'Stayman' Fruit Cracking as Affected by Surfactants, Plant Growth Regulators, and Other Chemicals

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Abstract. Submerging 'Stayman' apples in nonionic and anionic surfactant-water solutions caused increased water uptake and fruit cracking. The primary sites of water uptake were lenticels and injured areas of the fruit cuticle. Fruit cracking caused by submerging fruit in 1.25 ml X-77/liter surfactant was used to predict the natural cracking potential of 'Stayman' strains and apple cultivars in the field. Submerging apples in aqueous pesticide mixtures did not increase fruit cracking or water uptake. Fruit cracking and uptake of surfactant-water were not correlated between apple cultivars. In a surfactant-water bath, 'Starkrimson Delicious' absorbed more water than 'Stayman', 'York', 'Jonathan', and 'Golden Delicious'; no 'Starkrimson Delicious' fruits cracked, but 32% to 80% of the other cultivars did. In field tests, four airblast spray applications of GA₄₊₇ in July and Aug. 1987 reduced fruit cracking from 56% to 21%, and five applications in July, Aug., and Sept. 1988 reduced fruit cracking from 93% to 75%. In 1987, daminozide reduced cracking, but, in 1988, neither daminozide, NAA, nor Vapor Gard alone reduced cracking. However, in 1988, a combination treatment of GA₄₊₇, daminozide, NAA, and Vapor Gard reduced fruit cracking from 93% to 22%. Also, two scorings of the trunk with a carpet knife reduced fruit cracking 22%. Chemical names used: alkylaryl polyoxyethylene alcohol glycol (X-77); butanedioic acid mono(2,2-dimethylhydrazide) (daminozide); naphthaleneacetic acid (NAA); di-1-p-methene (Vapor Gard); gibberellic acid (GA₄₊₇).

In cherry, apple, grape, nectarine, plum, tomato, citrus, and many other fruits, cracking of the skin and fleshy tissues before harvest results in great economic loss to growers. Rapid deterioration of the fruit usually follows exposure of the ruptured tissue to air.

'Stayman' fruit cracking usually occurs only during relatively long rainy periods after fruit have attained 5 cm or more in diameter. Fruits borne on the outer 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 (Verner, 1935). 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) induced drought conditions by covering the soil with tarpaulins for 37 days, then flooding the soil with 10 cm of water. Within 10 hr, the percentage soil moisture increased from 12% to 20%, but this change failed to induce cracking. During the 37 days when the soil was covered, fruit on these trees cracked similarly to those on trees with no tarpaulins. Verner (1935) believed that fruit cracked in rain or high humidity periods only when the relative humidity was near 100% for 6 hr or more. Covering limbs with a tarpaulin during a rain period did not protect the fruit from cracking (Verner, 1935). Further research seemed to be needed to determine if prolonged

skin wetting increased cracking of 'Stayman' fruit and the involvement of leaves in water absorption.

In sweet cherry, fruit cracking was thought to be caused primarily by absorption of water through the fruit cuticle (Davenport et al., 1972). Verner (1935) found that some 'Stayman' fruit would crack if submerged in water for 1 to 3 days whether attached to the tree or not. In sweet cherries, Anderson and Richardson (1975) found that fruit cracking was not strictly related to soluble solids concentration, osmotic potential, turgor, or fruit water potential. These results suggest that the degree of cuticular permeability, cuticular strength, or cell wall strength may be more important than water potential characteristics.

Various growth regulators and nutrient sprays have reduced cracking of 'Stayman' apple—daminozide (Costa et al., 1983; Sullivan and Widmoyer, 1970); sweet cherry—NAA (Bullock, 1952), calcium ions (Callan, 1986), antitranspirants (Davenport et al., 1972), ethyl oleate (Harrington et al., 1978); and tomato—IAA, GA₃, NAA (Batal et al., 1972). Yoda and Ashida (1960) reported that the growth effect of auxins increased the plasticity and, to some extent, reduced elasticity of pea stems, and gibberellin acted in an opposite way. Adams et al. (1975), however, found that gibberellin greatly increased plasticity in *Avena* stems.

In grapes, spray adjuvants have been shown to increase water uptake and fruit cracking in the laboratory (Marois et al., 1987). Fungicides and insecticides are frequently formulated with surfactants to improve uniform coating of the fruit and leaves. Surfactants are known to decrease the surface tension of water, thus preventing the beading of spray materials on waxy surfaces. Surfactants are also known to increase the penetration of water, spray chemicals, and nutrients through apple cuticles (Westwood and Batjer, 1960).

The objectives of these experiments were to: 1) develop a laboratory technique for determining differences in susceptibility of 'Stayman' fruits to cracking, 2) evaluate the influence of various surfactants on fruit cracking, 3) determine if pesticide

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formulations would increase water uptake and crack the fruit, 4) determine the primary location of water uptake by fruit submerged in surfactant solutions, 5) evaluate potential chemical protectants (water repellents) in a surfactant-water bath test, 6) evaluate spray treatments for decreasing or increasing fruit cracking, 7) determine if root pruning, summer or winter branch pruning, or scoring the tree trunk would alter fruit cracking in the field, and 8) determine if bagging individual fruit would prevent fruit cracking when trees were watered from above.

Materials and Methods

A description of chemicals used in the following experiments is given in Table 1.

Experiment 1. 'Stayman' apples harvested on 21 Sept. 1987 from 10-year-old 'Stayman'/seedling trees ('201 Stayman' strain) were randomized and 25 fruits for each treatment were numbered on the skin with a marker, individually weighed on a top-loading balance (± 1 mg), and submerged in buckets of water or aqueous solutions of X-77 (nonionic surfactant) from 1.25 to

0.036 ml-liter⁻¹. After 1 and 3 days of submersion, each individual apple was blotted dry with paper towels and examined for fruit cracks, and each one was reweighed after 3 days. The percentage weight gain was determined separately for non-cracked and cracked apples.

Experiment 2. Noncracked 'Stayman' apples were harvested in mid-Oct. 1987 from a block of apples that had a high percentage of cracked fruit. Fruit were randomized into eight buckets containing 25 fruits each (two replicate buckets/treatment). Each fruit was marked, individually weighed, and submerged in: 1) water, 2) 1.25 ml X-77/liter (nonionic surfactant), 3) 1.25 ml Downey water softener/liter (cationic), and 4) 1.25 ml GR Miter (anionic surfactant). After 3 days of submersion, 25 apples from one bucket were blotted dry with paper towels, reweighed, and examined for cracks. The percentage weight gain was determined for noncracked and cracked apples. In addition, 25 apples were placed in either X-77 surfactant solution at 1.25 ml-liter⁻¹ or in water; 0.5 g methylene blue dye/liter was added to each bucket. Five apples from each bucket were peeled after

Table 1. Names of chemicals used.

Common or trade name	Chemical name	Manufacturer
Surfactants		
X-77 (nonionic)	Alkylaryl polyoxyethylene alcohol glycols, fatty acids, and isopropanol	Chevron Chemical Co.
L-77 (nonionic)	Polyalkyleneoxide modified polydimethyl siloxane	Union Carbide Corp.
GR-5 (anionic)	Diocetyl sodium sulfosuccinate	Rohm and Haas Co.
Dupont WK (nonionic)	Trimethylenonolpoly-ethoxyethanol	E.I. Du Pont De Nemours & Co.
Downey water softener (cationic)	Not available	Procter & Gamble
Harvest Brand surfactant (nonionic)	Alkylaryl polyoxyethylene glycols (80%), <i>N</i> -butyl alcohol	Rohm and Haas Co.
Insecticides		
Azinphosmethyl (Guthion 35 W)	<i>O, O</i> -dimethyl <i>S</i> -(4-oxo-123-benzotrazin-3(4 <i>H</i>))yl methyl phosphorodithioate	Mobay Corp.
Chlorpyrifos (Lorsban 50 W)	<i>O, O</i> -diethyl <i>O</i> -(3,5,6-trichloro-2-pyridinyl)	Dow Chemical Co.
Formetanate hydrochloride (Carzol 92 SP)	<i>N, N</i> -dimethyl- <i>N</i> -[[[(methylamino)carbonyl]oxy]phenyl]methanimidamide monohydrochloride	Nor-am Chemical Co.
Superior spray oil		Drexel
Fungicides		
Metiram (Polyram 80 W)	A mixture of ethylenebis dithiocarbamate zinc plus (dithiobis(thiocarbonyl-imino-ethylene)bis (dithiocarbamate) zinc	FMC Corp.
Benomyl (Benlate 50 W)	Methyl 1-(butylcarbonyl)-2-benzimidazole carbamate	E.I. Du Pont De Nemours & Co.
Dikar (Dikar W)	A blend of dinocap and mancozeb [dinocap-2,4-dinitro-6-(2-octyl)phenyl crotonate, mancozeb-manganese ethylene-bisdithiocarbamate]	Rohm and Haas Co.
Nutrients		
Ca(OH) ₂	Calcium hydroxide	Stephen City Lime Co.
CaCl ₂	Calcium chloride	Dow Chemical Corp.
Solubor	Sodium pentaborate	U.S. Borax Chemical Corp.
Urea	Urea	Agrico Chemical Corp.
Plant growth regulators		
Daminozide (Alar 85W)	Daminozide[butanedioic acid mono(2,2-dimethylhydrazide)]	Uniroyal Chemical Co.
GA ₄₊₇	Gibberellin A ₄ + gibberellin A ₇ mixture	Abbott Laboratories
NAA	Naphthaleneacetic acid	Rhone Poulenc AF Co.
Water repellents		
Sun Clear	Alumina-silica (19.5%) + surfactant (0.5%)	Solar Sunstill
RRW2	Silicon dioxide (19.5%) + surfactants (0.5%)	Solar Sunstill
Anti-transpirant		
Vapor Gard	di-1- <i>p</i> -menthene	Miller Chemical and Fertilizer Corp.

1 or 3 days to determine the possible sites of water entry into the fruit.

Experiment 3. 'Stayman' apples harvested 5 Oct. 1988 were randomized into 16 buckets containing 20 apples each. Two buckets of apples were randomly assigned to each of eight treatments (see Table 4 for a complete list of chemicals and rates used). Each fruit was examined for cracks after 3 or 7 days of submersion.

Experiment 4. 'Stayman' apples harvested in mid-Oct. 1987 were stored at 0C in regular cold storage until Feb. 1988. Fruit were randomized into 15 buckets containing 25 fruit each. Each fruit was marked and individually weighed and submerged in various surfactant or pesticide mixtures 2-7 Feb. 1987 (see Table 5 for a listing of treatments). Treatments 8-11 and 13-15 were treated, air dried, and then submerged in 1.25 ml X-77/liter.

Experiment 5. Twenty-five fruit from each of several cultivars harvested 22 Sept. 1987 were submerged in buckets with 1.25 ml X-77/liter. Each fruit was numbered on the skin with a marker and individually weighed. After 1 or 3 days of submersion, each apple was blotted dry with a paper towel and examined for cracks and reweighed after 3 days, when the percentage weight gain was determined for noncracked and cracked apples.

Experiment 6. 'Stayman' fruit were randomly collected at a height of 1 to 2 m from the periphery of trees sprayed with daminozide and GA₄₊₇, weighed, and submerged in buckets of X-77 at 1.25 ml·liter⁻¹. After 1 or 3 days of submersion, each individual apple was blotted dry with a paper towel and examined for cracks and reweighed at 3 days. The percentage weight gain was determined for noncracked and cracked apples.

Experiment 7. In 1987, 30 12-year-old 'Stayman'/seedling trees were selected for uniform crop load and grouped into six blocks according to terrain. Alternate trees within a single row were used to avoid drift when individual trees were sprayed with an airblast sprayer calibrated for 2805 liters·ha⁻¹ [300 gal/acre dilute that was calculated by the Tree-Row-Volume (TRV) method (Byers, 1987)]. Treatments were as follows: 1) control-no treatment; 2) 20 mg GA₄₊₇/liter on 5, 13, 21, and 29 May; 3) 20 mg GA₄₊₇/liter on 24 July, 3, 11, and 17 Aug.; 4) same as treatment 3 plus 9.6 g Ca(OH)₂/liter tank-mixed in each spray; and 5) 1000 mg daminozide/liter on 27 July.

Four limbs carrying a total of 30 to 60 fruit were tagged per tree. Weekly, from 24 July to 1.5 Oct., the cracked fruit on the tagged limbs were counted, removed, and the percentage fruit cracked was calculated for each date. Trees were evaluated for return bloom in 1988 using a rating scale from 0 to 10. A rating of 4 would be adequate bloom for a full crop.

Experiment 8. In 1988, 78 15-year-old 'Stayman'/seedling trees were selected for uniform crop load and grouped into six blocks according to terrain. Alternate trees within rows and two border rows between treatment rows were used to avoid drift when individual trees were sprayed with an airblast sprayer. Applications were made 7 and 21 July, 14 and 18 Aug., and 9 Sept. (except that daminozide was applied only on 7 July) with a Swanson three-point hitch airblast sprayer calibrated at 2337 liters·ha⁻¹ [250 gal/acre dilute (TRV)]. Treatments were as follows: 1) control-no treatment, 2) 10 mg GA₄₊₇/liter, 3) 2 mg GA₄₊₇/liter, 4) 2 mg GA₄₊₇/liter + 2.5 ml superior oil/liter, 5) 10 mg GA₄₊₇/liter + 1000 mg daminozide/liter, 6) 1000 mg daminozide/liter, 7) 2.5 ml superior oil/liter, 8) 5.0 ml Vapor Gard/liter, 9) 20 mg NAA/liter, 10) 20 mg NAA/liter + 10 mg GA₄₊₇/liter + 1000 mg daminozide/liter + 5.0 ml Vapor Gard/liter, 11) 1.25 ml X-77/liter, 12) 10 ml Sun Clear/liter, and 13) 10 ml RRW2/liter. Four limbs were selected on each tree having a total of 50 to 65 fruit per tree. Weekly, from 7 July to 11 Oct., the cracked fruit on the tagged limbs were counted, removed, and the percentage cracked fruit was calculated. Ten fruit from each tree were rated for percent of fruit showing some red surface on 28 Sept. 1988.

Experiment 9. In 1988, 45 15-year-old 'Stayman'/seedling trees were selected for uniform size and form and grouped into nine blocks according to terrain. Five cultural treatments were randomized in each block as follows: 1) control-light dormant pruning in Feb. 1988, 2) no pruning, 3) root pruned with a subsoiler on both sides of the tree ≈ 1.5 m from the trunk and ≈ 1.5 m in depth on 3 June, 4) two scores to the trunk with a carpet knife on 12 July, 5) all terminal growth longer than 0.3 m removed on 12 July. Four limbs were selected on each tree having a total of 50 to 65 fruit per tree. Weekly, from 7 July to 11 Oct., the number of cracked fruit on the tagged limbs were counted and removed and the percentage cracked fruit was calculated for each date. Ten fruit

Table 2. Effect of submerging 'Stayman' apples in water or surfactant (X-77) water solutions on fruit cracking and percentage weight gain (21-24 Sept. 1987, Expt. 1).

Surfactant concn (ml·liter ⁻¹)	Fruit cracked (%) ^a		Mean weight gain after 3 days (%) ^b		
	Day 1	Day 3	Noncracked apples	Cracked apples	All apples
0	4	16	0.46 ± 0.08	0.91 ± 0.75	0.53 ± 0.12
0.036	8	28	0.81 ± 0.10	1.39 ± 0.45	0.95 ± 0.15
0.078	12	28	0.94 ± 0.13	1.37 ± 0.31	1.06 ± 0.14
0.16	32*	40	1.13 ± 0.27	2.48 ± 0.99	1.67 ± 0.47
0.31	28*	36	1.39 ± 0.24	1.84 ± 0.76	1.55 ± 0.29
0.65	28*	64*	2.20 ± 0.78	2.27 ± 0.40	2.24 ± 0.36
1.25	32*	52*	1.86 ± 0.41	2.26 ± 0.38	2.07 ± 0.27
Significance ^c	L*	L**Q**	L**Q**	L**Q**	L**Q**

^aChi-square comparison of each treatment with the control, *P* = 0.05 (*). Means of one 25-apple replicate per treatment.

^bConfidence limits, *P* = 0.05 (*) for cracked, noncracked, and all apples in each 25-apple group.

^cSignificance: linear (L) and quadratic (Q); *P* = 0.05 (*) or 0.01 (**). For percent fruit cracked, *n* = 1 replicate of 25 fruit; for percent weight gain, *n* = 25 fruit or the portion thereof cracked or noncracked.

from each tree were rated for percent of fruit showing some red surface on 17 Oct. 1988.

Experiment 10. In 1988, 15-year-old 'Stayman'/seedling trees were selected for uniform crop load and grouped into eight blocks according to terrain. The following treatments were randomized within each block: 1) control-no treatment, 2) under-tree sprinkling for 12 hr for each of six consecutive nights (3 to 9 Aug.) with 5 cm of water per night, 3) overhead sprinkling for 12 hr for each of six nights (3 to 9 Aug.) with 5 cm of water per night. Buffer trees were used between treatments to prevent cross-treatment influence. Twenty-five fruit were tagged on each tree and observed 1 and 6 days after treatment. In addition, on trees that were sprinkled overhead, 25 fruit were bagged with paper bags and 25 fruit were coated with a thin layer of petroleum jelly on 3 Aug.

Statistical analyses were performed using SAS General Linear Model procedures. When differences were significant, least significance difference and Duncan's multiple range tests were used for mean separation. Chi-square tests were used to compare means of laboratory submersion tests when only one 20- to 40-apple sample was used. The mean and 95% confidence limits for the percent weight gain of submerged apples were calculated for each treatment and, where appropriate, were further analyzed using regression analysis. The percent weight gain for cracked and noncracked apples for each 25-apple sample had unequal numbers, since the number of noncracked and cracked fruit per treatment changed.

Results and Discussion

Experiments 1 and 2. Water uptake and fruit cracking within 24 hr increased linearly with increasing concentration of X-77 (Table 2). A nonionic (X-77) and an anionic (GR5) surfactant caused increased fruit cracking and water uptake, but the cationic surfactant (Downey) did not (Table 3). Apples submerged in methylene blue dye (with or without surfactant) and peeled indicated that the primary uptake of water was through lenticels and injured areas of the fruit cuticle. Some sides of the fruit showed no dye penetrating into the apple flesh and other sides showed blue spots in proportion to the lenticel size or injury (data not shown).

Experiment 3. Submerging 'Stayman' apples in pesticide combinations or nutrient solutions generally did not affect fruit cracking (Table 4). However, the daminozide + surfactant combination increased fruit cracking. We presume the surfactant was the constituent primarily responsible for fruit cracking.

Experiment 4. 'Stayman' apples held in cold storage for 3.5 months and then submerged in water or surfactants (Table 5)

Table 3. Effect of submerging 'Stayman' apples in water or a surfactant solution at 1.25 ml-liter⁻¹ on fruit cracking (26-29 Nov. 1987, Expt. 2).

Surfactant	Fruit cracked on day 3 (%) ^a	Weight gain after 3 days (%) ^b (noncracked apples)
None (water)	20 a	0.29 ± 0.075
X-77 (nonionic)	48 bc	1.11 ± 0.138
Downey (cationic)	27 ab	0.36 ± 0.077
GR5 (anionic)	55 c	1.53 ± 0.252

^aMean separation within columns by Duncan's multiple range test, $P = 0.05$. Mean of two 25-apple replicates submerged for each treatment.

^bConfidence limits, $P = 0.05$ for noncracked in one 25-apple replicate per treatment.

cracked less and took up less water than those treated immediately after harvest (Tables 2 and 3). The surfactant DuPont WK caused more water uptake, expressed as weight gain, than X-77 or L-77 (Table 5). Pretreatment of fruit with Vapor Gard

Table 4. Effect of submerging 'Stayman' apples in various spray mixtures on fruit cracking (5-12 Oct. 1987, Expt. 3).

Treatment	Concn (per liter)	Fruit cracked (%) ^a	
		Day 3	Day 7
1. Control	---	13	13
2. Harvest brand surfactant + daminozide	0.63 ml 1.00 g	38*	50*
3. Guthion	0.60 g	8	8
Polyram	1.19 g		
Benomyl	0.19 g		
4. Lorsban	1.19 g	18	25
Polyram	1.19 g		
Benomyl	0.19 g		
5. Urea	2.38 g	3	10
6. Dikar	2.38 g	5	13
7. Carzol	0.30 g	5	13
Dikar	2.38 g		
Urea	2.38 g		
CaCl ₂	2.38 g		
Solubor	1.19 g		
8. CaCl ₂	2.38 g	3	18

^aEach treatment within columns was compared to the control by χ^2 , $P = 0.05$. Differences indicated by (*). Means consisted of one 40-apple sample per treatment.

Table 5. Effect of submerging 'Stayman' apples after refrigerated storage in various chemical mixtures on fruit cracking (2-7 Feb. 1988, Expt. 4).

Chemical	Concn (per liter)	Fruit cracked (%) ^a		Weight gain after 2 days (%) ^b
		Day 2	Day 5	
1. Water (control)		0	4	0.19 ± 0.03
2. X-77	1.25 ml	8	8	0.65 ± 0.07
3. L-77	1.25 ml	8	12	0.69 ± 0.09
4. WK	1.25 ml	0	20	0.92 ± 0.08
5. Guthion	0.60 g	0	4	0.22 ± 0.03
Benomyl	0.19 g			
Polyram	1.19 g			
6. Lorsban	1.19 g	0	4	0.25 ± 0.06
Benomyl	0.19 g			
Polyram	1.19 g			
7. Carzol	0.30 g	4	16	0.23 ± 0.04
Dikar	2.39 g			
8. Vapor Gard ^c	10.00 ml	4	24*	0.63 ± 0.09
9. Vapor Gard ^c	40.00 ml	4	16	0.64 ± 0.17
10. Peach wax ^c	40.00 ml	16*	28**	0.73 ± 0.08
11. X-145A wax ^c	40.00 ml	0	4	0.42 ± 0.12
12. Sucrose + X-77	68.4 g 1.25 ml	0	16	0.65 ± 0.02
13. Acetone ^c	wash 3 sec	4	24*	1.14 ± 0.12
14. Xylene ^c	wash 3 sec	0	8	1.03 ± 0.10
15. Chloroform ^c	wash 3 sec	0	8	1.77 ± 0.17

^aAfter treatment, fruits were air dried, then submerged in 1.25 ml X-77/liter.

^bEach treatment was compared to the control by χ^2 , $P = 0.05$. Differences indicated by (*). Each treatment consisted of a 40-fruit sample.

^cConfidence limits, $P = 0.05$, for noncracked apples in each treatment.

Table 6. Effect of submersion of several apple cultivars in a surfactant solution (0.125% X-77) for 1 or 3 days on fruit cracking and percentage weight gain (22-25 Sept. 1987, Expt. 5).

Cultivar	Fruit cracked (%) ^a		Mean weight gain after 3 days (%) ^b		
	Day 1	Day 3	Noncracked apples	Cracked apples	All apples
Stayman	32	52	1.86 ± 0.41	2.26 ± 0.38	2.07 ± 0.27
Stayman-like (no crack)	0	0	1.64 ± 0.58	---	1.64 ± 0.58
York	24	32	2.64 ± 0.30	2.25 ± 0.77	2.60 ± 0.28
Jonathan	68	80	1.79 ± 2.05	1.90 ± 0.47	1.88 ± 0.43
Winesap	0	0	1.29 ± 0.23	---	1.29 ± 0.23
Starkrimson	0	0	3.08 ± 0.48	---	3.08 ± 0.48
Virginia Gold	0	0	2.51 ± 0.21	---	2.51 ± 0.21
Rome	0	0	2.05 ± 0.22	---	2.05 ± 0.22
Golden Delicious (Smoothie)	12	40	3.10 ± 0.43	---	3.10 ± 0.43

^aMeans of 25 apples submerged for each cultivar.

^bConfidence limits, $P = 0.05$, for noncracked, cracked, and all apples in each 25-apple group.

Fig. 1. Effect of four summer applications of GA_{4+7} at 20 mg-liter⁻¹ or one of daminozide at 1000 mg-liter⁻¹ on 'Stayman' fruit cracking. Vertical bars represent LSD ($P < 0.05$). Each point represents a mean of six replicates, with a total of 150 to 300 apples per treatment (Expt. 7).

or peach wax did not alter the percentage weight gain when fruit were submerged in X-77 solution. The X-145A wax reduced water uptake when fruit were later submerged in X-77. Sucrose added to the X-77 did not reduce water uptake or cracking caused by X-77. Acetone, xylene, and chloroform increased water uptake when treated fruit were submerged in X-77, but only acetone increased cracking.

Experiment 5. 'Starkrimson Delicious' absorbed more water from an X-77 solution than 'Stayman', 'York', or 'Jonathan', but no 'Starkrimson' cracked (Table 6). In addition, a 'Stayman'-like apple, 'Virginia Gold', 'Rome', and 'Winesap' absorbed water but did not crack. These data suggest that certain cultivars can absorb water without cracking but others can not. Apple maturity may have some influence on fruit cracking in this test; however, 'Stayman' apples may be susceptible to cracking for 3 months before harvest, as well as during cold storage.

Experiment 6. In 1987, GA_{4+7} reduced fruit cracking from 58% to 21% if applied in four summer applications (Fig. 1). Spring applications did not reduce cracking. The addition of $Ca(OH)_2$ to the GA_{4+7} spray applied in the summer did not reduce fruit cracking as much as GA_{4+7} alone. Daminozide reduced fruit cracking in 1987 but not as much as GA_{4+7} . The spring applications of GA_{4+7} greatly reduced return bloom (data not presented), but the summer applications did not.

Experiment 7. Submerging 'Stayman' apples harvested 14-17 Sept. 1987 from the GA_{4+7} summer spray treatment in Expt. 6 in 1.25 ml X-77/liter solutions reduced cracking; however, water uptake was not affected (Table 7). Daminozide-sprayed fruit that was submerged cracked and gained as much water as the control (X-77 surfactant solution.). On 6-8 Oct., both the GA_{4+7} and the daminozide field treatments reduced cracking, and daminozide reduced water uptake (Table 7). These data indicate that daminozide reduction of fruit cracking may be the result of reduced water uptake, but GA_{4+7} may be influencing cell wall strength or elasticity, but not water uptake.

Experiment 8. In 1988, spray application of daminozide (Fig. 2), Vapor Gard, NAA, RRW2, and superior spray oil (data not presented) did not reduce 'Stayman' fruit cracking; GA_{4+7} (10 mg-liter⁻¹) (Fig. 2) reduced fruit cracking by only 15%, from 95% to 80%. The addition of spray oil to GA_{4+7} at 2 mg-liter⁻¹ reduced cracking to a level similar to 10 mg GA_{4+7} /liter. Daminozide + 10 mg GA_{4+7} /liter reduced fruit cracking by 20%, from 95% to 75%. When NAA + GA_{4+7} + Vapor Gard + daminozide were used in combination, fruit cracking was reduced by 73%, from 95% to 27%. The surfactant X-77 and an aluminum oxide formulation that contained a surfactant caused increased fruit cracking of 10% to 15% in the summer months,

Table 7. Effect of submerging 'Stayman' apples 1 or 3 days in a surfactant solution (0.125% X-77) following GA₄₊₇ or daminozide airblast spray treatments on fruit cracking and percentage weight gain in the laboratory (1987, Expt. 7).^z

Treatment ^y	Concn (mg·liter ⁻¹)	Fruit		Mean weight gain after 3 days (%)			
		cracked (%)	Day 1	Day 3	Noncracked apples	Cracked apples	All apples
<i>Expt. 1 (harvested 14 Sept.)</i>							
Control (X-77)		21 a	48 a	1.80 a	2.31 a	2.04 a	
GA ₄₊₇	20	5 b	20 b	1.95 a	2.66 a	2.08 a	
Daminozide	1000	14 a	34 a	1.94 a	2.56 a	2.15 a	
<i>Expt. 2 (harvested 6 Oct.)</i>							
Control (X-77)		32 a	52 a	1.00 a	1.38 a	1.20 a	
GA ₄₊₇	20	18 b	30 b	1.06 a	1.39 a	1.16 a	
Daminozide	1000	10 b	23 b	0.80 b	1.09 a	0.85 b	

^zMean separation within columns within experiments by Duncan's multiple range test, $P = 0.05$; means of six replicates per treatment with 25 fruit per replicate.

^yGA₄₊₇ applied 27 July, and 3, 11, and 17 Aug.; daminozide applied 27 July.

Fig. 2. Effect of five applications of GA₄₊₇ at 10 mg·liter⁻¹, one application of daminozide at 1000 mg·liter⁻¹, or combination of these growth regulators on 'Stayman' fruit cracking. Data for treatments 3, 4, 7, 9, 12, and 13 of Expt. 8 were not graphically presented. Vertical bars represent LSD ($P < 0.05$). Each point represents a mean of six replicates, with a total of 300 to 400 apples observed per treatment.

but this was not statistically significant. Fruit size was not affected by the treatments (data not presented). Treatments 4, 5,

6, 10, and 11 (see Materials and Methods) increased reddening of the fruit surface when compared to the control (treatments 5, 6, 10, and 11 all contained daminozide; data not presented). Neither the GA₄₊₇ treatments nor any other treatment affected return bloom.

Experiment 9. Two scores around the trunk with a carpet knife reduced fruit cracking throughout the entire summer and fall (Fig. 3). If scoring had been done every 2 to 3 weeks, a greater effect on fruit cracking might have been realized. Root pruning only slightly reduced fruit cracking, from 93% to 86%. Pruning, summer or dormant, did not significantly affect fruit cracking in the summer or fall. Neither fruit size, fruit color, nor return bloom were affected by the treatments (data not presented).

Experiment 10. Over-tree or under-tree sprinkling for one 12-hr night period did not cause fruit cracking (Table 8). After 6 nights of sprinkling (9 Aug.), over-tree and under-tree sprinkling caused 9% and 7.6%, respectively, of the fruit to crack. Some dew was deposited during this period, but exact records of duration and occurrence were not available. If significant periods of dew occurred during the night, then the under-tree sprinkled trees might have had free water on the leaves and fruit, and the cracking response might have been similar to over-tree sprinkling. Fruit covered with bags or petroleum jelly on over-tree sprinkled trees did not crack, while 7.6% of the wetted fruit cracked. These data do not agree with those of Verner (1935), where fruit under a tarpaulin cracked. He found a small number of fruit cracked when a limb with 150 apples was covered with a tarpaulin.

Since the fresh market value of the 'Stayman' apple is frequently greater than that for 'Red Delicious', there is increasing

Fig. 3. Effect of scoring, root pruning, and dormant pruning on 'Stayman' fruit cracking. Vertical bars represent LSD ($P < 0.05$). Each point represents a mean of nine replicates, with a total of 400 to 600 apples observed per treatment (Expt. 9).

Table 8. Effect of overhead and under-tree watering on ‘Stayman’ apple fruit cracking (1988, Expt. 10).

Treatment ^z	Fruit cracked (%) ^y	
	4 Aug.	9 Aug.
No watering	0.0 a	0.9 a
Under-tree sprinkling	0.3 a	9.0 b
Overhead sprinkling		
Nontreated	0.0 a	7.6 b
Bagged fruit	0.0 a	0.0 a
Vaseline fruit	0.0 a	0.0 a

^zAll trees were trickle-irrigated. Overhead- and under-tree-sprinkled trees were given ≈ 5 cm of water during 12 hr for each of six nights, 3 to 9 Aug.

^yMean separation within columns by Duncan’s multiple range test, *P* = 0.05. Mean of 25 apples that were tagged on each of eight single-tree replicates per treatment (400 apples per treatment observed on the trees on each date).

interest in a solution to the fruit cracking problem in the eastern United States. The data presented here suggest that submerging ‘Stayman’ apples in a nonionic (i.e., X-77) surfactant solution could be used to predict the potential for ‘Stayman’ fruit to crack under field conditions. In addition, four or five summer sprays of GA₄₊₇ and its combination with daminozide, NAA, Vapor Gard, or scoring the tree trunk may lead to commercially acceptable reductions in fruit cracking.

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