Fruit Abscission and Leaf Drop in Citrus Cultivars Treated with Metsulfuron-methyl

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ADDITIONAL INDEX WORDS. oranges, grapefruit, tangerines, tangelos, tangors, fruit loosening, ethylene

SUMMARY. Fruit of 11 citrus cultivars were evaluated for their response to the experimental abscission material metsulfuron-methyl at 2 mg·L⁻¹ (ppm) active ingredient as an aid to mechanical or hand harvest. Cultivars evaluated included 'Ambersweet', 'Glen Navel', 'Hamlin', and 'Valencia' oranges [*Citrus sinensis* (L.) Osb.], 'Robinson' tangerine (Clementine x Orlando, *C. reticulata* Blanco), 'Sunburst' tangerine ['Robinson' x 'Osceola', *C. reticulata* x (*C. paradisi* Macf. x *C. reticulata*)], 'Murcott' and 'Temple' tangor (*C. reticulata* x *C. sinensis*), 'Orlando' tangelo (*C. reticulata* x *C. paradisi*), 'Ray Ruby', and 'Marsh' grapefruit (*C. paradisi*). Six of the 11 cultivars were effectively loosened by sprays of metsulfuron-methyl ('Hamlin', 'Valencia', 'Orlando', 'Murcott', 'Temple', and 'Ray Ruby'). Addition of an adjuvant (Kinetic, 0.125%) was necessary for abscission activity in fruit and leaves. Trees sprayed with metsulfuron-methyl in combination with an adjuvant had higher percent cumulative fruit drop, higher internal ethylene, and lower fruit detachment forces (FDF) than trees sprayed with metsulfuron-methyl alone. 'Sunburst' tangerine responded

poorly to the abscission material in the presence or absence of Kinetic. Leaf loss was greatest in trees sprayed with metsulfuron-methyl and adjuvant, intermediate in trees sprayed with metsulfuron-methyl alone, and least in control trees. Twig dieback was observed in trees of 'Valencia' orange and 'Marsh' grapefruit sprayed with metsulfuron-methyl. The peel of some cultivars had irregular coloration and developed pitted areas after harvest. Although metsulfuron-methyl is an effective abscission agent for mature citrus fruit, further work is needed to more accurately define conditions for its safe and dependable use.

Commercial mechanization of orange harvest was initiated in Florida over the past three harvest seasons (Brown, 1998). Trunk-shake and fruit catch systems are now used to harvest oranges for juice processing on a limited scale. Other types of mechanical harvesters are also being evaluated for commercial harvesting, namely canopy penetrators, foliage shakers, and air shakers. Although effective, trunk shakers are variable in their recovery of fruit and may remove from 60% to 95% of the fruit on a tree (Wilson, 1978). To improve the fruit removal process, a variety of abscission chemicals has been tested starting in the mid-1960s (Wilson, 1978). Several chemicals have successfully loosened oranges but for various reasons they were not registered (Kender, 1998).

A series of new abscission chemicals in the sulfonylurea and imidazolinone families have been reported to loosen citrus fruit without serious side effects (Wilcox and Taylor, 1996). Although prosulfuron (Peak; Novartis Crop Protection Inc., Greensboro, N.C.), a close relative of metsulfuron-methyl (Ally; DuPont, Wilmington, Del.), loosened 'Hamlin' oranges, it was erratic and unpredictable for inducing abscission of mature 'Valencia' oranges, a principal cultivar processed for juice in Florida (Kender et al., 1998). As a result, testing of prosulfuron was discontinued. In 1998, metsulfuron-methyl was extensively evaluated for its ability to loosen citrus fruit and aid mechanical harvesting. Although metsulfuron-methyl is intended for use on processing orange cultivars, other cultivars may also benefit. For example, loosening of tangerines, tangelos, tangors, fresh market orange, and

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Florida Agricultural Experiment Station journal series R-06565. We gratefully acknowledge the financial support of the Florida Department of Citrus to conduct this research and the excellent technical support of Angela Grant and Wu Houjiu. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper must hereby be marked *advertisement* solely to indicate this fact.

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Fig. 1. Effect of metsulfuron-methyl at 2 mg·L⁻¹ (ppm) a.i. on fruit detachment force (FDF) of 11 citrus cultivars following application without Kinetic on 21 Oct. 1997 (Group I), and with and without Kinetic on 12 Nov. 1997 (Group II), 29 Jan. 1998 (Group III), and 13 Feb. 1998 (Group IV). Bars indicate standard error of the mean. Control trees were sprayed with Kinetic in Groups II, III, and IV (1 kg = 2.2 lb).

grapefruit cultivars could ease hand harvest and reduce tearing of the peel and plugging the fruit. The objective of this study was to determine if metsulfuron-methyl could predictably induce fruit abscission in a wide range of citrus cultivars.

Materials and methods

Eleven citrus cultivars were treated with metsulfuron-methyl under field conditions at the Citrus Research and Education Center in Lake Alfred, Fla. in the 1997–98 harvest season. Seven-year-old trees growing in a Candler fine sand soil at a 4.5 × 6.0 m (15 × 20 ft) spacing were sprayed to incipient runoff at a rate of 5 L/tree (1.3 gal/tree) [1900 L·ha⁻¹ (200 gal/acre)] using an electric pump-

driven low-pressure sprayer (R&D Sprayers Inc., Opelousas, La.) equipped with a spray boom adjusted to the different tree heights [output of 3.3 L·min⁻¹ (0.87 gal/min)]. The cultivars were classified into four groups based on time of harvest and fruit maturity. Maturity as indicated by the Brix to acid ratio was determined measuring the sugar content (Brix) of the juice with a hand-held refractometer (Fisher Scientific, Pittsburgh, Pa.) and measuring titratable acid following standard juice analysis procedures (Wardowski et al., 1995).

Group I (early harvest). Applications of metsulfuron-methyl at 2 mg·L⁻¹ (ppm) a.i. without an adjuvant were made on 21 Oct. 1997. Cultivars included 'Ambersweet' and 'Glen Navel' oranges on 'Swingle' citrumelo [*C. paradisi* × *Poncirus trifoliata* (L.) Raf.] rootstock and 'Robinson' tangerine on Cleopatra mandarin (*C. reticulata*) rootstock. Mean Brix-acid ratios of the three cultivars on the date of application were 14.6, 16.8, and 15.2, respectively.

Group II. On 12 Nov. 1997, metsulfuron-methyl was applied at 2 mg·L⁻¹ a.i. with and without the addition of the nonionic, silicone-based adjuvant Kinetic (Setre Chemical Co.,

Memphis, Tenn.) at the rate of 0.125% to 'Sunburst' tangerine on 'Cleopatra' mandarin rootstock, and 'Orlando' tangelo and 'Hamlin' orange on 'Carrizo' citrange (*C. sinensis* × *Poncirus trifoliata*) rootstock. Mean Brix to acid ratios on the date of application were 10.7, 13.3, and 13.0, respectively.

Group III. On 29 Jan. 1998, metsulfuron-methyl at 2 mg·L⁻¹ a.i. with and without Kinetic adjuvant was applied to trees of 'Ray Ruby' grapefruit on Swingle citrumelo rootstock and 'Murcott' and 'Temple' tanger on Cleopatra mandarin rootstock. Mean Brix-acid ratios on the date of application were 10.5, 17.4, and 12.0, respectively.

Group IV (late harvest). 'Valencia' orange and 'Marsh' grapefruit on sour orange (*C. aurantium* L.) rootstock were treated with metsulfuron-methyl at 2 mg·L⁻¹ a.i. with Kinetic on 13 Feb. 1998. Mean Brix-acid ratios on the date of application were 12.1 and 6.7, respectively. Nine-year old 'Valencia' and 'Marsh' trees were grown in a separate block from the previous cultivars.

Unsprayed trees (Group I) or trees sprayed only with Kinetic at 0.125% (Groups II, III, IV) served as controls. Each treatment was applied to a single tree in each of three blocks (randomized complete-block design). The ground under and around each tree was cleared and fruit drop was counted every 3 to 4 d for 3 weeks. Leaf drop was observed and measured by weighing oven dried dropped leaves at the end of the experiment prior to harvest.

To determine fruit detachment force (FDF), 10 fruit from each tree were removed weekly by clipping the peduncle ≈3 cm (1.2 inches) from the point of attachment to the fruit. FDF was measured using a digital force gauge (Force Five; Wagner Instruments, Greenwich, Conn.) by pulling the fruit by hand parallel to the fruit axis until it separated from the peduncle.

To determine abscission related metabolic activity in the fruit, ethylene production was determined on three fruit from each cultivar of Group II on day 13. Internal air of fruit submerged in water was evacuated and the ethylene concentration was measured by gas chromatography (Burns et al., 1999). Peel disorders were scored visually and peel color was determined on day 14 on a 10 fruit sample of each cultivar using a chromometer (CR200; Minolta Co., Osaka, Japan).

Data were tested for treatment effects by analysis of variance, and treatment means were separated by Duncan's multiple range test at $P \leq 0.05$ or standard error (SE) using SAS statistical software (SAS Institute, Cary, N.C.).

Results

FRUIT LOOSENING AND FRUIT DROP. As recommended (Wilcox and Taylor, 1997; personal communication), we initially applied metsulfuron-methyl without an adjuvant in an attempt to avoid possible injury. However, poor reduction in FDF (Fig. 1) and fruit drop (Fig. 2) was observed in all cultivars in Group I without adjuvant. Later treatments to Group II through Group IV included 0.125% Kinetic, and FDF decreased and fruit drop increased over the 21 d period in all cultivars except 'Sunburst' tangerine (Figs. 1 and 2). In general, significant reductions in FDF were measured 7 d after metsulfuron-methyl application in the presence of the adjuvant. Significant increase in fruit drop was observed 10 d after application.

INTERNAL ETHYLENE CONCENTRATION. Internal ethylene was not detected in control fruit (Fig. 3) 13 d after application of the adjuvant alone. Fruit from trees treated with metsulfuron-methyl alone had increased internal ethylene concentration. 'Orlando' tangelo and 'Sunburst' tangerine had similar internal ethylene concentrations, and 'Hamlin' orange had significantly less. Application of metsulfuron-methyl with adjuvant markedly increased internal ethylene concentration in all three cultivars as compared to metsulfuron-methyl without adjuvant or to the control.

LEAF LOSS AND TWIG DIEBACK. Although metsulfuron-methyl was effective in loosening mature fruit, variable degrees of defoliation were observed depending on cultivar. Trees treated with metsulfuron-methyl alone generally had significantly more leaf drop than control trees in Groups I, II, and III (Table 1). Application of metsulfuron-methyl with an adjuvant to 'Ray Ruby' resulted in enhanced leaf loss when compared to trees treated with metsulfuron-methyl alone. Twig dieback, progressing distally from the apical bud, was pronounced in Group IV cultivars, 'Valencia' orange and 'Marsh' grapefruit. Twig dieback was not observed in cultivars of Groups I, II, and III (data not shown).

PEEL COLOR AND QUALITY. No effect of metsulfuron-methyl on peel color was observed (data not shown). However, some cultivars exhibited irregular patterns of yellow and orange coloration on the calyx end and shoulders of fruit 8 d after application. The intensity of this coloration effect was cultivar dependent and greater when metsulfuron-methyl was applied with adjuvant. Three to 4 d after harvest, yellow areas became soft and developed superficial peel pitting. Further color development was halted in these yellow areas. Fruit of control trees sprayed with Kinetic alone did not develop this undesirable coloration effect or peel pitting throughout the duration of the study. The average Brix-acid ratio of juice was lower in 'Sunburst' (10.7) than in any other orange cultivar. Ratios of the remaining cultivars were above 12.0 for oranges, 15.2 for tangerines, and 6.7 for grapefruit.

Discussion

Metsulfuron-methyl was an effective abscission agent for mature fruit of several cultivars important to the Florida citrus industry. Although Wilson (1973) reported that 2.2 kg (5 lb)

was the FDF threshold orange fruit should attain for efficient mechanical harvesting, our preliminary studies have demonstrated that a reduction in FDF to ≈ 4.5 kg (10 lb) is sufficient to efficiently harvest citrus fruit with trunk shakers (Kender et al., 1998). This discrepancy in target FDF values is largely due to redesigned trunk shakers that deliver the necessary shaking force more directly and efficiently (Brown, 1998). Of the 11 cultivars tested, 6 had FDF forces of ≤ 4.5 kg. Two of these cultivars, 'Hamlin' and 'Valencia' oranges, have significantly large acreages in Florida and are considered suitable candidates for abscission agents coupled with mechanical harvesting technologies. Fruit of both cultivars are largely destined for the

Fig. 2. Effect of metsulfuron-methyl on the cumulative percent fruit drop of 11 citrus cultivars after application of 2 mg·L⁻¹ (ppm) a.i. without Kinetic on 21 Oct. 1997 (Group I), with and without Kinetic on 12 Nov. 1997 (Group II), 29 Jan. 1998 (Group III), and 13 Feb. 1998 (Group IV). Bars indicated standard error of the mean. Control trees were sprayed with Kinetic in Groups II, III, and IV.

Fig. 3. Internal ethylene concentration of 'Orlando' tangelo, 'Sunburst' tangerine, and 'Hamlin' orange (Group II) in response to 2 mg·L⁻¹ (ppm) a.i. metsulfuron-methyl with and without the adjuvant Kinetic or with the adjuvant alone (0.125% v/v). Fruit were sampled 13 d after application. Vertical lines indicate SE; n.d. = none detected (1 µL·kg⁻¹ = 0.45 ppm/lb).

processed market where cosmetic peel injuries are not a problem. 'Sunburst' did not respond to metsulfuron-methyl despite significant internal ethylene accumulation, possibly because fruit were not of sufficient maturity.

Addition of an adjuvant was necessary to achieve the desired fruit loosening effect in most cultivars examined. Adjuvants enhance uptake of compounds such as plant growth regulators and herbicides. The increase in fruit drop, internal ethylene concentration, and the reduction in FDF in trees treated with metsulfuron-methyl and adjuvant compared with those sprayed with metsulfuron-methyl alone, suggests that more active ingredient penetrated the cuticle of sprayed surfaces. Unfortunately, leaf drop was also enhanced when the adjuvant was added to the spray mixture. Twig dieback was a significant problem in trees of 'Valencia' orange and 'Marsh' grapefruit, but we could not determine whether these cultivars were unusually

sensitive to metsulfuron-methyl or whether twig dieback was associated with a period of active tree growth the trees were in at the time of application. Metsulfuron-methyl inhibits acetolactate synthase, a key enzyme in branched chain amino acid biosynthesis (LaRossa and Schloss, 1984). Plants treated with metsulfuron-methyl have greatly altered amino acid metabolism marked by reduced levels of valine, leucine and isoleucine (Moberg and

Cross, 1990). Twig dieback could be the result of insufficient quantity or quality of amino acids necessary to sustain the growth rate of the apical meristem.

In conclusion, we have demonstrated that metsulfuron-methyl is an effective fruit loosening agent in most cultivars examined in this study. If metsulfuron-methyl were to be adopted for commercial use, additional research will be needed to identify the amount of active ingredient, application rate and timing necessary to balance fruit loosening with the deleterious effects of defoliation and twig dieback. Taylor et al. (1998) and Wilcox and Taylor (1997) reported no phytotoxicity associated with metsulfuron-methyl applications in citrus. In their work, metsulfuron-methyl was applied in combination with a nonsilicone based surfactant, suggesting that differences in uptake of active ingredient could account for discrepancies between their studies and ours. However, citrus trees in our follow-up screening work with metsulfuron-methyl in combination with silicone based nonionic surfactants continue to display phytotoxicity to the compound. Our future work will focus on 1) defining a more appropriate amount of active ingredient and rate of application for citrus and 2) the effect of fruit maturity on citrus abscission with metsulfuron-methyl and related compounds.

Table 1. Effect of metsulfuron-methyl applied at 2 mg·L⁻¹ (ppm) a.i. and 2 mg·L⁻¹ plus kinetic adjuvant (2 mg·L⁻¹ + K) on leaf drop of 11 citrus cultivars 21 d after application, 1997-98 (28.35 g = 1 oz).

Cultivar/treatments	Leaf drop (g dry wt)		
	Control	2 mg·L ⁻¹	2 mg·L ⁻¹ + K
Group I			
Ambersweet	3.3 b ^z	31.3 a	NA ^y
Glen Navel	9.8 b	31.3 a	NA
Robinson	27.2 a	65.1 a	NA
Group II			
Sunburst	31.1 a	69.5 a	80.5 a
Orlando	2.5 a	12.1 a	26.2 a
Hamlin	0.0 b	4.6 ab	22.6 a
Group III			
Ray Ruby	132.0 b	153.8 b	409.0 a
Murcott	5.9 b	374.2 ab	1123.3 a
Temple	38.8 a	24.7 a	143.6 a
Group IV			
Valencia	655.3 a	NA	835.3 a
Marsh	509.3 b	NA	1082.3 a

^zMean separation within rows by Duncan's multiple range test, *P* = 0.05.

^yNA = not applicable.

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