

75 fruit each. The test was done once with cv. Valencia oranges and twice with cv. Eureka lemons.

**Influence of high-pressure water washing on SC effectiveness.** To determine the influence of high pressure water washing on SC effectiveness, inoculated lemons and oranges were treated with one of the following: (i) immersed in water for 1 min at 44°C; (ii) washed in a high pressure water washer; (iii) immersed in 3% SC for 1 min at 44°C ( $\pm 1^\circ\text{C}$ ) without prior or post-treatment cleaning; (iv) washed in a high-pressure water washer and then immersed in 3% SC; or (v) immersed in 3% SC, then washed in a high-pressure water washer. The residence time in the pressure washer, which operated at 1,380 kPa, was approximately 45 s. The pressure washer was 61 cm wide, 3 m long, and contained 15 rows of three 45° flat-fan nozzles per row. Each nozzle applied 100 ml/s of water. The water in the pressure washer contained 10  $\mu\text{g}/\text{ml}$  of sodium hypochlorite. The fruit, which were not waxed after treatment, were placed in fiber board cartons and stored 4 for weeks at 10°C before the decayed fruit were counted. Each treatment was applied to four replicates of 60 to 75 fruit each. The test was repeated twice with navel oranges and done once with cv. Eureka lemons.

**Influence of SC solution temperature on rind injury of oranges.** Navel orange cvs. Atwood, Bonanza, Fisher, New Hall, and Thomson Improved, grown at the University of California Lindcove Citrus Research and Extension Center (Lindcove, CA), were harvested and randomized. Fruit (pulp temperature 12 to 13°C) were immersed in 3% SC maintained at 28, 33, 44, 50, 56, or 61°C ( $\pm 1^\circ\text{C}$ ) in a 2,000-liter-capacity tank for 1 min, rinsed with approximately 10 ml of water per fruit by an overhead spray over rotating brushes, waxed with a high solids content finishing wax containing 2,000  $\mu\text{g}/\text{ml}$  imazalil

(Fungaflor 500 EC, 44.6% a.i.; Janssen Pharmaceutica, Titusville, NJ), dried in a high-velocity, heated-air dryer, and placed into fiberboard cartons. Each treatment was applied to three replicates of 80 fruit of each cultivar. After storage for 3 weeks at 10°C with 90% relative humidity, fruit were classified into one of four categories, where 1 = no rind blemishes; 2 = slight blemishes present; 3 = moderate blemishes present; and 4 = severe rind injury. Fruit with rind injuries associated with classes 3 and 4 were of sufficient significance that the fruit could not normally be sold commercially without discount. The test was done once with each cultivar.

**Influence of SC on the effectiveness of subsequent imazalil or biological control applications.** Lemons or oranges were inoculated with *P. digitatum* as previously described, immersed 24 h later in 2 or 3% SBC or SC for 2.5 min at 40.5°C ( $\pm 1^\circ\text{C}$ ), and rinsed briefly with 10 ml of water per fruit. Imazalil at 1,000  $\mu\text{g}/\text{ml}$  in water or *Pseudomonas syringae* strain ESC10 (active ingredient of the registered product BioSave 10, a gift of EcoScience Corp.) at 10<sup>9</sup> CFU/ml was applied by an overhead spray until the solutions ran off the surface of the fruit. The fruit were stored for 2 to 4 weeks at 10°C and the incidence of green mold infections was determined. Each treatment was applied to four or five replicates of 25 fruit each. The test was repeated twice.

**Statistical analysis.** The concentrations of salts that caused 50 and 95% mortality of spores and the upper and lower 95% fiducial limits were estimated by Finney's Probit analysis (15). The incidence of green mold or rind injuries was analyzed by an analysis of variance applied to the square root of the arcsin of the proportion of infected or injured fruit, followed by Fisher's protected least significant difference (LSD) to separate means. Actual values are shown.

## RESULTS

**In vitro inhibition of spores of *P. digitatum* by bicarbonate and carbonate solutions.** The pH of the unbuffered carbonate solutions were similar to each other and higher than the bicarbonate solutions at every concentration (Fig. 1). Fiducial limits of concentrations that inhibited 50% of the spores ( $\text{ED}_{50}$ ) were narrower than those of  $\text{ED}_{95}$  concentrations (Table 1). The tox-

icity of SC ( $\text{ED}_{50} = 5.0$  mM) to spores of *P. digitatum* was significantly higher than potassium carbonate ( $\text{ED}_{50} = 6.2$  mM). The toxicity of SBC ( $\text{ED}_{50} = 14.1$  mM) to spores of *P. digitatum* was not significantly different than ammonium bicarbonate ( $\text{ED}_{50} = 16.4$  mM), but significantly superior to potassium bicarbonate ( $\text{ED}_{50} = 33.4$  mM). Spores removed from these solutions, rinsed in water, and incubated in potato dextrose broth for an additional 18 h had a germination rate of more than 99%. In tests with bicarbonate salts where the pH was 7.2 ( $\pm 0.2$ ) with phosphate buffer, the  $\text{ED}_{50}$  concentrations of ammonium bicarbonate, SBC, and potassium bicarbonate were 34.4, 37.2, and 38.1 mM, respectively, and not significantly different from each other.

**Comparison of bicarbonate and carbonate solutions for the control of green mold on lemons.** The control of green mold was significantly better by SC or SBC solutions compared to potassium or ammonium solutions (Table 2).

**Comparison of SC and SBC for the control of green mold.** The control of citrus green mold by SBC and SC was not significantly different ( $P \geq 0.05$ ) in repeated tests with lemons and oranges (Fig. 2). Water alone at 40 or 43°C significantly reduced green mold in most tests compared to the untreated, inoculated controls, but the magnitude of the reduction was usually small.

**Influence of chlorination on SBC effectiveness.** The addition of 200  $\mu\text{g}/\text{ml}$  of sodium hypochlorite to water or SBC slightly but significantly ( $P = 0.002$ ) improved control of green mold on lemons (Fig. 3). The total chlorine content declined slightly from the beginning to the end of the test, from the initial 200  $\mu\text{g}/\text{ml}$  to approximately 180  $\mu\text{g}/\text{ml}$  after the treatments were applied. The pH and bicarbonate concentrations did not change during the test.

**Influence of post-treatment water rinse volume on SC effectiveness.** The volume of water sprayed onto fruit after SC treatment did not influence the effectiveness of the treatment to control green mold (Table 3).

**Influence of high-pressure water washing on SC effectiveness.** Washing fruit with water at high pressure significantly impacted control of green mold by SC treatment (Fig. 4). The incidence of

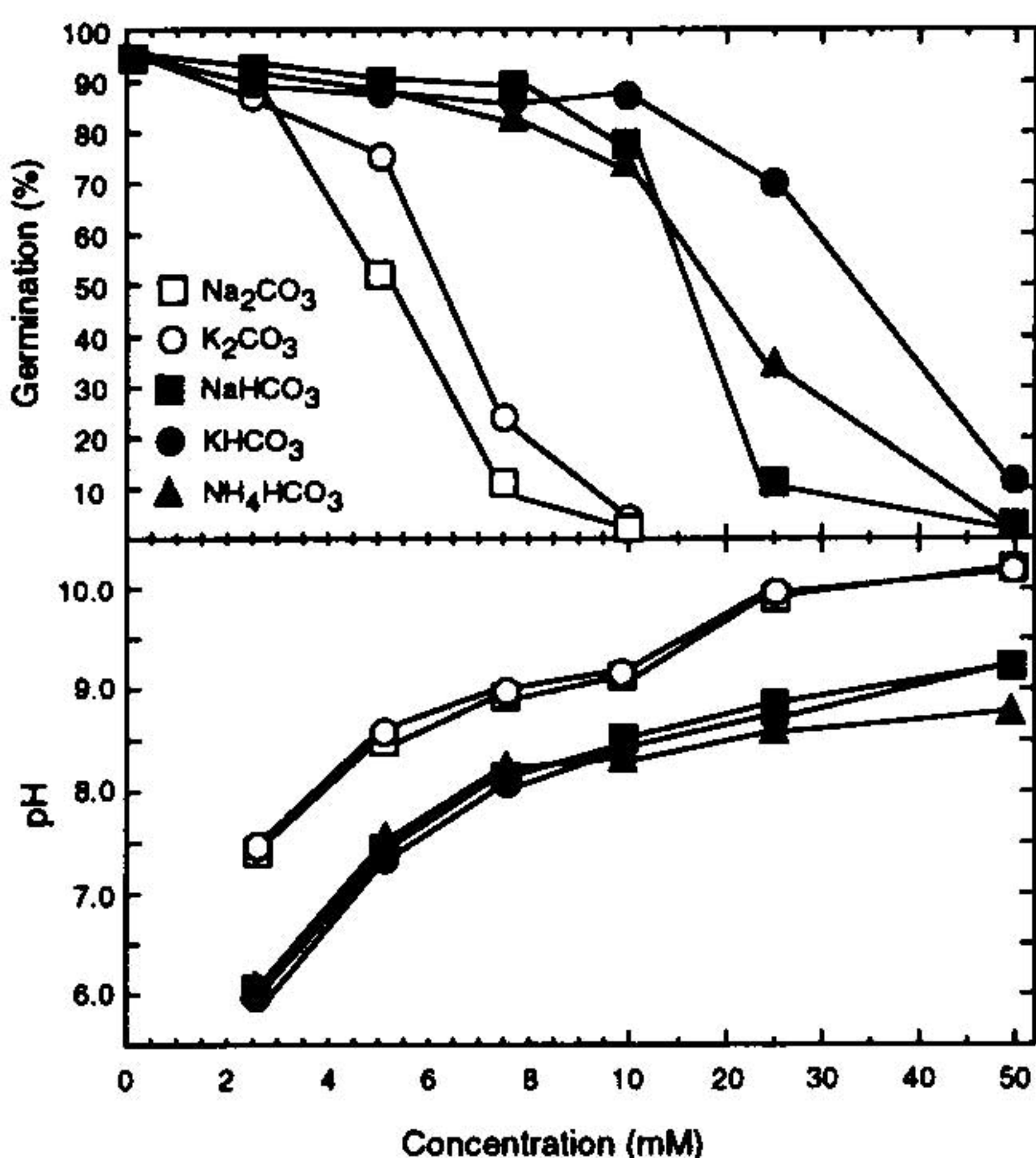


Fig. 1. The germination of spores of *Penicillium digitatum* after 24 h in potato dextrose broth in bicarbonate or carbonate solutions at the pH indicated.

Table 1. Concentrations (mM) of bicarbonate or carbonate salts that inhibited the germination of spores of *Penicillium digitatum*

Salt	$\text{ED}_{50}^z$	$\text{ED}_{95}$
$\text{Na}_2\text{CO}_3$	5.0 (4.8, 5.2)	9.9 (9.4, 10.5)
$\text{K}_2\text{CO}_3$	6.2 (5.3, 7.0)	9.6 (8.5, 13.4)
$\text{NaHCO}_3$	14.1 (13.4, 14.9)	31.0 (28.4, 34.4)
$\text{NH}_4\text{HCO}_3$	16.4 (13.1, 20.4)	43.6 (32.5, 72.1)
$\text{KHCO}_3$	33.4 (31.5, 35.4)	70.6 (63.4, 81.4)

<sup>z</sup>  $\text{ED}$  = effective dose. Each value was calculated from three observations. Values in parenthesis are the upper and lower 95% fiducial limits.