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GROWTH REGULATORS FACILITATE HARVESTING OF ORANGES[1]

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Abstract. **Four growth regulator-type chemicals are available for use as aids to mechanical harvesting of citrus fruits in Florida. Three of these chemicals function by causing superficial injury to mature fruit peel followed by ethylene formation within the fruit which subsequently induces abscission. One of the compounds is directly used as an aid to hand harvesting. The principal limitations of abscission chemicals are dependency on weather (daily high temperature should be at least 18.3°C (65°F) or greater) and possible loss of fruit due to decay following the superficial peel injury, should harvesting be delayed. However, the technology is available to mechanically harvest citrus fruit. Under Florida conditions, air shaker acceptance has been limited because of reduced fruit loosening when an abscission spray is followed by a change to colder weather conditions. Limb shakers, on the other hand, have been more practical because they can override the lack of chemical response. Acceptance of mechanical harvesting of citrus fruits is a function of economics. For the foreseeable future, mechanical harvesting of citrus probably will be used only with fruit for processing.**

Although citrus fruits have been successfully mechanically harvested without abscission chemicals,[8,10,22] field experience has shown that chemical loosening is desirable because less tree shaking time is required resulting in less physical abuse to the machinery and trees. However, chemicals have not allowed the construction of less powerful shakers because chemically induced fruit loosening is not always uniform,[26,30] resulting in about 10–15% still adhering strongly to the tree.

Abscission chemicals for citrus are classified as growth regulators, a good definition being, "substances capable of controlling key points in a living plant system so that the natural course of development is modified".[18] Most of the currently-used abscission compounds function by producing superficial peel burn followed by production of wound ethylene.[27] The latter moves in some manner through the fruit tissue and affects the abscission zone. The only commercially available chemical that appears to function through absorption by the tree and fruit, followed by conversion of the chemical into ethylene, is ethephon (2-chloroethylphosphonic acid).[11,27,32] In this case, it appears to function more in the classic "growth regulator" sense than the others.

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Commercially Available Abscission Chemicals

Dilute sprays have usually proven to be the most satisfactory concentrations for applying abscission chemicals.[19,30] The following chemical rates, therefore, are for dilute sprays applied with ground equipment. The quantity of spray solution applied will vary based on the size and number of trees per ha (acre), and under Florida conditions optimum spray coverage for mature trees usually ranges between 4,732 liters per ha (500 gallons per acre) and 7,098 liters per ha (750 gallons per acre). Recommendations for or against use of surfactants with an abscission chemical are based on findings by public agency research scientists and scientists with the respective commercial companies. These findings are incorporated into the label recommendations issued for each commercial abscission compound.

1. *Ethephon (Ethrel®)* is a product of Union Carbide Agricultural Products Co., Inc., Research Triangle Park, North Carolina, and is distributed worldwide. It is cleared by the EPA (Environmental Protection Agency of the United States Government) for use in Florida on lemons, tangerine hybrids and tangerines.[15] Suggested concentrations are dilute sprays of 250 ppm for all cultivars except 'Orlando' tangelo where the suggested rate is 200 ppm. This chemical, in addition to producing fruit loosening, enhances fruit color development.[11,15,33]

The chief problems with Ethrel® are its tendency to cause excessive leaf drop and its erratic fruit loosening. This latter problem seems to have caused many Florida growers to suspend its use. Although all abscission chemicals are to some extent unpredictable in action, this chemical requires more expertise in its use, and it appears to be more subject to the vagaries of the weather than other abscissors. A surfactant should not be used with Ethrel® and it should not be applied as a concentrate spray.

2. *Acti-Aid® (cycloheximide),* a product of the Upjohn Company, Kalamazoo, Michigan, is cleared by EPA for use in Florida on oranges intended for processing. This chemical has generally produced good loosening of early and midseason oranges when applied as dilute sprays of 10–20 ppm.[5,6,30] It should not be applied after the spring growth flush begins,[30] otherwise severe phytotoxicity can result. Unfortunately, its performance on 'Valencia', or late season oranges, has been unacceptable, although usually by 6 weeks following bloom the tree (but not necessarily the immature fruit) will tolerate concentrations up to 20 ppm. Immature fruit from 1 to 6 weeks post bloom is particularly sensitive to Acti-Aid® injury[24,30] but this decreases somewhat after that period. Acti-Aid® normally causes light to moderate rind pitting on mature fruit, thus eliminating its use for loosening fresh fruit.[15,30] Use of a suitable surfactant is suggested.[30,32] Some concentration of the spray appears to be possible, although best results are obtained by the use of dilute sprays.[30]

Florida experience has shown that Acti-Aid® should not be used if freezing temperatures are likely to occur because it reduces the cold hardiness of the tree for an undetermined period of time.[31] As the forecasting of freezing conditions in

Florida generally cannot be made accurately except for about a 3-day period, use of Acti-Aid®, therefore, involves a certain risk during the Florida winter period.

3. *Release® (5-chloro-3-methyl-4-nitro-1H-pyrazole)* was originally developed by Abbott Laboratories, North Chicago, Illinois, but all rights to use the compound as an abscission agent for citrus have been purchased by the Florida Department of Citrus, which is also financing toxicology studies for full EPA clearance. Currently, Release® is available in Florida for use under experimental permit on oranges destined for processing. The chemical was the first which showed the ability to loosen mature 'Valencia' oranges while causing virtually no injury to bloom, young fruit or foliage[14,25] when used as recommended. Label recommendations (for dilute sprays) are 75–125 ppm for early and midseason oranges and 175–250 ppm for late season or 'Valencia' oranges. Concentrations above 250 ppm, however, have been reported to cause some yield reduction of 'Valencia' oranges.[21,22] Best results are obtained by use of dilute sprays and use of a suitable surfactant is recommended.

Release® causes a superficial peel injury which most often appears on the fruit as a distinct ring burn at the blossom end.[25,27] Peel injury tends to be most severe near the beginning of the fruit season (December) on early and midseason oranges. 'Valencia' oranges are not as subject to the injury.[32]

4. *Pik-Off® (glyoxal dioxime),* a product of CIBA-GEIGY Corporation, Greensboro, North Carolina, is a chemical very similar in action to Release®[29,32] and is available for use under experimental permit by EPA. Although it does not usually produce as good abscission as some other chemicals, it is satisfactory for many uses. From a cost and residue standpoint, it is in an advantageous position, and is compatible with the 'Valencia' cultivar. It should not be used with surfactants. Pik-Off® should not be used after immature 'Valencia' fruit have attained a diameter of 2.5 cm (1 inch).[29]

Pik-Off® is restricted by label as to total quantity which can be applied per ha.[29] However, results of a series of field tests using dilute sprays showed that increased volumes of sprayed chemical per ha substantially improved abscission performance, particularly on larger trees which required more liters per ha (gallons per acre) than the label allowed.[29]

5. *Chemical combinations.* Two-way combinations of Release® and Acti-Aid® applied with surfactant as dilute sprays have given better fruit loosening than either chemical used alone.[32] Optimum concentrations for early and midseason oranges have been Release® (50–100 ppm) and Acti-Aid® (1–5 ppm). Field experience has shown that the amount of Acti-Aid® should be kept as low as practicable, preferably below 2.5 ppm, because of excessive leaf drop which has been observed occasionally. Release®-Acti-Aid® combinations may lower cold hardiness of the tree in the same manner as Acti-Aid® used alone.[31] Three way combinations of Release®, Acti-Aid®, and Sweep® (chlorothalonil) are no longer being tested. Suitable surfactants should be used with combinations.[17]

Factors Affecting the Abscission Process

Abscission response of early and midseason orange cultivars differs from those of the late, or 'Valencia', cultivar and these will be discussed individually.

A number of environmental and physiological factors affect the activity of citrus abscission agents.[2,3,4,6,24,30] Biggs and Kossuth[3,4] have compiled much of this information into the form of a general model for the late season, or 'Valencia' orange, although the stated factors probably would apply also to early and midseason oranges. While the model involves many factors, all are not defined. The model includes no input concerning the type of harvesting system to be employed, namely, abscission for hand harvesting only, or abscission for different types of mechanical harvesting operations. Each of these could require a different amount of desired fruit loosening.

A. Early and Midseason Oranges

In Florida, climatic conditions of temperatures and rainfall appear to cause the most problems. By the time fruit for processing has reached the minimum desired Brix/acid ratio of 13:1, which seems to be preferred by most processing plants, it is usually completely physiologically responsive and remains equally responsive, or becomes more so, as the fruit season progresses.

The effects of temperature on the abscission process(es) are well documented[2,3,4,6,12,24,26,28] Temperature can affect ability of the fruit to absorb chemicals as well as tissue responses.[3,4,12] Observations under field conditions would probably be a resultant of the temperature effects on both processes as there are substantial interactions.[3,4,12] Optimum temperature for chemical uptake appears to be about 25°C (77°F).[12]

The Florida winter period (in which early and midseason oranges are harvested) can be quite variable with almost any combination of warm-cold possibilities occurring in the normal 5-day period between abscission spray application and harvest. Growth chamber studies usually involve static temperature conditions, while field conditions present not only a fluctuating diurnal cycle but also variable temperature ranges. In general, it would appear that both systems agree fairly well when certain allowances are made. Fig. 1 shows the overall effect of various diurnal temperature regimes on ethylene evolution by excised fruits. Ethylene evolution has been demonstrated to be highly correlated with fruit loosening.[2,3,4,6,30]

Prediction of loosening using a fixed concentration of abscissor should be based on a 5-day temperature forecast. The most practical means of predicting fruit loosening seems to be predicted daily high temperatures for the selected period. "High" and "low" temperatures are those which are the most commonly available from local weather bureaus. Research is underway on a prediction scheme based on treatment of fruit explants with the resulting effectiveness measured as ethylene evolution,[28] but the system has not been thoroughly tested for accuracy under field conditions. Such predictions, of course, cannot be expected to exceed the accuracy of a 5-day (or extended period) forecast which is not always 100%. A simplified decision model for spraying is shown in Table 1. Decision temperatures are based on observed or predicted daily high temperature forecasts.

Rain following within a few hours of an abscission spray application has been reported to diminish or completely eliminate the resulting abscission activity.[3,4,24,32] Quantitative studies employing radioactive uptake[3,4] indicate that most of the chemical (Release®) is absorbed within 6 hours when temperatures are favorable. Most field studies also indicate at least 6

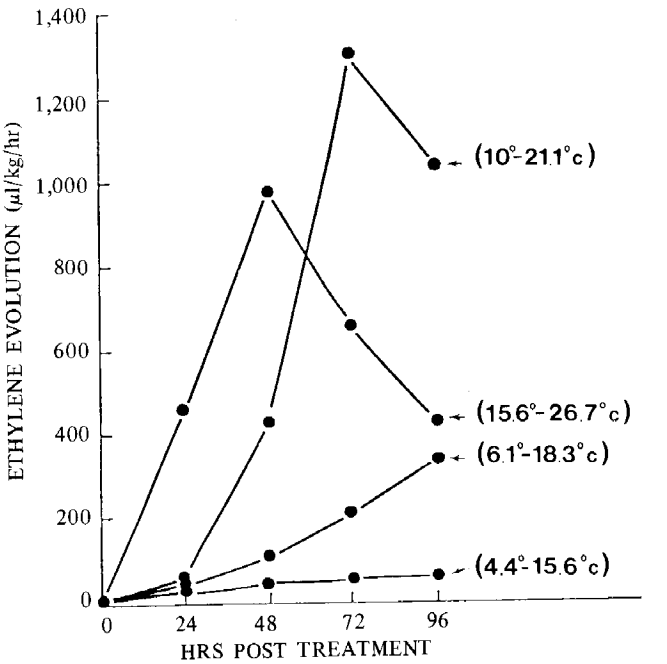

Fig. 1. Typical ethylene evolution patterns given off by Florida oranges treated with Release® + Acti-Aid® + surfactant and subjected to various diurnal temp regimes. Other ethylene-producing abscissors produce very similar evolution patterns. Ethylene production is highly correlated with abscission activity.

Table 1. Expected result of applications of 100 ppm Release® plus surfactant applied under and subject to various temperature conditions. Based on growth chamber studies by Wilson.[28] Table applicable to Florida early and midseason oranges with average Brix/acid ratios of 13:1 or better. Decisions regarding harvesting equipment to be used should be made prior to decision to be made regarding desired fruit loosening to be obtained.

Application Temp.[z]–48 Hr.	48–96 Hr. Temp.[z]	Decision	Expected Loosening
21.1°C (70°F) or above	21.1°C (70°F) or above	Spray	Excellent
18.3°C (65°F)	21.1°C (70°F) or above	Spray	Excellent
15.6°C (60°F) or below	21.1°C (70°F) or above	Spray	Fair-Excellent
21.1°C (70°F) or above	18.3°C (65°F)	Spray	Fair-Excellent[y]
18.3°C (65°F)	18.3°C (65°F)	Spray	Fair[y]
15.6°C (60°F) or below	18.3°C (65°F)	Spray	Fair–Poor[y]
21.1°C (70°F) or above	15.6°C (60°F) or below	Do Not Spray	–
18.3°C (65°F)	15.6°C (60°F) or below	Do Not Spray	–
15.6°C (60°F) or below	15.6°C (60°F) or below	Do Not Spray	–

z: Figures represent expected daily high temperature either observed or predicted by the appropriate local weather service.
y: Some increased fruit loosening is possible by applying the maximum concentration of Release® allowed by label (125 ppm) and/or inclusion of 2.5 ppm Acti-Aid®.

hours are necessary; however, field observations occasionally have shown that even 12 hours between application and rain may be insufficient. It is possible (Biggs, R. H., personal conversation) that the rain may under some conditions reduce abscission effectiveness because of the application of additional water. Until all the underlying conditions are better understood, growers should time their sprays so that, if possible, no rain will occur within 24 hours following application of the abscission spray.

Relative humidity has been quantified as affecting uptake of radioactive Release®.[3,4] These studies, which were conducted under static temperature and humidity conditions, indicated that optimum uptake took place at 60% relative humidity and decreased as humidity was either increased or decreased. Under Florida weather conditions, relative humidities below 40% seldom occur and then usually only at the maximum temperature during the diurnal cycle. Because of the dynamic (cyclic) nature of grove humidity, an abscission spray applied during morning hours would normally expect to be subjected to a decrease in relative humidity followed by an increase.

Field tests through the years have given very little positive indication that relative humidity plays an important role in abscission chemical activity in Florida, although in arid areas such as California, the opposite seems to be true.[30,32] Relative humidities below 30% are rarely encountered in Florida during the winter except in connection with a strong cold front. When this occurs, the low temperatures which follow are almost always below those necessary to produce good fruit abscission.

B. Late Season or 'Valencia' Oranges

As volume harvest of 'Valencia' for processing does not usually begin before late April or early May in Florida, daily high temperatures would rarely be less than 21.1°C (70°F) and, indeed, could average close to 26.7°C (80°F) or above. Relative humidity ranges in a diurnal cycle between 40–90%. The main environmental problem that inhibits abscission activity during this period would be the appearance of sudden thundershowers which could wash off the abscission chemical before it could be taken up by the fruit.

The principal limitation of abscission chemicals applied to 'Valencia' is physiological. This has been described[15,16,32] and further studied in detail.[3,4,12,23] The period of low response (often called the "non-responsive" or "regreening" period) usually begins in early May and lasts 2–3 weeks depending on the age of the trees.[16,17] Fruit on younger trees are normally associated with the longer time period. There appears to be adequate uptake of chemical,[3,4,12,21,23] but reduced ethylene evolution occurs and fruit is less responsive to exogenously applied ethylene.[12,23] During this period, 'Valencia' fruit have been shown to degrade Release® more rapidly than at other times.[3,4] Under field conditions, 'Valencia' is most responsive to abscission chemicals from mid-February through April, and is also again responsive following the period of reduced response.[16,17] Mass harvesting by mechanical methods before the non-responsive period is usually precluded by fruit immaturity (Brix/acid ratios below desired minimum for processing of 13:1). Following the non-responsive period, young fruit mass has usually become sufficiently large that excessive numbers are removed by the shaking action, use of abscission chemicals at this time has not produced sufficient selectivity between mature and green fruit to prevent crop reduction the following year.[1,10,22]

Abscission Chemical Effects on Mechanical Harvesting

A complete mechanical harvesting operation usually involves abscission spray application followed by removing (shaking) the fruit from the tree either with a limb or air shaker[13] and delivering it to the processing plant. Mechanically detached fruit are either dropped on a catchframe or directly on the ground under the tree where they are collected and picked up. When abscission chemicals are used, the fruit are usually dropped to the ground because the chemical causes some preharvest drop[7] which can cause some problems with the use of catchframes.

Limb shakers must attach to individual limbs on a tree and this limits fruit removal capacity per hour because a substantial amount of machine time is necessarily spent in positioning activities. However, limb shakers remove a high percentage of the fruit if given sufficient time. Air shakers direct a strong pulsating or oscillating air stream at the tree as the shaker is moved past and do not require stopping and positioning of the shaking mechanism. This continuous movement of the air shaker makes it a high-capacity per hour machine compared to limb shakers. However, fruit removal efficiency is generally lower than with the limb shaker, and maximum activity by an abscission chemical is necessary for high fruit removal percentages.

Abscission chemicals have increased limb shaker fruit hourly removal capacity up to 40% and fruit removal efficiency about 2%.[7] The possible capacity increase with limb shakers is limited because the positioning time per tree is not generally related to ease of fruit removal. Abscission chemicals have a greater effect on fruit removal capacity and removal efficiency with air shakers because of their non-selective, continuous moving characteristic. Abscission chemicals have increased air shaker capacity up to 400% and fruit removal efficiency up to 60%.[22]

Late season, or 'Valencia' oranges, are harvested when the young crop of fruit for next season is on the tree. It is desirable that the mature fruit be removed without damage to the young crop. By use of abscission chemicals, the mature fruit only can be loosened, thus developing a greater differential between the young and mature fruit attachment force. When adequate loosening of the mature fruit can be obtained, the removal or damage to the young crop as measured by subsequent fruit yields can be reduced by 60%.[10,20]

Abscission chemicals which cause superficial peel injury can increase fruit deterioration, thus reducing storage time at the processing plant before spoilage occurs. In warm weather with well-matured fruit, the storage time may be limited to 36 hours. Therefore, mechanical harvesting operations should be coordinated with processing operations so that fruit can be moved immediately into the processing plant upon arrival. Abscission chemicals, however, are beneficial to fruit for processing because the number of fruit with stems is greatly reduced.[9] Stems are a problem for fruit extractors, particularly the FMC in-line extractor which is widely used.

The efficiency of hand harvesting can be increased by the use of abscission chemicals.[30] It was found that abscission chemicals increased the efficiency of "good" pickers (harvesters) by 37%, "poor" pickers by 39%, and "average" pickers by 11%. The problem preventing the widespread use of these methods appears to be one of motivation, for some pickers tend to work until they

earn what they believe is sufficient money for that day; then, they cease working.

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