

imazalil depended on the deposition of imazalil in natural epicuticular wax, when the wax was removed, residues of 2  $\mu\text{g}\cdot\text{g}^{-1}$  did not control sporulation. Brown and Dezman (3) stated sufficient coverage to get control of sporulation required better contact between brushes and fruit than was achieved in many commercial packinghouses when a non-recovery aqueous imazalil spray was used; as a consequence, commercial packinghouses in Florida where imazalil is applied in aqueous sprays follow this application with imazalil in wax at 1,000 to 2,000  $\mu\text{g}\cdot\text{g}^{-1}$  to ensure adequate control of sporulation. Our results indicate that if imazalil is applied in heated solutions for 30 s or longer, adequate residue deposition can occur to make a second application of imazalil in wax for sporulation control unnecessary. However, treatments using heated imazalil for 15 s required an additional application of 1,070  $\mu\text{g}\cdot\text{ml}^{-1}$  imazalil in wax to leave residues sufficient to control sporulation.

Partial control of an imazalil-resistant *P. digitatum* isolate was achieved with aqueous imazalil, but relatively high residue levels were associated with its control. We reduced the incidence of green mold on oranges after inoculation with a resistant isolate by 78% by treatment for 1 min in 410  $\mu\text{g}\cdot\text{ml}^{-1}$  imazalil at 40.6°C. However, imazalil residues in the fruit where the resistant strain was partially controlled were 7.9  $\mu\text{g}\cdot\text{g}^{-1}$ ; much higher than the 1 to 2  $\mu\text{g}\cdot\text{g}^{-1}$  required to control an imazalil-sensitive isolate. Higher rates must be used with care because established tolerances can be exceeded. The U.S. imazalil tolerance is 10  $\mu\text{g}\cdot\text{g}^{-1}$  and that of many citrus-importing countries is 5  $\mu\text{g}\cdot\text{g}^{-1}$  (6). Although the incidence of imazalil-resistant isolates of *P. digitatum* in California is high (8,10), imazalil remains a useful fungicide to manage green mold. In addition to partial control of resistant isolates with higher rates of imazalil that we and others (8) reported, other aspects of imazalil-resistant isolates suggest they can be managed: i) resistant isolates are less fit than imazalil-sensitive isolates and decline in competition with sensitive strains in the absence of the fungicide (5,11,23); ii) imazalil-resistant isolates primarily occur

in packinghouses and not in groves, therefore imazalil effectively controls the sensitive isolates from the groves; iii) because imazalil-resistant isolates primarily occur only in packinghouses, sanitation measures can be successfully applied; and iv) although the proportion of resistant isolates collected in 26 California packinghouses was high (77.2 and 74.2% in 1990 and 1994, respectively) and it did not increase in this period (10).

No rind injury was observed in any of the our tests, and the risk of injury from heated aqueous imazalil treatments we evaluated is probably low. Rind injury from hot water alone usually does not occur below 50°C on lemons (12,20) or oranges (21,25), unless the fruit are cool and turgid at the time of treatment (9). A benefit of immersion in heated water or imazalil solutions is a reduction in the susceptibility of the fruit to subsequent chilling injury (14,17,24). We did not evaluate temperatures as high as those employed in those studies, however, because good control was obtained without using higher temperatures and prior reports that the addition of imazalil to water lowers the temperature at which rind injury and internal quality changes occur in lemons (18,19). Shirra et al. (19) immersed lemons in water or 250 to 1,500  $\mu\text{g}\cdot\text{ml}^{-1}$  imazalil for 3 min at 50°C and stored them for 14 weeks at 9°C. Imazalil-treated lemons did not differ in titratable acidity or soluble solids from untreated or water-treated fruit, but imazalil concentrations of 500  $\mu\text{g}\cdot\text{ml}^{-1}$  or higher applied at 50°C caused rind injuries and increased ethanol and acetaldehyde contents. These injuries did not occur when imazalil was applied at 20°C. To reduce the risk of injury, regimes we evaluated employed cooler (43.3°C or less), briefer (60 s or less), and lower aqueous imazalil concentrations (less than 500  $\mu\text{g}\cdot\text{ml}^{-1}$ ) than those Schirra and co-workers (18,19) showed to injure lemons.

Imazalil effectiveness on citrus can be substantially improved when the fruit are passed through heated aqueous solutions of the fungicide compared to the current commercial practice of spraying the fungicide at ambient temperatures in waxes. The improvement is probably due to more ef-

fective infiltration of the fungicide into the wound infection courts that are exploited by *P. digitatum* on the rind of citrus fruit (2). From our work, 30 s immersion of lemons or oranges in 350 to 400  $\mu\text{g}\cdot\text{ml}^{-1}$  imazalil heated to 37.8°C should deposit residues of 2 to 4  $\mu\text{g}\cdot\text{g}^{-1}$ . This regime enhanced imazalil efficacy, deposited sufficient residues to control sporulation, facilitated rapid treatment, partially controlled an imazalil-resistant isolate of *P. digitatum*, and posed minimal risk of injury to the fruit. The treatment could be shortened to 15 s if it is followed by the application of about 1,000  $\mu\text{g}\cdot\text{ml}^{-1}$  imazalil in wax, or if higher imazalil concentrations or temperatures were used in tanks, although the risk of injury to the fruit may be increased.

#### ACKNOWLEDGMENTS

We gratefully acknowledge useful ideas and suggestions of G. E. Brown, J. W. Eckert, and William Goodwine, and the assistance of Microbac Laboratories, Inc. and Pent-A-Vate, Inc. Biological Testing and Research Laboratory with imazalil analysis, the donation of supplies by of Janssen Pharmaceutica and Makhteshim Agan, and the financial support of the California Citrus Research Board.

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Table 3. Imazalil residues ( $\mu\text{g}\cdot\text{g}^{-1}$ ) on lemons immersed for 15 s in water or imazalil followed by application of a storage wax containing imazalil

Imazalil ( $\mu\text{g}\cdot\text{ml}^{-1}$ )	Temperature (°C)	Imazalil concentration in wax ( $\mu\text{g}\cdot\text{ml}^{-1}$ )			Slope	Intercept	$R^2$	P
		0	1,070	1,910				
0	0	0.00 <sup>a</sup>	1.08	2.34	0.001	-0.067	0.99	0.072
93	32.2	0.22	2.10	5.47	0.003	-0.090	0.95	0.147
93	37.8	0.34	2.49	6.32	0.003	-0.010	0.95	0.147
93	43.3	0.50	2.07	5.79	0.003	0.007	0.90	0.210
160	32.2	0.54	3.52	6.37	0.003	0.457	0.99	0.036
160	37.8	0.68	3.14	7.55	0.004	0.275	0.95	0.148
160	43.3	0.79	3.17	5.67	0.003	0.687	0.99	0.053
405	32.2	0.92	3.65	6.76	0.003	0.762	0.99	0.068
405	37.8	1.42	4.03	7.33	0.003	1.216	0.98	0.087
405	43.3	2.06	4.31	8.44	0.003	1.674	0.94	0.152

<sup>a</sup> Each value ( $\mu\text{g}\cdot\text{g}^{-1}$ ) is the mean of two analyses.