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Continuing the Search for an Effective Preharvest Fungicide with Residual Posthavest Decay Control for Florida Fresh Citrus

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Three studies were conducted in 2010 on 'Sunburst' tangerine and 'Marsh' or 'Ruby Red' grapefruit to evaluate the effectiveness of applying fungicides before harvest, on reducing postharvest fruit decay. Commercially mature fruit were harvested twice, between 1 and 8 days after administering the field treatments, degreened for 2 days with 5 ppm ethylene at 85 °F (29 °C) and 90% relative humidity, and then stored at near ambient conditions around 77 °F (25 °C). Relative humidity was maintained between 80% and 90% during storage. As in previous years, preharvest application of benomyl (Benlate) or thiophanate-methyl (Topsin) resulted in the best decay control, usually resulting in at least 66% less decay after storage compared to the control (water-dipped) fruit. Unfortunately, these two materials are no longer labeled for citrus. Results with materials containing fludioxonil (Switch and Scholar) were mixed, with significantly less postharvest decay developing in some tests, and no effect in others. Even though materials containing fludioxonil occasionally reduced postharvest decay, they do not appear to be consistent replacements for benomyl or thiophanate-methyl.

Postharvest control of decay is a major challenge for fresh citrus growers and shippers. Postharvest losses due to decay are not only costly, but also diminish domestic and export consumer confidence in product quality. Unlike Mediterranean climates where penicillium (*Penicillium* spp.) mold is the most important cause of citrus decay, stem-end rot (SER; primarily *Lasiodiplodia theobromae*) is usually the most common cause of postharvest decay in fresh Florida citrus (Brown and Albrigo, 1970). Postharvest fungicides are used in most commercial packinghouses to control these and other decay organisms. However, preharvest application of benomyl, and later thiophanate-methyl, effectively reduced fruit decay throughout harvest, packing and marketing operations, and provided growers and shippers an important management option for postharvest decay control (Brown and Albrigo, 1970, 1972; Ritenour and Timmer, 2007; Ritenour et al., 2004; Salvatore and Ritenour, 2007; Zhang and Timmer, 2007). Both materials break down to form carbendazim, which is the primary source of fungicidal activity (Clemons and Sisler, 1969; Saleh and Negm, 1980). Preharvest use of these fungicides decreased postharvest decay during times of high decay pressure and greatly retarded fungal development between harvest and packing operations, which is especially important when warm weather retards natural color development and degreening of the fruit with ethylene is required. Ethylene exposure and the warm [up to 85 °F (29.4 °C)], humid (~95% relative humidity) conditions during degreening increase the incidence of diplodia SER and anthracnose (Brown and Barmore, 1976; Grierson and Newhall, 1955). While fungicide drenches before degreening are common, early season fruit peel may be injured by the drench chemicals (Ritenour and Dou, 2000).

Effective preharvest fungicides with continuing postharvest decay control is an important management option for the fresh citrus industry. The manufacture and sale of benomyl (Benlate; Dupont, Wilmington, DE) was discontinued in late 2001. Preharvest application of thiophanate-methyl (Topsin; Cerexagri, Inc., King of Prussia, PA) for postharvest stem-end rot control was allowed under an EPA Section 18 emergency use exemption from Feb. 2004 until Mar. 2009 when they were discontinued as efforts ceased to add citrus to the Topsin label. There is now no known effective preharvest treatment with residual postharvest decay control. Alternatives need to be identified and registered for commercial use.

Fludioxonil is a relatively new fungicide with a mode of action that is effective against postharvest diplodia SER (Zhang, 2007). Because traditional postharvest fungicides (thiabendazole, Imazalil, and sodium-o-phenylphenate) continue to be effective in Florida with very little fungal resistance developed, postharvest use of fludioxonil remains minimal in the state. The current studies were conducted to evaluate the effectiveness of fludioxonil-based fungicides, applied preharvest, for reducing postharvest fruit decay in fresh Florida citrus.

Materials and Methods

Three studies were conducted in 2010 on 'Sunburst' tangerine and 'Marsh' or 'Ruby Red' grapefruit to evaluate the effectiveness of applying fungicides before harvest, on reducing postharvest

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Table 1. Common name, trade name, percent active ingredient, manufacturing company, and rate applied for the materials tested assuming a 250 gal per acre spray volume.

Generic name	Trade name	Active ingredient (%)	Company, city, state	Rate applied
Benomyl	Benlate SP	50.0	DUPONT, Wilmington, DE	2 lb/acre (2.2 kg·ha^{-1})
Fludioxonil	Scholar SC	20.4	Syngenta, Greensboro, NC	14.6 fl oz/acre (1.1 L·ha^{-1})
Fludioxonil + cyprodinil	Switch 62.5 WG	25.0/37.5	Syngenta, Greensboro, NC	14 fl oz/acre (1.0 L·ha^{-1})
Thiophanate-methyl	Topsin M WSB	70.0	United Phosphorus, Inc., King of Prussia, PA	2 lb/acre (2.2 kg·ha^{-1})

fruit decay. Table 1 lists the names, percent active ingredient, manufacturer, and rate of application for the materials used. All materials were applied at the manufacturer's suggested label rate assuming a 250 gal per acre spray volume. The experimental plots were located in Indian River and St. Lucie counties of Florida. Eighty individual fruit per treatment were flagged in a randomized block design on 20 trees, with four replicates per tree. Each rep was grouped within a quadrant of each tree. Individual fruit were briefly, but completely submerged (dipped) into a fungicide solution or water (control). Outer-canopy fruit located between 0.5 and 2.5 m above the ground were chosen so that no other fruit were located below those treated and no residual solution dripped onto underlying fruit.

Commercially mature fruit were harvested 1 or 2 d, and 7 or 8 d after application, degreened with 5 ppm ethylene at 85 °F (29 °C) and 90% relative humidity (RH) for 2 d, and then stored at near ambient conditions of around 77 °F (25 °C) and 80% to 90% RH. Decay from natural infections and the development of physiological disorders were evaluated during storage. The type of decay present on each fruit was visually identified, with almost all being caused by diplodia SER (*Lasiodiplodia theobromae*). Cumulative results throughout the storage period are reported.

Data were transformed to arcsine values and analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, NC). When differences were significant ($P \leq 0.05$), individual treatment means were separated using Duncan's multiple range tests ($P = 0.05$). Means presented are untransformed values.

Results and Discussion

In the present studies, different fungicides were evaluated over three experiments on Florida tangerines and grapefruit for their ability to reduce both postharvest decay and physiological disorders. Physiological disorders were rare, with peel breakdown occurring only in grapefruit after 50 d of storage, just prior to terminating the experiments. There were generally no significant differences in physiological disorders, except for only the first 'Ruby Red' harvest where control fruit and those treated with fludioxonil + cyprodinil (Switch) developed significantly more peel breakdown than other treatments (data not shown). Peel breakdown also occurred in the second harvest of both grapefruit cultivars, but there were no significant differences. Oleocellosis (oil spotting) also developed soon after the first harvest of 'Ruby Red' grapefruit, with more tending to show up in control and benomyl treated fruit (data not shown). Fungicidal effects on oleocellosis have not been reported in the past and it is unclear why they would significantly affect the disorder in this case. Oleocellosis occurs when oil glands within very turgid fruit are easily burst during harvest and handling, releasing oil that is toxic to the surrounding cells (Wardowski et al., 1997). While fruit with oleocellosis are more likely to decay, fungicides are not thought to influence the occurrence of the disorder itself. Thus, it is believed that this was a spurious finding of significance.

As expected, postharvest decay was most affected by preharvest fungicides. Commercially, SER usually causes the greatest postharvest losses in fresh Florida citrus fruit (Brown and Albrigo, 1970). During the present studies, almost all decay was a result of stem-end rot (SER; primarily Diplodia). Therefore, the primary indicator of success for these compounds was their ability to reduce SER and increase the total amount of healthy fruit after storage compared to the control.

Significant reductions in total decay were observed in all three experiments, although for grapefruit, significant differences occurred only in fruit collected during the first harvest (Table 2). Preharvest application of benomyl (Benlate) or thiophanate-methyl (Topsin) was most consistent in reducing postharvest decay. The decay severity index of benomyl or thiophanate-methyl treated fruit were at least 66% less than the controls. Even when differences were not significant, these treatments still tended to have lower decay indexes than the control. While the current harvests took place a maximum of 8 d after application, previous research showed that benomyl and thiophanate-methyl effectively controlled postharvest decay even when harvests occur up to 3 weeks after application (Ritenour et al., 2004; Salvatore and Ritenour, 2007) and that relative efficacy did not change during this interval. The lack of significant differences for the second grapefruit harvests are likely related to low decay incidence in 'Marsh' grapefruit, and increased variability of 'Ruby Red' grapefruit due to peel breakdown. In addition, 0.24 inch (6.1 mm) of rain fell on 3 and 4 Nov. 2010, between the first and second grapefruit harvests. It is unclear what, if any, effect the rain might have had on the results. Ritenour et al. (2004) reported rain soon after a preharvest benomyl application on 'Sunburst' tangerines, but still recorded significant reductions in postharvest decay. The only other time rain fell during the experiments was 0.01 inch (0.25 mm) on 20 Oct. 2010. The storage experiments were terminated when healthy fruit dropped to about 50%, or when the fruit lost moisture and became unacceptably soft after holding more than 50 d under these relatively warm storage temperatures.

Fludioxonil (Scholar) or fludioxonil + cyprodinil (Switch) significantly reduced postharvest decay compared to the control in the first harvest of 'Marsh' grapefruit, but only fludioxonil alone significantly reduced decay in the first harvest of 'Ruby Red' grapefruit (Table 2). The lack of significant decay reduction for the second grapefruit harvests is not surprising given that benomyl and thiophanate-methyl were not effective either, but the lack of significant decay control in 'Sunburst' suggests that the performance of these fungicides may not be consistent under the conditions specified.

Table 2. Rating of fruit showing any decay symptoms following preharvest application of different fungicides and postharvest storage for the indicated durations at 77 °F (25 °C) with about 90% relative humidity. Each fruit was evaluated for decay severity on a 0 (healthy) to 10 (100% of the fruit surface showing decay) scale. Results are from different citrus varieties treated and evaluated between Oct. and Dec. 2010.

	Sunburst 18 Oct. 2010[z]		Marsh 28 Oct. 2010		Ruby Red 1 Nov. 2010	
Compound	20 Oct.[y] 33 d[x]	25 Oct. 28 d	29 Oct. 42 d	5 Nov. 55 d	3 Nov. 50 d	9 Nov. 57 d
Control	3.3 a[w]	4.5 a	1.5 a	0.8	1.5 a	1.0
Switch	2.1 a	5.9 a	0.5 b	0.0	1.0 ab	1.8
Scholar	3.5 a	5.2 a	0.3 b	0.5	0.1 b	1.5
Benlate	0.5 b	0.4 b	0.0 b	0.5	0.3 b	0.0
Topsin-M	0.2 b	0.5 b	0.5 b	0.0	0.0 b	0.8
Significance	***	***	**	NS	***	NS

[z]Application date.
[y]Harvest date.
[x]Days after harvest for final decay evaluation.
[w]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS, **, ***]Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

Table 3. Percentage of healthy fruit following preharvest application of different fungicides and postharvest storage for the indicated durations at 77 °F (25 °C) with ~90% relative humidity. Results are from different citrus varieties treated and evaluated between Oct. and Dec. 2010.

	Sunburst 18 Oct. 2010[z]		Marsh 28 Oct. 2010		Ruby Red 1 Nov. 2010	
Compound	20 Oct.[y] 33 d[x]	25 Oct. 28 d	29 Oct. 42 d	5 Nov. 55 d	3 Nov. 50 d	9 Nov. 57 d
Control	57.5 b[w]	50.0 b	85.0 b	90.0	40.0 c	77.5
Switch	72.5 ab	37.5 b	95.0 ab	95.0	67.5 b	69.2
Scholar	60.0 b	40.0 b	95.0 ab	90.0	72.5 ab	82.1
Benlate	82.5 a	90.0 a	97.5 a	92.5	62.5 b	77.5
Topsin-M	87.5 a	92.5 a	97.5 a	95.0	90.0 a	82.1
Significance	**	***	*	NS	***	NS

[z]Application date.
[y]Harvest date.
[x]Days after harvest for final evaluation.
[w]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS,*, **, ***]Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Taking into account all decay and physiological disorders, preharvest application of benomyl or thiophanate-methyl most often resulted in significantly more healthy fruit after storage than the control (Table 3). Again, treatment differences for the second grapefruit harvests were not significant. While fruit treated with fludioxonil + cyprodinil had significantly more healthy fruit than the control in the first harvest of 'Ruby Red' grapefruit, they were not significantly different for the other harvest or experiments.

Benomyl and thiophanate-methyl served as important tools for effective postharvest decay control while they were available (Ritenour et al., 2004; Salvatore and Ritenour, 2007; Zhang and Timmer, 2007). Searches for replacement preharvest materials providing effective residual postharvest decay control under Florida conditions have been unsuccessful so far. Previous studies showed that products such as acibenzolar-S-methyl, azoxystrobin, copper hydroxide, fenbuconazole, fosetyl-Al, or phosphorous acid (Nutri-Phite) are not effective in this regard (Ritenour et al., 2004; Salvatore and Ritenour, 2007). Occasionally, preharvest use of pyraclostrobin significantly reduced postharvest SER and increased the percentage of healthy fruit, but results have not been consistent or as effective as benomyl or thiophanate-methyl (Ritenour et al., 2004; Salvatore and Ritenour, 2007; Zhang and Timmer, 2007). The current study suggests that fludioxonil-based fungicides may also have some residual postharvest decay control activity, but that such control is not as great or consistent as benomyl or thiophanate-methyl.

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