days did not crack, even though water had condensed on the fruit. When these DPA-treated fruits were run across an apple grader and then re-bagged, no cracking occurred; but if the fruits were then placed in water for a period of 3 days, 24% of the fruit which had been run across the grader cracked; those that did not go across the grader remained non-cracked. Apparently the cuticle was sufficiently disturbed to cause fruit cracking when submerged. Interestingly, the fruit lost weight during the 22 days of cold storage, regained some weight when placed in water, but gained less than that lost in cold storage. Even those cracked fruits that had gone across a commercial grader and were submerged for three days in water, weighed less than before placement in cold storage, yet cracked when placed in water. (Table 14). In addition, since weight gained by the non-graded and graded fruits was the same, the strength or weakness of the epidermis may be what is involved in fruit cracking and perhaps not the amount of water uptake.

**Experiment 15. Laboratory test for evaluation of apple cultivars or strains of 'Stayman' for fruit cracking**

***Materials and Methods.*** Fifty kg of fruit were harvested from 10 trees from 5 different orchards for laboratory experiments (Table 15): 1) '201 Stayman'/Mark, '201 Stayman'/seedling, 'Supreme Stayman'/seedling, 'Triple Red Delicious'/seedling, 'Golden Delicious'/seedling. Seventy-five fruits from each orchard were divided into 2 groups and submerged into water, or 1.25 ml/liter X-77, for 3 days. After 1 and 3 days of submersion, each apple was examined for cracks, and after 3 days each apple was blotted dry with paper towels and re-weighed. The percentage weight gain was determined separately for non-cracked and cracked apples.

***Results.*** When submerged in a water-surfactant solution of X-77, more apples cracked from '201 Stayman'/Mark trees than did fruits taken from '201 Stayman'/seedling trees, even though the trees were located in the same orchard about 100 meters apart on similar soil (Table 15). Visual observation indicated that more than 50% of the fruits on the 'Mark' trees had cracked, and less than 10% on the seedling trees. The 'Supreme Stayman', which seldom cracks in the field, did not crack when submerged in X-77 water solution. Neither 'Golden Delicious' nor 'Red Delicious' cracked. 'Golden Delicious' and 'Red Delicious' gained more weight than did the three 'Stayman' samples of fruit. The 'Supreme Stayman' and the '201 Stayman'/seedling fruits gained less water and also cracked the least when compared to the '201 Stayman'/Mark.

**Experiment 16. Apple peel resistance tests**

***Materials and Methods.*** Near harvest the skin puncture firmness was tested on four sides of 5 apples from each orchard using a Wagner (500 g) dynamometer fitted with a plunger. In addition, a razor blade was used to cut a uniform slit in the cheek of each apple, which was then submerged in 1.25 ml/liter X-77. After 1 day the width of the opening of the slit was measured with a hand caliper (± 0.01mm).

Two microtome razor blades mounted 5.65 mm apart were used to cut a piece of apple peel approximately 75 mm long from the cheeks of 5 apples from each orchard. The pieces were removed from the apple along with about 1 mm of apple flesh by undercutting with a sharp knife. Two Plexiglas clamps (55-60 mm apart) were used to suspend the peel vertically. A 300-g weight was hung from the peel for 15 seconds and then removed. The total increased extension (extensibility), the relaxation distance (elasticity), and the distance not elastic (plasticity) were expressed as a percentage of the original peel length between the two clamps (Yoda and Ashida, 1960; Adams et al., 1975). After extension measurements were made, the break force of each peel was determined by pulling the bottom clamp with a Wagner (1000 g) dynamometer (Greenwich, Conn.).

***Results.*** In a previous preliminary study, 10 'Golden Delicious', 10 'Red Delicious' and 10 '201 Stayman' apples were cut with a razor blade on the tree in the field. Overnight 6 of the 'Stayman' cracked, but none of the 'Golden Delicious' or 'Red Delicious' cracked.

The '201 Stayman'/Mark fruit sample (the 'Stayman' strain most susceptible to fruit cracking on the tree) appeared to have more internal pressure (as indicated by the razor blade cut test) than did the other two 'Stayman' samples (Table 16). In addition, there seemd to be a negative relationship between the puncture test (lower apple skin resistance) and fruit cracking. Both 'Golden Delicious' and 'Red Delicious' had low internal pressure (razor blade test), and they also had low skin resistance (puncture test), unlike the 'Stayman' samples. Stretching the apple skin with 300 g of weight did not show differences in elasticity, plasticity, or total extensibility between the 3 'Stayman', 'Golden Delicious', or 'Red Delicious' samples (Table 16). In addition, the break force of the apple skin was not different between the 'Stayman' samples, but 'Red Delicious' and 'Golden Delicious' had much lower break forces.

These data suggest that high internal pressure (razor blade test), perhaps combined with lower skin resistance (puncture test), is correlated with fruit cracking (Table 15). The 'Golden Delicious' and 'Red Delicious' samples had lower epidermal break force and higher water absorption than 'Stayman' did, suggesting that these factors by themselves are not the cause for fruit cracking. We believe the lower internal fruit pressure of the 'Golden Delicious' and 'Red Delicious' varieties upon the absorption of water was responsible for their resistance to cracking. It is possible that when fruits absorb water, 'Stayman' fruits swell more than do 'Golden Delicious' or 'Red Delicious'.

## Summary

Multiple sprays of 5 ppm $GA_{4+7}$ were as effective as 20 ppm sprays for reducing fruit cracking (Exp. #12). The addition of foliar nutrients to $GA_{4+7}$ sprays caused non-colored areas of the fruits to be lumpy and green, and the fruit failed to develop color properly at harvest (Exp. #6). The use of superior oil, a surfactant, or Vapor Gard appeared to be equally effective for potentiating $GA_{4+7}$ in one experiment (Exp. #10).

Root pruning reduced fruit cracking more when done in June than when done in April or May (Exp #4).

Spray combinations that included NAA at 20 ppm did not appear to reduce fruit cracking, but 20 ppm NAA reduced fruit drop at harvest (Exp. #5), delayed bloom, and decreased flowering (Exp # 6, 7), but NAA did not delay bloom or decrease flowering at 5 ppm (Exp # 9). A minor trend to increased color and softening of fruit was detected in another experiment in which NAA was used in the spray combination (Exp # 6).

In one experiment, scoring of the tree trunk reduced fruit cracking (Exp # 6), but not in another (Exp # 7). Copper sprays had no effect on fruit cracking (Exp # 11). Sprays of Ethephon (Exp # 9) or soil-applied $NH_4NO_3$ (Exp # 3) increased fruit cracking.

When 'Stayman' apples were harvested from trees with a high percentage of cracked fruit and were submerged in water for 3 days, few apples cracked; but if a surfactant (0.125% X-77) was added to the water, greater water uptake and cracking occurred (Exp # 15, Byers et al., 1990). Apples taken from trees not susceptible to cracking had a much lower percentage of cracked fruit when submerged in a surfactant solution (Exp # 1,15). Thus, we believe the surfactant submersion test can predict the susceptibility of 'Stayman' to cracking in field.

Occasionally growers report cracking of 'Stayman' fruit in cold storage. Our data indicate that fruit that have been across the grader brushes are more susceptible to cracking (Exp. #14). In addition, fruit submerged in scald inhibitors (Ethoxquin or Diphenylamine) cause fruit cracking and water uptake similar to X-77-water solutions (Exp. #13).

Our laboratory data indicate that high internal fruit pressure results, the fruit swells, and the swelling is responsible for fruit cracking (Exp # 16). 'Red Delicious' and 'Golden Delicious' resistance to cracking appears to be related to less swelling and lower internal fruit pressures when these fruits absorb substantial quantities of water (Exp # 16).

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**Table 1. Effect of submerging 'Stayman' apple strains in a surfactant solution (0.125% X-77) on fruit cracking and percentage weight gain (1989)**

| Cultivar-strain/rootstock | Location/block | Date submerged | % Fruit cracked[z] submerged in X-77 | | % Field cracked | % Weight gain after 3 days[y] | | |
|---|---|---|---|---|---|---|---|---|
| | | | Day 1 | Day 3 | | Non-cracked apples | Cracked apples | All apples |
| Stayman-201/seedling | Winchester #G1 | 17 Sept | 0 | 0 | 0 | 0.94 ± 0.16 | --- | 0.94 ± 0.16 |
| Stayman-201/seedling | Winchester #G2 | 22 Sept | 10 | 18* | 23 | 1.67 ± 0.21 | 2.02 ± 0.40 | 1.73 ± 0.18 |
| Stayman-201/M.9 | Timberville #T3 | 22 Sept | 0 | 16* | 21 | 3.17 ± 0.25 | 3.56 ± 0.87 | 3.23 ± 0.24 |
| Stayman-201/seedling | Timberville #K4 | 22 Sept | 0 | 6 | 17 | 1.33 ± 0.22 | 2.55 ± 0.83 | 1.41 ± 0.22 |
| Stayman-201/seedling | Massies Mill #S5 | 19 Sept | 54** | 75** | 58 | 2.21 ± 1.41 | 3.17 ± 0.50 | 2.91 ± 0.50 |
| Stayman-Supreme/seedling | Massies Mill #S5 | 19 Sept | 0 | 4 | 0 | 1.41 ± 0.38 | 0.64 | 1.38 ± 0.37 |
| Stayman-Staybrite/M.111 | Massies Mill #S5 | 19 Sept | 76** | 88** | 95 | 1.52 ± 9.72 | 2.81 ± 0.44 | 2.70 ± 0.44 |
| Stayman-Supreme/seedling | Winchester #M3 | 17 Sept | 0 | 0 | 0 | 0.74 ± 0.15 | --- | 0.74 ± 0.15 |

[z]Means of 25 apples submerged for each cultivar. Each treatment was compared within columns to the Winchester #G1 block by Chi-square, 5% and 1% levels (*,**).

[y]Confidence limits, 5% level, for non-cracked, cracked, and all apples in each 25-apple group.

**Table 2. Effect of paper bags on 'Stayman' fruit cracking (1989)**

| Treatment[z] | Application date of bags (days after full bloom--DAFB) | % Stem end cracked[y] DAFB | | | | | % Cumulative side cracked - DAFB | | | | | | Side russet rating[x] | Scarf skin[w] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 51 | 65 | 111[y] | 120 | 129 | 97 | 111 | 120 | 129 | 149 | 168 | | |
| 1. Control | Tagged 24 DAFB | 0 | 26 a[v] | 0 | 0.5 | 0 | 1 | 4.1 a | 8.3 a | 11.1a | 17.6a | 41.2 a | 2.49 a | 1.84 a |
| 2. Bagged | 16 to 44 | 0 | 5 bc | 0 | 0 | 0 | 1 | 1.5 ab | 3.5 b | 5.0 ab | 9.2 bc | 28.9 bc | 1.34 c | 0.88 c |
| 3. Bagged | 24 to 51 | 1 | 2 c | 0 | 0 | 0 | 0 | 1.2 ab | 1.2 b | 1.2 b | 6.5 c | 21.0 cd | 1.26 c | 1.03 c |
| 4. Bagged | 38 to 65 | - | 10 b | 0.5 | 0 | 0 | 2 | 4.3 a | 5.9 ab | 8.3 a | 10.8abc | 22.2 cd | 1.46 c | 1.42 b |
| 5. Bagged | 65 to 97 | - | - | 0 | 0 | 0 | 1 | 2.0 ab | 5.6 ab | 6.1 ab | 7.8 bc | 24.8 bc | 2.20 b | 2.10 a |
| 6. Bagged | 80 to 111 | - | - | 0 | 0 | 0 | - | 0.0 b | 3.6 b | 8.7 a | 12.0abc | 26.5 bc | 2.32 ab | 1.50 b |
| 7. Bagged | 121 to harvest | - | - | - | - | - | - | - | - | - | - | 11.6 d | 2.24 b | ----- |
| 8. Control | Tagged 44 DAFB | 0 | 25 a | 0 | 0 | 0 | 0 | 2.1 ab | 5.2 ab | 8.3 a | 11.4abc | 35.8 ab | 2.36 ab | 1.53 b |
| 9. Control | Tagged 87 DAFB | - | - | 0 | 0.5 | 0.5 | 1 | 1.5 ab | 5.5 ab | 7.1 a | 13.8 ab | 29.7 abc | 2.21 b | 1.49 b |

[z]Full bloom occurred -- April 25, 1989. Hail occurred May 15 -- 20 DAFB. Control # 1 was hailed fruit. Non-hailed fruit were selected for all treatments except # 1 and # 3 since the hail was not obvious when fruit were bagged 16 DAFB.

[y]Fruit that cracked near the stem end in the period from 51 to 65 days AFB healed with some scarring by 111 days AFB and were not included in further cracking data (some scars would have thrown some fruit out of grade).

[x]Side russet raing: 0=lenticel enlargement; 2=lenticel enlargement and some russet between lenticels; 3=lenticel enlargement and slightly raised to touch, moderate to heavy russet between lenticels; 4=lenticel enlargement and moderately raised to touch and moderate to heavy russet between lenticels; 5=severe and 50% affected.

[w]Scarf skin: 1=light and 10% of the fruit surfaced affected; 3= moderate and 30% affected; 5=severe and 50% affected.

[v]Mean separation within columns by Duncan Multiple Range Test, 5% level.

**Table 3. Effect of fertilizers applied to the soil at the tree trunk on 'Stayman' fruit cracking (1989)**

| | | Cumulative % cracked fruit | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment[z] | Rate/ tree (kg) | Jun 26 | Jul 25 | Aug 15 | Aug 23 | Sep 7 | Sep 19 | Oct 6 |
| 1. Control | 0 | 0 | 0 | 3 b[y] | 12 ab | 19 b | 22 b | 26 b |
| 2. $NH_4NO_3$ (33% N) | 2.27 | 0 | 0 | 6 a | 17 a | 28 a | 30 a | 35 a |
| 3. KCl (50% K) | 2.27 | 0 | 0 | 2 b | 8 b | 14 b | 15 b | 22 b |
| 4. $P_2O_5$ (48% P) | 2.27 | 0 | 0 | 2 b | 9 b | 16 b | 19 b | 23 b |
| 5. $CaSO_4$ (20% Ca) | 36.3 | 0 | 0 | 3 ab | 9 b | 18 b | 20 b | 28 ab |

[z]Ten single whole tree replicates per treatment. Treatments 2, 3, 4 were applied as a split application May 2 and May 16 in 1 gallon of water, and treatment 5 was applied to the soil May 9. Approximately 800 apples per treatment.

[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

**Table 4. Effect of root pruning on 'Stayman' fruit cracking (1990)**

| Treatment[z] | Date pruned | % Cumulative stem end cracked | | % Cumulative side cracked | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | May 30 | Jul 16 | Jul 16 | Jul 30 | Aug 13 | Aug 27 | Sep 14 | Oct 1 |
| 1. Control -- | | 45 a | 0 | 4.3 a | 7.7 a | 11.3 a | 21.2 a | 27.8 a | 32.6 a |
| 2. Root pruned | 20 Apr | 42 a | 0 | 4.1 a | 6.5 a | 9.2 a | 14.0 b | 18.7 b | 24.5 ab |
| 3. Root pruned | 22 May | 46 a | 0 | 3.1 a | 6.3 a | 9.8 a | 17.0 ab | 22.2 ab | 28.4 ab |
| 4. Root pruned | 22 Jun | 50 a | 0 | 4.0 a | 5.9 a | 7.7 a | 13.4 b | 18.2 b | 23.1 b |

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 5. Effect of scoring and growth regulator sprays on 'Stayman' fruit cracking (1989, Nelson County)

| Treatment[z] | Rate ai (g/ha) | Formu-lation per acre | Application dates | | | Cumulative % cracked fruit | | | | % Fruit drop 14 Sept to 13 Oct |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Jun | Jun | Jul | 16 Aug | 31 Aug | 14 Sept | 13 Oct | |
| 1. Control | | | | | | 24.6 a[y] | 55.1 a | 64.4 a | 71.6 a | 58 a |
| 2. Scored | | | 12 | | | 3.8 b | 14.0 b | 20.6 b | 44.8 b | 30 b |
| + $GA_{4+7}$ | 11.2 g | 8 oz | 14 | | | | | | | |
| + NAA 800 | 22.4 g | 8 oz | 14 | | | | | | | |
| + Vapor Guard | 2.3 liter | 2 pt | 14 | | | | | | | |
| 3. Scored | | | 12 | 28 | | 2.0 b | 3.9 b | 12.3 b | 36.5 b | 19 b |
| + $GA_{4+7}$ | 11.2 | 8 oz | 14 | 30 | | | | | | |
| + NAA 800 | 22.4 g | 8 oz | 14 | 30 | | | | | | |
| + Vapor Guard | 2.3 liter | 2 pt | 14 | 30 | | | | | | |
| 4. Scored | | | 12 | 28 | | 1.9 b | 4.7 b | 8.0 b | 32.1 b | 24 b |
| + $GA_{4+7}$ | 11.2 | 8 oz | 14 | 30 | 18 | | | | | |
| + NAA 800 | 22.4 g | 8 oz | 14 | 30 | 18 | | | | | |
| + Vapor Guard | 2.3 liter | 2 pt | 14 | 30 | 18 | | | | | |

[z]Four whole tree replicates per treatment. Approximately 400 apples per treatment.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5 % level.

**Table 6. Effect of scoring, growth regulators, and other chemicals on 'Stayman' fruit cracking (1989)**

| Treatment[z] | Rate (mg, ml/ liter) | Application dates Jul | Jul | Aug | Sep | Cumulative % cracked fruit Jul 4 | Jul 21 | Aug 17 | Aug 26 | Sep 11 | Sep 21 | Oct 5 | Fruit diameter (cm) | % Red color | Firmness (neutons) at harvest | Firmness (neutons) 14 Dec 90 | Return bloom (0-10) 16 Apr 90 | % Bloom open 16 Apr 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Control | | | | | | 0 | 0 | 1 a[y] | 4 a | 8 a | 14 a | 23 a | 7.77 b | 86 b | 72 a | 62 a | 8.42 a | 51 a |
| 2. GA | 20 mg | 7 | 28 | 10 | 1 | 0 | 0 | 0 b | 2 ab | 6 abc | 10 ab | 18 abc | | | | | 4.75 ab | 37 abc |
| 3. GA | 5 mg | 7 | 28 | 10 | 1 | 0 | 0 | 1 ab | 1 b | 1 cd | 3 cd | 7 cde | | | | | 6.25 ab | 38 abc |
| 4. GA | 20 mg | 7 | 28 | 10 | 1 | 0 | 0 | 1 ab | 2 ab | 6 abc | 8abcd | 18 abcd | | | | | 4.42 b | 39 abc |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | |
| 5. GA 5 mg | | 7 | 28 | 10 | 1 | 0 | 1 | 1 ab | 3 ab | 4 bcd | 6 bcd | 9 cde | | | | | 6.58 ab | 25 abc |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | |
| 6. GA 5 mg | | 7 | 28 | 10 | 1 | 0 | 0 | 0 b | 2 ab | 3 bcd | 3 cd | 9 cde | | | | | 5.25 ab | 31 abc |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| 7. GA 5 mg | | 8 | 28 | 10 | 1 | 0 | 1 | 1 ab | 2 ab | 2 bcd | 3 cd | 7 cde | | | | | 3.67 b | 25 abc |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| + 6-BA | 50 mg | | | | | | | | | | | | | | | | | |
| 8. 6-BA | 50 mg | 7 | 28 | 10 | 1 | 0 | 0 | 3 a | 5 a | 9 a | 12 ab | 21 ab | | | | | 6.00 ab | 36 abc |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | |
| 9. GA 20 mg | | 7 | 28 | 10 | 1 | 0 | 0 | 1 ab | 2 ab | 3 bcd | 5 cd | 7 cde | | | | | 5.92 ab | 38 abc |
| +VG | 2.5 ml | | | | | | | | | | | | | | | | | |
| 10. GA 5 mg | | 7 | 28 | 10 | 1 | 0 | 0 | 1 ab | 3 ab | 4abcd | 7 bcd | 11 bcde | | | | | 5.67 ab | 27 abc |
| +VG | 2.5 ml | | | | | | | | | | | | | | | | | |
| 11. GA 5 mg | | 7 | 28 | 10 | 1 | 0 | 0 | 0 b | 1 b | 2 bcd | 3 cd | 7 cde | 7.57 b | 85 bc | 68 abc | 62 a | 4.17 b | 18 bc |
| +VG | 2.5 ml | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |

**Table 6. Effect of scoring, growth regulators, and other chemicals on 'Stayman' fruit cracking (1989) (continued)**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12. Scoring | | 7 | 27 | 10 | | 0 | 0 | 1 ab | 1 b | 1 d | 1 d | 5 e | 8.03 a | 90 ab | 65 c | 59 a | 5.67 ab | 16 bc |
| +GA | 5 mg | 8 | 27 | 27 | 1 | | | | | | | | | | | | | |
| +VG | 2.5 ml | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| +20-20-20 | 2.4 g | | | | | | | | | | | | | | | | | |
| 13. GA | 5 mg | 8 | 27 | 10 | 1 | 0 | 0 | 0 b | 1 b | 2 bcd | 2 cd | 6 e | 7.72 b | 80 c | 67 bc | 60 a | 3.50 b | 22 bc |
| +VG | 2.5 ml | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| +20-20-20 | 2.4 g | | | | | | | | | | | | | | | | | |
| 14. GA | 5 mg | 10 | 27 | 10 | 1 | 0 | 0 | 1 ab | 3 ab | 3 bcd | 5 bcd | 8 cde | | | | | 3.50 b | 24 abc |
| +VG | 1 | | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| +KCl | 2.4 g | | | | | | | | | | | | | | | | | |
| 15. GA | 5 mg | 10 | 27 | 10 | 1 | 0 | 0 | 0 b | 1 b | 2 bcd | 3 cd | 6 de | | | | | 5.08 ab | 14 c |
| +VG | | 1 | | | | | | | | | | | | | | | | |
| +NAA | 20 mg | | | | | | | | | | | | | | | | | |
| +KCl | 2.4 g | | | | | | | | | | | | | | | | | |
| +EDTA | 1.7 g | | | | | | | | | | | | | | | | | |
| 16. Scoring | | 7 | 27 | 10 | | 0 | 0 | 2 ab | 3 ab | 4abcd | 5 cd | 8 cde | 8.18 a | 92 a | 69 ab | 59 a | 6.33 ab | 40 ab |
| 17. Scoring | | 7 | 27 | 10 | | 0 | 0 | 2 ab | 4 ab | 6 ab | 9abcd | 14abcde | 7.69 b | 89 ab | 69.0 ab | 59 a | 5.68 ab | 38 abc |
| +20-20-20 | | 7 | 27 | 10 | 1 | | | | | | | | | | | | | |

[z]Six whole tree replicates per treatment. Approximately 400 apples per treatment.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 7. Effect of scoring, growth regulators, fertilizer, and other chemicals on 'Stayman'/M 9 fruit cracking (1989)

| Treatment[z] | Rate (mg, ml/ liter) | Application dates Jun | Jul | Aug | Aug | Cumulative % cracked fruit Jun 26 | Jul 25 | Aug 9 | Aug 23 | Sep 5 | Sep 17 | Oct 3 | Fruit diameter (cm) | % Red color | Firmness (neutons) at harvest | Firmness (neutons) 14 Dec 89 | % Clusters separated 19 Apr 90 | % Full bloom and beyond 25 Apr 90 | No. fruit/ $cm^2$/cross sectional area limb 15 May 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Control | —— | | | | | 0 | 0 | 0 | 3 a[y] | 7 a | 9 a | 15 a | 7.87 a | 71 a | 72 a | 64 a | 90 a | 90 a | 4.7 a |
| 2. Scored | | 28 | 20 | 9 | 23 | 0 | 0 | 0 | 2 a | 6 a | 10 a | 15 a | 8.13 a | 76 a | 71 a | 63 ab | 92 a | 92 a | 5.0 a |
| 3. Scored | | 28 | 20 | 9 | 23 | 0 | 0 | 0 | 0 b | 0 b | 1 b | 1 b | 8.13 a | 79 a | 66 b | 61 b | 7 b | 40 b | 1.8 a |
| +GA | 5 mg | 28 | 20 | 9 | 23 | | | | | | | | | | | | | | |
| +Oil | 2.5 ml | | | | | | | | | | | | | | | | | | |
| +NAA 800 | 20 mg | | | | | | | | | | | | | | | | | | |
| +20-20-20 | 6.0 g | | | | | | | | | | | | | | | | | | |

[z]Five replicates per treatment. Each replicate was the upper half of 5 trees. Approximately 600 apples per treatment.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 8. Effect of growth regulator sprays on 'Stayman' fruit cracking, fruit diameter, and skin resistance (1989)

| Treatment[z] | Rate (mg/ liter) | Application dates | | Cumulative % cracked fruit | | | | | | | Fruit diameter (cm) | Skin resistance (puncture test) (g force) | apple side | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Apr | Jul | Jun 13 | Jul 26 | Aug 15 | Aug 25 | Sep 13 | Sep 29 | Oct 16 | | 4 sides | green side | red side | other side |
| 1. Control | | | | 0 | 0 | 1 a[y] | 3 b | 8 b | 17 ab | 19 ab | 7.83 a | 347 * | 328 * | 366 | 347 * |
| 2. Dicamba | 5 | 27 | | 0 | 0 | 0 a | 3 b | 8 b | 18 ab | 20 ab | | | | | |
| 3. Triclopyr | 5 | 27 | | 0 | 0 | 3 a | 9 a | 15 a | 25 a | 32 a | | | | | |
| 4. Dicamba | 20 | | 6 | 0 | 0 | 0 a | 0 b | 1 c | 2 b | 5 b | 7.85 a | 302 * | 287* | 317 | 301 * |
| 5. Triclopyr | 5 | | 6 | 0 | 0 | 1 a | 3 b | 4 bc | 6 b | 9 b | | | | | |

[z]Six whole tree replicates per treatment sprayed with an airblast sprayer at 275 gal/acre. Approximately 400 apples per treatment.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.
* Significance of mean pairs within columns by t-test $P<0.05$.

Table 9. Effect of various chemicals on 'Stayman' fruit cracking (1990)

| Treatment[z] | Rate (mg, ml/l) | Cumulative % fruit cracked | | | | | | % Spurs flowering (19 Apr 91) | % Nodes flowering (1-year wood) |
|---|---|---|---|---|---|---|---|---|---|
| | | Jul 17 | Jul 31 | Aug 13 | Aug 28 | Sep 12 | Sep 29 | | |
| 1. Control | -- | 27 a[y] | 32 b | 37 b | 48 b | 57 b | 60 b | 89 b | 16 b |
| 2. GA<br>+NAA 10 mg<br>+Vapor Gard | 5 mg<br><br>1.25 ml | 14 a | 19 b | 23 c | 27 d | 31 d | 33 c | 97 a | 22 ab |
| 3. Dicamba<br>+GA 5 mg<br>+NAA 10 mg<br>+Vapor Gard | 20 mg<br><br><br>1.25 ml | 18 a | 20 b | 21 c | 23 d | 25 d | 26 c | 91 b | 21 b |
| 4. Dicamba | 20 mg | 22 a | 27 b | 30 bc | 32 cd | 36 cd | 40 c | 89 b | 22 b |
| 5. Ethephon | 540 mg | 15 a | 51 a | 78 a | 86 a | 89 a | 91 a | 96 ab | 42 a |
| 6. Anti-stress 550 | 20 ml | 24 a | 29 b | 33 bc | 44 bc | 48 bc | 56 b | 94 ab | 18 b |
| 7. Farwell's seal | 20 ml | 24 a | 30 b | 39 b | 51 b | 58 b | 65 b | 98 a | 24 ab |

[z]Spray applications were made Jul 10, Jul 24, Aug 13, and Sep 4 except ethephon was applied only July 10 and July 24.

[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

**Table 10. Effect of growth regulators and adjuvants on 'Stayman' fruit cracking (1991)**

| Treatment[z] | Rate | Rate/ 3.5 liter | % Fruit cracked | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | July 17 | July 31 | Aug 14 | Aug 28 | Sep 11 | Sep 25 | Oct 9 |
| 1. Control | | | 0.2 a[y] | 2.0 a | 6.7 a | 13.5 a | 19.9 a | 23.0 a | 31.8 a |
| 2. Li 700 | 1250 ppm | 4.4 ml | 0.1 a | 0.1 b | 0.3 b | 0.9 b | 2.0 b | 2.8 b | 3.8 b |
| + $GA_{4+7}$ | 5 ppm | 0.875 ml | | | | | | | |
| + NAA | 5 ppm | 1.12 g | | | | | | | |
| 3. Li 700 | 625 ppm | 2.2 ml | 0.1 a | 0.1 b | 0.1 b | 0.8 b | 1.5 b | 2.5 b | 5.2 b |
| + $GA_{4+7}$ | 5 ppm | 0.875 ml | | | | | | | |
| + NAA | 5 ppm | 1.12 g | | | | | | | |
| 4. Vapor Gard | 625 ppm | 2.2 ml | 0.0 a | 0.0 b | 0.1 b | 0.5 b | 0.9 b | 1.2 b | 3.3 b |
| + $GA_{4+7}$ | 5 ppm | 0.875 ml | | | | | | | |
| + NAA | 5 ppm | 1.12 g | | | | | | | |
| 5. $GA_{4+7}$ | 5 ppm | 0.875 ml | 0.0 a | 0.1 b | 1.2 b | 3.1 b | 5.3 b | 6.7 b | 10.5 b |
| + NAA | 5 ppm | 1.12 g | | | | | | | |
| LSD P=0.05 | | | 0.3 | 1.0 | 2.5 | 4.1 | 5.6 | 6.3 | 6.9 |
| Contrasts | | | | | | | | | |
| 2 vs 3 | | | .82 | .91 | .60 | .77 | .96 | .92 | .50 |
| 2,3 vs 4 | | | .44 | .68 | .86 | .64 | .51 | .15 | .44 |
| 2,3 vs 5 | | | .44 | .96 | .04 | .02 | .02 | .03 | .01 |
| 1 vs 5 | | | .10 | .00 | .00 | .00 | .00 | .00 | .00 |
| 2 vs 5 | | | .44 | .99 | .12 | .06 | .03 | .06 | .01 |
| 3 vs 5 | | | .58 | .92 | .04 | .03 | .04 | .05 | .04 |
| 4 vs 5 | | | 1.00 | .70 | .05 | .02 | .01 | .00 | .00 |
| 2,3,4 vs 5 | | | .59 | .59 | .03 | .01 | .01 | .01 | .00 |

[z]Full bloom occurred 24 April 91 and applications were made June 12, June 26, July 10, July 24, August 7, August 21, September 4, and September 18.

[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level. Data were transformed to arcsin square root before analysis.

**Table 11.Effect of growth regulators and copper on 'Stayman' fruit cracking (1991)**

| Treatment[z] | | Rate | Rate/ 100 gal | % Cracked fruit/tree July 17 | July 31 | Aug 14 | Aug 28 | Sep 11 | Sep 25 | Oct 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Control | | | | 0 | 0.5 a | 5.7 a | 10.0 a | 14.9 a | 17.6 a | 37.3 ab |
| 2. $GA_{4+7}$ | Provide 2% | 5 ppm | 95 ml | 0 | 0.1 a | 0.5 c | 2.4 b | 4.1 b | 7.1 b | 23.0 c |
| + NAA | Nutone 3.5% | 5 ppm | 61.7 g | | | | | | | |
| 3. $GA_{4+7}$ | Provide 2% | 5 ppm | 95 ml | 0 | 0.1 a | 1.0 c | 2.4 b | 5.3 b | 8.2 b | 28.4 bc |
| + NAA | Nutone 3.5% | 5 ppm | 61.7 g | | | | | | | |
| + COCS | | | 0.25 lbs | | | | | | | |
| 4. COCS | | | 0.25 lbs | 0 | 0.3 a | 4.6 ab | 8.0 a | 12.7 a | 16.5 a | 40.9 a |
| 5. COCS | | | 2 lbs | 0 | 0.2 a | 2.3 bc | 5.7 ab | 10.1 ab | 13.4 ab | 38.9 ab |

[z]Applications were made July 11, July 24, August 7, August 21, Sept 3, and Sept 18.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level. Data were transformed to arcsin square root before analysis.

## Table 12. Effect of growth regulators and adjuvants on 'Stayman' fruit cracking (1992)

| # | Treatment[z] | Rate | Rate/ 100 gal | % Fruit cracked | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Jul 27 | Aug 4 | Aug 12 | Aug 21 | Aug 29 | Sep 8 | Sep 16 | Sep 25 | Oct 1 | Oct 14 |
| 1. | Control | | | 0 b[y] | 1 bc | 2 abc | 14 a | 17 a | 22 a | 27 ab | 31 a | 43 a | 65 a |
| 2. | NAA 200 | 5 ppm | 36.5 ml | 0 b | 1 bc | 1 bcd | 12 ab | 15 ab | 19 ab | 25 ab | 29 a | 40 ab | 57 ab |
| 3. | NAA | 5 ppm | 36.5 ml | 0 b | 0 c | 1 cd | 2 de | 3 def | 5 def | 6 de | 6 cde | 10 d | 14 ef |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| 4. | $GA_{4+7}$ | 5 ppm | 94.6 ml | 0 b | 0 c | 1 bcd | 1 de | 1 ef | 2 fgh | 2 ef | 3 def | 5 de | 12 ef |
| 5. | $GA_{4+7}$ | 20 ppm | 378.5 ml | 0 b | 0 c | 0 d | 0 e | 0 f | 0 h | 0 f | 0 f | 1 e | 5 f |
| 6. | XYZ | 150 ppm | 61.5 g | 0 b | 1 bc | 2 ab | 9 abc | 11 ab | 15 ab | 24 ab | 25 a | 41 ab | 58 ab |
| 7. | XYZ | 150 ppm | 61.5 g | 1 a | 2 a | 4 a | 10 ab | 14 a | 20 ab | 30 a | 31 a | 49 a | 62 a |
| | + Li 700 | 0.125% | 473 ml | | | | | | | | | | |
| 8. | XYZ | 150 ppm | 61.5 g | 0 b | 1 b | 2 abc | 9 bc | 10 bc | 15 b | 20 bc | 22 ab | 40 ab | 54 ab |
| | + Oil | 0.25% | 946 ml | | | | | | | | | | |
| 9. | XYZ | 150 ppm | 61.5 g | 0 b | 0 c | 0 d | 2 de | 3 cde | 5 cde | 5 de | 6 cd | 14 cd | 22 de |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| | + NAA | 5 ppm | 36.5 ml | | | | | | | | | | |
| 10. | XYZ | | 61.5 g | 0 b | 0 c | 1 cd | 4 cd | 5 cd | 7 cd | 9 d | 11 bc | 24 c | 41 bc |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| | + NAA | 5 ppm | 36.5 ml | | | | | | | | | | |
| | + Regulaid | 473 ml | | | | | | | | | | | |
| 11. | XYZ | | 61.5 g | 0 b | 0 c | 0 d | 4 cd | 5 cd | 7 c | 11 cd | 13 bc | 26 bc | 36 cd |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| | + NAA | 5 ppm | 36.5 ml | | | | | | | | | | |
| | + LI 700 | | 473 | | | | | | | | | | |
| 12. | XYZ | | 61.5 g | 0 b | 0 c | 0 d | 1 de | 1 ef | 2 fg | 2 f | 2 ef | 7 d | 13 ef |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| | + NAA | 5 ppm | 36.5 ml | | | | | | | | | | |
| | + Oil | | 946 ml | | | | | | | | | | |
| 13. | XYZ | | 61.5 g | 0 b | 0 c | 0 d | 1 de | 2 def | 3 defg | 4 ef | 4 def | 14 cd | 22 de |
| | + $GA_{4+7}$ | 5 ppm | 94.6 ml | | | | | | | | | | |
| | + NAA | 5 ppm | 36.5 ml | | | | | | | | | | |
| | + Vapor Gard | | 473 ml | | | | | | | | | | |

[z]Full bloom occurred 30 April 92 and applications were made July 2, July 22, August 11, and August 30.
[y]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

**Table 13. Effect of submerging 'Stayman' apples in a surfactant or stop-scald solutions on fruit cracking and percentage weight gain in the laboratory (1989)**

| Treatment | Rate (mg, ml $liter^{-1}$) | % Fruit cracked | | % Weight gain after 3 days | | |
|---|---|---|---|---|---|---|
| | | Day 1 | Day 3 | Non-cracked apples | Cracked apples | All apples |
| Control | ---- | 8 a[z] | 15 a | $0.32 \pm 0.09$[y] | $1.32 \pm 3.53$ | $0.44 \pm 0.23$ |
| X-77 | 1.25 ml | 60 bc | 83 b | $1.68 \pm 0.68$ | $2.47 \pm 0.40$ | $2.35 \pm 0.36$ |
| Ethoxyquin | 2600 mg | 79 c | 83 b | $1.07 \pm 0.63$ | $2.31 \pm 0.48$ | $2.01 \pm 0.44$ |
| Diphenylamine | 2000 mg | 56 b | 71 b | $0.94 \pm 0.26$ | $1.69 \pm 0.55$ | $1.42 \pm 0.38$ |

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level, for 3--25 apple groups/treatment.

[y]Confidence limits, 5% level, for non-cracked, cracked, and all apples in each 25-apple group.

Table 14. Effect of DPA on cracking of 'Stayman' apples held in cold storage and later submerged in water for 3 days

| Treatment | Dipped 10 sec Diphenylamine 2000 mg/liter | % Cracked (after 22 days in cold storage) | % Cracked (submerged in water 3 days) | % Weight gain or loss after 22 days of cold storage | (submerged in water 3 days) | Total after 22 days and 3 days of water |
|---|---|---|---|---|---|---|
| Non-graded | x | 0 | 0 | $-1.42 \pm 0.12$[y] | $+0.18 \pm 0.11$ | $-1.24 \pm 0.12$ |
| Graded | x | 0 | 24 | $-1.29 \pm 0.12$ | $+0.29 \pm 0.10$ | $-1.01 \pm 0.14$ |

[y]Confidence limits, 5% level. Twenty-five apples in each group.

**Table 15. Effect of submersion on various apple cultivars or strains of 'Stayman' in a surfactant**

| Cultivar/strain/rootstock | % Fruit cracked | | % Weight gain after 3 days | |
|---|---|---|---|---|
| | Day 1 | Day 3 | Non-cracked | All apples |
| Stayman/201/Mark | | | | |
| Water | 4 | 4 | $0.64 \pm 0.22$[z] | $0.73 \pm 0.28$ |
| X-77 1.25 ml/l | 48 | 64 | $2.42 \pm 0.84$ | $3.03 \pm 0.54$ |
| Stayman/201/seedling | | | | |
| Water | 4 | 4 | $0.32 \pm 0.06$ | $0.32 \pm 0.06$ |
| X-77 1.25 ml/l | 4 | 12 | $1.68 \pm 0.30$ | $1.82 \pm 0.30$ |
| Stayman/supreme/seedling | | | | |
| Water | 0 | 0 | $0.21 \pm 0.04$ | |
| X-77 1.25 ml/l | 0 | 0 | $1.42 \pm 0.26$ | same |
| Red Delicious/Triple red/M.106 | | | | |
| Water | 0 | 0 | $1.25 \pm 0.44$ | |
| X-77 1.25 ml/l | 0 | 0 | $3.35 \pm 0.17$ | same |
| Golden Delicious/standard/seedling | | | | |
| Water | 0 | 0 | $0.41 \pm 0.07$ | $0.41 \pm 0.07$ |
| X-77 1.25 ml/l | 0 | 16 | $3.64 \pm 0.17$ | $3.61 \pm 0.16$ |

[z]Confidence limits, 5% level.

**Table 16. Response of apple cultivars and 'Stayman' strains to apple peel tests**

| Cultivar/strain/rootstock | Razor cut test (mm width of cut pascals) | % Split after razor cut (1 day) | Puncture test (g/force) | Break force (g) | % Change (300 gram weight) | | | Minutes to splitting (at 34 kilo-pascals) |
|---|---|---|---|---|---|---|---|---|
| | | | | | Extensibility | Elasticity | Plasticity | |
| 201 Stayman/Mark | 2.57 a[z] | 100 | 354 c | 960 a | 3.04 a | 2.26 a | 0.78 a | 7.3 a |
| 201 Stayman/seedling | 1.49 b | 36 | 390 b | 900 a | 2.99 a | 2.44 a | 0.54 a | 5.8 a |
| Supreme Stayman/seedling | 1.31 b | 2 | 444 a | 970 a | 3.18 a | 2.59 a | 0.60 a | 4.9 a |
| Triple Red Red Delicious/M.106 | 0.90 c | 0 | 355 c | 580 b | 3.40 a | 2.77 a | 0.62 a | 7.5 a |
| Standard Golden Delicious/seedling | 1.07 c | 0 | 260 c | 400 c | 3.59 a | 2.76 a | 0.83 a | 7.0 a |

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

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