Assessing the Efficacy of Preharvest Fungicide Applications to Control Postharvest Diseases of Florida Citrus

Mark A. Ritenour^{1,2}

Robert R. Pelosi,¹

Michael S. Burton,¹

Eddie W. Stover,¹

Huating Dou,³ and

T. Gregory McCollum⁴

ADDITIONAL INDEX WORDS. benomyl, thiophanate-methyl, pyraclostrobin, acibenzolar-S-methyl, azoxystrobin, fosetyl-Al, fenbuconazole, copper hydroxide, phosphorous acid, ferbam, stem-end rot, *Diplodia natalensis*, anthracnose, *Colletotrichum gloeosporioides*, green mold, *Penicillium digitatum*

SUMMARY. Studies were conducted between November 1999 and April 2003 to evaluate the effectiveness of compounds applied preharvest for reducing postharvest decay on many types of fresh citrus (*Citrus* spp.) fruit. Commercially mature fruit were harvested two different times after the compounds were applied, degreened when necessary, washed, waxed (without fungicide), and then stored at 50 °F (10.0 °C) with 90% relative humidity. Compared to control (unsprayed) fruit, preharvest application of benomyl or thiophanate-methyl resulted in

significantly ($P < 0.05$) less decay of citrus fruit after storage in nine out of ten experiments, often reducing decay by about half. In one experiment, pyraclostrobin and phosphorous acid also significantly decreased total decay by 29% and 36%, respectively, after storage compared to the control. Only benomyl and thiophanate-methyl significantly reduced stem-end rot (SER; primarily *Diplodia natalensis* or *Phomopsis citri*) after storage, with an average of 65% less decay compared to the control. Though benomyl significantly reduced anthracnose (*Colletotrichum gloeosporioides*) in two of four tests with substantial (>20%) infection and phosphorous acid significantly reduced it once, thiophanate-methyl did not significantly reduce the incidence of anthracnose postharvest. The data suggests that preharvest application of thiophanate-methyl may reduce postharvest SER and total decay similar to preharvest benomyl treatments.

Effective postharvest decay control is critically important when marketing fresh citrus, especially with the extended shipping distances and storage durations often required to successfully market the fruit. Unlike Mediterranean climates where penicillium (*Penicillium* spp.) mold is the most important cause of citrus decay, SER often causes the greatest postharvest losses in fresh Florida citrus (Brown and Albrigo, 1970). Decay due to anthracnose can also be severe, especially in early-season tangerines (Brown, 1978). As part of an integrated approach to decay control, postharvest fungicides are used in most packinghouses. In addition, preharvest application of benomyl, with its ability to reduce fruit decay through harvest, packing and marketing operations, has provided an important management option for growers and shippers (Brown and Albrigo, 1970, 1972). Preharvest use of benomyl decreases postharvest decay during times of high decay pressure and may allow for the use of fewer postharvest fungicides. Furthermore, it can greatly retard decay 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* stem-

end rot 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). Thus, an effective preharvest fungicide with continuing postharvest decay control is an important management option for the fresh citrus industry.

With the constant threats of losing currently available fungicides and development of fungicide resistance in decay-causing organisms (McDonald et al., 1979), there is also a need to expand and diversify decay control options for citrus. The discontinued manufacturing and sale of benomyl (Benlate; Dupont, Wilmington, Del.) in late 2001—currently the only registered preharvest fungicide for postharvest decay control—underscores this importance. After current, scarce inventories of this product are exhausted, there will be no effective preharvest fungicide for the control of postharvest decay on fresh citrus. Alternatives need to be identified and registered for commercial use.

The current studies were conducted to evaluate the effectiveness of compounds applied preharvest for reducing postharvest decay in fresh Florida citrus fruit. In addition, fruit were harvested at different times after application to evaluate how harvest delays might affect decay suppression.

Materials and methods

Field trials were conducted between Fall 1999 and Spring 2003 on seven different citrus cultivars to test the ability of different preharvest-applied compounds to provide continuing suppression of fruit decay during harvest, postharvest handling and storage. Experimental plots were established in commercial citrus groves in the Fort Pierce, Fla. area and at the University of Florida Indian River Research and Education Center in Fort Pierce, Fla. Table 1 lists the common and trade names of the compounds tested, the percentage of active ingredient, the manufacturers of the compounds, and the rates of each compound applied. In all, 11 different products were evaluated.

Tests were conducted on 'Sunburst' tangerines (*Citrus reticulata*) three times, on 'Marsh' grapefruit (*C. paradisi*) twice, and on 'Ruby Red' grapefruit, 'Fallglo' tangerines, 'Murcott' tangor (*C. reticulata* × *C. sinensis*), and 'Valencia' and navel oranges (*C.*

This research was supported by the Florida Agricultural Experiment Station, and approved for publication as journal series R-09554. The use of trade names in this publication does not imply endorsement by the University of Florida Institute of Food and Agricultural Sciences of the products nor criticism of similar ones not mentioned.

¹University of Florida-IFAS, Indian River Research and Education Center, Ft. Pierce, FL 34945-3138.

²To whom reprints should be requested; e-mail: mritenour@ifas.ufl.edu.

³Florida Department of Citrus, Citrus Research and Education Center, 700 Experiment Station Road, Lake Alfred, FL 33850-2299.

⁴United States Department of Agriculture, Agricultural Research Service, U.S. Horticultural Research Laboratory, 2001 S. Rock Rd., Fort Pierce, FL 34945.

Table 1. Common names of each compound tested, their corresponding trade name, percentage of active ingredient, manufacturer, and preharvest application rates. The spray volume for all treatment applications was 125 gal/acre (1169.2 L·ha⁻¹).

Generic name	Trade name	Active ingredient (%)	Company, City, State/Country	Rate applied
Ferbam	Ferbam Granuflo	76.0	UCB Cehmicals Corp., Smyrna, Ga.	8 lb/acre (9.0 kg·ha ⁻¹)
Phosphorous acid (nutritional)	Nutri-Phite (0N-16.1P-0K) ^z	40.0	Biagro Western Sales, Inc., Visalia, Calif.	4 pt/acre (4.7 L·ha ⁻¹)
Phosphorous acid (fungicide)	Phostrol	53.6	AGTROL International, Houston, Texas	4 pt/acre (4.7 L·ha ⁻¹)
Copper hydroxide	Kocide DF	61.4	Griffin, Valdosta, Ga.	4 lb/acre (4.5 kg·ha ⁻¹) metallic copper
Fenbuconazole	Enable 2F	23.5	Dow AgroSciences, Indianapolis, Ind.	8 fl oz/acre (0.6 L·ha ⁻¹)
Fosetyl AL	Aliette WDG	80.0	Bayer CropScience, Montvale, N.J.	5 lb/acre (5.6 kg·ha ⁻¹)
Azoxystrobin	Abound	22.9	Syngenta, Greensboro, N.C.	16 fl oz/acre (1.2 L·ha ⁻¹)
Acibenzolar-S-methyl	Actigard 50 WG ^y	50.0	Syngenta, Greensboro, N.C.	1.8 oz/acre [50 g/acre (123.6 g·ha ⁻¹)]
Pyraclostrobin	Headline	23.6	BASF, Mount Olive, N.J.	16 fl oz/acre (1.2 L·ha ⁻¹)
Benomyl	Benlate SP	50.0	DUPONT, Wilmington, Del.	2 lb/acre (2.2 kg·ha ⁻¹)
Thiophanate-methyl	Topsin M WSB	70.0	Cerexagri, Inc., King of Prussia, Pa.	2 lb/acre (2.2 kg·ha ⁻¹)

^zNot a fungicide.

^yNot registered for use on citrus.

Table 2. Percentage of fruit with any visible decay symptoms following preharvest application of different compounds and postharvest storage at 50 °F (10.0 °C) with 90% relative humidity. Results are from different citrus varieties treated and harvested between November 1999 and June 2001.

Compound	'Sunburst'	'Fallglo'	'Sunburst'	'Marsh'
	4 Nov. 1999 ^z	18 Sept. 2000	11 Dec. 2000	16 Mar. 2001
	23 Nov. ^y	20 Sept. 9 Oct.	13 Dec. 21 Dec.	19 Mar. 2 Apr.
	58 d ^x	34 d 78 d	77 d 41 d	86 d 79 d
Control	45.4 a ^w	48.2 79.9	18.8 a 21.2 a	34.1 ab 37.8 ab
Ferbam	46.7 a	---	---	---
Acibenzolar-S-Methyl	---	65.5 78.8	16.2 a 15.6 a	51.2 a 45.1 a
Fenbuconazole	51.6 a	50.6 76.2	18.7 a 24.3 a	37.0 ab 46.0 a
Fosetyl AL	60.3 a	50.2 77.6	16.4 a 14.1 ab	30.0 b 34.1 abc
Phosphorous acid	29.3 ab	44.7 84.8	20.9 a 36.4 a	51.6 a 22.0 bc
Copper hydroxide	39.6 a	48.2 78.7	13.3 a 37.9 a	40.6 ab 26.0 bc
Azoxystrobin	---	39.7 70.2	13.5 a 25.5 a	37.2 ab 38.0 ab
Benomyl	6.2 b	40.1 74.0	3.0 b 1.4 b	2.9 c 18.2 c
Significance	*	NS NS	** *	*** **

^zApplication date.

^yHarvest date.

^xDays after harvest for final decay evaluation.

^wValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

ns,*,***,****Non-significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

sinensis) once each. In all but one spray application, the compounds were applied in the morning with wind speeds ≤ 5 miles/h (8.0 km·h⁻¹) and no rain on the day of application. The exception occurred when rain started to fall after the 'Sunburst' tangerines were sprayed on 11 Dec. 2000 and the wind increased with gusts up to about 10 miles/h (16.1 km·h⁻¹). All materials were applied using an air-blast sprayer with a volume of 125 gal/acre (1169.2 L·ha⁻¹). Each replicate consisted of one to three healthy trees and there were four replicates per treatment before April 2002, and five replications per treatment after that. Field plots were arranged in a completely randomized design. Control trees were not sprayed.

From November 1999 to April 2002, commercially mature fruit were harvested about 2 d and then 2 weeks

after chemical application. During the 2002–03 season, fruit were harvested 1 and 3 weeks after application to compare the effectiveness of benomyl and thiophanate-methyl under extended harvest delays. It is recommended that fruit be harvested within 3 weeks of benomyl application (Wardowski and Brown, 1993). In two instances, fruit from one of the two harvests were lost due to unforeseen circumstances. Representative samples of about 50 to 60 fruit were harvested from all trees within a replicate, placed into fiberboard cartons and transported to the laboratory where they were washed with an alkali surfactant solution (Fruit Cleaner 395, FMC Corporation, Lakeland, Fla.), coated with a shellac wax (Sta-Fresh 590 HS, FMC Corp., Lakeland, Fla.), and then stored at 50 °F with high ($\approx 90\%$) relative humidity (RH). Only 'Fallglo' tanger-

ines treated September 2000 and navel oranges treated October 2002 had not developed adequate natural color and were degreened overnight with 5 ppm ($\mu\text{L}\cdot\text{L}^{-1}$) ethylene at 85 °F with 90% RH. Except for the absence of postharvest fungicide applications, postharvest handling of the above fruit simulated commercial practices in Florida.

Decay from natural infections and the development of physiological disorders were evaluated during storage. The type of decay occurring on each fruit was visually identified as either SER, green mold (*Penicillium digitatum*), or anthracnose. Other decays such as sour rot (*Geotrichum citri-aurantii*) were only rarely observed, but could be present on up to 18% of the fruit. A single fruit may exhibit more than one type of decay and/or physiological disorder. The total percentage of fruit with any visible decay was also recorded. Fruit were evaluated about every 28 d during storage and the experiments terminated after significant decay had developed. Cumulative results throughout the storage period are reported and total days in storage are reported in Tables 2 and 3. At each evaluation, decayed fruit were removed before placing the fruit back into storage.

Data were transformed to arcsine values and analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, N.C.). 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 compounds (mostly preharvest fungicides registered for use on citrus) were evaluated over more than three seasons

Table 3. Percentage of fruit with any visible decay symptoms following preharvest application of different compounds and postharvest storage at 50 °F (10.0 °C) with 90% relative humidity. Results are from different citrus varieties treated and evaluated between December 2001 and April 2003.

Compound	'Sunburst'		'Marsh'		'Valencia'		Navel	'Ruby Red'		'Murcott'	
	4 Dec. 2001 ^z		25 Feb. 2002		23 Apr. 2002		21 Oct. 2002	14 Nov. 2002		4 Feb. 2003	
	6 Dec. ^y	18 Dec.	27 Feb.	11 Mar.	25 Apr.	6 May.	28 Oct.	21 Nov.	5 Dec.	11 Feb.	25 Feb.
	81 d ^x	84 d	118 d	123 d	133 d	122 d	67 d	123 d	109 d	59 d	56 d
Control	60.0	71.8 a ^w	41.7 a	31.8 a	30.5	60.2 a	40.5 a	20.3 a	10.7	11.4	23.3 a
Pyraclostrobin	51.8	50.8 b	36.5 ab	17.7 ab	28.3	48.2 a	---	---	---	---	---
Phosphorous acid	46.4	45.9 b	29.1 ab	16.7 ab	29.9	47.2 a	---	---	---	---	---
Thiophanate methyl	45.1	47.2 b	14.1 c	6.1 b	17.2	15.0 b	19.4 b	7.6 b	4.7	9.0	3.4 b
Benomyl	42.4	41.3 b	22.5 bc	14.2 ab	12.3	14.0 b	17.8 b	9.8 b	4.9	8.4	4.8 b
Significance	NS	*	*	*	NS	**	**	**	NS	NS	**

^zApplication date.

^yHarvest date.

^wDays after harvest for final decay evaluation.

^xValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^{ns,*,**}Nonsignificant at $P \leq 0.05$ or 0.01, respectively.

(Table 1). Ferbam, phosphorous acid, copper hydroxide, fosetyl Al, and benomyl have been available to commercial citrus growers for years. Others, such as fenbuconazole, azoxystrobin, pyraclostrobin, and thiophanate methyl are relatively new. Acibenzolar-S-methyl (Actigard; Syngenta, Greensboro, N.C.) is reported to be an activator of plant defenses (Romero et al., 2001) that has been used for vegetables, but is not registered for use in citrus. Phosphorous acid is labeled as a fungicide (Phostrol; AGTROL International, Houston, Texas) or used as a nutritional product (Nutri-Phite; Biagro Western Sales, Inc., Visalia, Calif.).

After initial tests using ferbam, fenbuconazole, fosetyl-Al, phosphorous acid (Nutri-Phite), copper hydroxide, acibenzolar-S-methyl, azoxystrobin, and benomyl, the lack of significant results for decay control from all except benomyl (Table 2) led to discontinuing tests on most of those compounds. Thiophanate-methyl, pyraclostrobin, and phosphorous acid (from a different source—Phostrol) were added for the 2001–02 trials. Because benomyl and thiophanate-methyl significantly reduced postharvest decay most often, these fungicides were tested again during the 2002–03 season (Table 3).

After field application, harvest, simulated commercial handling, and storage at 50 °F, significant reductions in total decay were observed in nine of ten experiments (Tables 2 and 3). Preharvest application of benomyl or thiophanate-methyl were the most consistent in reducing postharvest decay. Rates of postharvest decay among benomyl or thiophanate-methyl treated

Table 4. Percentage of fruit with stem-end rot (SER) following preharvest application of different compounds and postharvest storage at 50 °F (10.0 °C) with 90% relative humidity. Results are from different citrus varieties treated and harvested between November 1999 and June 2001.

Compound	'Sunburst'		'Fallglo'		'Sunburst'		'Marsh'	
	4 Nov. 1999 ^z		18 Sept. 2000		11 Dec. 2000		16 Mar. 2001	
	23 Nov. ^y	20 Sept.	9 Oct.	13 Dec.	21 Dec.	19 Mar.	2 Apr.	
Control	11.3	0.5	63.8	16.8 a ^x	10.4 b	34.6 a	37.3 ab	
Ferbam	11.6	---	---	---	---	---	---	
Acibenzolar-S-Methyl	---	0.9	73.2	15.3 a	8.8 b	49.2 a	42.4 a	
Fenbuconazole	18.8	0.0	65.6	15.8 a	14.1 b	36.5 a	45.5 a	
Fosetyl AL	14.1	0.4	57.6	14.0 a	7.2 b	30.0 a	31.1 abc	
Phosphorous acid	13.4	1.4	77.0	18.8 a	19.9 ab	30.3 a	21.5 bc	
Copper hydroxide	18.1	0.0	72.0	11.5 a	31.9 a	39.2 a	25.0 bc	
Azoxystrobin	---	0.5	56.9	13.5 a	18.8 ab	36.7 a	35.5 ab	
Benomyl	1.6	0.0	65.2	0.5 b	0.5 c	2.9 b	17.2 c	
Significance	NS	NS	NS	***	***	***	**	

^zApplication date.

^yHarvest date.

^xValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^{ns,*,***}Nonsignificant at $P \leq 0.01$ or 0.001, respectively.

fruit averaged about 50% lower than the controls. Even when differences were not significant, these treatments still tended to have less total decay than the control. These products provided significant postharvest decay control even when harvests were delayed for up to 3 weeks. Relative efficacy between benomyl and thiophanate-methyl did not change between the first and second harvests. Over 3 years of studies with 'Nagpur' mandarin (*Citrus reticulata*), Naqvi and Dass (1991) also found significant decreases in postharvest decay after preharvest application of benomyl or thiophanate-methyl.

In one test ('Sunburst' tangerines harvested 18 Dec. 2001), pyraclostrobin and phosphorous acid (Phostrol) also resulted in 29% and 36% less total decay, respectively, than the control fol-

lowing storage (Table 3). When data from 2001–02 were combined (with no cultivar interaction), phosphorous acid (Phostrol) and pyraclostrobin significantly reduced total decay to 36% and 39%, respectively, from 49% in the control (data not shown). Combined total decay was significantly lowest in thiophanate-methyl and benomyl-treated fruit (24% for both). Earlier tests with phosphorous acid from a different source (Nutri-Phite) revealed no significant effects on total decay after harvest (Tables 2). Fosetyl-Al is thought to act through its conversion into phosphorous acid after plant uptake (Afek and Szejnberg, 1989). Naqvi and Dass (1991) reported a significant reduction in postharvest decay from preharvest application of fosetyl-Al on citrus. However, the current results indicate

no significant reduction in postharvest decay after preharvest application of fosetyl-Al (Table 2). Brown (1992) reported that postharvest treatments of fosetyl-Al did not reduce SER, green mold, or anthracnose compared to the control, but did reduce decay when fruit were inoculated with brown rot (*Phytophthora* spp.). No treatment resulted in significantly more total decay than the control after storage.

Commercially, SER often causes the greatest postharvest losses in fresh Florida citrus fruit (Brown and Albrigo, 1970). During the present studies, SER was often the primary cause of decay (Tables 4 and 5). Benomyl and thiophanate-methyl were the only treatments that significantly reduced SER following storage at 50 °F, averaging 65% less SER compared to the controls. These products provided significant postharvest decay control even when harvests were delayed up to three weeks. When data from 2001–02 were combined (with no cultivar interaction), significant reductions in SER from

phosphorous acid (20% SER) compared to the control (25% SER) were also revealed (data not shown). SER was still significantly lowest in thiophanate-methyl and benomyl-treated fruit (9% and 11%, respectively). Previous studies have reported the effectiveness of preharvest applications of benomyl at reducing postharvest SER (Brown and Albrigo, 1970). Both benomyl and thiophanate-methyl break down to form carbendazim, which is the primary source of fungicidal activity (Clemons and Sisler, 1969; Saleh and Negm, 1980). Even when their effectiveness was not significant, these two treatments were always associated with a lower incidence of SER than the control.

Even though postharvest fruit losses were primarily a result of SER, anthracnose was high (>15%) in four harvests and was the primary cause of decay in two harvests ('Fallglo' tangerines harvested 20 Sept. 2000, and 'Sunburst' tangerines harvested 6 Dec. 2001) (Table 6). Data is not

shown for experiments conducted between November 1999 and June 2001, because only 'Fallglo' tangerines treated 18 Sept. 2000 developed greater than 2% anthracnose and differences among treatments were not significant. Anthracnose development was particularly severe among 'Fallglo' tangerines, likely because natural fruit color development was greatly delayed necessitating ethylene degreening. Poorly colored fruit are more susceptible to anthracnose infection, and exposure to ethylene stimulates fungal growth and increases rind susceptibility to invasion (Brown and Barmore, 1976). Although degreening conditions were the same, further color development between the two 'Fallglo' harvests is thought to have retarded anthracnose development (Brown, 1978) in fruit from the second harvest and allowed the establishment of relatively more SER (Table 4).

Significant reductions in post-harvest anthracnose by preharvest treatments were rare (Table 6). Of

Table 5. Percentage of fruit with stem-end rot (SER) following preharvest application of different compounds and postharvest storage at 50 °F (10.0 °C) with 90% relative humidity. Results are from different citrus varieties treated and evaluated between December 2001 and April 2003.

	'Sunburst'		'Marsh'		'Valencia'		Navel	'Ruby Red'		'Murcott'	
	4 Dec. 2001 ^z		25 Feb. 2002		23 Apr. 2002		21 Oct. 2002	14 Nov. 2002		4 Feb. 2003	
Compound	6 Dec. ^y	18 Dec.	27 Feb.	11 Mar.	25 Apr.	6 May.	28 Oct.	21 Nov.	5 Dec.	11 Feb.	25 Feb.
Control	16.8	33.9	37.3 a ^x	25.2 a	25.5	30.4 a	32.2 a	15.7 a	10.3	10.0 a	20.9 a
Pyraclostrobin	11.3	17.4	30.1 ab	15.9 ab	25.8	36.8 a	---	---	---	---	---
Phosphorous acid	12.8	22.8	24.7 ab	12.0 abc	23.9	31.0 a	---	---	---	---	---
Thiophanate methyl	9.4	12.6	10.7 c	4.1 c	13.6	9.2 b	9.4 b	4.6 b	4.3	4.1 b	1.5 b
Benomyl	10.3	12.2	19.6 bc	7.9 bc	10.9	10.1 b	11.6 b	7.8 b	4.5	3.1 b	2.7 b
Significance	NS	NS	**	**	NS	***	**	**	NS	*	**

^zApplication date.

^yHarvest date.

^xValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^{ns,*,***}Nonsignificant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 6. Percentage of fruit with anthracnose following preharvest application of different compounds and postharvest storage at 50 °F (10.0 °C) with 90% relative humidity. Results are from different citrus varieties treated and evaluated between December 2001 and April 2003.

	'Sunburst'		'Marsh'		'Valencia'		Navel	'Ruby Red'		'Murcott'	
	4 Dec. 2001 ^z		25 Feb. 2002		23 Apr. 2002		21 Oct. 2002	14 Nov. 2002		4 Feb. 2003	
Compound	6 Dec. ^y	18 Dec.	27 Feb.	11 Mar.	25 Apr.	6 May.	28 Oct.	21 Nov.	5 Dec.	11 Feb.	25 Feb.
Control	15.8	19.5 a ^x	1.5	1.9	5.0 a	6.0	8.3	3.9	0.4	1.4	2.4
Pyraclostrobin	22.7	16.8 ab	3.4	0.5	1.3 ab	3.3	---	---	---	---	---
Phosphorous acid	20.2	9.8 b	2.9	0.5	3.4 a	3.7	---	---	---	---	---
Thiophanate methyl	18.9	20.6 a	1.5	2.0	3.6 a	1.0	10.1	1.9	0.4	4.9	1.9
Benomyl	15.6	9.9 b	1.0	5.4	0.0 b	1.5	6.2	2.0	0.0	5.3	2.1
Significance	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS

^zApplication date.

^yHarvest date.

^xValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^{ns,*}Nonsignificant at $P \leq 0.05$, respectively.

these, benomyl significantly reduced anthracnose in two tests, and phosphorous acid significantly reduced it once. Benomyl has been recommended as the most effective fungicide at reducing post-bloom fruit drop (PFD) in citrus, caused by a different species of *Colletotrichum* (*C. acutatum*) (Timmer et al., 2003). Wardowski and Brown (1993) reported that benomyl is only somewhat effective against postharvest anthracnose, and our results support this conclusion. However, although both thiophanate-methyl and benomyl form the same fungitoxic compound, thiophanate-methyl did not result in significant reductions in anthracnose compared to the control. Thiophanate-methyl has been granted a specific exemption by the U.S. Environmental Protection Agency (EPA) (Timmer, 2003) specifically for the control of PFD in citrus. Because anthracnose was usually low in these tests and significant treatment differences were rare, further tests are needed before making definite conclusions about the efficacy of thiophanate-methyl on postharvest anthracnose.

Following cold storage, the occurrence of green mold, was usually very low and often appeared as secondary infections after SER developed (data not shown). Smoot (1977) reported that it was not uncommon for incidence of penicillium mold to be 10-fold lower than stem-end rot on Florida citrus. In the current tests, significant differences from the control were only observed in 'Sunburst' tangerines harvested 13 Dec. 2000 and in 'Valencia' oranges harvested 6 May 2002 where the development of green mold in control fruit reached 5% and 23%, respectively. Of the preharvest treatments, only benomyl, thiophanate-methyl, and pyraclostrobin significantly reduced green mold by 89%, 81%, and 69%, respectively, compared to the control (data not shown). Others have also reported reduction of penicillium molds after preharvest or postharvest treatments with benomyl or thiophanate-methyl (Brown and Albrigo, 1972; Kuramoto, 1976; McCornack, 1974).

The development of physiological disorders was usually low following storage, but occasionally developed to relatively high levels. Stem-end rind breakdown (SERB) was by far the most common physiological disorder with incidence as high as 31% in navel oranges treated 21 Oct. 2002 (Data not

shown). Only in these navel oranges was SERB significantly affected by the preharvest treatments, increasing from 15% in the control to 24% in benomyl-treated fruit and 32% in thiophanate-methyl-treated fruit. There was no interaction between incidence of SERB and decay. It is unclear why the fungicide treatments would increase SERB. The other experiments revealed no significance or even trends in SERB development relating to the preharvest treatments. Postharvest pitting (Petracek et al., 1998) was also observed in one instance ('Fallglo' harvested 9 Oct. 2000), but its appearance was not affected by the treatments (data not shown).

The above data suggest that preharvest application of thiophanate-methyl may provide postharvest decay control similar to benomyl. The only exception was that in fruit from two harvests, thiophanate-methyl did not reduce decay from anthracnose as well as benomyl (Table 6). More tests are required before definite conclusions can be made about the efficacy of thiophanate-methyl on postharvest anthracnose. Thiophanate-methyl (Topsin M; Cerexagri, Inc., King of Prussia, Pa.) has been granted a specific exemption by the EPA (Timmer, 2003) for control of citrus PFD. Though fruit harvest is allowed 2 d after thiophanate-methyl application, it is not currently registered for application to control postharvest decay. Efforts are underway to obtain an EPA specific exemption for preharvest application of thiophanate-methyl to control postharvest decay of citrus fruit.

Literature cited

- Afek, U. and A. Szejnberg. 1989. Effects of fosetyl-Al and phosphorous acid on scoparone, a phytoalexin associated with resistance of citrus to *Phytophthora citrophthora*. *Phytopathology* 79:736-739.
- Brown, G.E. 1992. Evaluation of iprodione and fosetyl-Al and other fungicides for postharvest citrus decay control. *Proc. Fla. State Hort. Soc.* 105:131-134.
- Brown, G.E. 1978. Hypersensitive response of orange-colored Robinson tangerines to *Colletotrichum gloeosporioides* after ethylene treatment. *Phytopathology* 68:700-706.
- Brown, G.E. and L.G. Albrigo. 1970. Grove application of Benlate for control of postharvest citrus decay. *Proc. Fla. State Hort. Soc.* 83:222-225.
- Brown, G.E. and L.G. Albrigo. 1972. Grove application of benomyl and its persistence in orange fruit. *Phytopathology* 62:1434-1438.
- Brown, G.E. and C.R. Barmore. 1976. The effect of ethylene, fruit color, and fungicides on susceptibility of Robinson tangerines to anthracnose. *Proc. Fla. State Hort. Soc.* 89:198-200.
- Clemons, G.P. and H.D. Sisler. 1969. Formation of a fungitoxic derivative from Benlate. *Phytopathology* 59:705-706.
- Grierson, W. and W. F. Newhall. 1955. Tolerance to ethylene of various types of citrus fruits. *Proc. Amer. Soc. Hort. Sci.* 65:224-250.
- Kuramoto, T. 1976. Resistance to benomyl and thiophanate-methyl in strains of *Penicillium digitatum* and *P. italicum* in Japan. *Plant Dis. Rptr.* 60:168-172.
- McCornack, A.A. 1974. Control of citrus fruit decay with postharvest application of Benlate. *Proc. Amer. Soc. Hort. Sci.* 87:230-233.
- McDonald, R.E., L.A. Risse, and B.M. Hillebrand. 1979. Resistance to thiabendazole and benomyl of *Penicillium digitatum* and *P. italicum* isolated from citrus fruit from several countries. *J. Amer. Soc. Hort. Sci.* 104:333-335.
- Naqvi, S.A.M.H. and H.C. Dass. 1991. Pre-harvest fungicidal sprays to control the post-harvest decay of Nagpur mandarin. *Proc. Intl. Citrus Symp., Guangzhou, China, 5-9 Nov. 1990.* p. 715-717.
- Petracek, P.D., H. Dou, and S. Pao. 1998. The influence of applied waxes on postharvest physiological behavior and pitting of grapefruit. *Postharvest Biol. Technol.* 14:99-106.
- Ritenour, M.A. and H. Dou. 2000. Factors contributing to the "green ring" disorder of fresh market citrus. *Proc. Fla. State Hort. Soc.* 113:297-299.
- Romero, A.M., C.S. Kousik, and D.F. Ritchie. 2001. Resistance to bacterial spot in bell pepper induced by acibenzolar-S-methyl. *Plant Dis.* 85:189-194.
- Saleh, M.K.I. and S. el S. Negm. 1980. Fate of carbendazim, benomyl and thiophanate-methyl in three isolates of *Botrytis cinerea*. *Ann. Agr. Sci. (Moshtohor)*. 13:123-128.
- Smoot, J.J. 1977. Factors affecting market diseases of Florida citrus fruits. *Proc. Intl. Soc. Citriculture.* 1:250-254.
- Timmer, L.W. 2003. 2003 Florida citrus pest management guide: Pesticides registered for use on Florida citrus. *Fla. Coop. Ext. Serv. Doc. ENY601.* 1 Apr. 2003. <<http://edis.ifas.ufl.edu/CG017>>.
- Timmer, L.W., P.D. Roberts, and K.R. Chung. 2003. 2003 Florida citrus pest management guide: Postbloom fruit drop. *Fla. Coop. Ext. Serv. Doc. PP45.* 1 Apr. 2003. <<http://edis.ifas.ufl.edu/CG007>>.
- Wardowski, II., W.F. and G.E. Brown. 1993. Postharvest decay control recommendations for Florida citrus fruit. *Fla. Coop. Ext. Serv. Circ.* 395-A.