DECAY CONTROL/FUNGICIDE APPLICATIONS

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DECAY FUNGI

Introduction

Florida's warm and high rainfall climate favors the development of various fungi that may cause excessive amounts of postharvest decay under certain handling and environmental conditions. Fungi are plants that lack the ability to produce their own food. They live by growing on dead and living plant tissue. Fungi are disseminated by spores and hyphae which are best seen through a microscope because of their small size. Development of the decay fungi on the fruit leads to the formation of characteristic symptoms. These can normally be used to identify the specific causal fungus and to develop the proper control measures.

Certain postharvest diseases of Florida citrus fruit are initiated by infections that originate in the grove during the growing season, but do not manifest themselves until after harvest. Other diseases originate from infections after harvest that occur in injuries formed during picking and subsequent handling of the fruit.

The decays that originate from preharvest infections are Diplodia and Phomopsis stem-end rot, black rot, brown rot and anthracnose. Green and blue mold and sour rot result from infections that occur postharvest through injuries inflicted by handling. Of the various decay fungi, only inoculum of green and blue mold and sour rot can be significantly produced and dispersed in the packinghouse environment. Spores of the two molds are produced on infected fruit, are airborne and may accumulate in packing and storage rooms. Spores of sour rot are produced on rotten fruit and may be dispersed on brushes, belts and packinghouse machinery.

Decays of Florida Citrus

Stem-End Rot (*Diplodia natalensis*) - This decay is a major problem in Florida citrus, particularly at the start of the season in degreened fruit. Spores of this fungus are produced during the summer growing season on deadwood in the tree canopy. The incidence of stem-end rot is greatly influenced by the amount of deadwood. As trees become older and contain more deadwood, or following a freeze, incidence will increase. Spores are carried in water during irrigation or rainfall to the button of the fruit where they germinate and the fungus establishes itself in dead tissue on the button surface. After harvest, the fungus grows from the button only when natural openings are formed during loosening of the button at abscission. Anything that encourages abscission, such as injuries, over-maturity, and ethylene degreening, will stimulate development of Diplodia stem-end rot.

The fungus penetrates the rind and core of the fruit at the stem-end. The infection progresses rapidly down the spongy core, usually reaching the stylar-end much sooner than through the surface rind causing the fruit to exhibit decay at both ends. There is frequently more rapid decay in the rind along the lines that mark the divisions between the segments of the pulp, giving an appearance of "fingers". The affected rind turns tan to brown, and sometimes black at advanced stages.

Degreening enhances Diplodia stem-end rot because ethylene loosens the button and the temperature of 85°F used in degreening is optimum for growth of this rapidly growing fungus. For some reason, excessive amounts of ethylene will enhance the decay. Stem-end rot has been observed to triple in lots of fruit degreened with 50 ppm ethylene compared to similar fruit degreened with 10 ppm. Diplodia stem-end rot is more difficult to control in fruit degreened longer than 36-48 hours because the fungus may penetrate so deeply into the fruit that it escapes the fungicide treatment applied after washing. The incidence of stem-end rot is reduced in early fruit if harvest is delayed to allow more natural color to develop so that degreening requires less than 48 hours. Decay is also less if early fruit are harvested from trees with minimal deadwood, such as trees in young plantings or blocks receiving the best nutrition, pesticide, and irrigation programs.

Since spores of this fungus are not produced on decayed fruit, spread of this fungus in the packinghouse is not a problem as with Penicillium digitatum (green mold). The decay will not spread from infected fruit to healthy fruit in packed cartons. The decay develops rapidly during and after lengthy degreening, and can be observed in fruit at the packinghouse. It is often observed at market arrival or shortly thereafter.

Stem-End Rot (Phomopsis citri) - This disease is usually not as serious a decay problem as that caused by Diplodia. The fungus causing Phomopsis stem-end rot is the same organism that causes melanose (small sandpaper-like corky pustules on fruit surfaces). The life cycle is similar to Diplodia in that spores are produced on deadwood during the summer and the incidence is affected by the amount of deadwood in the tree canopy. The button of the immature fruit becomes infected and the fungus progresses through openings during abscission after harvest.

Phomopsis stem-end rot can occur throughout the season, but most frequently after the degreening season during the cooler winter months. This decay is also observed in fruit held in cold storage where it will develop slowly. The optimum temperature for the growth of Phomopsis is near 73°F. Phomopsis decay is slower than Diplodia, and there is usually some shriveling of the decayed tissue at the stem-end which causes a shoulder or line of demarcation between decayed and sound tissue. Decay progresses equally through the core and rind until the entire fruit is encompassed. Decayed tissue is soft with tan or brown discoloration and usually appears in ten days to two weeks after harvest. Phomopsis will not spread from infected to healthy fruit in packed cartons.

Green Mold (Penicillium digitatum) - Green mold is easily identified by the mass of olive-green spores produced on infected fruit. Infection takes place only through wounds where nutrients are available to stimulate germination of spores. Wounds are caused primarily by injuries during picking, hauling, and packing. Injuries do not have to be visible, even a broken oil gland is a sufficient injury for penetration by a germinating spore of the fungus. Green mold develops most rapidly at temperatures near 75°F, and to be most effective, fungicides should be applied within 24 hours of infection at this temperature. Initial infections appear as a water-soaked, soft area easily punctured by finger pressure. The area enlarges and white mycelium appears on the surface followed by the development of the olive-green spore mass. One spore infecting a susceptible fruit can produce as many as 100,000,000 spores in ten days under optimum environmental conditions. These spores can survive for months and are transported by air currents to healthy fruit. The surface of virtually every citrus fruit is contaminated with these spores at harvest, particularly during the fall and winter months when temperatures favor optimum development of the fungus. Spores are quite concentrated on healthy fruit surfaces in those years when excessive numbers of split fruit develop on trees in the grove. Virtually all of these splits become infected by P. digitatum, fall to the ground, and support the formation of billions of spores. The incidence of green mold, particularly in round oranges and grapefruit, is decreased by the degreening process. High temperatures and humidities of the degreening room favor the healing of superficial injuries to the flavedo. The fungus, growing slowly at the high degreening room temperature, is unable to penetrate many of the injuries before they heal and become resistant to infection.

Soilage of fruit in packed cartons occurs when healthy fruit are covered with spores from decayed fruit. This detracts from the appearance of the entire carton and reduces consumer appeal. Green mold does not usually spread from infected to healthy fruit in packed cartons. If it does, it usually only spreads to the one adjacent healthy fruit that is touching the area where infection originated in the decayed fruit.

Blue Mold (*Penicillium italicum*) - Blue mold is easily identified by the mass of blue spores produced on infected fruit. The life cycle and mode of infection is similar to that of green mold. Blue mold develops less rapidly than green mold under ambient conditions. For that reason, green mold is most commonly observed in mixed infections.

Blue mold is not as prevalent as green mold under Florida conditions. It is most commonly encountered in fruit held under cold storage for summer sale. There, blue mold develops slowly at low temperatures that more completely inhibit the green mold. Blue mold will spread in packed cartons more readily than green mold, causing a "nest" of decayed fruit.

Sour-Rot (*Geotrichum candidum*) - Sour-rot develops on mature to over-mature fruit and most frequently on specialty fruits, such as tangerines, tangelos and temples. The fungus grows most rapidly at temperatures near 80°F and is often a serious problem on specialty varieties during warm and wet fall and winter days. *Geotrichum* is widespread in the soil and is spread to fruit by soil contact and to low-hanging fruit by wind-blown dust and by water splash. The fungus is often present in dirt and debris that accumulates beneath the sepals of the button at the stem-end of the fruit. The fungus only infects injured fruit, and particularly, injuries into the albedo formed by plugging and deep punctures.

Symptoms of the initial stage of sour rot are very similar to those of green and blue molds, and the rots are often confused. Initial infection appears as a water-soaked spot and can be distinguished from mold by the increased ease with which the cuticle can be slipped from the decayed area. Some white to cream-colored mycelium may develop on the infected surface. When the entire fruit is decayed, sour rot is the messiest, smelliest and most unpleasant of any of the fungal deteriorations of citrus fruit.

Sour rot is attractive to fruit flies which will spread inoculum from infected to healthy fruit in the packinghouse. Hyphae of the fungus in rotted fruit fragment into chains of spores. These will not become airborne but will contaminate pallets and all equipment, conveyor rolls, and belts in the packing-line as well as water sources such as drenchers or soak tanks. Sour rot will develop fairly rapidly at degreening temperatures, but develops very slowly at temperatures below 40°F. Unfortunately, the fungus is resistant to most fungicides and can only be reduced by careful handling, harvest of fruit before it becomes over-mature, and by cold storage. Sour rot will spread from infected to healthy fruit in packed cartons and will spread throughout cartons in a stack held for several weeks, such as during storage or export. Sour rot is often associated with green mold and is stimulated by the presence of the mold.

Anthracnose (Colletotrichum gloeosporioides) - The fungus causing this decay also produces its spores on deadwood within the tree canopy. The spores are released in rain during the summer where they are carried to surfaces of immature fruit. The spores germinate and form a microscopic thick-walled structure called an appressorium which remains inactive on the fruit surface until after harvest. For some reason, ethylene applied during degreening causes infection hyphae formed by the appressorium to penetrate the uninjured rind and cause decay. Degreened Robinson tangerines and related hybrids are exceptionally susceptible to this decay. If the length of degreening exceeds 36 hours, the disease can become quite severe. The lesions may occur anywhere on the surface of Robinson tangeries and initially appear firm and silvery-gray in color. Later, the area becomes softer and leathery brown and eventually develops into a soft decay brown to black in appearance. The incidence of anthracnose on Robinson fruit can be decreased by spot-picking for color so that no degreening or less than 24 hours is required. This form of the decay has also been observed on Dancy tangerines and navel oranges early in the season when excessive green color has required three to four days of degreening. In some cases, the decay develops immediately around the button at the stem-end.

Anthracnose may also develop on all types of citrus in damaged areas on the rind. Generally, this form of the decay occurs in fruit from weak, unhealthy trees, in overripe or injured or bruised fruit, and in fruit stored for long periods of time. Lesions appear brown to black and may contain pink areas formed when masses of spores are produced.

Brown Rot (Phytophthora citrophthora and P. parasitica) - Brown rot caused by two species of Phytophthora occurs on mature fruit, predominatly from the east coast of the state. Periods of cloudy, rainy weather which favor infection are usually more frequent in that area. Phytophthora citrophthora is more aggressive than P. parasitica because of its ability to form more spores under similar environmental conditions. These two fungi are present in the soil and produce spores which are splashed onto fruit on the lower part of the tree canopy during wet periods. Wind and water splash from lower infected fruit can cause additional infections higher in the tree. Infected but symptomless fruit can be picked and packed without being detected.

Lesions are light brown in color and very firm and leathery with a distinctive earthy odor. The affected areas remain flush with the level of the surrounding unaffected rind. Under very humid conditions, delicate, white fungal mycelium will develop on the lesion surfaces. The decay will spread among fruit in packed cartons during storage and has on occasion been severe in Indian River grapefruit exported to Japan.

Control of brown rot is achieved in the grove by spraying the lower part of the tree canopy with neutral copper, applying the spray about the middle of August in groves where the disease has been troublesome in the past. Where brown rot is only an occasional problem, spraying may be delayed until immediately after appearance of the disease when the entire tree should be sprayed. In the absence of fungicides, harvesting can be delayed for two weeks after detecting the disease to allow infected fruit to decay and fall on the ground, providing weather conditions are unfavorable during that period for additional infection. Chopping of cover crops, hedging of trees, and pruning off low hanging branches will improve ventilation and reduce the likelihood of infection.

Black Rot (Alternaria citri) - This decay can develop either at the stylar or stem-ends of the fruit, causing black discoloration of the peel and core. Airborne spores in the grove infect dead tissue of the button and tissues at the stylar-end through incomplete closures. Infection of navel oranges and Orlando tangelos, in particular, will cause premature color break and fruit drop. Infections developing at the button cause a stem-end rot which develops after harvest and only after extensive storage. The decay is not normally found in fruit that is consumed within three to four weeks and may be present in Valencia oranges or grapefruit held for summer sale. In some fruit, the fungus may only develop internally and remain undetectable until peeled for eating. At that time, the core will be composed of rotted, black tissue.

Non-Fungicidal Control of Decay

Though use of fungicides is the major method for controlling citrus decay, other cultural and handling practices are very important. By lowering inoculum levels, the incidence of decay can be significantly reduced. Fruit harvested from trees with minimal deadwood in the canopy develop less stem-end rot. Good production practices that produce a healthy tree and effective pruning will reduce the amount of deadwood. Good sanitation practices in the packinghouse will help reduce inoculum of green and blue mold and sour rot. Contamination of healthy fruit by airborne inoculum can be reduced by proper design of the packinghouse. Disinfestation of handling equipment prevents spread of inoculum to healthy fruit.

Careful handling of fruit to minimize injuries will significantly reduce decay caused by the wound pathogens, green and blue mold and sour rot.

Attention to proper degreening to minimize time of exposure and ethylene concentration will reduce the incidence of <u>Diplodia</u> stem-end rot and anthracnose. Minimal delay between harvesting and degreening or packing, and degreening and storage at high relative humidities will retard dessication and development of peel injuries that are sites for fungal infection.

Storage at low temperature and high humidity is beneficial to maintain vitality of the rind and button and to retard senescence. The most obvious effect of low temperature is to retard the growth of the decay fungi in infected fruit. Disease symptoms, however, will appear in a few days after the infected fruit are held at ambient temperatures. Low temperatures maintain the quality of fresh fruit and retard the development and spread of infections that are not eradicated by the fungicide treatments.

FUNGICIDES FOR DECAY CONTROL, EFFICACY, AND METHODS OF APPLICATION

Introduction

Presently, we have several fungicides available to the industry that have good activity against most of the major decays. Fungicides can reduce decay losses by inhibiting the development of quiescent infections of the stem-end rot fungi, by inactivating spores in fresh wounds, by protecting the peel from infection at injuries that occur after application of the fungicide, and by inhibiting sporulation of Penicillium on the surface of decaying fruit and the contact spread of several diseases. A discussion of these various fungicides follows with reference to methods of application, description of characteristics that influence effectiveness, and identification of the decays controlled by the individual chemicals. All of these materials, except guazatine, are registered in the U.S. for use on citrus with specific residue tolerances.

Fungicides for Citrus Decay Control

Sodium o-phenylphenate (SOPP) (DOW-HEX) - SOPP has been applied in Florida houses as a drench or recovery flood to unwashed or washed fruit. The mixture contains 2% sodium o-phenylphenate tetrahydrate, 1% hexamine, and 0.2% sodium hydroxide. The mixture is normally applied at ambient temperature and the pH must be maintained in the range of 11.5-12.0. The hexamine precipitates free o-phenylphenol before the concentration reaches the phytotoxic level, and it also exerts a buffering effect upon the solution at about pH 11.8. Concentrations of SOPP solutions, applied with hexamine, should be maintained near 2.5^{o} with a Brix hydrometer standardized at $68^{o}F$. A treatment of at least two minutes before washing or rinsing is required for optimum decay control. This method of applying SOPP requires critical pH control, attention to cleanliness of the SOPP solution, and washing of brushes daily to prevent gumming by removing the SOPP.

Application of SOPP in the foam washer is the most popular means of applying SOPP to citrus. A solution containing 2% SOPP, 0.1% sodium dodecylbenzene-sulfonate, and 0.2% sodium carbonate is agitated into a foam and dropped as a curtain on fruit revolving on washer brushes. The fruit are usually washed about 15-30 seconds before being rinsed with fresh water. The foam treatment is less effective for decay control than the bath treatment, but has the advantage that pH control is not a problem because the foam is not recycled. Residues of o-phenylphenol are lower on fruit treated with the foam formulation compared to fruit which have been submerged or flooded with a solution of SOPP. Recently, SOPP has been used for 45 seconds in wash treatments to comply with canker regulations for disinfesting symptomless fruit.

SOPP has also been applied at a concentration of 1% in water-based wax formulations or as 1% o-phenylphenol in solvent wax formulations.

The o-phenylphenate from the SOPP treatment diffuses selectively into injuries where it is hydrolyzed to o-phenylphenol. Rinsing the treated fruit with water removes most of the SOPP residue from the fruit, but a substantial amount remains associated with injuries and helps prevent development of green mold and sour rot at these sites. The SOPP treatment is our most effective fungicide for the control of sour rot, however it is far from perfect. The fungicide provides control of green mold and stem-end rot but less than with thiabendazole or benomyl. The use of SOPP in the washing process helps to maintain the brushes in a sanitary condition and free from decay inoculum. Separate treatments of SOPP and thiabendazole or benomyl are frequently used.

A risk of burn and discoloration of the rind exists if SOPP is not handled properly. Fruit should not be left in 2% SOPP formulations for extended periods of time during equipment shut-down, nor should washer brushes be extremely abrasive. Since early, degreened fruit is the most sensitive to SOPP burn, use of SOPP can be delayed until later, if replaced with chlorine for canker disinfesting, when the rind is more mature. SOPP is frequently used to reduce sour rot which is more prevalent on mature fruit that are less susceptible to SOPP burn. If formulations of SOPP are diluted with water, the proper pH must be maintained or burn may occur even if the SOPP is applied at concentrations less than 2%.

PPM O-PHENYLPHENOL IN SOLUTION

	SOPP (%)		
pH	0.5	1.0	2.0
12.0	45	70	140
11.8	55	110	205
11.6	85	170	320
11.4	140	260	515
11.2	200	390	800
11.0	300	620	-
10.8			
10.6			

POTENTIAL INJURY

Adapted from Eckert, Kolbezin & Kramer, Proc. 1st Int. Citrus Symposium 2: 1097-1103, 1969.

Thiabendazole (TBZ) - Thiabendazole is an effective fungicide which is most commonly applied as a non-recovery spray to washed fruit rotating on brushes. It can also be applied to unwashed fruit as a drench treatment, particularly before degreening. The fungicide is relatively insoluble in water and preparations should be continually agitated during application in a system designed to prevent settling of TBZ at any point. Excessive water should be removed from washed fruit to prevent dilution of the fungicide. Some of the residue may be removed if applications of the fungicide in water are followed by brushing in polisher-driers. If such driers are used, the application of TBZ in a water-based wax may be more desirable.

The fungicide should be applied at 1000 ppm in water and 2000 ppm in water-based wax. Applications in water are more effective for decay control than similar concentrations in wax, but efficacy in wax is enhanced by using twice the water rate. Thiabendazole is quite stable in water-based waxes. The material is non-systemic with most of the residues remaining on the fruit surfaces. Applications of TBZ at 4000-6000 ppm have been used in water-based waxes to inhibit sporulation of *Penicillium* on decaying fruit.

Thiabendazole is more effective than SOPP for control of green and blue mold, anthracnose, and stem-end rot caused by *Diplodia* and *Phomopsis*. The fungicide does not control sour, black and brown rots.

<u>Benomyl</u> <u>(Benlate)</u> - Benomyl is a fungicide similar in chemical structure and fungicidal activity to TBZ. Benomyl can be used in applications like TBZ with certain precautions. The material is not as stable as TBZ, and relatively fresh preparations should be used at all times.

Benomyl is highly insoluble in water and it decomposes slowly to methyl benzimidazolecarbamate (MBC) which is only slightly less fungitoxic than benomyl. However, MBC is non-systemic like TBZ, while benomyl is systemic and will penetrate into the rind. In alkaline formulations above pH 8, benomyl is converted to 1,2,3,4-tetrahydro-3-butyl-2,4-dioxo-<u>s</u>-triazino a- benzimidazole (STB) which has very weak, if any, fungitoxic activity.

When benomyl is mixed with water or water-based waxes, it starts to convert to MBC. At ambient temperatures at or below pH 8, approximately 50% of the benomyl will be converted to MBC within two weeks. After a month at pH 8 or less, most of the benomyl will have been converted to MBC. It is not an equal conversion, and the MBC concentration is 33% less than the original strength of benomyl. For optimum decay control with benomyl, suspensions at pH 8 or less should be utilized within the week of preparation where most of the fungicide exists as benomyl. If it is not utilized within one week, the concentration of benomyl in mixtures at pH 8 or less should be increased to compensate for the loss in fungicide material due to conversion to MBC. Such mixtures should be utilized within a month.

More serious problems occur with benomyl stability in suspensions prepared at a pH range of 8.5 - 10 which commonly occurs in commercial water-based waxes. In such suspensions, benomyl is converted to STB at a rate which increases as the pH increases. At pH 9, nearly 20% of the benomyl will be changed to STB within a two-week period. At a pH of 10, approximately 25% of the benomyl will be converted to STB after two days and 50% within two weeks. Approximately all of the benomyl will convert to STB within one day at a pH of 10.5. Water-based wax preparations of benomyl near pH 10 should be prepared daily and at least twice a week when the waxes range from pH 8-9.

Benomyl (fresh preparation) is much better than SOPP and slightly better than TBZ for control of green and blue molds, anthracnose, and stem-end rot caused by <u>Diplodia</u> and <u>Phomopsis</u>. Like TBZ, it does not control the other decays. Benomyl should be applied at 600 ppm in water and 1200 ppm in water-based wax. Similarly to TBZ, efficacy in waxes is slightly less than water applications. Higher rates of 2000-3000 ppm in water-based wax have been used to control sporulation of Penicillium. Benomyl at a rate of one to two lbs of product (Benlate)/acre can be applied within three weeks to the day of harvest to control postharvest decay. This treatment provides protection against decay initiated in the degreening room that is not effectively controlled by subsequent postharvest fungicide treatments. This practice does introduce a risk of selecting resistant strains of Penicillium that may develop after harvest.

Imazalil - Imazalil can be applied like TBZ and benomyl. It may be used as a drench before degreening or applied to washed fruit as a non-recovery spray. Imazalil forms water soluble salts that are more convenient to apply than suspensions of TBZ or benomyl. Imazalil is systemic, some moving into the fruit rind so that all residues are not removed by washing.

The fungicide is as effective as TBZ or benomyl against green and blue mold and will control strains of these molds that have developed resistance to the benzimidazole fungicides. Imazalil is less effective than TBZ or benomyl for stem-end rot control, particularly in degreened fruit. The fungicide is active against black rot and inactive against sour and brown rot.

Imazalil should be applied at a concentration of 1000 ppm in water and 2000 ppm in water-based waxes. Activity of imazalil is reduced more greatly by applications in water-based waxes than benomyl or TBZ, particularly for control of Diplodia stem-end rot in degreened fruit and control of green mold developing in post-treatment injuries. Imazalil at 2000 ppm is more effective in water than wax for sporulation control of Penicillium. Imazalil is most beneficial where resistant green or blue molds are known to be present or for sporulation control of green mold. The fungicide will eradicate resistant strains which accumulate under certain handling conditions.

Biphenyl (Diphenyl) - Biphenyl is a vapor-phase fungistat that must be present in the free vapor form to be effective. It is a slightly volatile compound that vaporizes from the solid form during storage and spreads throughout the atmosphere in the packed carton, storage room, or transport container. Biphenyl is a fungistat; that is, fungal growth is inhibited only as long as an effective concentration is in the atmosphere. Once the biphenyl supply is exhausted or the fruit are removed from the biphenyl atmosphere, fungal growth will resume. Biphenyl residues absorbed by the fruit are ineffective in controlling fungal growth.

Biphenyl is impregnated into pads or paper sheets which contain approximately 2.2 grams of biphenyl. These pads must be stored in air-tight containers as they soon lose their effectiveness in an open package. Pads are sized to fit in the standard 4/5 bushel carton and two pads are usually used in each carton except in instances where maximum tolerances may be exceeded. One pad is usually placed over the bottom layer of fruit and the second under the top layer. Biphenyl is sometimes objectionable because it imparts a characteristic odor to treated fruit. This odor, however, is detectable for only two or three days after fruit are removed from biphenyl. Decays will develop within a week after the fruit are removed from the biphenyl atmosphere.

The legal biphenyl residue tolerance for citrus fruit marketed within the United States, Canada, and Sweden is 110 ppm, whereas, 70 ppm is the legal tolerance for Japan and countries in the European Economic Community. Some problems have been encountered in exceeding these tolerances, particularly in early grapefruit exported to Japan or in mandarin-type fruits which absorb greater amounts of biphenyl. Early harvested fruit tend to absorb more biphenyl as do fruit stored at higher temperatures. More biphenyl is absorbed in the presence of two pads than with one pad. Oranges and mandarins absorb at least twice as much biphenyl per unit of fruit surface as do lemons or grapefruit. Washed and waxed fruit absorb more biphenyl than unwashed fruit.

Biphenyl controls Diplodia and Phomopsis stem-end rots less effectively than TBZ or benomyl. It does not control anthracnose or sour, black and brown rots. The greatest value of the biphenyl treatment is that it is effective against Penicillium decay and inhibits sporulation, thereby preventing soilage in packed cartons. The biphenyl treatment is more effective in inhibiting sporulation of Penicillium on lemons than on oranges because the high rate of absorption by oranges tends to reduce the concentration of biphenyl in the atmosphere surrounding the fruit.

Potassium sorbate - This material is a salt of sorbic acid, an organic acid, which has been used for many years as a preservative for processed foods. Potassium sorbate is water soluble and has been used as a 2% treatment to citrus to control decay. The material can be applied as a drench treatment before degreening and as a non-recovery spray after washing.

Potassium sorbate can be used to supplement treatments of TBZ or benomyl where benzimidazole-resistant strains of Penicillium have developed. The material is less effective than the benzimidazoles for control of stem-end rot and it does not control sour, black or brown rots.

Guazatine (Kenopel) (experimental) - Guazatine has been used on citrus fruit in Australia for several years and residue tolerances have been established in several countries. However, the fungicide has not yet been registered in the U.S. Guazatine is a water-soluble fungicide that is effective against sour rot and green mold, including benzimidazole-resistant strains, at concentrations of 1000 ppm. The fungicide does not control sporulation of green mold. It provides some control of *Diplodia* stem-end rot, particularly if applied as a drench before degreening, but activity is not as good as with benomyl or TBZ.

Chlorine - A discussion of chlorine is included as a decay control chemical though it does not act in the same fashion as the previously discussed fungicides. That is, chlorine solutions are relatively ineffective in preventing decay of citrus which has been inoculated with the decay pathogen before treatment. Chlorine reduces decay by killing inoculum in treated water and on treated fruit surfaces, thereby reducing the chances of infection. Chlorine also reduces bacterial populations of citrus canker that may be on surfaces of symptomless fruit.

Chlorine can be helpful if used properly to reduce some of the decay fungi within the packinghouse environment. Chlorine (200 ppm) added to the water spray following the dry dump will kill spores of green mold on fruit surfaces within 10-15 seconds, but not all spores on sporulating lesions. Many spores are then killed before they are forced into injuries by the washing process where the fungus is more difficult to eradicate with fungicide treatments. This chlorine spray treatment to unwashed fruit will not kill sour rot, and thus, is not as effective as a similar treatment with SOPP. If dump tanks or drenchers are necessary, chlorine should be added to kill green mold and sour and brown rot that accumulates in the water. Chlorinated water can also be used to wash down equipment and clean pallet boxes and storage rooms. Since chlorine is corrosive to metal, there will be evidence of this on your equipment.

The most effective use of chlorine is in a system where it is continually metered into the water at a constant rate near a pH of 7. At this pH, fungicidal activity increases with time and concentration of free chlorine which

Type of Fungicide Application	Fungicide(s)	Advantages and Disadvantages
Pallet bin drench	benomyl, thiabendazole, imazalil	1. Provides effective control of *Diplodia* SER and green mold in degreened fruit. 2. Less expensive treatment than the preharvest spray. 3. Fungicide suspensions require chlorination (50-100 ppm free, active chlorine, pH 6.5-7.5) to eradicate sour or brown rot or resistant spores of green mold that may accumulate in the drench suspension. Sour rot can be a major decay of specialty fruits and mature oranges and grapefruit. 4. Requires environmentally-safe procedure for discarding used drench suspensions. 5. Cost of the material would probably prevent the use of imazalil unless benzimidazole-resistant strains of green mold are a significant problem.
Wash application	chlorine, SOPP	1. Either material can be used to comply with canker regulations for disinfesting symptomless fruit. 2. Chlorine is a sanitizer, killing some surface spores but not those in injuries. The material provides no residual protection from decay because it does not persist in the rind. 3. Chlorine is corrosive, and will cause metal to rust. 4. SOPP provides control of green mold, including strains resistant to benomyl or TBZ. 5. SOPP reduces fungal contamination of the washer brushes, particularly sour rot and green mold, and is the only fungicide with some activity against sour rot.

Type of Fungicide Application	Fungicide(s)	Advantages and Disadvantages
		6. SOPP may be phytotoxic, particularly to early degreened fruit. Excessively long exposure times or stiff washer brushes will enhance burn. Dilution of the treating solution below the recommended strength of 2% may enhance burn because proper pH is not maintained.
		7. Recovery drench applications of SOPP for two minutes provide better decay control than foam applications for 30-45 seconds.
Non-recovery spray - aqueous	benomyl, thiabendazole, imazalil	1. Aqueous applications generally provide optimum decay control.
		2. Non-recovery formulations are less easily contaminated or diluted than preparations applied in recovery systems.
		3. Residues from non-recovery applications may be reduced if followed by polisher driers. Removal of some surface residues by brushing may reduce sporulation control of green mold.
		4. Excessive water should be removed from fruit before fungicide treatment to prevent dilution of the fungicide.
Non-recovery spray - water wax	benomyl, thiabendazole, imazalil	1. Wax and fungicide can be applied in a single procedure with one piece of equipment.
		2. The concentration of fungicide in wax is doubled to achieve decay control similar to that of the material in water.
		3. Decay control efficacy of imazalil in wax is reduced more significantly than that of benomyl or TBZ.

Type of Fungicide Application	Fungicide(s)	Advantages and Disadvantages
		4 High concentrations (3000+ ppm) of benomyl or TBZ can be applied in wax for sporulation control of green mold. Sporulation control with imazalil (2000 ppm) is usually better in water than wax even if aqueous applications are followed by polisher driers.
		5. Benomyl is unstable in highly alkaline water waxes, and suspensions should be used shortly after preparation.
		6. Equipment break-downs that interrupt the fungicide application are quickly discerned because of the lack of wax coverage.
Vapor-phase	biphenyl	1. Biphenyl can be applied without specialized equipment by placing porous pads impregnated with the fungicide in cartons at packing. Biphenyl pads must be stored in air-tight containers before use.
		2. Sporulation of green mold and strains resistant to benomyl or TBZ are controlled by biphenyl.
		3. Biphenyl is effective only as long as a sufficient concentration is in the atmosphere surrounding the fruit.
		4 Residues may exceed legal tolerances in early maturing or mandarin-type fruits or at high shipping temperatures.
		5. Biphenyl imparts a characteristic odor to treated fruit. It is detectable only for two-three days after removing the pads, but it may be objectionable to some consumers.

General Rating of the Efficacy of Fungicides Against the Major Florida Citrus Decays

	GREEN AND BLUE MOLD	STEM-END ROT	SOUR ROT	BLACK ROT
TBZ	+++	+++	0	0
BENOMYL	+++	+++	0	0
SOPP	++	+	+	0
BIPHENYL	++	+	0	0
IMAZALIL	+++	++	0	+
GUAZATINE (Experimental)	+++	++	++	0

Efficacy: 0 = None + = Some ++ = Moderate +++ = Good

RESISTANCE OF DECAY FUNGI TO FUNGICIDES

Introduction

It has been observed for several years that certain citrus decay fungi can develop resistance to postharvest fungicides. *Penicillium digitatum* (green mold) and *P. italicum* (blue mold) developed resistance to SOPP and biphenyl in the early 1960's and to TBZ and benomyl in the early 1970's. Resistant strains, which occur naturally in fungal populations at a very low frequency, develop rapidly in the presence of the fungicide. *Penicillium* has been particularly troublesome in this regard because it produces billions of airborne spores within a relatively short period of time within the packinghouse and storage rooms. No resistant strains of the stem-end rot fungi have been detected as yet. These fungi do not produce spores on the fruit. Rather, they produce their spores on deadwood within the tree canopy. Selection pressure for development of resistant strains of stem-end rot will be minimal as long as fungicides or related fungicides used in the packinghouse are not consistently used in the grove.

Strains of *Penicillium* resistant to TBZ and benomyl have been detected in Florida packinghouses. The most serious outbreaks have occurred in houses that pack lemons. The reason for this is that the storage period required for coloring is sufficiently long for resistant strains to infect and sporulate in the coloring rooms. Eventually, within one season, these rooms and the packinghouse become contaminated with resistant spores which will persist and infect other citrus varieties during the fall and winter season.

Combatting Resistance

Several approaches can be taken to reduce the resistance problem. One of these is good sanitation, which should be undertaken whether resistance is a problem or not. The packinghouse should be kept thoroughly cleaned and broad spectrum antimicrobial agents (chlorine, quaternary ammonium compounds, 1% formaldehyde, 30% isopropyl alcohol) can be applied to disinfest the fruit-handling equipment. Rotten fruit should be removed immediately from the packinghouse. Treated fruit being repacked because of excessive decay should never be repacked in the packinghouse. Much of the decay may be due to resistant green mold and the spores would be immediately released to cause infection of incoming fruit. Design changes can be installed in the packinghouse so that spores are removed from the house environment or distribution of spores can be controlled so that contamination of the fruit is reduced during the packing process.

Populations of spores of P. digitatum should be monitored continuously by culture sampling to determine if resistance is indeed present and to which fungicide. The fungicide program should then be altered to control the resistant strains.

Application of two or more fungicides of unrelated chemistry may be used to keep resistance in check. Since SOPP and biphenyl are chemically similar as are TBZ and benomyl, strains of P. digitatum resistant to one fungicide are usually resistant to the other fungicide of similar chemistry. Therefore, to be effective, fungicides of dissimilar chemistry should be used in combinations, such as, SOPP or biphenyl with either TBZ or benomyl. Other fungicides such as potassium sorbate or imazalil can be added if additional control of resistance is needed. Of these, imazalil is most effective. In situations where fruit are treated with fungicides, both before and after storage or a holding period (e.g., degreening), fungicides applied before holding are chosen on the basis that they will not encourage the development during holding of Penicillium strains that are resistant to the fungicides applied after holding. The last fungicide treatments are critical, since they must protect the fruit from decay during shipment and marketing.

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