Improved Control of Green Mold of Citrus with Imazalil in Warm Water Compared with Its Use in Wax

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ABSTRACT

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The effectiveness of imazalil for the control of citrus green mold (caused by *Penicillium digitatum*) improved significantly when fruit were treated with heated aqueous solutions of the fungicide as compared with the current commercial practice of spraying wax containing imazalil on fruit. When applied at less than 500 $\mu g \cdot ml^{-1}$ in solutions heated to 37.8°C, control of postharvest green mold of citrus was significantly superior to applications of 4,200 $\mu g \cdot ml^{-1}$ imazalil in wax sprayed on fruit at ambient temperatures. The improvement in imazalil efficacy was obtained with a decrease in fungicide residues on the fruit. Residues of about 3.5 $\mu g \cdot g^{-1}$ imazalil deposited by the application of imazalil in wax reduced the incidence of green mold on lemons from 94.4% among untreated controls to 15.1%, whereas an equal residue deposited by passing fruit through heated aqueous imazalil reduced green mold incidence to 1.3%. Similar differences were found in tests with oranges. Residues of 2 and 3.5 $\mu g \cdot g^{-1}$ imazalil were needed to control the sporulation of *P. digitatum* on oranges and lemons, respectively. The mode of application of imazalil did not influence control of sporulation. The influence of immersion time, imazalil concentration, and solution temperature on imazalil residues on oranges and lemons was determined in tests using commercial packing equipment, and a model that describes residue deposition was developed. Residues after a 30- or 60-s treatment in heated aqueous imazalil were sufficient to control sporulation, but residues after 15-s treatments were too low and required an additional application of 1,070 $\mu g \cdot ml^{-1}$ imazalil in wax to deposit an amount of imazalil sufficient to control sporulation. An imazalil-resistant isolate of *P. digitatum* was significantly controlled by heated aqueous imazalil. The incidence of green mold of navel oranges was reduced from 98.8 to 17.4% by treatment in 410 $\mu g \cdot ml^{-1}$ imazalil at 40.6°C for 90 s. However, control of the resistant isolate required imazalil residues on the fruit of 7.9 $\mu g \cdot g^{-1}$, which is within the U.S. tolerance of 10 $\mu g \cdot g^{-1}$ but above the 5 $\mu g \cdot g^{-1}$ tolerance of some countries that import citrus fruit from the United States.

Imazalil is a fungicide registered for postharvest application to citrus fruit to reduce both the incidence of decay and sporulation of *Penicillium digitatum* (Pers.:Fr.) Sacc., cause of citrus green mold. In Arizona and California, imazalil is usually added to fruit waxes and applied to fruit as a non-recovery spray over rotating brushes. This method is used because it is convenient and effective, although Brown and coworkers (2,4) showed that imazalil, unlike other fungicides used for this purpose, controlled green mold significantly better when applied in water than when applied in wax. Similarly, other researchers (8,15,16) reported superior control of green mold by the application of aqueous as compared with wax imazalil formulations. Imazalil loses effectiveness in wax because a substantial portion of the residue remains immobilized in the wax, and because waxes are more viscous than water, they less effectively penetrate the small wound infection courts that are exploited by *P. digitatum* on the rind of citrus fruit (2).

One reason the application of imazalil in wax has continued, in addition to its convenience, is its reliable control of *P. digitatum* sporulation. Anti-sporulant activity is important because it controls a condition termed soilage, a cosmetic defect that occurs when healthy fruit within cartons are soiled by spores from adjacent decayed fruit (7). Reducing sporulation also reduces the airborne inoculum within citrus packinghouses. This is particularly important because the inoculum within packinghouses is often composed of fungicide-resistant isolates (8). Brown and Dezman (3) reported that control of sporulation on Valencia oranges with aqueous, non-recovery sprays of imazalil or imazalil in wax both required a residue of about 2 $\mu g \cdot g^{-1}$ fresh fruit weight. However, with a non-recovery aqueous spray, coverage sufficient for sporulation control required better contact between brushes and fruit than was achieved in many commercial packinghouses. Therefore, in commercial packinghouses in Florida where imazalil is applied in aqueous sprays, this is followed by a second application of 1,000 to 2,000 $\mu g \cdot g^{-1}$ imazalil in wax. Fruit treated in this manner have residues of about 4 $\mu g \cdot g^{-1}$, which is within the tolerance of 10 $\mu g \cdot g^{-1}$ in the United States and the 5 $\mu g \cdot g^{-1}$ tolerance of most importing countries (6).

An alternative to optimize the efficacy of imazalil would be to apply the fungicide by immersing fruit in heated aqueous solutions of the fungicide. Rapid treatment, an important attribute when very large numbers of fruit are processed, would be facilitated because imazalil residues accumulate on oranges about three times faster when the fruit are dipped in the fungicide rather than sprayed with it (3). Heating fungicide solutions also accelerates the accumulation of fungicide residues in fruit (19). Sufficient residues from a heated aqueous imazalil solution could control sporulation of *P. digitatum* and make a second application of imazalil in wax, such as is needed after aqueous sprays, unnecessary. Efficacy is also improved by heating. The control of postharvest decay by imazalil on mangos (22), grapefruit (14), and lemons (18,19) was enhanced when the fungicide was heated. Furthermore, a synergistic interaction between heat and imazalil treatment might provide better control of imazalil-resistant isolates than imazalil applied alone.

The purpose of this work was to determine with commercial-scale packing equipment the influence of immersion time, imazalil concentration, and temperature on concentration of imazalil residues in citrus fruit; to compare the efficacy of optimal regimes of imazalil applied in

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