Comparison of imazalil efficacy when applied in wax or in water heated to 37.8°C. The control of green mold on oranges and lemons was significantly superior ($P < 0.0001$, orthogonal contrast) by imazalil applied in heated water to that in wax (Fig. 1), although the imazalil residues deposited on the fruit significantly exceeded ($P < 0.0001$, orthogonal contrast) those of imazalil applied in heated water (Fig. 2). 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 about 11.0%, whereas an equal residue deposited by passing fruit through heated aqueous imazalil reduced green mold incidence to less than 1.0% (Fig. 2). Similar differences occurred with oranges. Treatment with water at 37.8°C reduced green mold incidence of oranges and lemons by about 30 and 55%, respectively. Residues of 2 and 3.5 $\mu g \cdot g^{-1}$ imazalil were needed to control sporulation on oranges and lemons, respectively (Fig. 3). Because control of sporulation by imazalil applied in water or wax sporulation was not significantly different, all rating of control of sporulation were pooled.

Augmentation of imazalil residues by a second application of imazalil in wax, in order to obtain residue levels sufficient to control *P. digitatum* sporulation, were most effectively achieved by a concentration of 1,070 $\mu g \cdot ml^{-1}$ imazalil in the wax (Table 3). When the second application of wax with 1,910 $\mu g \cdot ml^{-1}$ imazalil was applied, residues were higher than needed to control sporulation and above the 5 $\mu g \cdot g^{-1}$ imazalil residue tolerance for citrus fruit of many importing countries.

Control of imazalil-sensitive or imazalil-resistant *P. digitatum* isolates. Growth of mycelial plugs of isolates M6R and 151 was stopped in PDA with imazalil concentrations of 0.1 $\mu g \cdot ml^{-1}$ and more than 2 $\mu g \cdot ml^{-1}$, respectively. Heating the imazalil solution increased residues in navel oranges and improved control of both *P. digitatum* isolates (Fig. 4). Control of imazalil-sensitive isolate M6R was superior to control of imazalil-resistant isolate 151. Heating 410 $\mu g \cdot ml^{-1}$ imazalil from 21.1 to 40.6°C further reduced green mold incidence from 16.2 to 5.3% among oranges inoculated with isolate M6R, and from 71.2 to 17.4% among oranges inoculated with isolate 151. Heating 410 $\mu g \cdot ml^{-1}$ imazalil from 21.1 to 40.6°C also increased imazalil residues on oranges three- to fourfold. Sporulation of the sensitive isolate was controlled by all imazalil treatments, while sporulation of the imazalil-resistant isolate was not controlled (data not shown). Treatment with water alone at 40.6°C had no significant influence on the incidence of green mold in this test.

DISCUSSION

The higher effectiveness of imazalil shown in this study was due to three factors: i) application of the imazalil in water instead of wax; ii) heating of the aqueous imazalil solution; and iii) immersing the fruit in a tank of the solution instead of spraying the fungicide on fruit to make the treatment brief enough to be practical. In our tests, fruit immersed briefly in heated aqueous imazalil, leaving residues of 1 to 3 $\mu g \cdot g^{-1}$, had about 95% less green mold than control fruit, while similar residues deposited by spraying fruit with imazalil in wax reduced green mold incidence only about 60%. Several aspects of this work were established in prior studies. Eckert et al. (8) showed imazalil reduced green mold more effectively when applied in water instead of wax. Imazalil applied at 2000 $\mu g \cdot ml^{-1}$ in wax or in water reduced the incidence of green mold by 48 and 98%, respectively. Brown and Dezman (3) reported that application of aqueous solutions of imazalil by immersion in a tank deposited imazalil residues approximately three times faster than spraying the same solution on citrus fruit. Heating imazalil improved its effectiveness on mangos (22), grapefruit (14), and lemons (18,19). Temperatures we used are too low to reliably control green mold by heat (20), although partial control of green mold by heated water alone did occasionally occur in our work.

Imazalil residues required to control green mold sporulation we report are slightly higher those reported by others. Most researchers reported residues of about 1 to 2 $\mu g \cdot g^{-1}$ were needed to control sporulation on oranges and lemons (3,13), whereas we found 2 and 3.5 $\mu g \cdot g^{-1}$ were needed, probably because of differences in incubation temperatures of the fruit or the subjectivity of sporulation indices. Brown and Dezman (3) reported that control of sporulation of the green mold fungus on Valencia oranges with aqueous, nonrecovery sprays of imazalil required a residue of about 2 $\mu g \cdot g^{-1}$, the same level required when imazalil is applied in wax (13). They (3) showed control of sporulation on Valencia oranges with aqueous

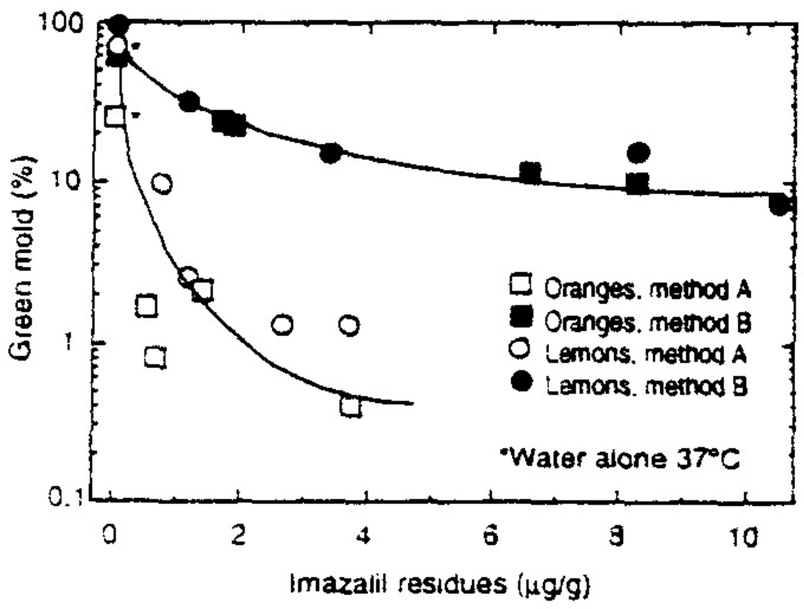

Fig. 2. The relationship between imazalil residues on fruit and the method of application of imazalil on the incidence of postharvest green mold of oranges and lemons. In method A, the fruit were immersed for 15 s in 136–490 $\mu g \cdot ml^{-1}$ imazalil in water at 37°C. The incidence of green mold = 1.995 (imazalil residue)$^{-0.576}$, $r^2 = 0.62$. In method B, the fruit were sprayed with 1,100 to 4,200 $\mu g \cdot ml^{-1}$ imazalil in wax over rotating brushes at 23°C. The incidence of green mold = −20.421 * log(imazalil residue) + 29.23, $r^2 = 0.89$. All fruit were inoculated 24 h before treatment with spores of *Penicillium digitatum*.

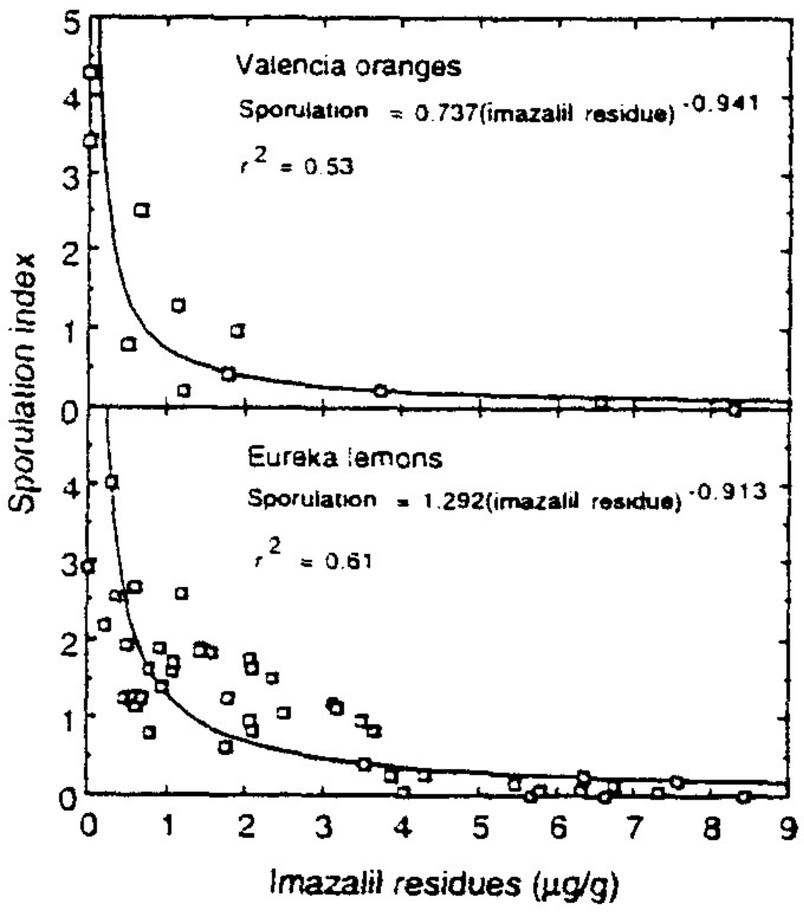

Fig. 3. Influence of imazalil residues on the sporulation of *Penicillium digitatum* on green mold infected oranges and lemons stored 3 wk at 10°C after imazalil treatment. The sporulation index describes the percentage of the fruit surface covered with green mold spores where 5 = 100%; 4 = 90–99%; 3 = 50–89%; 2 = 11–49; 1 = 1–10%; and 0 = no sporulation on the surface of the fruit.

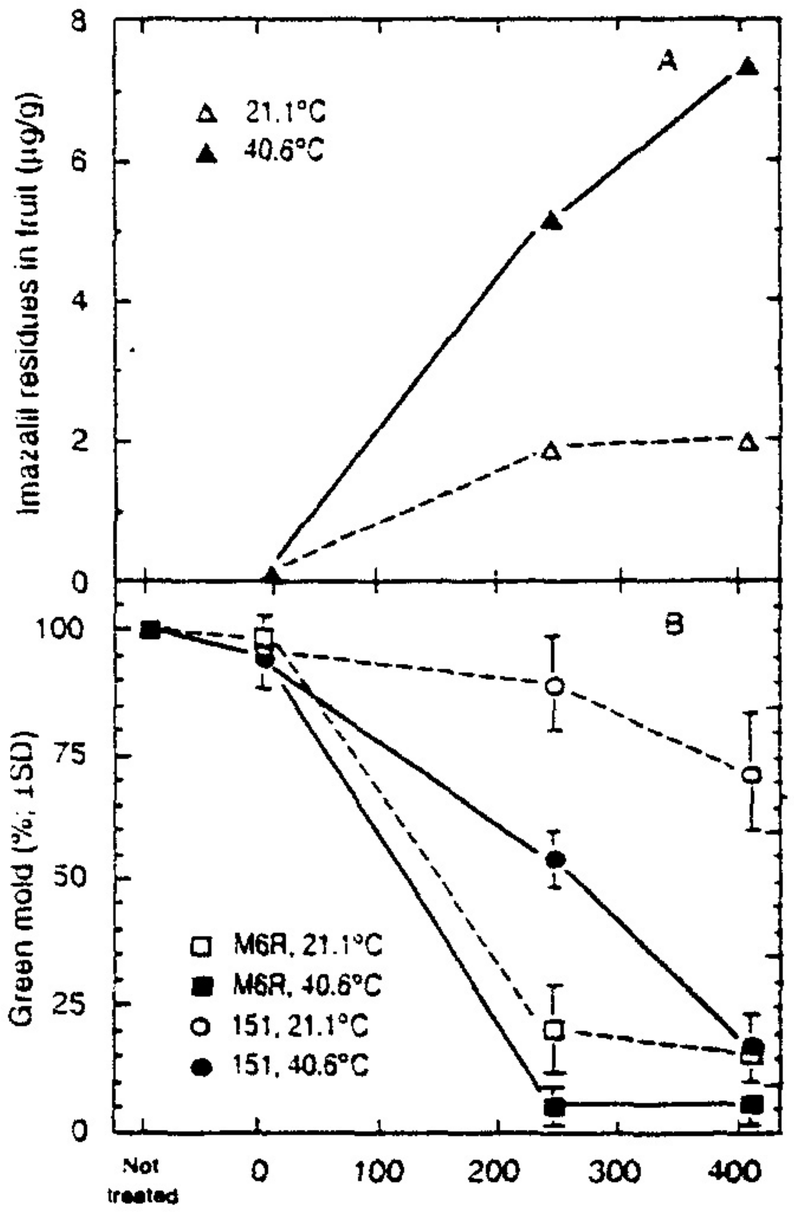

Fig. 4. Imazalil residues (A) and the incidence of green mold (B) of navel oranges immersed in imazalil in water at 21.1 or 40.6°C for 90 s. All fruit were inoculated 24 h before treatment with spores of imazalil-sensitive isolate M6R or imazalil-resistant isolate 151 of *Penicillium digitatum*.