FIELD TRIALS WITH POTENTIAL ABSCISSION CHEMICALS AS AN AID TO MECHANICAL HARVESTING OF CITRUS IN FLORIDA

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ABSTRACT

During the 1967-68 season ascorbic acid and various additives, including citric acid and ferric ammonium citrate, were used successfully to aid mechanical harvesting of Hamlin, Pineapple, Jaffa, and Valencia oranges on a commercial basis. Ascorbic and citric acids are natural food products that are safe for human consumption. These two chemicals are now available for commercial use if needed by the industry. The greatest drawback to their use is the high concentration required, the prevalence of chemical injury to the rind, and the high cost. Chemical harvest sprays of ascorbic and citric acids offer little or no economic saving over manual harvest and can be used only on fruit moving rapidly to the concentrate plant.

Another chemical, cycloheximide, when used alone, was highly effective in inducing abscission of Valencia oranges at concentrations of 2 to 25 ppm. It has not been tested on other varieties and has not undergone extensive field trials on a commercial basis. Cycloheximide harvest sprays offer an economic saving over manual harvest. Its possible use in a spray mist for harvesting citrus for concentrate purposes without the aid of mechanical harvesters is discussed.

INTRODUCTION

As an orange fruit matures, a starch-filled layer of cells called the abscission layer develops in the rind across the veins around the button separating it from the fruit (8). When the fruit of some varieties are fully colored and remain attached to the tree for an additional 6 to 8 weeks, they usually abscise cleanly from the button at the abscission layer. This, however, does not occur readily in fruit with green rind adjacent to the button, even though the flesh of the fruit may have attained acceptable maturity standards for eating quality (3). Degreening of the rind of oranges usually occurs at the onset of cool weather in the winter, beginning at the stylar end and progressing gradually to the stem end. The rind adjacent to the button is the last portion to degreen. Different varieties of oranges vary in the degreening pattern. 'Pineapple' (*Citrus sinensis* [L.] Osb.) oranges are usually completely degreened when mature in January and February, and usually at this time separate readily at the button. If Pineapple fruit are not harvested at this time, preharvest fruit drop may occur. The rind of 'Valencia' (*Citrus sinensis* [L.] Osb.) oranges, on the other hand, may be degreened in March and later on in April and May will regreen at the stem end adjacent to the button. Such fruit may actually become more tightly attached to the fruit stem in May than they were in March (3).

When fruit is mechanically harvested and the cells of abscission layer have not begun to separate, a break or tear may take place through the parenchymatous tissue of the rind and a plug of tissue, including the button, is removed from the rind (4). Sometimes the fruit stem is broken, leaving a jagged woody stem attached to the fruit (4).

Accelerated development of an abscission layer, so that the fruit separates cleanly at the button, should greatly facilitate mechanical harvesting. Last year we reported that ascorbic acid (AA)[1] at concentrations of 2 to 5% hastens fruit abscission of Pineapple and Valencia oranges in Florida (3). Later, Rasmussen and Jones (7) found that AA-treated fruit produced enough ethylene to account for the fruit abscission.

With increasing evidence that ethylene is a plant growth regulator capable of controlling or influencing many developmental processes, it is also evident that a chemical which could induce

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[1]The following abbreviations are used for chemical names throughout this paper:
Ascorbic acid (AA)
2-Chloroethylphosphonic acid (ethrel)
Citric acid (CA)
Cycloheximide (CYH)
2,4-Dichlorophenoxy acetic acid (2,4-D)
Erythorbic acid or isoascorbic acid (EA)
Ferric ammonium citrate (FeAC)
Ferric ethylenediaminetetracetic acid (FeEDTA)
Indoleacetic acid (IAA)
Naphthalene acetic acid (NAA)

production of ethylene within a plant can be effective in increasing abscission. Until recently, IAA, NAA, and 2,4-D and related compounds (1) have been the most effective chemicals to induce ethylene in plants. Yet, when IAA, NAA, and 2,4-D are applied to citrus, fruit abscission is likely to be retarded because of the growth-promoting activity of these compounds. Because of this property of IAA, NAA, and 2,4-D, there has been considerable interest in finding compounds that induce ethylene in fruit but show no growth-promoting activity. CYH, ethrel, FeAC, AA, EA, and CA have this property (4, 6). The present paper describes experiments with these chemicals, to determine their relative effectiveness in hastening fruit abscission on trees of various orange varieties under commercial field conditions in Florida. In some of the tests the effectiveness of the abscission chemicals was evaluated by the use of mechanical harvesters. The purpose was not so much to evaluate harvesters per se, as to evaluate the abscission chemicals as an aid to mechanical harvesting.

Methods and Materials

The experiments were conducted with mature trees of 'Hamlin' [*Citrus sinensis* (L.) Osb.], Pineapple, 'Jaffa' [*Citrus sinensis* (L.) Osb.], and Valencia oranges. The FMC[2] airblast machine was used in four tests and a tree shaker was used in a single test. These machines are described elsewhere (2, 5). In the FMC airblast tests on Pineapple and Jaffa oranges, 10 trees were harvested after being treated with each of the three abscission chemical treatments (EA, EA + CA, and EA + FeAC), plus an untreated control. In two similar tests with Valencia oranges, 4 trees per treatment per test were used. Tree-shaker tests were conducted on 39 trees of Hamlin oranges treated with 3.5% EA.

In most of the tests with mechanical harvesters, EA and CA were used because these chemicals occur naturally in citrus and are presumed to be safe for human consumption. It was reported earlier (4) that AA and EA are equally effective in inducing abscission, and the results reported with one apply equally well to the other. The fruit from these tests were run through the concentrate plant, and palatability tests were made on the frozen concentrate.

In some of the mechanical harvesting tests, as noted under "Results and Discussion," additives to EA such as FeEDTA and FeAC were used, in order to try to lower the effective concentration of EA needed for abscission. CYH was used in two mechanical harvesting tests.

Additional work on ethrel and CYH was done on single trees or limb units with 45 to 100 fruits, and the efficacy of the treatments was tested by pull force tests and fruit drop counts after manually shaking the limbs. Records were also made of chemical injury to the fruit and defoliation resulting from the use of the various chemicals.

The methods of preparation and application of the spray solutions of the chemicals are described elsewhere (3). In one test a mist of a concentrated solution of CYH was used.

Results and Discussion

Tree shaker test.—In a single test 39 Hamlin orange trees were sprayed with a 3.5% EA solution on January 15, 1968. These were compared with a similar number of unsprayed trees. The trees were 30 feet tall and hedged on four sides; they had multiple trunks; and the bottom of the tree canopy was 6 feet aboveground. Such trees are suited for tree-shaker operations because the work can be performed under the canopy rather than through it. About 95% of the fruit was shaken from the tree, and all of it separated cleanly from the buttons. However, about 10% of the fruit was split, hitting the limbs on the fall to the ground from the tops of the trees. The 3.5% EA solution was apparently stronger than necessary to loosen Hamlin oranges at this time of the year; but the fruit and the older leaves were sensitive to 3.5% EA, and the leaf fall was 10%. Fruit from treated and untreated trees were made into concentrate at the U. S. Fruit and Vegetable Products Laboratory,[3] and there was no difference in the juice composition and flavor. The bulk of the fruit harvested from the test was concentrated by the South Lake Apopka Citrus Growers Association which reported that the concentrate was of good flavor. Because of a mechanical failure, untreated trees were not harvested with the shaker in this test.

[2]Food Machinery Corporation. Mention of a trademark name or a proprietary product does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

[3]The authors are indebted to Mr. Clifford Scott, U. S. Fruit and Vegetable Products Laboratory, Winter Haven, Florida, for providing this data.

FMC airblast harvester tests.—We conducted four separate tests, using the FMC airblast harvester to evaluate the effectiveness of the abscission chemicals as an aid to mechanical harvesting. On January 31, 1968, we sprayed Pineapple orange trees with three abscission chemical combinations. The next day, 10 Jaffa orange trees were sprayed with the same abscission chemicals.

With both varieties, the percent of crop harvested was increased by the use of either CA or FeAC as an additive to EA (Table 1). Their use makes it possible to potentiate the effectiveness of EA as a abscission chemical and enable the apparent successful use of lower concentrations of EA. However, these additives accentuated chemically induced pitting of the rind, as compared to EA alone. All chemicals, nevertheless, caused a clean separation of the fruit from the button and substantially decreased physical injury to the fruit caused by the mechanical harvesting, as compared to that of untreated controls.

An attempt to evaluate the effect of abscission chemicals and the airblast on the new fruit set of the 1969 crop was made by the use of frame counts (counting the number of fruit set in a 2 foot x 2 foot frame) on four sides of the canopy of the trees 3 months after bloom. These records (Table 1) show no consistent pattern for effect of either chemical or airblast on fruit set of the 1969 crop (Table 1).

Two additional tests, to determine the effectiveness of abscission chemicals and an aid to mechanical harvesting with the airblast machine, were conducted with Valencia oranges in June 1968. Three problems, not encountered with the abscission of early and midseason varieties with Valencia oranges at this time of year are: (1) The rind at the stem end may be regreened, making the fruit more tightly attached to the stem; (2) the rind pitting induced by the abscission chemicals provides a pathway for the entrance into the fruit of scavenger weevils which are prevalent in orange groves during the summer; and (3) the presence of small green fruit of the next year's crop are injured by some abscission chemical formulations. The chemical formulations used consisted of more EA and less citric acid than in the Pineapple and Jaffa orange tests. Also, FeEDTA and CYH additives were tested.

Table 1. Effect of abscission chemicals on fruit harvest of 1968 crop and fruit set of 1969 crop of Pineapple and Jaffa orange trees[1/]

Treatment No., chemicals and concentration[2/]	Pull force[3/]	Airblast harvest (1969 crop) Crop harvested	Chemical injury	Physical injury	Fruit set count on 8/7/68 (1969 crop) Airblast	Hand picked
	(lb)	(%)	(%)	(%)	(No. fruit/16 sq ft canopy)	
	Test I - Pineapple orange trees sprayed 1/31/68; harvested 2/6/68					
1. Water (control)	14	77	0	86	32	42
2. 2% EA	9	80	10	27	35	41
3. 1% EA + 1% CA	6	94	60	20	38	43
4. 1% EA + 0.25% FeAC	10	89	30	11	46	43
	Test II - Jaffa orange trees sprayed 2/1/68; harvested 2/8/68					
1. Water (control)	14	88	0	77	40	38
2. 2% EA	12	88	10	42	43	44
3. 1% EA + 1% CA	8	99	70	18	33	43
4. 1% EA + 0.25% FeAC	12	99	60	26	33	49

1/ Each treatment was applied to 10 trees and harvest was performed with FMC airblast machine.

2/ 15 gallons of spray were applied to each tree to give complete coverage of fruit and leaves.

3/ Average of 25 measurements on each of 10 trees just prior to harvest.

As with the tests on Pineapple and Jaffa oranges, the abscission chemicals greatly increased the yield of Valencia oranges and decreased the physical injury to those harvested by the airblast machine (Table 2). The 2 and 5 ppm CYH treatments received two applications, a factor which may account for abscission as good as or better than that which occurred for the single 10 ppm CYH treatment. Shortly after harvesting in June, wind injury was observed on most of the small green fruit (about ½ inch in diameter). Since fruit drop was still prevalent throughout the orchard, we waited until mid-July to determine influence of treatments on fruit set and fruit scarring. On July 17, the fruit set was less and wind scarring was greater in the machine-harvested trees of Test I, but not in Test II. We observed 29% scarring from natural causes on young green fruit from hand-picked trees. Chemical injury to the green fruit in July was easily distinguished from wind injury (except for Test I, treatment 3, in which CA was used). Chemical injury was not severe in any treatment and was nonexistent on trees with CYH.

Limb unit tests with CYH and ethrel.—The abscission activity of CYH at the low *concentrations* used in the airblast harvester test prompted us to evaluate the abscission activity of this compound over a wide range of concentrations. Valencia oranges were used (Table 3). A correlation is indicated between the concentration of CYH used and the lowering of pull force and the amount of fruit drop, fruit pitting, and leaf drop. At levels of 25 ppm and below, leaf drop was insignificant and the rind pitting was below 25%. The fruit drop record was based on fruit falling to the ground when the limb was shaken manually. Probably, if a mechanical harvester had been used at the end of 1 week, most of the fruit would have been harvested.

The CYH effect on lowering the pull force is extremely rapid. The data in Table 4 show that there is a substantial lowering of the pull force after 2 days; whereas, fruit drop and rind pitting began after 4 days.

Washing the fruit 2 hours after treatment did not slow the drop in pull force but it did prevent development of rind pitting during the first week (Table 5). Just how significant this will

Table 2. Effect of abscission chemicals on fruit harvest (airblast machine) of 1968 crop and fruit set of 1969 crop of Valencia orange trees[1/]

Treatment No., chemicals and concentration	Pull force[2/]	Airblast harvest (1968 crop)			Fruit set count on 1969 crop		Green fruit chemical injury	Green fruit wind injury	
		Crop harvested	Chemical injury	Physical injury[3/]	Airblast	Hand picked		Airblast	Hand picked
	(lb)	(%)	(%)	(%)	(No. fruit/16 sq ft canopy)		(%)	(%)	(%)
	Test III - Trees sprayed 5/21/68; harvested 5/27/68								
1. Water (control)	18	65	0	37	20	29	0	43	29
2. 2% EA + 0.2% FeEDTA	14	95	20	23	21	...	15	43	...
3. 1.5% EA + 0.5% CA	13	95	26	19	19	...	20	60	...
4. 0.5% EA + 5 ppm CYH	11	89	8	3	20	...	0	37	...
	Test IV - Treatments 1-4 sprayed 6/1/68, 2.11" rain 6/2-5/68; treatments 2, 3, and 5 sprayed 6/7/68. All treatments harvested 6/10/68								
1. Water (control)	17	53	0	53	29	29	0	19	29
2. 2 ppm CYH	13	92	17	20	22	...	0	22	...
3. 5 ppm CYH	13	80	13	14	31	...	0	12	...
4. 10 ppm CYH	12	84	6	22	25	...	0	30	...
5. 2% EA + 0.2% FeAC	11	95	30	21	21	...	0	29	...

1/ Each treatment was applied to 4 trees and harvest was performed with FMC airblast machine.

2/ Average 25 measurements on each of the 4 trees just prior to harvest.

3/ Includes fruit plugging, splitting, and stems attached.

Table 3. Effect of CYH on abscission of Valencia oranges[1/]

Treatment No.	Conc of CYH (ppm)	Pull force[2/] (lb)	Mature fruit drop (%)	Green fruit drop count (%)	Leaf drop (%)	Rind pitting (%)
1.	Water (control)	18	2	5	0	0
2.	10	10	12	5	2	0
3.	25	6	32	5	2	18
4.	50	4	56	5	5	68
5.	100	3	70	5	10	100
6.	500	0	100	5	25	100

1/ Limb units containing 45 fruits each were sprayed with each treatment; sprayed 5/3/68 and fruit harvested 1 week later.

2/ Average of 25 fruits remaining on the limb after shaking it by hand. In Treatment 6, all fruit dropped to the ground.

be in controlling rind injury we do not know. In the fruit-washing test we harvested all the fruit 1 week after treatment and made no further observation on fruit injury. In other tests, where washing was not employed, we found that pitting of the rind may develop during the 2nd week after treatment. It is desirable to test the shelf life of CYH-treated fruit before we can be sure that washing the fruit 2 to 24 hours after treatment will prevent pitting.

Table 4. Rate of fruit and leaf abscission of Valencia oranges at various intervals during the first week after spraying with dilute solutions of CYH

Treatment No.[1/]	Conc CYH (ppm)	Pull force after 2 days (lb)	Pull force after 4 days (lb)	Pull force after 7 days (lb)	Cumulative fruit drop after 2 days (%)	Cumulative fruit drop after 4 days (%)	Cumulative fruit drop after 7 days (%)	Rind pitting after 2 days (%)	Rind pitting after 4 days (%)	Rind pitting after 7 days (%)	Cumulative leaf drop count after 2 days (%)	Cumulative leaf drop count after 4 days (%)	Cumulative leaf drop count after 7 days (%)
1.	Water	16	18	18	0	0	4	0	0	0	0	1	2
2.	1	15	15	15	0	0	4	0	0	0	0	1	2
3.	5	12	13	12	0	4	12	0	0	4	0	1	1
4.	10	11	12	9	0	8	12	0	0	22	0	1	2
5.	25	11	8	5	0	12	60	0	20	40	0	1	2

1/ Treatments applied to limb units that contained 100 fruit each on 5/17/68.

Table 5. Effect of spraying fruit and leaves with water following the CYH treatment on fruit and leaf abscission of Valencia oranges

Hours after CYH treatment when sprayed with water[1/]	Pull force after			Cumulative fruit drop after			Fruit pitting after			Cumulative leaf drop after 7 days
	2 days	5 days	7 days	2 days	5 days	7 days	2 days	5 days	7 days	
	(lb)			(%)			(%)			(%)
Control (No CYH)	16	16	17	0	3	6	0	0	0	2
2	13	9	8	2	12	40	0	0	0	3
4	12	7	12	2	25	65	0	0	0	5
24	11	9	6	3	28	66	0	0	0	5
Not washed	10	8	9	10	23	40	0	0	40	6

1/ Whole tree was sprayed with 25 ppm CYH and selected limbs containing 60 fruits were sprayed with water at various intervals after the CYH treatment.

Comparison of CYH and ethrel as abscission chemicals.—Ethrel is a potent abscission chemical and Cooper et al. (4) have shown that the ethylene biosynthesis of citrus treated with ethrel is much greater than in control fruit. This results in considerable defoliation. In order to obtain fruit abscission, 100 to 250 ppm ethrel are required. In an experiment with Valencia orange, a comparison of day and night applications was made with both 25 ppm CYH and 250 ppm ethrel. The minimum nighttime temperature was 75° F, and the maximum daytime temperature was 95°. In each instance, the treated fruit was washed with water 11 hours after treatment. CYH lowered the pull force and increased fruit drop more than ethrel; whereas, leaf drop was excessive with ethrel (Table 6). There was no apparent difference in the effectiveness of either treatment during daylight or darkness.

In another experiment, a fine mist of 1000 ppm CYH was applied to the fruit and leaves of Valencia oranges. The mist left an average of 32 microdroplets per fruit, and approximately 25 mg of CYH were used to cover the limb unit containing about 60 fruit and 300 leaves. In com-

Table 6. Effectiveness of abscission chemicals when applied at 10:00 AM and 9:00 PM. Chemicals washed off after 11 hours

Treatment No., chemical and concentration (ppm)	Method of application[1/]	Time of treatment	Pull force after			Rind pitting after			Fruit drop after			Leaf drop count 7 days
			2 days	5 days	7 days	2 days	5 days	7 days	2 days	5 days	7 days	
			(lb)			(%)			(%)			(%)
1. Water(control)	Spray	Day	16	16	17	0	0	0	0	3	6	2
2. " "	Spray	Night	16	17	17	0	0	0	0	6	6	1
3. CYH, 25	Spray	Day	11	8	5	0	40	40	2	26	50	2
4. CYH, 25	Spray	Night	10	6	4	0	20	20	10	34	55	2
5. Ethrel, 250	Spray	Day	17	11	10	0	0	0	3	17	30	100
6. Ethrel, 250	Spray	Night	16	11	11	0	0	20	5	17	28	100
7. CYH, 1000	Mist	Day	12	5	0	0	70	100	17	59	100	7
8. CYH, 1000	Mist	Night	11	6	0	0	80	100	13	60	100	5

1/ Sprays applied to 60-fruit limb units of Valencia oranges on 7/25/68.

parison, the single-strength spray to cover a similar limb unit with 25 ppm CYH required 750 ml of solution, or approximately 20 mg of CYH. The mist application was much more potent abscission agent than the single-strength spray. Thus, with about the same amount of chemical, the concentrated mist caused 100% of the fruit to drop by the 7th day, without even manually shaking the limb. Probably all of the fruit could have been shaken from the limb on the 5th day. This compares with 26% fruit drop by shaking the limb sprayed with the 25 ppm single-strength solution. All of the mist-treated fruit were pitted on the 7th day, as compared to 40% for the single-strength spray. The pits at this time were all confined to the outer flavedo and had not penetrated to the albedo. The rind appeared firm enough to withstand the normal transporting operations to the concentrate plant.

General Discussion

The results describe two alternative approaches to the citrus fruit abscission problem.

Ascorbic acid (either AA or EA) plus a CA additive are safe natural fruit products and are safe to use from the standpoint of human tolerance. There will probably be no difficulty getting FDA clearance for commercial use if the industry wants it. The greatest drawbacks to their use are the high concentrations required and the prevalence of chemical injury to the rind. Chemical harvest sprays of ascorbic and citric acids offer little or no economic saving over manual harvest but provide an aid to harvesting when pickers are not available.

The EA + CA combination causes chemical injury to the fruit and can be used only for fruit destined to the canning or concentrate plant. Since most of the fruit in Florida is used as concentrate, this is potentially a significant benefit to the industry. However, the chemical pitting is a potential hazard if the fruit is left in the groves for more than a day after harvesting. The fruit has very little shelf life and cannot be used for fresh fruit purposes.

Another effective chemical abscission agent described herein is CYH. This chemical is used as an antibiotic under the name Acti-dione in the control of certain foliage diseases of fruit trees. The chemical is effective at 2 to 25 ppm or at plant hormone levels. It is a more potent abscission chemical than AA or EA and would be less expensive. This chemical also causes rind pitting, but it is more superficial than that obtained with EA + CA. Nonetheless, such pitting prevents its use for fresh fruit purposes. However, CYH is a quick-acting chemical, and preliminary tests indicate that spraying the trees with water 2 to 24 hours after the application of the chemical does not interfere with its abscission activity. The spraying appears to minimize rind pitting. However, no holding tests have been conducted to verify this speculation.

The most spectacular effect of CYH is its extreme potency as a fruit abscission agent when applied as a concentrated mist. It is within the realm of possibility that this chemical could cause all the fruit to drop to the ground 5 days after treatment simply by manually shaking the tree. However, CYH is not something that can be recommended at present. It is an antibiotic and is cleared for use only on a no residue basis. Analyses for CYH juice and pulp from fruit on treated trees are now being made to determine if CYH residues occur.

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