Evaluation of Fenpropimorph and Flutriafol for Control of Sour Rot, Blue Mold, and Green Mold in Lemon Fruit

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ABSTRACT

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Fenpropimorph and flutriafol added to agar at 10–500 ppm completely inhibited growth of most postharvest pathogens of citrus fruit. When these fungicides were applied to lemons within 24 hr after inoculation with *Geotrichum candidum* or within 48 hr after inoculation with *Penicillium italicum* or *P. digitatum*, the subsequent development of disease was significantly reduced. Experimental treatment of lemons at a packinghouse with these chemicals reduced postharvest decay up to 94% of the control. Lesions and sporulation at inoculation sites on treated fruit appeared to be arrested. No phytotoxic effects were evident on citrus fruit treated with these fungicides.

Sour rot, caused by *Geotrichum candidum* Link ex Pers., is a major postharvest disease of citrus fruit (5). Decay is most prevalent during the second half of the harvest season when fruit are mature and high temperature and humidity provide conditions favorable for infection (3). A severe outbreak of the disease occurred in California in 1985 among lemon fruit stored for late summer markets (1). Losses of 10–20% were not unusual, and some exceeded 50%.

Green mold, caused by *Penicillium digitatum* Sacc., and blue mold, caused by *P. italicum* Wehm., are also prevalent during the citrus harvest season. These two pathogens, along with *G. candidum*, enter through wounds incurred during harvesting and handling. Moreover, synergism of *G. candidum* and *P. digitatum* in infected citrus fruit has been reported (14). Postharvest application of benzimidazole and imidazole fungicides controls *P. digitatum* and *P. italicum* but not *G. candidum* (6); strains of *Penicillium* spp. resistant to these chemicals have been reported (7), however. Both *P. digitatum* and *G. candidum* were controlled by guazatine applied within 24 hr after inoculation (2,8,10,13,15), but strains of *P. italicum* (6) and *P. digitatum* (16) resistant to guazatine have developed. In the laboratory, fenpropimorph prevented sporulation and mycelial growth of *P. italicum* (11,12) and protected fruit against *P. digitatum, P. italicum*, and *G. candidum* (8,10). Cohen et al (4) recently evaluated the effect on *G. candidum* of different concentrations of 28 fungicides representing 13 different types of chemicals. Both fenpropimorph and flutriafol prevented mycelial growth in vitro and controlled infection of the fruit.

During citrus harvests from 1984 to 1987, 13 laboratory and packinghouse experiments were conducted to determine if application of fenpropimorph and flutriafol could control decays of lemons caused by *G. candidum* and *Penicillium* spp.

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MATERIALS AND METHODS

The chemicals used were fenpropimorph (75% a.i., Corbel, Mistral); flutriafol (12.5% a.i., Impact); guazatine (40% a.i., Panoctine); sodium-*o*-phenylphenate tetrahydrate (100% a.i., SOPP); thiabendazole (80% a.i., TBZ, Tecto); imazalil (80% a.i., Fungaflor); and Britex, a water-based polyethylene wax (18% solid matter) used commercially for coating citrus fruit for export.

In vitro experiments. The fungi tested were *G. candidum, P. digitatum, P. italicum, Phytophthora citrophthora* (Smith & Smith) Leonian, *Diplodia natalensis* (P. Evans), and *Alternaria citri* (Ell. & Pierce). These fungi were originally isolated from decayed citrus fruit and maintained on slants of potato-dextrose agar (PDA). Cultures were grown on PDA for 3–4 days at 25 C. A 6-mm-diameter plug was removed from the culture and placed on PDA amended with the fungicides at concentrations of 0.1–500 mg a.i./L (0.1–500 ppm) in 90-mm petri plates. The diameter of fungal colonies was measured daily. Inhibition of mycelial growth was expressed as percentage of the growth on unamended PDA. There were three single plate replicates per concentration. The experiment was repeated.

In vivo experiments. *Laboratory tests.* Tree-ripe, yellow lemon fruit (*Citrus limon* (L.) Burm. f.) of uniform size were hand-harvested with a clipper from a grove at the southern part of Israel and divided into three groups of 120 fruit each. One group was inoculated with *G. candidum*, one with *P. digitatum*, and one with *P. italicum*. The suspensions of *G. candidum* were prepared from 5- to 7-day-old cultures that were flooded with sterile water and gently rubbed with a glass rod. The suspended conidia were diluted with 2 L of sterile water containing a sterile macerate of decayed lemon peel (20%, v/v) (9). Based on spore counts made with a hemacytometer, the final concentration was diluted to approximately 1×10^6 spores per milliliter. Each fruit was submerged into this conidial suspension and punctured with three pins to a depth of 3 mm at five sites about the equator. For *P. digitatum* and *P. italicum*, fruit were wounded as described and dry fungal spores from decayed lemons were applied to the punctures (9). The inoculated fruit were stored at 25 C and nearly 100%

relative humidity for 6, 24, or 48 hr and then treated with the fungicides.

Fenpropimorph, flutriafol, and guazatine were diluted with water to a concentration of 2,000 ppm. Fruit were dipped for 1 min in each chemical. Inoculated fruit dipped in water served as controls. After treatment, fruit inoculated with *G. candidum* were incubated 10 days at 25 C and those inoculated with *Penicillium* spp. were incubated at 17 C, optimal temperatures for disease development. Each treatment comprised 10 fruit.

Packinghouse tests. Lemons were harvested from two groves. A high percentage of the fruit from grove 2 was overripe. Such fruit are known to be highly susceptible to sour rot, blue mold, and green mold.

Fenpropimorph, flutriafol, and guazatine were compared with the standard packinghouse treatment. Fruit from each grove were divided into eight groups. Three groups were dipped in fenpropimorph, flutriafol, or guazatine at 2,000 ppm water for 3 min, then washed with water to remove the chemical deposit. Three groups were dipped in the same chemicals for 1 min and not washed. All fruit from these six groups were coated with Britex wax at 14 ml/kg of fruit. One of the remaining two groups was dipped in a tank of SOPP (5,000 ppm), washed with water to remove excess residue, dried, and coated with wax amended with thiabendazole and imazalil, each at 2,000 ppm. The eighth group was dipped in water as a control. The treated fruit were stored for 10 or 30 days at 20 C. There were three cartons (replicates) of 100 fruit in each treatment. Because results observed in 13 different experiments were similar, only those from one laboratory and one packinghouse experiment are reported here.

Table 1. Mean percent inhibition of radial growth of citrus pathogens on potato-dextrose agar amended with fenpropimorph, flutriafol, or guazatine

Fungicide concentration (ppm)	Mean percent inhibition of radial growth on amended plates[a]					
	Geotrichum candidum	*Penicillium digitatum*	*Penicillium italicum*	*Phytophthora citrophthora*	*Diplodia natalensis*	*Alternaria citri*
Fenpropimorph						
0.1	0	74	41	0	0	35
1	23	100	62	0	80	72
10	54	100	88	0	100	88
100	82	100	100	78	100	100
250	100	100	100	83	100	100
500	100	100	100	83	100	100
Flutriafol						
0.1	17	12	0	0	0	17
1	51	78	83	0	0	47
10	84	100	100	17	58	69
100	100	100	100	81	88	100
250	100	100	100	82	100	100
500	100	100	100	100	100	100
Guazatine						
0.1	20	...	40	0	29	...
1	64	35	56	0	41	26
10	84	83	46	14	51	61
100	88	100	41	37	68	87
250	88	100	42	44	68	88
500	88	100	52	52	78	100

[a]At 8–10 days after incubation at 25 C. The average at each concentration was calculated from three replicated plates in each of two experiments.

Table 2. Effect of postinoculation fungicide treatments on infection of lemon fruit by *Geotrichum candidum, Penicillium digitatum*, or *P. italicum*[a]

Fungicide[b] (2,000 ppm)	Hours after inoculation	Average number of active lesions per fruit[c]		
		G. candidum	*P. digitatum*	*P. italicum*
Fenpropimorph	6	0.0	ND[d]	ND
	24	0.5	0.0	0.0
	48	2.6	2.6	1.7
Flutriafol	6	0.7	ND	ND
	24	0.7	0.0	0.0
	48	1.9	4.0	3.0
Guazatine	6	0.2	ND	ND
	24	1.2	0.6	2.2
	48	2.3	4.6	3.4
Control (water)	6	1.7	ND	ND
	24	4.1	5.0	5.0
	48	4.5	5.0	5.0
LSD 0.05%		1.17	0.86	1.17
LSD 0.01%		1.55	1.14	1.56

[a]Fruit immersed in an aqueous spore suspension of *G. candidum* were punctured with pins at five sites on the equator. For *P. digitatum* and *P. italicum*, fruit were punctured and a mass of fungal spores was applied to the wounds.
[b]Inoculated fruit were incubated at 25 C for 6–48 hr, dipped for 1 min in the aqueous formulations, and incubated for 10 days at 17 or 25 C.
[c]Each value is the average of 10 fruit, each with five inoculation sites.
[d]ND = not determined.

RESULTS

In vitro experiments. Fenpropimorph and flutriafol were equally inhibitory to growth of the major postharvest pathogens of citrus fruit (Table 1). The ED_{100} for all fungi except *P. citrophthora* was between 10 and 240 ppm. Guazatine was less toxic; its ED_{100} exceeded 500 ppm for all except *P. digitatum* and *A. citri* (Table 1). Both fenpropimorph and flutriafol prevented sporulation on the agar plugs of the *Penicillium* spp. at concentrations that inhibited mycelial growth, with the exception of the 0.1-ppm fenpropimorph treatment of *P. digitatum*.

In vivo experiments. *Laboratory tests.* Fenpropimorph appeared to be the most effective treatment of inoculated lemon fruit (Table 2). It prevented sour rot when applied within 6 hr after inoculation and prevented molds caused by the *Penicillium* spp. if applied within 24 hr. In contrast, a few active sour rot lesion were observed in the 6-hr flutriafol and guazatine treatments, and only modest reductions in blue and green mold were associated with guazatine treatment. Flutriafol was as effective on blue and green mold as fenpropimorph. Lesions with extensive sporulation were associated with the control fruit and those treated with guazatine. On fruit treated with fenpropimorph and flutriafol, however, lesions either did not develop or remained brown, dry, and firm, did not extend into the fruit, and were free from fungal sporulation for longer than 30 days.

Packinghouse tests. The incidence of disease on lemons from grove 1 treated with fenpropimorph, flutriafol, or guazatine was lower than on those given the standard commercial treatment (SOPP, thiabenzadole, and imazalil) (Table 3). However, all treated fruit had significantly less decay than control fruit. The method of application of fenpropimorph, flutriafol, and guazatine did not affect the level of control significantly. Nearly twice as much decay developed among the control fruit from grove 2 as among those from grove 1. All treatments provided good control of the diseases, however.

No evidence of phytotoxicity was

Table 3. Effect of fungicide treatments in a packinghouse on decay of tree-ripe lemon fruit harvested commercially[a]

Fungicide (2,000 ppm)	Incidence of decay (%) in nonrinsed fruit[b]					Incidence of decay (%) in rinsed fruit[c]				
	Penicillium digitatum	*Penicillium italicum*	*Geotrichum candidum*	*Diplodia natalensis*	Total	*Penicillium digitatum*	*Penicillium italicum*	*Geotrichum candidum*	*Diplodia natalensis*	Total
Grove 1										
Fenpropimorph	0.4	0.0	0.0	0.9	1.3	0.4	0.0	0.4	0.0	0.8
Flutriafol	1.2	0.0	1.8	0.8	3.8	0.4	0.0	3.3	2.4	6.1
Guazatine	0.0	0.4	0.0	0.8	1.2	0.0	0.0	2.0	0.0	2.0
SOPP + thiabendazole + imazalil[d]	3.2	0.5	4.0	0.8	8.5	...	...	...	...	...
Grove 2										
Fenpropimorph	1.9	0.0	4.1	0.3	6.3	2.3	0.0	6.3	1.7	10.3
Flutriafol	3.0	0.0	1.3	2.4	6.7	3.4	0.0	2.0	3.0	8.4
Guazatine	3.6	1.7	1.3	2.0	8.6	6.5	4.0	0.6	2.5	13.6
SOPP + thiabendazole + imazalil	3.4	0.6	3.4	0.6	8.0	...	...	...	...	...

[a]Incidence of decay in untreated fruit from grove 1 was 22.6% and in untreated fruit from grove 2, 44.5% (a large percentage of fruit from grove 2 was overripe).
[b]Fruit were dipped in fungicide treatment for 1 min and not washed.
[c]Fruit were dipped in fungicide treatment for 3 min, then washed with water.
[d]Fruit were dipped in a tank of SOPP (5,000 ppm), washed with water, dried, and coated with wax amended with thiabendazole (2,000 ppm) and imazalil (2,000 ppm).

associated with any of the chemical treatments.

DISCUSSION

Previously, fenpropimorph has been effective against sour rot and green mold of citrus fruit (8,10). Eckert et al (8) reported that fenpropimorph at 500 ppm prevented infection of wounds by *P. digitatum*. Up to 2,000 ppm were applied to existing lesions but had no effect on sporulation. Gutter (10) found that 4,000 ppm controlled both sour rot and green mold and prevented sporulation at existing lesions. In the tests reported here, fenpropimorph and, to a lesser extent, flutriafol were more therapeutic than guazatine. They were highly effective when applied on lemons 24 hr after inoculation with *G. candidum*, *P. italicum*, and *P. digitatum*. They controlled growth on PDA of *D. natalensis* and *A. citri* at concentrations of 10–250 ppm. Moreover, at concentrations up to 10,000 ppm, they did not injure the peel of treated citrus fruit (4). This was encouraging, since guazatine, the only compound reported so far to control sour rot effectively, has occasionally caused a slight phytotoxicity, mainly at the begining of the season (10). The apparent benefit of the fenpropimorph and flutriafol treatments requires further investigation. These fungicides have potentially great value to citrus-exporting countries for controlling fruit-to-fruit spread of sour rot and fruit spoilage by spores of the *Penicillium* spp. in packed cartons.

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