

Control of Citrus Green Mold by Carbonate and Bicarbonate Salts and the Influence of Commercial Postharvest Practices on Their Efficacy

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ABSTRACT

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.

The toxicity to *Penicillium digitatum* and practical use of carbonate and bicarbonate salts to control green mold were determined. The effective dose (ED_{50}) concentrations to inhibit the germination of *P. digitatum* spores of sodium carbonate (SC), potassium carbonate, sodium bicarbonate (SBC), ammonium bicarbonate, and potassium bicarbonate were 5.0, 6.2, 14.1, 16.4, and 33.4 mM, respectively. All were fungistatic because spores removed from the solutions germinated in potato dextrose broth. SC and SBC were equal and superior to the other salts for control of green mold on lemons and oranges inoculated 24 h before treatment. When sodium content and high pH must be minimized, SBC could replace SC. Furthermore, because a higher proportion of NaOCl would be present in the active hypochlorous acid at the lower pH of SBC compared to SC, sanitation of the SBC solution should be easier to maintain. NaOCl (200 μ g/ml) added to SBC at pH 7.5 improved green mold control. Rinse water as high as 50 ml per fruit applied after SC did not reduce its effectiveness; however, high-pressure water cleaning after SC did. Conversely, high-pressure water cleaning of fruit before SC improved control of green mold. The risk of injury to fruit posed by SC treatment was determined by immersing oranges for 1 min in 3% (wt/vol) SC at 28, 33, 44, 50, 56, or 61°C ($\pm 1^\circ$ C) and followed by storage for 3 weeks at 10°C. Rind injuries occurred only after treatment at 56 and 61°C. The risk of injury is low because these temperatures exceed that needed for control of green mold. SC was compatible with subsequent imazalil and biological control treatments.

Bicarbonates and carbonates are common food additives for leavening, pH-control, taste, texture modification, and spoilage control (8). They also control many plant pathogens (12,19,29,33,41). Regulatory barriers to their use are few; most are classified as generally recognized as safe by the US Food and Drug Administration for many applications. In 1997, the US Environmental Protection Agency declared that bicarbonates were exempt from residue tolerances on all agricultural commodities, and the United States Department of Agriculture classified many carbonates and bicarbonates as approved ingredients on products labeled "organic" in proposed regulations to standardize organic practices. Brief immersion of citrus fruit in solutions of sodium bicarbonate (NaHCO_3) or sodium carbonate (Na_2CO_3 , soda ash) reduces the subsequent incidence of postharvest green mold, caused by *Peni-*

cillium digitatum (2,13,20,23,26,31,35). This practice is inexpensive, poses a minimal risk of injury to the fruit, and can be a useful tool in the management of fungicide resistant isolates, which have become particularly problematic (6,11). Its effectiveness can approach that of the fungicides employed for this purpose (36), and in general is superior to other treatments that are alternatives to fungicides, such as heat (5,7,21,36,37) or biological control (4,34). Sodium carbonate (SC) controls green mold even when applied long after inoculation; the incidence of infections from wounds on lemons inoculated 48 h before treatment was reduced more than 90% (36). Control of green mold after inoculation is important because most infections occur through wounds inflicted during or just after harvest (13,16,32), and often a day or more can elapse before treatments are applied. Previously, we developed a model describing the influence of SC concentration, temperature, and duration of contact on the control of green mold on oranges, where SC had been seldom used (35). Like heat and biological treatments applied to citrus, SC only reduces the incidence of green mold but, unlike fungicides, does not suppress the subsequent production of spores on those fruit that do decay. The deposition of spores on adjacent healthy fruit, termed "soilage," makes

cleaning of the remaining fruit necessary (10). SC use has become increasingly popular in California; however, certain aspects of the practical use of SC are incompletely known. Although both SC and sodium bicarbonate (SBC) have been recommended for this purpose, they have not been compared to each other or with ammonium or potassium carbonate salts. This information is of particular interest because the quality of water discharged from SC tanks can exceed pH and sodium content tolerances in some areas; the use of other solutions of lower pH, lower sodium content, or containing salts of less regulatory concern could alleviate this problem.

The inhibitory activity of carbonate or bicarbonate solutions against many microorganisms (28), including *P. digitatum* (22,26), is low and generally fungistatic. Therefore, it is probable that a residue of carbonate or bicarbonate must remain on the fruit, or at least within the wound infection courts occupied by this pathogen, for the treatment to control green mold. Winston (40) showed that the efficacy of the immersion of citrus fruit in heated solutions of borax-boric acid to control postharvest decay, in regimes very similar to those of SC, was greatly reduced by subsequent rinsing of the fruit with large volumes of water, and he stated some optimal level of post-treatment rinsing should be determined empirically where this treatment is used. It is likely that post-treatment rinsing also will influence the effectiveness of carbonate or bicarbonate solutions, because borax-boric acid and carbonate-bicarbonate solutions are both fungistats and of similar effectiveness (22). Rinsing is an important issue because the solutions must be rinsed off the fruit surface after treatment to prevent the deposition of the salts on brushes and belts of packing and sorting equipment, and to prevent phytotoxicity, seen as staining and desiccation of the fruit rind. Another process required after harvest is cleaning of the fruit. Introduced recently for this purpose are high-pressure water washers that blast scale insects, sooty mold, and soil from fruit with water applied at high pressure (150 to 500 psi or 1,000 to 3,500 kPa) in very high volumes. High pressure washing can be applied at any step after harvest before the application of waxes.

Other issues of concern for packinghouse managers contemplating the adop-

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Accepted for publication 15 October 1998.

Publication no. D-1998-1123-01R

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