Control of Postharvest Blue and Green Molds of Oranges by Hot Water, Sodium Carbonate, and Sodium Bicarbonate

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ABSTRACT

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Control of citrus blue mold, caused by *Penicillium italicum*, was evaluated on artificially inoculated oranges immersed in water at up to 75°C for 150 s; in 2 to 4% sodium carbonate (wt/vol) at 20 or 45°C for 60 or 150 s; or in 1 to 4% sodium bicarbonate at room temperature for 150 s, followed by storage at 20°C for 7 days. Hot water controlled blue mold at 50 to 55°C, temperatures near those that injured fruit, and its effectiveness declined after 14 days of storage. Sodium carbonate and sodium bicarbonate were superior to hot water. Temperature of sodium carbonate solutions influenced effectiveness more than concentration or immersion period. Sodium carbonate applied for 150 s at 45°C at 3 or 4% reduced decay more than 90%. Sodium bicarbonate applied at room temperature at 2 to 4% reduced blue mold by more than 50%, while 1% was ineffective. In another set of experiments, treatments of sodium bicarbonate at room temperature, sodium carbonate at 45°C, and hot water at 45°C reduced blue mold incidence on artificially inoculated oranges to 6, 14, and 27%, respectively, after 3 weeks of storage at 3°C. These treatments reduced green mold incidence to 6, 1, and 12%, respectively, while incidence among controls of both molds was about 100%. When reexamined 5 weeks later, the effectiveness of all, particularly hot water, declined. In conclusion, efficacy of hot water, sodium carbonate, and sodium bicarbonate treatments against blue mold compared to that against green mold was similar after storage at 20°C but proved inferior during long-term cold storage.

Additional keywords: baking soda, citrus, cold storage, *Penicillium digitatum*, postharvest decay, soda ash

Postharvest green mold, caused by *Penicillium digitatum* (Pers.:Fr.) Sacc., is the most economically important postharvest disease of citrus in Spain (34), California, and all production areas characterized by low summer rainfall (11). However, when citrus fruit such as Valencia oranges or Clementine mandarins are stored for long periods, usually at temperatures below 5°C, postharvest blue mold, caused by *Penicillium italicum* Wehmer, becomes more important because it grows faster than *P. digitatum* below 10°C (37). In Spain, several orange cultivars are often stored at about 3°C for long periods to take advantage of seasonal changes in market prices. In California, Valencia oranges are stored at very low temperatures to reduce losses of fruit stored for preparation of fresh juice. Blue mold may also predominate in fruit treated with benzimidazole fungicides, because resistance to these

materials occurs more frequently in isolates of *P. italicum* than in *P. digitatum* (14). Currently, both diseases are primarily controlled by application of the fungicides imazalil, sodium ortho-phenyl phenate, or thiabendazole (21,30). Alternative methods are needed because the widespread use of these chemicals in commercial packing-houses has led to the proliferation of resistant strains of the pathogens (4,9). Furthermore, concerns about public health and environmental issues (8,24) have increased the need for alternatives.

Postharvest hot water treatments have been well studied for the control of postharvest decay of citrus fruits (3,19,33,35) and, in the case of long-term refrigerated storage, for the improvement of fruit resistance to chilling injury (26). When combined with fungicides, hot water greatly enhances their efficacy and makes it possible to reduce their application rates (2,32,35).

Carbonic acid salts, such as sodium carbonate (Na₂CO₃, soda ash) and sodium bicarbonate (NaHCO₃, baking soda), are common food additives allowed with no restrictions for many applications by European and North American regulations (18,23). Sodium bicarbonate is classified as generally recognized as safe by the

United States Food and Drug Administration and also proposed exempt from residue tolerances on all agricultural commodities by the United States Environmental Protection Agency. Both sodium carbonate and sodium bicarbonate were listed as approved ingredients on products labeled "organic" as proposed by the United States Department of Agriculture. The antimicrobial activity of these compounds has been described in vitro (5), in meat (12), in fish (6), and on leaves and fruit (29,38). Sodium bicarbonate to control postharvest green and blue molds of citrus was first described by Barger in 1928 (1) as an alternative to the use of borax. Sodium carbonate has been used to improve cleaning and also to reduce postharvest decay of lemons in California for more than 70 years (11). Both salts can be useful tools to manage postharvest decay because they are inexpensive, readily available, and can be used with a minimal risk of injury to the fruit. Recent work shows that sodium carbonate and sodium bicarbonate solutions, used correctly, approach the effectiveness of common synthetic fungicides used to control *P. digitatum* on lemons (30) and oranges (29). A model to predict green mold incidence among sodium carbonate-treated oranges, describing the influence of sodium carbonate concentration, temperature, and immersion period, was developed and validated under commercial conditions (29). Although somewhat less effective on oranges than on lemons, the effectiveness of sodium carbonate was high enough that its commercial use on oranges is justified for the control of green mold. Recently, the influence of commercial postharvest practices on the control of green mold by sodium carbonate and sodium bicarbonate was published to facilitate their commercial adoption (31). However, little research has been focused on the control of blue mold by carbonate and bicarbonate salts.

Objectives of the present work were to (i) determine the range of water temperatures able to control blue mold on oranges without rind injury; (ii) evaluate the efficacy of sodium carbonate and sodium bicarbonate at different concentrations, temperatures, and immersion periods; and (iii) evaluate their effectiveness against blue and green molds during long-term cold storage.

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MATERIALS AND METHODS

Fruit. Oranges (*Citrus sinensis* (L.) Osbeck) cvs. Washington Navel, Navelate, Lanelate, and Valencia, from commercial orchards in southern Tarragona (Catalonia, Spain) or California, were selected by hand from field bins after harvest and used in the experiments before any commercial postharvest treatments were applied. The fruit were used the same day or stored up to 2 weeks at 5°C and 90% relative humidity (RH) before use. Before each experiment, fruit were randomized, washed with fresh water, disinfected superficially for 1 min in a diluted bleach dip (0.5% sodium hypochlorite), rinsed with water, and allowed to air dry at room temperature.

Inoculum. Several *P. italicum* isolates were obtained from decayed oranges or mandarins from Tarragona citrus packing-houses and one isolate (PIM-7), showing the highest aggressiveness in preliminary tests, was used in subsequent experiments. Petri dishes of potato dextrose agar (PDA) were inoculated with this isolate and incubated at 25°C for 7 to 10 days. A conidial suspension was prepared in Tween 80 (0.05% wt/vol) in water and diluted to 10⁶ spores per milliliter after counting spores with a hemacytometer. This density is recommended for evaluation of postharvest treatments to control blue and green molds (10). About 2 h before treatments, 25 µl of this suspension was placed, using a micropipet, in a 1-by-5-by-2-mm deep wound made with a stainless steel scalpel on the equator of each fruit. The wound penetrated the albedo tissue, but not the juice sacs, and simulated frequent infection under commercial conditions. In the experiments conducted in California, *P. italicum* isolate PIM-7 or *P. digitatum* isolate M6R (obtained from J. W. Eckert, University of California, Riverside) was cultured on PDA dishes at 25°C for 7 to 14 days. Spores were rubbed from the agar surface with a sterile glass rod after 5 ml of 0.05% (wt/vol) Triton X-100 in water were added. The spore suspension was passed through two layers of cheese cloth and diluted with water to an absorbance of 0.1 at 420 nm determined with a spectrophotometer. This density is approximately equivalent to 10⁶ spores per milliliter (22). About 24 h before treatments, fruit were inoculated by immersing a stainless steel rod with a probe tip 1 mm wide and 2 mm in length into the spore suspension and wounding each fruit once on the equator. The inoculated fruit were held at room temperature.

Hot water treatments. Three stainless steel buckets, each holding 24 liters of water, were heated to the test temperature in a 172-liter stainless steel water tank fitted with a 9-kW electric resistance heater and thermostat. Metallic grid baskets, containing the oranges inoculated with *P. italicum* 2 to 3 h previously, were submerged in the buckets for 150 s. Three experiments, two with Navelate and one

with Valencia oranges, were conducted to determine the approximate range of effective and safe temperatures. The tested temperatures were 20 (control), 35, 45, 48, 50, 53, 55, 57, 60, 65, and 75°C (±1°C). Another set of control fruit were inoculated but not treated. Within each experiment, each treatment was applied to four replicates of five fruit each. Treated fruit were placed in plastic cavity trays that prevented contact infections, dried in air on wooden trays at room temperature, and stored at 20°C and 90% RH. After 7 and 14 days, the infected oranges were counted. After the first 7 days of storage, fruit were also classified into one of four categories, depending on rind appearance: (i) no rind damage, (ii) slight blemishes present, (iii) moderate blemishes present, and (iv) severe rind injury.

Sodium carbonate treatments. California-grown Valencia oranges were inoculated with *P. italicum* 24 h before treatment as previously described, placed into plastic baskets, and immersed in 22-liter tanks containing sodium carbonate solutions (pH 11.3 to 11.5; Sigma-Aldrich, St. Louis). The treatment equipment consisted of 12 stainless steel tanks, each one individually fitted with a computer-controlled electrical heater, a temperature sensor, and a mechanical agitation system. Four sodium carbonate concentrations (0 [control, water alone], 2, 3, and 4% [wt/vol]), two temperatures (20 and 45°C), and two immersion periods (60 and 150 s) were tested. The temperature of the solutions did not change more than 0.5°C during treatment. After treatment, the fruit were rinsed with 10 ml of deionized water per fruit at low pressure (200 kPa) in a spray 30 cm above the fruit for 5 s, placed on plastic cavity trays on wooden trays, and stored at 20°C and 90% RH. After 7 days of storage, the incidence of blue mold was determined. Each treatment was applied to five replicates of 25 oranges each. The experiment was repeated twice with Valencia oranges.

Sodium bicarbonate treatments. Washington Navel and Navelate oranges from Tarragona were inoculated with *P. italicum* with a micropipet and, about 2 h later, immersed for 150 s in 0 (control, water alone), 1, 2, 3, or 4% (wt/vol) sodium bicarbonate (pH 8.3 to 8.6; Sigma-Aldrich) solutions at room temperature (20 ± 2°C), using buckets and water tank as previously described. The pH of sodium bicarbonate solutions rises rapidly at high temperature; therefore, only room temperature was tested (31). Each treatment was applied to four replicates of 10 fruit each. Treated fruit were placed into plastic cavity trays and stored at 20°C and 90% RH for 7 days, at which time the incidence of blue mold infections was determined. Valencia oranges from California were inoculated, dipped 22 to 24 h later for 150 s in 0 (control, water alone), 1, 2, 3, or 4%

(wt/vol) sodium bicarbonate solutions at 20°C (±0.5°C), rinsed, stored at 20°C for 7 days, and checked for decay incidence, all as described above for the sodium carbonate treatments. Four replicates of 25 fruit each were used within each treatment, and the experiment was repeated twice.

Long-term cold storage. California-grown Lanelate oranges, inoculated with *P. italicum* or *P. digitatum* 24 h before treatment, were dipped in sodium carbonate or sodium bicarbonate solutions and rinsed as previously described, then stored at 3°C (±1°C) and 90% RH for 2 months. The treatments applied in the sodium carbonate experiment were (i) water alone at 20°C, (ii) water alone at 45°C, and (iii) 3% (wt/vol) sodium carbonate at 45°C. Each treatment was applied to six replicates of 15 oranges each. The treatments applied in the sodium bicarbonate experiment were (i) water alone at 20°C and (ii) 3% (wt/vol) sodium bicarbonate at 20°C. Each treatment was applied to five replicates of 10 fruit each. Each solution was prepared twice and each pathogen was assayed separately to avoid mixing spores. The incidence of decayed fruit was determined weekly.

Statistical analysis. Analysis of variance was applied to the arcsine of the square root of the proportion of decayed fruit using SAS software (SAS Institute Inc., Cary, NC).

RESULTS

Hot water treatments. In the first experiment with Navelate oranges, a temperature range of 35 to 75°C (in increments of 10°C) was evaluated. Treatment with hot water at 65°C controlled blue mold (Fig. 1A) but severely injured the rind surface of 100% of the oranges (Table 1). Fruit treated at 75°C were entirely discolored and soft. These fruit could not be sold commercially and had many secondary infections by contaminating saprophytic microorganisms. Below these temperatures, only the 55°C treatment controlled *P. italicum* effectively after 7 days of storage at 20°C, but control was unsatisfactory when fruit were examined after 14 days (Fig. 1A). About 30% of the fruit treated at 55°C had slight and moderate rind blemishes (Table 1). No rind damage was observed on oranges treated at temperatures of 45°C and lower. In the second experiment with Navelate oranges, temperatures from 50 to 60°C were tested. All these temperatures consistently suppressed disease development after 7 days, with a 90 to 100% reduction in decay incidence compared to the control treatments (no treatment and treatment at 20°C; Fig. 1B). After 7 days of storage, severe rind injuries were present on 30% of the fruit treated at 57°C and on 90% of those treated at 60°C (Table 1). In the third experiment, the effect of 150 s of hot water treatment from 45 to 55°C on Valencia oranges was as-

sessed. Blue mold incidence after 7 days was high among the controls (90 to 100%) and hot water effectiveness was low (Fig. 1C). Satisfactory control was obtained after treatment at 53 and 55°C, but not after treatment at 50°C or lower. No injuries were caused by the 53 or 55°C treatment (Table 1). A significant increase in decay incidence occurred during the second week of storage in all three experiments (Fig. 1).

Sodium carbonate treatments. The combined effects of sodium carbonate concentration, temperature, and immersion period were evaluated on Valencia oranges. All three factors significantly influenced the control of blue mold, although the influence of temperature was greater than that of concentration or immersion period (Table 2). Sodium carbonate improved blue mold control in comparison with water alone (Fig. 2). At room temperature, with decay incidence on the control treatment (water alone) adjusted to 100%, the incidence of blue mold at concentrations of 3 and 4% sodium carbonate was 20 to 30%. Similarly, decay incidence was 20 to 25% after treatment of the fruit for 60 s in 3 or 4% sodium carbonate at 45°C. Lower blue mold incidence (<10%) was obtained by treatment of the fruit for 150 s in these sodium carbonate solutions at 45°C. The effect of the concentration was significantly dependent on the temperature (Table 2): differences in effectiveness among sodium carbonate concentrations, and especially between concentration 0 (water alone) and those treatments with sodium carbonate, were more important at 20°C than at 45°C (Fig. 2). The effect of the immersion period was also significantly dependent on the temperature; a treatment of 150 s enhanced the effectiveness of all the treatments compared to 60 s at 45°C, but not at 20°C. No visible rind injury occurred in any test.

Sodium bicarbonate treatments. Washington Navel and Navelate oranges inoculated 2 h before treatment and immersed for 150 s in 2, 3, and 4% sodium bicarbonate solutions at room temperature reduced blue mold incidence substantially (down to 10 to 15%; Fig. 3), while the blue mold incidence after 1% sodium bicarbonate treatment was significantly inferior on both cultivars (25 to 40%). Similar results, although the decay incidence was higher, were obtained with Valencia oranges inoculated 24 h before treatment, which was followed by a low-pressure water rinse (Fig. 3).

Long-term cold storage. Both sodium carbonate at 45°C and sodium bicarbonate applied at room temperature significantly reduced the incidence of both green and blue molds during the 2-month storage period (Fig. 4). After 3 weeks at 3°C, the incidence of blue and green molds on oranges treated with sodium bicarbonate,

sodium carbonate, or hot water at 45°C was 6, 14, and 27%, and 6, 1, and 12% respectively, while it was 100% among the controls. Hot water at 45°C greatly reduced decay incidence compared to treatment with water at 20°C (control), and sodium carbonate treatment at 45°C re-

duced decay incidence compared to treatment with hot water at this temperature. After 2 months of storage at 3°C, blue mold incidence was 38% for sodium bicarbonate, 56% for sodium carbonate, and 76% for hot water. Green mold incidence was 32, 22, and 60%, respectively (Fig. 4).

Fig. 1. Incidence of blue mold on artificially inoculated orange cvs. A, B, Navelate and C, Valencia immersed for 150 s in water at different temperatures (control fruit were inoculated but not treated) after 7 and 14 days of storage at 20°C and 90% relative humidity.

Table 1. Influence of water temperature on the appearance of Navelate (N) and Valencia (V) oranges immersed for 150 s and stored at 20°C and 90% relative humidity for 7 days

Water temp. (°C)	Rind injury frequency (%) ^a					
	Slight		Moderate		Severe	
	N	V	N	V	N	V
20	0	0	0	0	0	0
35	0	...	0	...	0	...
45	0	0	0	0	0	0
48	...	0	...	0	...	0
50	0	0	0	0	0	0
53	17	0	0	0	0	0
55	22	8	6	0	0	0
57	17	...	32	...	27	...
60	0	...	11	...	89	...
65	0	...	0	...	100	...
75	0	...	0	...	100	...

^a ... = temperature not assayed.

The incidence of blue mold was higher than the incidence of green mold and the magnitude of the difference was smaller in sodium bicarbonate-treated fruit than in sodium carbonate- or hot water-treated fruit.

DISCUSSION

Control of blue mold was obtained by brief hot water treatment of Navelate and Valencia oranges without injury of apparent commercial impact, although the effective temperatures were close to those

Table 2. Analysis of variance of the incidence of blue mold on artificially inoculated Valencia oranges immersed in sodium carbonate solutions and stored at 20°C and 90% relative humidity for 7 days

Source ^a	df	MS	F	P > F
Experiment (E)	1	91.08	1.40	0.2384
Temperature (T)	1	22,239.78	342.30	<0.0001
Concentration (C)	3	13,686.77	210.66	<0.0001
Immersion period (t)	1	2,846.48	43.81	<0.0001
T × C	3	3,497.75	53.83	<0.0001
T × t	1	1,195.06	18.39	<0.0001
C × t	3	181.77	2.80	0.0424
T × C × t	2	15.74	0.24	0.8667
Error	143	64.97	...	...

^a Analysis was applied to the arcsine of the square root of the proportion of decayed fruit.

Fig. 2. Influence of solution temperature, sodium carbonate concentration, and immersion period (○ = 60 s, ■ = 150 s) on the incidence of blue mold on cv. Valencia oranges artificially inoculated 24 h before treatment, rinsed at low pressure, and stored at 20°C and 90% relative humidity for 7 days. Data are the means of two experiments with five replicates of 25 fruit each.

Fig. 3. Influence of sodium bicarbonate concentration on the incidence of blue mold on orange cvs. Washington Navel (○), Navelate (■), and Valencia (●) treated at room temperature for 150 s and stored at 20°C and 90% relative humidity for 7 days. Washington Navel and Navelate oranges were inoculated 2 h before treatment and not rinsed; values are the means of four replicates of 10 fruit each. Valencia oranges were inoculated 24 h before treatment and rinsed at low pressure; values are the means of four replicates of 25 fruit each.

that caused injury. Control at 7 days of storage was observed with treatments between 50 and 55°C but, after 14 days, control was significantly inferior. Satisfactory control was not achieved at lower temperatures and severe rind injury occurred above 55°C. Similarly, Barkai-Golan and Apelbaum (2) found that hot water immersion for 3 min at 36°C did not reduce the incidence of blue mold in inoculated Shamouti oranges, and treatment at 45°C only caused a reduction of 6% after 14 days of storage at 14°C. Our results with blue mold are similar to those reported for green mold by other workers. Most of the research on the use of hot water to prevent postharvest citrus decay has focused on control of *P. digitatum*. Smoot and Melvin (33) and Tuset et al. (35) reported that immersion of oranges in water at 53°C controlled green mold of artificially inoculated oranges. In Houck's tests (16), the temperature required to control green mold on Eureka lemons was 52°C. Hot water treatment at 50 to 54°C did not injure the rind of Fortuna mandarins, but treatment at 56 to 58°C was injurious (27). In our work, when the incidence of the decay was low among the controls, more significant control was obtained at lower temperatures than when the incidence among the controls was high. This may be related to the physiological condition of the fruit, which clearly influences the susceptibility of citrus fruit to decay. The susceptibility of Tarocco oranges to postharvest decay, chilling injury, and rind injury caused by hot water was greatly influenced by the harvest date (28). At the temperature range in which the satisfactory control of green mold occurred, the effectiveness of hot water was not very persistent. We found the same results with blue mold as with green mold in previous work (25); namely, the control of blue mold after 14 days of storage at 20°C was significantly inferior to that after 7 days of storage. Commercial adoption of hot water treatment must be done with caution because the difference in temperature between control and severe injury was small. In general, our work and that of others indicates that hot water used alone to control green and blue molds is accompanied by considerable risk of rind injury and lack of persistent control.

Significant control of blue mold was achieved by 2, 3, and 4% sodium carbonate or sodium bicarbonate solutions at room temperature. Heating sodium carbonate solutions to 45°C improved its efficacy compared to treatment at room temperature. Heated sodium carbonate solutions were more effective than hot water alone even at lower temperatures, which is important to minimize risks of rind damage by heat. Many authors observed synergistic effects of heat and chemicals used to control postharvest decay (2,19,29,32,35). In our tests, oranges treated with carbonates were not injured. Sodium carbonate and

sodium bicarbonate efficacy against blue mold was comparable to that obtained against green mold in related previous experiments (25,29–31). *P. italicum* and *P. digitatum* have similar infection processes and disease cycles; therefore, commercial application of these treatments may provide acceptable protection against both molds. Although sodium carbonate and sodium bicarbonate controlled naturally inoculated citrus fruit more effectively than artificially inoculated fruit (1,29), the present results should be confirmed in commercial-scale tests. Efficacy of sodium carbonate and sodium bicarbonate decreased when fruit susceptibility to decay was high (indicated by higher decay levels among control fruit). A high proportion of *P. italicum* and *P. digitatum* conidia remained germinable after 5 min of exposure to 10% sodium carbonate or sodium bicarbonate (20); therefore, the compounds probably are not lethal. We removed *P. italicum* spores from inoculated wounds on oranges, both just after sodium carbonate or sodium bicarbonate treatment and after a 7-day storage period at 20°C, and plated the spores on PDA dishes that were incubated at 25°C. The spores germinated and developed colonies. The increase in decay incidence that occurred during the second-week storage period at 20°C also indicated that the pathogen survived treatment. Therefore, the effect is primarily fungistatic and not very persistent, and is very likely due to the presence of carbonate or bicarbonate residues within the wound infection courts occupied by the fungus.

The impact of the concentration of the chemical, the immersion period, and the temperature of the solution can influence the presence of residues and, consequently, may play an important role on the magnitude of control obtained. Smilanick et al. (29) developed a model describing the influence of these factors on the control of green mold on sodium carbonate-treated oranges and validated it under commercial conditions. Green mold incidence was significantly influenced by all three factors. The best control of green mold was obtained after treatment for 2 min at 40.6 or 43.3°C in 4 or 6% sodium carbonate. In the present work, blue mold incidence on sodium carbonate-treated oranges was also significantly influenced by all three factors, although the influence of temperature was greater than those of concentration or immersion period. Hwang and Klotz (17) found that inhibitory activity of carbonate, bicarbonate, and other salt solutions on spores of *P. italicum* and *P. digitatum* was more dependent on temperature than on concentration. A practice that could influence the effectiveness of carbonates is the addition of emulsifiers or surfactants to their solutions. Homma et al. (15) reported that the addition of such compounds, commonly used in food and pesticide formulations, improved the sodium bicarbon-

ate effectiveness against green mold on Satsuma mandarins. They proposed that improvement might result from less sodium bicarbonate crystallization in solution, better adhesion of sodium bicarbonate to the rind, or improved surface distribution of the sodium bicarbonate.

Sodium carbonate and sodium bicarbonate mode of action against *Penicillium* spp. on citrus fruit has not been completely elucidated. Disease development is a result of complex interactions between host, pathogen, and environment (13). Notable differences have been detected between results of in vitro and in vivo tests. In vitro activity of several carbonate salts against germinated or ungerminated spores of *P. italicum* and *P. digitatum* was higher than that of bicarbonate salts, although their efficacy was similar in vivo (17,20,31). Hwang and Klotz (17) suggested that the original toxicity of the treating solution to the spores is altered by interactions in wounds with constituents of the rind. The relatively high pH of these solutions has been proposed to be the mode of action (7), although there is evidence that high pH alone cannot explain the inhibitory action of these salts (15,17,20). The in vitro and in vivo control of green mold by sodium carbonates and bicarbonates were superior to those by potassium or ammonium carbonates and bicarbonates (20,31), which suggests that the sodium cation has some

role in the control of the disease. Marloth (20) found that germinated spores of both fungi were more readily killed by sodium carbonate and sodium bicarbonate than were nongerminated spores. Hwang and Klotz (17) observed that *P. italicum* spores were more sensitive to the in vitro inhibitory effect of sodium carbonate, sodium bicarbonate, and other salts than were *P. digitatum* spores.

This is the first work in which citrus *Penicillium* decay on artificially inoculated fruit treated with sodium carbonate or sodium bicarbonate was periodically assessed during long refrigerated storage. Our results, especially during the first 3 weeks of storage, indicate that the treatments complemented the inhibitory action of low temperature. Control of blue mold was inferior to that of green mold, very likely because of the better adaptation of *P. italicum* to grow at low temperature.

In contrast to *P. digitatum*, *P. italicum* is readily able to spread from fruit to fruit in packed containers and create nests of decayed fruit (11). Moreover, healthy fruit can be soiled by spores of both fungi dislodged from diseased fruit (11,37). Hot water, sodium carbonate, and sodium bicarbonate are poor eradicants that do not kill spores and their inhibitory action is not very persistent; therefore, additional complementary treatments could be needed to provide protection of the fruit from rein-

Fig. 4. Incidence of green (PD) and blue (PI) molds on artificially inoculated cv. Lanelate oranges after treatment and storage at 3°C and 90% relative humidity for 2 months. **A**, Immersion in water alone (CON) or 3% sodium bicarbonate (SBC) at room temperature; **B**, immersion in water alone at room temperature (CON), water at 45°C (HW), or 3% sodium carbonate at 45°C (SC).

fection after treatment. Biological control antagonists, which can persist for long periods, may accomplish this task (31). The effectiveness of sodium carbonate and sodium bicarbonate against green mold was significantly improved when these treatments were followed by the application of *Pseudomonas syringae* strain ESC10 (31). Work in our laboratory is being conducted to test the possible complementary effect of the strain CPA-2 of the antagonistic bacterium *Pantoea agglomerans* (36) and carbonate treatments against citrus postharvest green and blue molds.

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LITERATURE CITED

1. Barger, W. R. 1928. Sodium bi-carbonate as a citrus fruit disinfectant. *Calif. Citrogr.* 13:164-174.
2. Barkai-Golan, R., and Apelbaum, A. 1991. Synergistic effects of heat and sodium o-phenyl phenate treatments to inactivate *Penicillium* spores and suppress decay in citrus fruits. *Trop. Sci.* 31:229-233.
3. Barkai-Golan, R., and Phillips, D. J. 1991. Postharvest heat treatment of fresh fruits and vegetables for decay control. *Plant Dis.* 75:1085-1089.
4. Bus, V. G., Bongers, A. J., and Risse, L. A. 1991. Occurrence of *Penicillium digitatum* and *Penicillium italicum* resistant to benomyl, thiabendazole, and imazalil on citrus fruit from different geographic origins. *Plant Dis.* 75:1098-1100.
5. Corral, L. G., Post, L. S., and Montville, T. J. 1988. Antimicrobial activity of sodium bicarbonate. *J. Food Sci.* 53:981-982.
6. Curran, D. M., Tepper, B. J., and Montville, T. J. 1990. Use of bicarbonates for microbial control and improved water-binding capacity in cod filets. *J. Food Sci.* 55:1564-1566.
7. DePasquale, D. A., and Montville, T. J. 1990. Mechanism by which ammonium bicarbonate and ammonium sulfate inhibit mycotoxigenic fungi. *Appl. Environ. Microbiol.* 56:3711-3717.
8. Dezman, D. J., Nagy, S., and Brown, G. E. 1986. Postharvest fungal decay control chemicals: treatments and residues in citrus fruits. *Residue Rev.* 97:37-92.
9. Díaz, M. A., and Vila, R. 1988. El problema de la resistencia a los fungicidas: referencia a la situación en los almacenes españoles de comercialización de cítricos. *Rev. Agroquím. Tecnol. Aliment.* 28:151-158.
10. Eckert, J. W., and Brown, G. E. 1986. Evaluation of postharvest treatments for citrus fruits. Pages 92-97 in: *Methods for Evaluating Pesticides for Control of Plant Pathogens*. K. D. Hickey, ed. American Phytopathological Society Press, St. Paul, MN.
11. Eckert, J. W., and Eaks, I. L. 1989. Postharvest disorders and diseases of citrus fruits. Pages 179-260 in: *The Citrus Industry*. Vol. 5. W. Reuter, E. C. Calavan, and G. E. Carman, eds. Univ. Calif. Press, Berkeley.
12. Fletcher, D. L., Russell, S. M., Walker, J. M., and Bailey, J. S. 1993. An evaluation of a rinse procedure using sodium bicarbonate and hydrogen peroxide on the recovery of bacteria from broiler carcasses. *Poultry Sci.* 72:2152-2156.
13. Green, F. M. 1932. The infection of oranges by *Penicillium*. *J. Pomol. Hortic. Sci.* 10:184-215.
14. Gutter, Y. 1975. Interrelationship of *Penicillium digitatum* and *P. italicum* in thiabendazole-treated oranges. *Phytopathology* 65:498-499.
15. Homma, Y., Arimoto, Y., and Misato, T. 1981. Effects of emulsifiers and surfactants on the protective values of sodium bicarbonate. *J. Pestic. Sci.* 6:145-153.
16. Houck, L. G. 1967. Hot water treatments for control of *Penicillium* green mold of Eureka lemons. (Abstr.) *Phytopathology* 57:99.
17. Hwang, L., and Klotz, L. J. 1938. The toxic effect of certain chemical solutions on spores of *Penicillium italicum* and *P. digitatum*. *Hilgardia* 12:1-38.
18. Lindsay, R. C. 1985. Food additives. Chapter 10 in: *Food Chemistry*. O. R. Fennema, ed. Marcel Dekker, Inc., New York.
19. Lurie, S. 1999. Postharvest heat treatments. *Postharvest Biol. Technol.* 14: 257-269.
20. Marloth, R. H. 1931. The influence of hydrogen-ion concentration and of sodium bicarbonate and related substances on *Penicillium italicum* and *P. digitatum*. *Phytopathology* 21:169-198.
21. Martínez-Jávega, J. M., Cuquerella, J., and Navarro, P. 1995. Perspectiva actual de la tecnología postcosecha de frutos cítricos. *Levante Agrícola* 332:220-225.
22. Morris, S. C., and Nicholls, P. J. 1978. An evaluation of optical density to estimate fungal spore concentrations in water suspensions. *Phytopathology* 68:1240-1242.
23. Multon, J. L. 1988. Aditivos y Auxiliares de Fabricación en las Industrias Agroalimentarias. Editorial Acirbia, Zaragoza, Spain.
24. National Research Council. 1993. *Pesticides in the Diets of Infants and Children*. National Academy Press, Washington, DC.
25. Palou, L., Usall, J., Aguilar, M. J., Pons, J., and Viñas, I. 1999. Control de la podredumbre verde de los cítricos mediante baños con agua caliente y carbonatos sódicos. *Levante Agrícola* 348:412-421.
26. Rodov, V., Ben-Yehoshua, S., Albagli, R., and Fang, D. Q. 1995. Reducing chilling injury and decay of stored citrus fruit by hot water dips. *Postharvest Biol. Technol.* 5:119-127.
27. Schirra, M., and D'hallewin, G. 1997. Storage performance of 'Fortune' mandarins following hot water dips. *Postharvest Biol. Technol.* 10:229-238.
28. Schirra, M., D'hallewin, G., Cabras, P., Angioni, A., and Garau, V. L. 1998. Seasonal susceptibility of Tarocco oranges to chilling injury as affected by hot water and thiabendazole postharvest dip treatments. *J. Agric. Food Chem.* 46:1177-1180.
29. Smilanick, J. L., Mackey, B. E., Reese, R., Usall, J., and Margosan, D. A. 1997. Influence of concentration of soda ash, temperature, and immersion period on the control of postharvest green mold of oranges. *Plant Dis.* 81:379-382.
30. Smilanick, J. L., Margosan, D. A., and Henson, D. J. 1995. Evaluation of heated solutions of sulfur dioxide, ethanol, and hydrogen peroxide to control postharvest green mold of lemons. *Plant Dis.* 79:742-747.
31. Smilanick, J. L., Margosan, D. A., Mlikota, F., Usall, J., and Michael, I. F. 1999. Control of citrus green mold by carbonate and bicarbonate salts and the influence of commercial postharvest practices on their efficacy. *Plant Dis.* 83:139-145.
32. Smilanick, J. L., Michael, I. F., Mansour, M. F., Mackey, B. E., Margosan, D. A., Flores, D., and Weist, C. F. 1997. Improved control of green mold of citrus with imazalil in warm water compared with its use in wax. *Plant Dis.* 81:1299-1304.
33. Smoot, J. J., and Melvin, C. F. 1963. Hot water as a control for decay of oranges. *Proc. Fla. State Hortic. Soc.* 76:322-327.
34. Tuset, J. J. 1987. Podredumbres de los Frutos Cítricos. Conselleria d'Agricultura i Pesca. Generalitat Valenciana, Valencia, Spain.
35. Tuset, J. J., Hinarejos, C., Mira, J. L., and Martínez-Jávega, J. M. 1996. Tratamientos térmicos a los frutos cítricos para el control de las enfermedades de la post-recolección. *Levante Agrícola* 337:342-347.
36. Viñas, I., Usall, J., Nunes, C., and Teixidó, N. 1999. Nueva cepa de la bacteria *Pantoea agglomerans* (Beijerinck, 1998) Gavini, Mergaert, Beji, Mielcareck, Izard, Kerstersy De Ley y su utilización como agente de control biológico de las enfermedades fúngicas de frutas. *Solicitud P9900612*. Oficina Española de Patentes y Marcas, Madrid, Spain.
37. Whiteside, J. O., Garnsey, S. M., and Timmer, L. W., eds. 1988. *Compendium of Citrus Diseases*. 2nd ed. American Phytopathological Society Press, St. Paul, MN.
38. Ziv, O., and Zitter, T. A. 1992. Effects of bicarbonate and film-forming polymers on cucurbit foliar diseases. *Plant Dis.* 76:513-517.