Integrated Approaches to Postharvest Disease Management in California Citrus Packinghouses

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Abstract

Practices in the citrus industry evolve rapidly to minimize postharvest decay losses, mostly a result of green mold or blue mold, caused by *Penicillium digitatum* or *P. italicum*, respectively. Current problems include the continued development of fungicide resistance among these pathogens, and compliance with emerging secondary residue standards and other privatized regulation of production and postharvest practices, the rising popularity of new cultivars (such as mandarin oranges, where natural decay resistance is low) and the decline of others (such as Valencia oranges, where natural decay resistance is high), and marketing issues, including exceptionally long storage for distant markets or a requirement for food safety interventions, such as chlorination at high rates. Recently (since 2000) introduced practices in California include fungicide bin drenching of harvested fruit on transit trailers, the use of fungicides in aqueous solutions rather than in waxes to improve their performance, the application of sodium bicarbonate or potassium sorbate in heated tanks or through high-pressure washer nozzles, ozonation of storage rooms to oxidize ethylene and retard sporulation of *Penicillium digitatum* and *P. italicum*, and the introduction of new fungicides (pyrimethanil, azoxystrobin, fludioxonil). Recently evaluated experimental practices include pre-harvest applications of fungicides and growth regulators, mycofumigation with natural volatiles from the fungus *Muscodor albus*, UV-assisted sorting to remove fruit with mechanical injuries before storage (since these later decay at a high frequency), thermal and chemical disinfection of packinghouses and storage rooms, and the use of phosphites before and after harvest.

INTRODUCTION AND DISCUSSION

The responses of the California citrus industry to recent biological, regulatory, and marketing changes that impact the postharvest management of their fruit have been diverse and innovative. The purpose of this brief review is to describe and discuss some of these recent issues and challenges. Several thorough technical reviews of integrated biological control, physical, and chemical approaches to postharvest disease management were recently issued (Smilanick et al., 2006; Palou et al., 2008, 2010; Janisiewicz and Conway, 2010; Montesinos-Herrero and Palou, 2010).

Penicillium digitatum causes postharvest green mold, the most destructive postharvest pathogen in the arid environments like that of California. It developed resistance to the older postharvest fungicides (imazalil, thiabendazole, and sodium ortho-phenyl phenate) and resistant isolates are widespread within packinghouses (Kinay et al., 2007). They cause costly losses during fruit storage, marketing, and export. Isolates of grove origin, where fungicides of these classes are not used, are typically fungicide sensitive (Holmes and Eckert, 1999; Kinay et al., 2007; Kanetis et al., 2008). In response to this problem, three new fungicides (pyrimethanil, fludioxonil, and azoxystrobin), all belonging to different mode of action classes, were recently registered for postharvest use on citrus fruit in the United States (Adaskaveg and Förster, 2010). All were registered through the US EPA Office of Pesticide Program's Conventional Reduced Risk Pesticide Program, a review and regulatory decision-making process to expedite approval of conventional pesticides that pose less risk to human health and the environment than existing conventional alternatives. Although registered for use in the United States, tolerances for residues of these compounds are low or absent in some countries that import citrus fruit.

A recent development is the emergence of privatized regulation of production and postharvest practices; some include very low residue tolerances or bans on some pesticides. Domestic and international buyers state the treatments and practices they deem acceptable, and decline fruit that can be entirely in compliance with legal regulatory practices and residue tolerances. For example, some buyers may specify that chlorine be used in dump tanks at a concentration of 200 $mg\text{-}L^{-1}$, while others specify it must not exceed 100 or 25 $mg\text{-}L^{-1}$. In most locations, a concentration 200 $mg\text{-}L^{-1}$ is the regulatory maximum. Some of the rationale employed behind these chlorine standards is to limit the concentration used to minimize exposure of the fruit to chlorine disinfection by-products and the human health risk they may pose. Conversely, others are motivated to request a higher chlorine concentration as an intervention to minimize microbial food safety risks. Some request all solutions that touch the fruit be chlorinated, which would interfere with the use of postharvest biological control agents.

Another significant change has been the rising popularity of mandarin oranges, which have relatively low natural decay resistance and a brief postharvest life, and concomitant decline of Valencia oranges, which have relatively high natural decay resistance and a long postharvest life. Because of their susceptibility to decay, a short storage life that is ended primarily by loss of flavor, and the lack of experience in the handling and storage of mandarin fruit in California by packinghouse managers, they hesitate to subject them to the thermal treatments that they would readily apply to oranges and lemons. Because the options for packingline treatments are limited with mandarin fruit, they are good candidates for postharvest biological control.

Some practices, commonly used elsewhere, have entered practice in California in recent years. The drenching of harvested fruit on transit trailers with thiabendazole or imazalil has become relatively popular. Re-circulating solutions of thiabendazole are chlorinated, while those of imazalil are heat-pasteurized. It is well established that adding bicarbonate salts will boost the performance of these fungicides, but since *P. digitatum* isolates from groves are rarely resistant to these fungicides, addition of the salts is not needed and their corrosiveness harms the truck trailers and exacerbates water discharge problems. In packinghouses, the addition of bicarbonate salts or potassium sorbate with the fungicides in heated, aqueous solutions has become common (Montesinos-Herrero and Palou, 2010). With these measures, the concentrations of the fungicides used can be decreased by up to 90% compared to the use of the fungicide/wax combinations, yet the level of effectiveness is higher (Smilanick et al., 1997). However, to retard sporulation of *P. digitatum* on those few fruit that do decay subsequently, the practice of incorporating imazalil in fruit waxes is still used by many packinghouses. A partial replacement for the suppression of sporulation by imazalil is ozonation during storage. Constant ozonation at concentrations of 100 to 300 parts per billion of storage rooms retards sporulation of *Penicillium digitatum* and *P. italicum* while the fruit is in storage, and it oxidizes 'fugitive' ethylene (Palou et al., 2001; Skog and Chu, 2001), produced from decaying citrus fruit and other sources, that can accelerate senescence of remaining fruit (Wild et al., 1976). Many of the larger facilities in California employ ozonation during storage.

Many experimental practices have been recently evaluated; it is possible some may enter commercial use. Pre-harvest applications of fungicides and growth regulators in citrus groves have been evaluated, however, only the older, conventional fungicide thiophanate methyl has been reliably effective in this role to control postharvest decay (Smilanick et al., 2006). Although its residues are accepted worldwide and its price is low, this fungicide is now used increasingly as a preservative for paints and the citrus registration has lapsed. Although in use many years to control diseases caused by

Oomycetes, such as *Phytopthora* or *Pythium* spp., potassium or calcium phosphites inhibit other classes of fungi as well (Cohen et al., 1987; Guest and Grant, 1991). Preharvest applications partially controlled postharvest green mold, but effective rates harmed trees in some tests. Postharvest applications were more effective and did not harm the fruit. Recently a potassium phosphite formulation was approved for postharvest use in California and large-scale trials are in progress. A biological control approach employing fumigation with natural volatiles from the fungus *Muscodor albus* effectively controlled postharvest green mold, but regulatory approval for this antagonist is not in progress (Mercier and Smilanick, 2005). UV-assisted sorting to remove fruit with decay lesions is an old and common practice. Recently, however, it was shown that fruit with moderate levels of UV fluorescence, that are not now targeted for removal, can later exhibit rind quality problems and decay at a high frequency (D.O. Obenland, pers. commun.). Fruit with little or no natural rind fluorescence were of better quality after storage. Therefore, modification of the grading process to identify and remove those trouble-prone fruit with moderate levels of fluorescence will reduce subsequent decay and rind quality problems among the remaining fruit, which would be best for long storage or distant export markets. Packinghouse sanitation, when the fruit are absent, is an important and laborious task now accomplished primarily by harsh chemical disinfection, most often with formaldehyde. Ethylene degreening rooms are of particular concern, since populations of fungicide-resistant conidia can be very high within them, particularly since the adoption of truck drenching means these fruit are fungicide-treated when degreened, when previously they were not. Recent work showed conidia of *P. digitatum* and *P. italicum* are inactivated by relatively mild thermal treatments; there were no survivors after heat treatments of 55°C for 2 h (Smilanick and Mansour, 2007). These rooms already have adequate heat generation capacity to reach this temperature, since ethylene degreening is conducted 20°C and the winter-harvested fruit are rapidly warmed to this temperature routinely. To generate the temperatures required for thermal disinfection in most facilities, the installation of a thermostat with a higher temperature range is the sole requirement to introduce this practice.

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