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Control of Brown Rot in Peach Orchards

Fruit decay in orchards and packing sheds is a perennial problem for most people who grow fresh fruit. Many fungi cause decay of peaches, but *Monilinia fructicola*, one of the two fungi causing brown rot in the United States, is the most common in most orchards. *M. laxa*, the other fungus involved in brown rot, is important in some western regions and has been reported elsewhere but is less important on peaches than on certain other stone fruits. An excellent discussion of the biology of these two fungi was written by Wilson and Ogawa (11).

Fungi other than *M. fructicola* cause significant losses of fruit in packing sheds and during postharvest storage. Because control of postharvest decay is of itself a complex subject, the following discussion is confined to control of brown rot in peach orchards.

Changing Concepts

There are two important phases of brown rot. Blossom blight is important because 1) the number of blighted blossoms may be sufficient to reduce yield, 2) twigs with blighted blossoms attached usually are killed, thus reducing the amount of bearing surface, and 3) conidia produced on the blighted blossoms and twigs may serve as inoculum for later infections. Fruit decay causes the most severe economic loss, however. Immature fruits are resistant to decay, but latent or incipient infections of green fruits are important in the West (11) and perhaps elsewhere. Green fruits also may become infected after insect injuries.

As fruits ripen, they become increasingly susceptible to infection. Because the fungus produces huge numbers of spores within a few days of infection, explosive outbreaks of brown rot are a constant threat in humid climates as peaches approach maturity.

Brown rot has been responsible for crop failures in all areas of the United States except some arid climates. Before effective fungicides were available, orchard sanitation was emphasized for control. Decaying fruits were collected and destroyed. Infected twigs or branches were cut and removed. The orchard floor was cultivated to bury mummies and disrupt formation of apothecia. Wild hosts near orchards were eradicated. These practices were partly successful but were not reliable for consistent, effective control.

The development of fungicides to protect blossoms and fruits improved control of brown rot. The use of sulfur and other inorganic fungicides decreased fruit losses substantially, but unacceptable crop losses continued. Huge amounts of sulfur were applied to orchards in Georgia and other southeastern states in attempts to limit fruit decay in the humid climate of the region, and the acid soil conditions that followed contributed to premature death of peach trees in the Southeast (6,9).

More effective brown rot control became possible after introduction of captan and dicloran in the 1950s and the benzimidazole fungicides in the 1970s. Farmers began to neglect laborious tasks of removing infected fruits and eradicating wild hosts near their orchards. Fungicides were reasonably priced, fuel was inexpensive, improvements in machinery enabled effective control, and attention to alternative control practices decreased.

But now the concepts of brown rot control may be changing. Increased concern about pesticides in the environment; rising fuel, pesticide, and equipment costs relative to market prices of fruit; and resistance to the benzimidazole fungicides stimulated renewed interest in alternatives to chemical pesticides and in reduced rates or frequency of fungicide application. New, effective fungicides still in the development stage signal greater flexibility in the strategy for disease control.

The effectiveness of the benzimidazoles and other new fungicides for brown rot control changed some traditional assumptions about the life cycle of the brown rot fungi in commercial peach orchards. Ascospores and conidia from infected fruits in peach orchards are important for initiation of blossom blight and fruit decay (1,7,11), but in many well-managed orchards blossom blight seldom occurs and infected fruits are infrequent. Orchard cultivation to bury mummies and interfere with production of apothecia is not needed because few mummies exist. Careful pruning of diseased limbs, twigs, and infected fruit is not required because little diseased material can be found.

Where do the fungi survive? Has the threat of brown rot diminished significantly? With the support of most plant

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pathologists, farmers continue to spray their orchards in the time-honored fashion, fearing the impact on their profits and reputation if a brown rot outbreak should occur.

Fig. 1. Apothecia of *Monilinia fructicola* from 1-year-old peach mummy. (Courtesy L. W. Baxter)

Sources of *Monilinia*

Ascospores from apothecia developing from mummies on the orchard floor (Fig. 1) and conidia from mummies (Fig. 2), peduncles, twig cankers, blighted blossoms (Fig. 3), and fruits (Fig. 4) serve as inoculum (1,7). The relative importance of these sources in orchards differs from place to place. Conidia from blighted blossoms are very important in western states (11) and are thought to be important also in the East. For mid- and late-season cultivars, however, blighted blossoms may not be important sources of inoculum in South Carolina and perhaps elsewhere in the Southeast (4). Latent or quiescent infections of young fruits following blossom blight are important in Australia (1) and California (11) but have not been demonstrated in the more humid regions of the eastern United States.

Fig. 2. Mummies and peach twigs infected with *Monilinia fructicola*.

Kinds of disease control practices in or near peach orchards are important. When inoculum sources in well-managed peach orchards have been eliminated by effective disease control, sources near or adjacent to peach orchards are of primary concern. The wild plums (*Prunus angustifolia* and other *Prunus* spp.) prevailing throughout peach-growing

Fig. 3. Blossom blight of peach following infection by *Monilinia fructicola*. Note sporulation on the twig below the infected blossom.

Fig. 4. Infection of ripening peach fruit by *Monilinia fructicola*. Note the infected, nonabscised, aborted fruit immediately above the infected ripening fruit.

Fig. 5. Blighted blossom and shoot and infected fruit of wild plum collected 200 m from a peach orchard.

Fig. 6. Sporulation of *Monilinia fructicola* on peach fruits thinned just after pit hardening. (Courtesy Frances A. Landgraf)

localities of the Southeast (Fig. 5) have been identified as continuous reservoirs of inoculum during the growing season (4). Nearby orchards of stone fruits in which brown rot has not been controlled also may be important reservoirs of inoculum. The distance traveled by spores from these sources has not been determined, so the distance necessary for eliminating such sources is unknown. Empirical evidence in South Carolina indicates that at least 400 m must separate such inoculum sources from peach orchards before fungicide sprays during bloom can be omitted. Under these conditions a few random blossom infections, usually fewer than five per tree, still may occur.

During the interval between bloom and fruit maturity, young fruits are resistant to *Monilinia* infections but some infections of injured fruits or those adjacent to blighted blossoms may be found. However, young fruits that fail to mature and remain on the tree (Fig. 4) or fruits that are removed during thinning become susceptible. When infected, large numbers of spores may be produced on these fruits until the time of fruit maturity (Fig. 6). Fungicides may be required during this interval to suppress these infections.

Regional Differences

Regional differences affect strategies to control brown rot. Horticultural management practices, climate, insect control practices, and other disease problems have important influences, and all differ from one locality to another. In the Southeast, where cultivation is discouraged because it affects tree longevity, apothecia may have more opportunity to develop than where clean cultivation is practiced. Further, the use of sod between rows in the Southeast may affect insect vectors of *M. fructicola* and other pathogens and aggravate problems with *Glomerella cingulata*, the cause of anthracnose, if the sod cover includes hosts susceptible to this fungus.

In the West, where *M. laxa* is widespread and winter temperatures are moderate, blossom blight may be relatively more important than in the East. Coryneum blight caused by *Coryneum beijerinckii* also is more significant in the West than in the East, largely because of climatic influences and cultural practices. Conversely, problems with peach scab caused by *Cladosporium carpophilum* develop in the humid summer conditions of the East but not in the arid or semiarid regions of the West.

Chemical Control

After sulfur was introduced, chemical sprays became a main line of defense against outbreaks of brown rot. Sulfur was even more effective for control of *C. carpophilum*, and routine sprays with sulfur at 7–14 day intervals beginning at prebloom and continuing until maturity were common in the eastern states. Sulfur was not very effective for blossom blight and often failed to control fruit decay during wet weather. Extensive use also led to acid soil conditions in some areas.

Captan and dicloran, when introduced in the 1950s, controlled brown rot much better than sulfur did. Captan was superior to dicloran for brown rot control, but dicloran was excellent for Rhizopus decay. A mixture of the two fungicides in postharvest applications became the standard treatment for fruit shipped to large city markets. Neither fungicide was effective for blossom blight, but captan and later dichlone were widely used during the bloom period because their partial effectiveness sometimes limited disease outbreaks.

Introduction of the benzimidazole fungicides in 1970 and thereafter dramatically improved control of brown rot in the field and in packing sheds. Two sprays of benomyl or thiophanate-methyl during bloom were sufficient for almost complete control of blossom blight. Two or three preharvest sprays at appropriate intervals protected against brown rot in most environments, and in some locations a single preharvest spray was adequate when rainfall was light.

Resistance to Benzimidazoles

Problems of resistance to the benzimidazoles soon developed. In 1975, resistance in *M. fructicola* was discovered and reported from Australia (10), Michigan (3), and New York (8). In 1976, it was found in South Carolina and then in California (5). Resistance developed first in orchards where benomyl was used exclusively for decay control, but it also appeared in two South Carolina orchards where captan or sulfur had been used during the interval between blossom sprays and preharvest sprays of benomyl. These experiences indicated that problems with resistance could result with either exclusive use of benomyl during the entire season or use only during bloom and preharvest sprays. In the Southeast, only two or three applications each are made during bloom and preharvest (the periods of greatest susceptibility), and opportunities to alternate benzimidazoles with other fungicides are limited. Therefore, peach growers in the Southeast were advised to use mixtures of benomyl or thiophanate-methyl with captan, sulfur, or maneb except in orchards where resistance to benzimidazoles was already established; farmers were advised to discontinue the use of benzimidazoles entirely in such orchards.

The advice to use mixtures was based only on preliminary evidence from other disease situations indicating that mixtures delayed the development or predominance of resistant strains (2). Although the value of mixtures for preventing or delaying resistance to benzimidazoles has not been demonstrated conclusively for *M. fructicola*, experience in South Carolina supports this practice. Few new sites of resistance have been found since the use of mixtures was adopted in South Carolina in 1977. The importance of resistance in commercial peach orchards in South Carolina seems to have diminished, and little economic loss due to resistance occurred in 1981.

Beginning in 1977, benomyl-resistant strains of *M. fructicola* that developed in South Carolina were introduced into a peach orchard at Clemson University by inoculating ripening fruits with pure cultures that grew on media containing 1,000 μg/ml of benomyl, by inoculating open blossoms with the resistant strains, or both. This practice has been repeated each year since 1977. Trees were sprayed after inoculation with benzimidazoles alone, benzimidazoles mixed with other fungicides, or fungicides not of the benzimidazole group. Although considerable secondary spread occurred after these inoculations, the resistant strains have failed to become established. They must be reintroduced each year. This experience and the apparent decline of resistance problems in South Carolina peach orchards indicate that benzimidazole-resistant strains in this state may not compete well in nature when fungicide mixtures or nonbenzimidazole fungicides are used.

Preliminary data from these experiments (E. I. Zehr, *unpublished*) suggest that resistant strains in South Carolina may not spread as rapidly as benomyl-sensitive strains do. Routinely, in preharvest inoculations for these experiments, equivalent numbers of fruit have been inoculated with sensitive and resistant strains. The infections developing after secondary spread have been monitored for resistance or sensitivity to benomyl. Except during 1977, resistant strains usually have caused less than 10% of secondary infections regardless of fungicide treatment. In 1977, the resistant strain caused 21.9% of the infections in unsprayed trees (Table 1) but 75 and 86.4% of the infections in trees sprayed with thiophanate-methyl and benomyl, respectively. These data show the predominance of resistance under certain conditions when benzimidazoles alone are used. Brown rot also was not controlled effectively with benzimidazoles alone. Mixtures controlled decay, but the percentage infected with the resistant strain was higher than in check fruits and those sprayed with nonbenzimidazole fungicides (Table 1).

New Fungicides

Additional fungicides with efficacy equal or superior to the benzimidazoles are needed for control of peach brown rot. The recent registration of triforine for use on peach trees relieved the acute problems that developed with resistance to benzimidazoles. Other new fungicides appearing to have potential for control of brown rot include iprodione, vinclozolin, prochloraz, β-[(1,1-biphenyl)-4-yloxy]-α-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol (Bayçor), and 1-[(2-(2,4-dichlorophenyl)-4-ethyl-1,3-dioxolan-2-yl) methyl]-1H-1,2,4-triazole (Vangard). Some of these compounds also may have potential for the development of resistance problems. It will be important to use them judiciously and to observe carefully for potential resistance after their use.

Future Strategies

Only a few sprays are required for brown rot control in dry climates, but most peach growers in humid climates follow a routine spray schedule based on the concept of continuous coverage of susceptible tissue with fungicides during the entire period of susceptibility. This strategy was the only viable option at times when fungicides were barely adequate for acceptable control. As several superior fungicides are developed and become available for use, there may be other options.

Spray schedules in the Southeast are designed to control several other diseases besides brown rot and scab, and allowances must be made for these problems when spray schedules are adjusted. For example, peach leaf curl caused by *Taphrina deformans* is a threat even though its appearance is sporadic. Because the appearance of peach leaf curl is not easily predicted, one spray during dormancy probably is needed in most orchards regardless of the spray schedule chosen. Anthracnose caused by *G. cingulata* is a threat in some orchards in the Carolinas. Captan used to control scab in cover sprays controls anthracnose as well, but late-season cover sprays probably should not be omitted when anthracnose is a threat.

Table 1. Proportion of benomyl resistant:sensitive isolates of *Monilinia fructicola* as affected by spray applications on peach in 1977

Treatment	No. resistant/no. isolates	Percent resistant[y]
Benomyl	19/22	86.4 a
Thiophanate-methyl	12/16	75.0 a
MBC/non-MBC fungicide mixtures[z]	37/68	54.4 b
Non-MBC fungicides[z]	19/73	26.0 c
Unsprayed control	14/64	21.9 c

[y] Means followed by the same letter do not differ significantly ($P = 0.01$), using the chi-square test.
[z] MBC (benzimidazole) fungicides are benomyl and thiophanate-methyl; non-MBC fungicides are captan, chlorothalonil, and maneb.

Table 2. Number of fungicide applications required for mid-season peach varieties in South Carolina at various levels of disease potential

Growth stage	Full schedule	Reduced schedule	Minimum schedule
Late dormant	1	1	1
Prebloom and bloom	2–3	1	0
Petal fall	1	0	0
Cover sprays	4–6	3–5	3–4
Preharvest	3	2	2

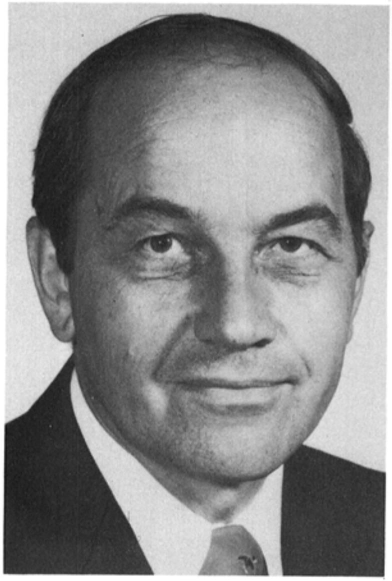
In South Carolina, investigations have been made during the past 11 years to determine the minimum number of fungicide sprays required for acceptable control of brown rot and scab in peach orchards. These experiments progressed to the use of pilot demonstrations for minimum or reduced spray schedules in 18 commercial orchards in 1981.

The number of sprays used in the full, reduced, and minimum schedules is shown in Table 2. To determine which schedule is best suited to a particular orchard, the history of diseases in the orchard is studied, the surrounding area is examined for sources of inoculum of *M. fructicola*, and the orchard is scouted for blossom blight, brown rot of immature fruits, and other diseases. Numbers of sprays and fungicides used are adjusted to weather conditions, kinds of threatening diseases, and stage of plant development. Because brown rot has explosive potential for development in humid climates, stage of development as related to susceptibility receives greater emphasis than weather conditions.

The full-season schedule of essentially routine sprays at regular intervals (Table 2) is used when the orchard has had brown rot problems during the previous 2 or 3 years, inoculum sources are abundant in or near the orchard, resistance to benzimidazole fungicides has occurred, or there is uncertainty about the potential for brown rot in the orchard. The reduced schedule is used when the orchard has had no brown rot problems, wild hosts or other inoculum sources within 400 m of the orchard are essentially absent or have been eradicated, and other diseases (scab, powdery mildew, anthracnose) are minor threats. The minimum schedule is used when brown rot has not been a problem previously, there are no known sources of inoculum within 400 m of the orchard, diseases other than scab rarely occur, and the farmer can carefully adjust spray applications to stage of development. Orchard sanitation in terms of weed control and elimination of inoculum sources receives strong emphasis in reduced and minimum spray schedules.

Careful monitoring of orchards having reduced or minimum spray schedules is very important. If blossom blight develops, fungicides that are very effective for brown rot control (usually benomyl, thiophanate-methyl, or triforine) are used in the first two cover sprays. Discovery of other inoculum sources in the orchard as the season progresses is followed promptly by application of an effective fungicide.

There may be potential to reduce the number of fungicide applications by 40–50% in some South Carolina peach orchards, using the criteria just described. Pilot demonstrations in commercial



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peach orchards and further testing in research plots will continue for several more years. The reduced and minimum schedules probably apply in other southeastern states and perhaps elsewhere, depending on climatic conditions, cultural practices, and diseases present. Additional study is needed to integrate reduced fungicide use with pest control and cultural practices.

Added in galley: In July 1982, benomyl-resistant *Monilinia fructicola* appeared in many South Carolina peach orchards that had been sprayed routinely with benomyl-captan mixtures for brown rot control (R. W. Miller, *personal communication*). This outbreak followed a bloom period that was favorable for blossom blight, a postbloom period of severe frosts that destroyed the crop in many orchards, fewer sprays because of a small crop, and above-normal rainfall during the growing season. The prevalence of resistant strains in 1982 shows that the use of benomyl-captan mixtures in southeastern peach orchards probably delays but does not prevent the development and spread of resistant strains. The use of mixtures to control fungicide-resistant *M. fructicola* requires further study and evaluation.

Literature Cited

1. Byrd, R. J. W., and Willets, H. J. 1977. The Brown Rot Fungi of Fruit. Pergamon Press, New York. 171 pp.
2. Delp, C. J. 1980. Coping with resistance to plant disease control agents. Plant Dis. 64:652-657.
3. Jones, A. L., and Ehret, G. R. 1976. Isolation and characterization of benomyl-tolerant strains of *Monilinia fructicola*. Plant Dis. Rep. 60:765-769.
4. Landgraf, F. A., and Zehr, E. I. 1982. Inoculum sources for *Monilinia fructicola* in South Carolina peach orchards. Phytopathology 72:185-190.
5. Ogawa, J. M., Manji, B. T., Rough, D., and Sonoda, R. M. 1981. Monitoring and control of benomyl-resistant *Monilinia fructicola*. (Abstr.) Phytopathology 71:246.
6. Perkins, H. F., Giddens, J. E., and Daniell, J. W. 1979. Effect of lime and fertilizer and peach root residues on peach trees in a decline area. Ga. Agric. Exp. Stn. Res. Bull. 246. 24 pp.
7. Roberts, J. W., and Dunegan, J. C. 1932. Peach brown rot. U.S. Dep. Agric. Tech. Bull. 328. 59 pp.
8. Szkolnik, M., and Gilpatrick, J. D. 1977. Tolerance of *Monilinia fructicola* to benomyl in western New York. Plant Dis. Rep. 61:651-657.
9. Weaver, D. J., and Wehunt, E. J. 1975. Effect of soil pH on susceptibility of peach to *Pseudomonas syringae*. Phytopathology 65:984-989.
10. Whan, J. H. 1976. Tolerance of *Sclerotinia fructicola* to benomyl. Plant Dis. Rep. 60:200-201.
11. Wilson, E. E., and Ogawa, J. M. 1979. Fungal, bacterial, and certain nonparasitic diseases of fruit and nut crops in California. Ag. Sci. Pub., University of California, Berkeley. 190 pp.