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Abscission Materials as an Aid for Harvesting Florida Citrus

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Abstract. **The use of machines to harvest Florida's orange crop (for processing) has expanded in recent years and is predicted to be the primary means of harvest in the future. An impediment to efficient harvesting is the inability of the different types of harvesters to remove 100% of the fruit from the tree. Harvesting efficiency has been estimated to be 70% to 95%. Abscission chemicals have been effective in loosening fruit, including citrus, as an aid for mechanical harvesting. Starting in 1995, scientists from the Citrus Research and Education Center in Lake Alfred have engaged in a comprehensive citrus fruit abscission research program to complement the effort to develop mechanical harvesters. The objectives of this program are to: 1) search for and evaluate existing and new abscission chemicals, 2) define the factors affecting the efficacy of abscission chemicals, 3) study the hormonal fluxes that affect citrus fruit abscission, 4) identify abscission genes and proteins, and 5) develop cultural practices that maximize citrus harvesting efficiency. Over 100 potential abscission chemicals, experimental compounds, and growth regulators alone and in combination have been extensively evaluated in the field and laboratory. Methods used to assess these compounds are described. *CMN-pyrazole* has been the most effective fruit loosener of those tested, consistently loosening oranges without significant detrimental side effects. *Methyl jasmonate* was generally effective for citrus fruit loosening but at optimal concentrations caused substantial defoliation. CMN-pyrazole in combination with methyl jasmonate at low concentrations was promising. *Ethephon* was erratic as a fruit abscission agent and caused severe defoliation. Calcium salts were not effective in reducing ethephon-induced leaf drop of 'Valencia' or 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] trees although calcium hydroxide did prevent leaf drop in tangerine cultivars. Several experimental compounds demonstrate promising citrus fruit abscission activity and research will continue to explore new approaches to control fruit and leaf abscission, including hormonal regulation.**

Because of the decreasing availability and increasing cost of harvest labor, the development of machines to harvest Florida's processing orange crop has received high priority by the citrus industry in recent years. The use of mechanical harvesters is predicted to be the primary means of harvest of oranges intended for juicing in the future (Brown, 1998). For this reason, the Florida Department of Citrus has sponsored a large scale research and development program to design and evaluate harvesters.

An impediment to an efficient harvesting operation is the inability of the different types of harvesters to remove all of the fruit from the tree. Without abscission chemicals, harvesting efficiency has been estimated to range from 70% to 95% with little predictability (Whitney, 1999). Abscission chemicals have been effective in loosening various fruit crops, including citrus, as an aid for mechanical harvesting (Bukovac et al., 1969; Bukovac, 1979; Lavee and Haskal, 1975; Martin et al., 1981; Perez et al., 1981; Wilson et al., 1981). In addition to increasing fruit removal, abscission chemicals may enhance the mechanical harvesting operation by eliminating or reducing tree injury from the harvester and reducing damage to the machinery by reducing tree shaking time.

From the mid-1960s to the mid-1980s, researchers with the Florida Department of Citrus and U.S. Department of Agriculture evaluated a great number of experimental compounds that had potential for loosening citrus fruit (Davies et al., 1975; Kender, 1998; Wilson et al., 1977, 1981). Among them were PIK-OFF (glyoxal dioxime), Release (2-chloro-3-methyl-4-nitro-1*H*-pyrazole, i.e., CMN-Pyrazole), Acti-aid (cycloheximide), and ethephon (2-chloroethylphosphoric acid). Unfortunately, because of a declining interest in labor issues at the time and severe freezes in the 1980s, none of the harvesters or abscission agents were commercialized.

Starting in 1995, scientists from the Citrus Research and Education Center in Lake Alfred, Fla., have engaged in a new comprehensive citrus abscission research program to complement the effort to develop mechanical harvesters. Financial support for this program is provided by the Florida Department of Citrus. The objectives of this program are to: 1) search for and evaluate existing and new abscission chemicals, 2) define the factors affecting the efficacy of abscission chemicals including delivery to the canopy, 3) study the hormone fluxes that affec abscission, 4) identify abscission genes and proteins, and 5) develo cultural practices that maximize harvesting efficiency.

In addition to screening over 100 promising abscission component for specificity, phytotoxicity, and efficiency, special attention has bee given to the evaluation of older compounds such as CMN-pyrazole an ethephon as well as new compounds such as methyl jasmonate metsulfuron-methyl, and prosulfuron (Hartmond et al., 2000a).

Procedures

The chemical evaluation program consists of a systematic search fo active materials using several experimental approaches depending o previously reported responses, amount of material available, and th need for advanced studies.

Abscission zone applications. We developed a test to specifically determine if a chemical can induce fruit abscission by applying th solution directly to the abscission zone. In earlier studies (Hartmond e al., 2000c), we found that contact with the abscission zone is necessar for optimum response to an abscission chemical. An absorbent collar o twisted tissue paper 12 cm in length is wrapped around the peduncle a the juncture of the fruit. The collar is saturated with a known quantity of the abscission chemical using a pipette to allow prolonged contact o the solution with the abscission zone. Usually 20 fruit per treatment are evaluated. This test is also used to study hormone interactions on frui abscission.

Fruit explant tests. Explant tests have been used in the past t evaluate potential new abscission chemicals. They are simple and can be conducted under controlled laboratory conditions (Burns et al., 1999). Observations on foliage, however, are not possible and results have not been consistent.

Calamondin as a test plant. The use of potted, fruiting calamondin trees (*Citrus madurensis* Lour.) has been used in our program to evaluate abscission chemical treatments. This approach has the advantage of using small greenhouse-grown plants which are relatively easy to handle. Continuous flowering and fruiting allows year-round testing. They are useful for initial screening but results may be erratic and not

always applicable to commercial citrus cultivars.

Branch applications. The most promising chemicals are advanced to branch tests to observe possible effects on leaf abscission or phytotoxicity as well as fruit loosening on a small scale under field conditions. Entire branches usually with 20 to 50 mature fruit per branch are sprayed with relatively small amounts of solution (≈0.5 L) using a pump-up hand or backpack sprayer. Tests are limited to the harvest season of the test cultivar.

Whole tree applications. Advanced evaluation of selected abscission chemicals are further tested using replicated treatments to entire trees (one or three-tree sets) to determine field scale responses. Solutions are applied at a rate of 5 L per tree using an electric field sprayer equipped with a hand-held spray boom and flat-fan nozzles. The boom length is adjusted to the tree height and held vertically permitting applications with minimal spray drift or overlap (Hartmond et al., 2000b). Larger trees are sprayed with a commercial air blast sprayer (Kender et al., 1998, 1999).

'Hamlin' is used to represent early and midseason oranges harvested from November through February, 'Valencia', a late season cultivar, is used to evaluate abscission chemicals from February through June. 'Valencia' offers the advantage of observing effects on flowers, immature fruit, new flush, and mature fruit during the same period.

Measurements. Routine measurements include °Brix, acidity, Brix-acid ratio, fruit detachment force (FDF) after 7 d, fruit drop, and phytotoxicity including defoliation, peel injury, and young fruit drop ('Valencia'). Where possible, chemicals are applied to both the early-midseason cultivar 'Hamlin' and the late cultivar 'Valencia' since the response of these cultivars may vary.

Most chemicals are identified by code to insure that the chemistry is kept confidential and protected.

Criteria for evaluation. The criteria used to determine if a chemical is a suitable candidate include:

- Effective fruit loosening to 50 N FDF or lower within 7 d;
- Effective at low concentrations;
- No adverse effect on internal or external fruit quality (i.e. peel injury);
- Removes stems from the fruit during mechanical harvest;
- Does not induce significant leaf or floral abscission or phytotoxicity (i.e. twig dieback, vegetative growth inhibition);
- Loosens fruit uniformly within the tree canopy and throughout the harvest season (particularly for 'Valencia');
- Loosens mature 'Valencia' fruit but not young fruit (next year's crop) on the same tree;
- Causes no residual yield reduction;
- Has acceptable residue levels;
- Is nontoxic to animals.

The abscission chemical evaluation program is complemented by basic research on hormone physiology and molecular biology (Burns, 1998). Additionally, advanced field studies are conducted on machine/abscission chemical interactions (Whitney and Muraro, 1998) and abscission chemical application methodology (Koo et al., 1999; Salyani et al., 1999).

Factors affecting the responsiveness of citrus fruit to application of abscission chemicals. Among the factors we must consider when applying abscission chemicals are:

1) Weather conditions. Temperature, humidity, and rainfall may vary considerably during the harvest season in Florida, which could influence the efficacy of abscission chemicals. For example, hastening or delaying fruit loosening as a result of temperature fluctuations could disrupt the coordination of harvest and delivery of fruit to the processing plant. Also, unpredictable rain events anytime during the harvest season may dilute or wash the abscission chemical from the fruit. Under drought conditions, abscission chemicals may induce excessive defoliation because of water stress conditions of the tree.

2) Fruit maturity. The response to an abscission chemical may vary with the Brix-acid ratio of the fruit (juice). In general, the fruit detachment force decreases as the ratio increases. Less mature fruit may require higher concentrations or may not respond.

3) Response to abscission chemicals may vary depending on cultivar (Kender and Hartmond, 1998). Unique to the 'Valencia' cultivar, the "less responsive period" during April and May reduces the effectiveness of abscission chemicals (Hartmond, et al., 2000b; Wheaton et al., 1977). Our studies have shown that levels of endogenous hormones, namely IAA and ABA, play a role in determining the response of 'Valencia' oranges to abscission chemicals (Yuan et al., 2001).

4) Timing, deposition, and the use of adjuvants also must be considered when evaluating potential abscission chemicals in advanced tests.

Results

Since 1996, our laboratory conducted numerous experiments to better understand the characteristics of selected abscission materials.

CMN-pyrazole has been the most effective abscission chemical of those tested. It consistently loosened mature oranges without causing significant side effects (Table 1) such as abscission of young fruit or phytotoxicity (Whitney et al., 2000, Wilson et al., 1981). Because of uncertain toxicity, registration has not been pursued, but CMN-pyrazole is used as the standard in all of our experiments.

Metsulfuron methyl, a sulfonylurea compound, applied at concentrations as low as 1 to 2 mg·L^{-1} was shown to significantly loosen mature oranges for mechanical harvesting (Hartmond et al., 2000b). Defoliation and twig dieback was extensive at concentrations of 1, 2, and 4 mg·L^{-1}. In addition, metsulfuron methyl induced excessive drop of young fruit of 'Valencia' oranges, which severely reduced the following year's crop (Kender et al., 1999). Prosulfuron, a related compound, also loosened 'Hamlin' and 'Valencia' oranges at 30 to 45 mg·L^{-1}, but resulted in severe phytotoxicity and subsequent yield

Table 1. Response of citrus trees and fruit to selected abscission chemicals at optimum concentrations for loosening.

Chemical	Fruit loosening	Leaf drop	Peel injury	Phytotoxicity
CMN-pyrazole	+++[z]	-	+	-
Ethephon	++	+++	-	-
Metsulfuron methyl	+++	+++	+	+++
Prosulfuron	+++	+++	+	+++
Methyl jasmonate	++	++	-	+
LA-139	+++	+	-	
LA-167	++	+	-	++
LA-173	+	+	-	+
LA-174	+	+	-	+
LA-177	++	?	?	?

[z] +++ = high response;
+ = low response;
- = no response

reductions (Kender et al., 1998; Whitney, 1998). Evaluation of the sulfonylurea compounds has been discontinued by our laboratory.

Methyl jasmonate (MJ) was generally effective for citrus fruit loosening but at optimal concentrations caused substantial defoliation. In comparing MJ at concentrations ranging from 0 to 50 mM, increasing the concentration above 5 mM increased fruit abscission when applied directly to the abscission zone (AZ) (Hartmond et al., 2000c). In field experiments, solutions of 1, 5, 10, 20, or 100 mM methyl jasmonate were applied to 'Hamlin' and 'Valencia' orange trees as whole tree sprays. Solutions of 20 and 100 mM methyl jasmonate reduced the FDF and caused high defoliation, while 10 mM and less caused negligible phytotoxicity and lowered FDF.

A combination of CMN-pyrazole and MJ both at low concentrations induced fruit abscission without affecting leaf drop substantially (Kender at al., 2000a). Such an approach could possibly: 1) facilitate the EPA registration by lowering residues and toxicity, 2) lower cost of materials, and 3) reduce the risk of defoliation and peel burn.

Ethephon was erratic as a fruit abscission agent and caused severe defoliation (Kender et al., 2000b). Ethephon concentrations of 200 to 500 $mg \cdot L^{-1}$ were effective in loosening Hamlin oranges and 'Sunburst' and 'Robinson' tangerines. The addition of adjuvants increased the activity of ethephon at 500 ppm resulting in good fruit abscission but excessive defoliation. Calcium hydroxide, calcium acetate, and monopotassium-phosphate applied with ethephon did not reduce ethephon-induced defoliation. In all cases where ethephon caused significant fruit loosening, unacceptable defoliation resulted. Based on these studies, ethephon was not recommended for commercial use on oranges in Florida.

Potential new abscission chemicals. Several experimental chemicals exhibit fruit abscission activity. Among the most promising are compounds coded LA-139 and LA-177.

LA-139, the most effective new candidate abscission material, was tested in five separate field experiments on 'Hamlin' and 'Valencia' oranges. In general, LA-139 was similar to CMN-pyrazole in its fruit loosening ability and limited leaf drop, but at significantly higher concentrations. LA-177, an auxin transport inhibitor, alone and in combination with ethephon, induced fruit and leaf abscission in 'Valencia' oranges similar to CMN-pyrazole. Other experimental compounds demonstrating some abscission traits include LA-167, LA-173, and LA-174. A summary of responses to selected abscission chemicals that we evaluated for loosening of mature citrus fruit is presented in Table 1.

At present, CMN-pyrazole is the only abscission chemical ready for registration application as an aid for mechanical harvesting of citrus. The development of mechanical harvesters will no doubt continue at a rapid pace and will proceed with or without abscission materials. We are confident that effective abscission materials that meet our harvesting needs will emerge in the future so that we can integrate them into the harvest operation for a more efficient harvesting system.

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