Inoculum Sources for *Monilinia fructicola* in South Carolina Peach Orchards

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ABSTRACT

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Sources of *Monilinia fructicola* inoculum near peach orchards were studied during 1979–1980. Apothecia were found in 1980 under peach and wild plum trees (*Prunus angustifolia* Marsh and other *Prunus* spp.). During bloom, few conidia were observed on peach mummies, cankers, and fruit peduncles. Blighted blossoms sporulated profusely in early spring, but sporulation declined as the season progressed. Small increases in sporulation followed rainy periods, and in moist chambers limited sporulation could be induced on 70–100% of the blighted blossoms throughout the season. Nonabscised, aborted fruits in the tree and thinned fruits on the ground were important sources of conidia as fruits were approaching maturity. Fruits thinned before pit hardening decomposed quickly, but conidia were produced on some. Fruits thinned after pit hardening often were infected and sporulation occurred on up to 38% of them. Captan and benomyl cover sprays suppressed sporulation on thinned fruits, but sulfur was ineffective. Conidia were produced abundantly on infected wild plum trees throughout the season. Nonabscised, aborted fruits; infected thinned fruits on the ground; and plum infections appear to be the more important sources of the inoculum that affect ripening peach fruits than do blighted peach blossoms.

Brown rot caused by *Monilinia fructicola* (Wint.) Honey continues to be among the most important diseases of peach, *Prunus persica* (L.) Batsch. Inoculum sources have been studied by many workers. Byrde and Willetts (2) reviewed the literature and concluded that the fungus overwinters and produces primary inoculum from two sources: mycelia in the fruit mummies, fruit peduncles, cankers on twigs and branches, leaf scars, and buds that sporulate under favorable conditions; and stromata that produce ascospores in the spring. Secondary inoculum can arise from any infected tissue in which the moisture content is sufficient for sporulation. Wild hosts growing in the vicinity of cultivated crops also can serve as inoculum sources (13).

There is only limited quantitative information on the importance of the different inoculum sources. Kable (7) considered infected fruit peduncles to be very important in the Murrumbidgee Irrigation Areas (MIA) in New South Wales. He reported that mummified fruits were potential sources but that their importance can be overemphasized. Sutton and Clayton (15) found that in North Carolina *M. fructicola* overwinters in the fruit peduncle, but they did not assess its relative importance as an inoculum source. Roberts and Dunegan (13) reported that apothecia were produced from mummified peach fruits for 6 yr in Georgia. Because apothecia are not often observed in South Carolina peach orchards, their relative importance as primary inoculum sources in that area is uncertain.

The relative importance of secondary inoculum sources is also uncertain. The fungus is reported to sporulate heavily on blighted peach blossoms late in the season (3,4,11,12) when rain occurs; however, in recent years the occurrence of blossom blight has not correlated well with the incidence of fruit rot in our test orchards. Also, cursory observations reveal that few conidia are produced on infected blossoms by early summer. Many wild plum (*Prunus angustifolia* Marsh and other *Prunus* spp.) thickets exist in commercial peach-growing areas of South Carolina, and these might provide primary and secondary inoculum.

The objectives of this study were to examine the trend of sporulation on blighted blossoms, the production of apothecia, and to identify sources for secondary inoculum as fruits approach maturity.

MATERIALS AND METHODS

Apothecium production. In 1980, the orchard floor from the drip line inward of 72 peach trees in six orchards was thoroughly searched for apothecia several times during bloom. The peach trees studied were known to have had infected fruits in 1979. Also, 16 wild plum thickets located near commercial peach orchards were observed.

Sporulation on blighted blossoms. Open peach blossoms were inoculated with two strains of *M. fructicola* (one benomyl sensitive and the other benomyl resistant) previously isolated from peaches in South Carolina. The fungus was grown on potato-dextrose agar (PDA) at 25 C. Conidia were harvested by flooding the culture with water, and the resulting suspension was adjusted to 2×10^5 conidia per milliliter. At 50% bloom, open blossoms on selected branches of Redhaven and Redskin trees were sprayed to runoff with the suspension and covered with plastic bags that were sealed with wire ties. The bags were removed approximately 10 days after

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inoculation.

Washings from random blighted blossoms were taken at 2-wk intervals between 30 April and 26 June 1979. Five groups were sampled: Redhaven and Redskin cultivars each inoculated with either benomyl-resistant or sensitive strains, and a neglected Redhaven orchard with naturally infected blossoms. Ten blossoms from each group were selected randomly for each sampling. Each blighted blossom was washed with 20 ml of distilled water that was recovered in a beaker, used to wash the blossom a second time, and then collected in a glass vial. The vials were shaken, and 10 ml of the suspension was poured into a hypodermic syringe and filtered through a 0.2-μm Metricel membrane filter placed in a Gelman Swinney-type adapter. Filters were placed on a glass slide, stained with cotton blue, covered with a glass coverslip, and observed microscopically at ×430. Conidia in 20 random fields per filter were counted.

In 1980, blossoms of cultivar Dixired were inoculated with both strains of the fungus as previously described. Naturally occurring infected blossoms also were observed on trees of cultivar Dixired. Samples were taken weekly from 9 April to 26 June.

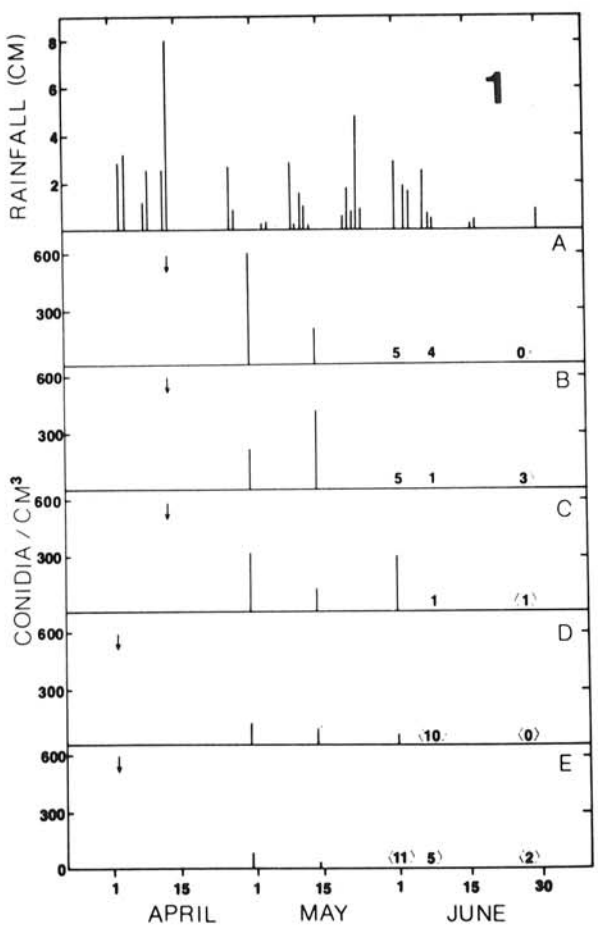
In 1979, additional blighted blossoms were examined for sporulation with the aid of a dissecting microscope. Approximately 100 blighted Redhaven blossoms were observed on 12 April, 18 April, 15 May, 2 June, and 27 June. Blighted Redskin blossoms were examined on these dates and again on 27 July.

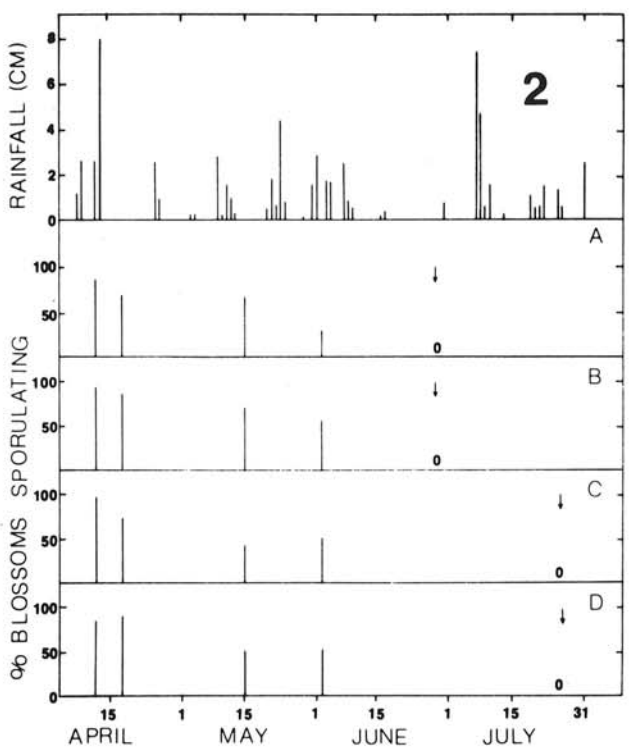
Inoculum from wild plums. In 1980, a wild plum thicket was monitored for blossom blight and sporulation. Ten randomly selected blighted blossoms were selected for each weekly sampling between 27 March and 26 June. Wild plum twigs with blighted blossoms were induced to sporulate periodically between 30 April and 26 June as described for peach.

Induced sporulation. In 1979, many fruits on unsprayed trees in two experimental orchards were infected with brown rot and remained attached to the trees. In 1980, twigs with blighted blossoms, infected fruit peduncles, cankers, or attached mummified fruits were removed from these trees and placed in a moist chamber at room temperature (~25 C). The moist chamber consisted of a glass container lined on the bottom with moist paper towels and sealed with Parafilm. Ten each of twigs with blighted blossoms, peduncles with cankers, and mummified fruits were collected weekly beginning 24 April and incubated until sporulation occurred or for a maximum of 4 days. Twigs were observed daily for sporulation with the aid of a dissecting microscope. During dry periods the twigs and mummies were sprayed lightly with water before the moist chamber was sealed.

Sporulation on nonabscised aborted fruits. All branches on approximately 60 trees in four orchards in Anderson County, SC, were surveyed between 10 May and 2 June 1979 for sporulation on nonabscised aborted fruits. In May 1980, a similar survey was conducted with 81 trees in an orchard in Anderson County. Fungicide treatments applied to these trees ranged from no sprays to minimal sprays of sulfur, benomyl, or captan.

Sporulation on thinned fruits. Usually, excess peach fruits that are thinned from trees are dropped and remain on the orchard floor. We found *M. fructicola* sporulation on thinned fruits on the floor of an experimental orchard in 1979 and determined the frequency of sporulation on 100 thinned fruits randomly selected under Blake, Redhaven, and Redskin trees that had received no fungicide sprays. Fruits of cultivars Blake and Redhaven were thinned at pit-hardening in mid- to late-May. Redskin trees were thinned in April before pits began to harden. Thinned fruits of cultivars Redhaven, Blake, and Redskin were examined for sporulation approximately 14, 21, and 28 days, respectively, after thinning. Wet weather prevailed during this period. Measurable rainfall was recorded on 25 of the 41 days preceding the final





Figs. 1 and 2. 1, Number of conidia of *Monilinia fructiola* produced per blighted peach blossom at 2-wk intervals compared with daily rainfall in South Carolina, 1979. (A) Natural infections on Redhaven blossoms. Redhaven blossoms inoculated with (B) benomyl-resistant and (C) benomyl-sensitive strains of *M. fructicola.* Redskin blossoms inoculated with (D) benomyl-resistant and (E) benomyl-sensitive strains of the fungus. Arrow indicates calyx-split. Numbers within brackets indicate values too small to appear within the scale. **2,** Percentage of infected peach blossoms with sporulation in 1979. Blossoms inoculated with a benomyl-resistant strain of *M. fructicola* on (A) Redhaven and (C) Redskin or with a sensitive strain on (B) Redhaven and (D) Redskin cultivars. Arrow indicates harvest.

observation for a total of 19.7 cm.

In 1980, the effect of fruit thinning time on sporulation was tested with Redhaven trees. Treatments were distributed in a randomized complete block and replicated five times. Fruits were thinned before pits began to harden (6 May), at the beginning of pit-hardening (21 May), and after the pits had hardened (31 May). On 7 June, all fruits up to a maximum of 100 fruits under each tree were examined for sporulation.

Influence of fungicidal sprays on sporulation on thinned fruits. In 1979, captan and sulfur cover sprays were applied on Redhaven peach trees at the rate of 1.2 and 7.0 g a.i. per liter of water, respectively. Trees that received a full spray program were first sprayed at calyx-split on 16 April, 10 days later (26 April), 14 days later on 10 May, and 14 days after that a final spray was applied on 24 May. In other treatments the first, second, third, fourth, or combinations of these sprayings were omitted. Fungicide applications were made with a single-nozzle handgun at 1,700–2,000 kPa (17–20 atm). Check trees received no fungicide sprays. All treatments were replicated four times in a randomized complete block design. All trees were hand-thinned in mid-May. Approximately 17 days after being thinned, 100 fruits under each tree were selected at random and examined for sporulation of *M. fructicola.* All data were subjected to analysis of variance and the means of appropriate treatments were compared for statistical significance, $P = 0.05$.

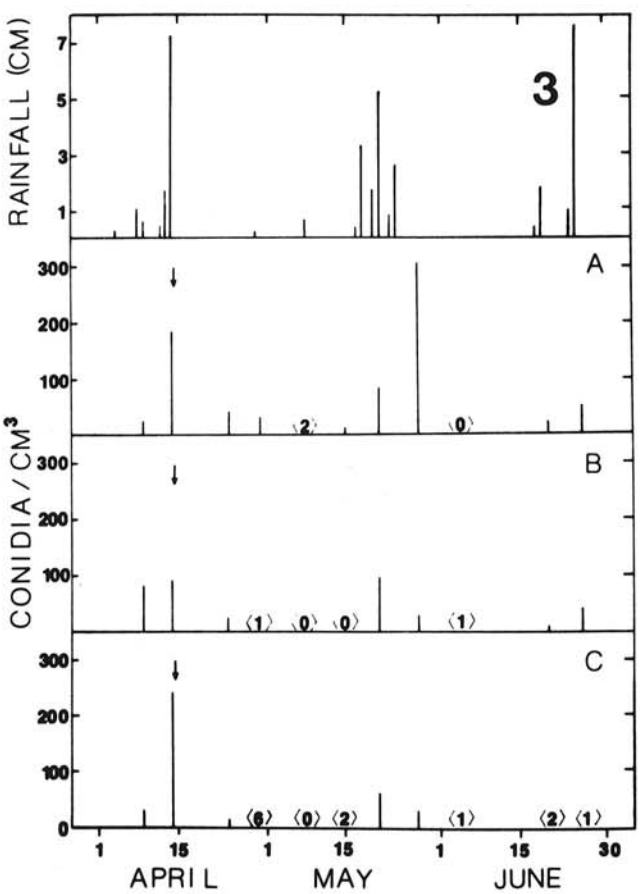
In 1980, a similar fungicide test was conducted. Open blossoms on one branch of each tree in the test were inoculated with the fungus. Captan, sulfur, and benomyl were applied to trees at 1.2, 7.0, and 0.3 g a.i., respectively, per liter of water. Trees that received a full spray program were sprayed at calyx-split (19 April), and at ~2-wk intervals thereafter (3, 19, and 30 May) for a total of four sprays. In other treatments (as in 1979) the first, second, third, fourth, or combinations of these sprayings were omitted. The third spray was repeated 2 days later because rain began during the application and continued for 2 days. Fruits were hand-thinned on 31 May when pits were hardening. On 7 June, all fruits up to a maximum of 100 fruits under each tree were examined for sporulation. All data were subjected to analysis of variance and the means of appropriate treatments were compared for statistical significance, $P = 0.05$.

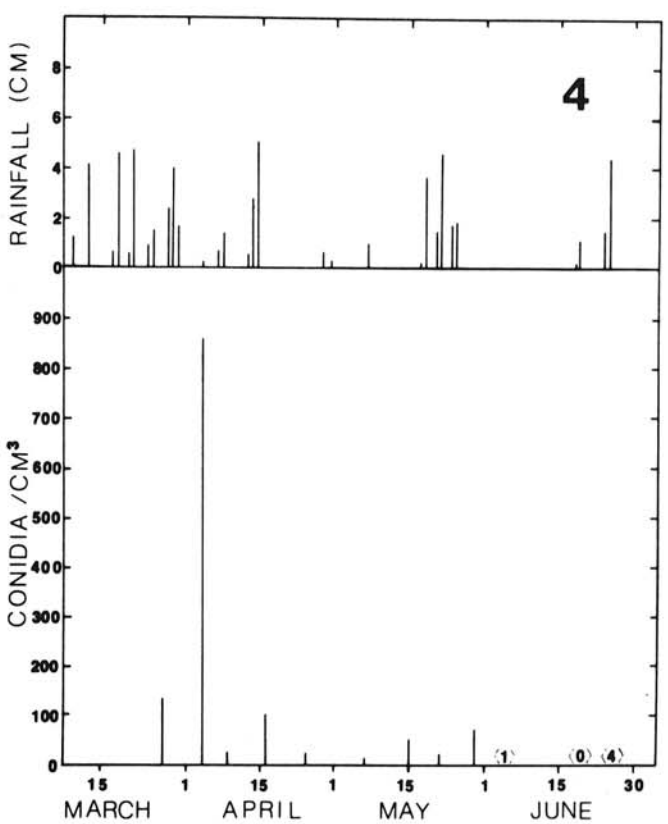
RESULTS

Apothecial production. Apothecia of *M. fructicola* were found in the spring of 1980 on mummified fruits partially or completely buried in the ground under 11 of 73 peach trees and in 9 of 16 wild plum thickets. The production of apothecia corresponded with the bloom period of both peach and wild plum in March, when measurable rainfall occurred on 6 of 10 days from early to full bloom. A total of 116 apothecia were found in a commercial peach orchard, a fungicide test orchard, and a neglected peach orchard; and 155 were found in wild plum thickets. All orchards and thickets where apothecia were found had numerous mummified fruits beneath the trees and the soil surface was moist. The maximum numbers of apothecia found were 23 under one peach tree and 95 in one wild plum thicket which was only 0.3 km from a commercial peach orchard.

Sporulation on blighted peach blossoms. In 1979, rainfall was frequent throughout the season. Sporulation of *M. fructicola* was profuse on blighted blossoms sampled 30 April, but declined thereafter (Fig. 1). This trend of sporulation decline was verified for Redhaven by visual observations of many additional blighted blossoms (Fig. 2).

In the 1980 peach growing season, rainfall was much less frequent than in 1979 (Figs. 1 and 3) and early season sporulation levels were generally lower (Fig. 3). In April 1980, there was limited sporulation (Fig. 3). During the dry period from late April to mid-May numbers of conidia were low. Small peaks of sporulation followed in late May. Naturally infected blossoms generally appeared to sporulate more on 31 May than did inoculated





Figs. 3 and 4. 3, Number of conidia of *Monilinia fructiola* produced per blighted Dixired blossoms at week intervals compared with daily rainfall in South Carolina, 1980. Blossoms either (A) naturally infected, or inoculated with a (B) benomyl-resistant or (C) benomyl-sensitive strain of *M. fructicola.* Arrow indicates calyx-split. **4,** Number of conidia per blighted wild plum blossom compared with daily rainfall, 1980.

blossoms, but the differences were not significant ($P = 0.05$).

During the 1980 season, blighted peach blossoms were induced to sporulate in moist chambers (Table 1). Sporulation was induced on 70–100% of the blossoms sampled 24 April–26 June. The sporulation was usually light, however, with an average of 63 conidia per milliliter of water recovered from washings.

Inoculum from wild plums. Every phase of brown rot was found in wild plum thickets. Apothecia and conidia on mummified fruits hanging in the trees were present during the bloom period. Later, sporulation on blighted blossoms was profuse in some thickets (Fig. 4). The sporulation level declined as the season progressed. However, sporulation could be induced from April through June (Table 1). Profuse sporulation on rotting wild plum fruits was first seen on 15 May and it continued until observations were terminated on 26 June.

Sporulation on other infected peach tissues. Washings taken from mummified fruits and fruit peduncles with associated cankers had few or no conidia in 1980 (Fig. 5). Visual observations of mummies and peduncles confirmed these results. Attempts to induce sporulation from these tissues were unsuccessful, except on one fruit peduncle sampled 30 April (Table 1).

In early May 1979, small shriveled fruits were found in peach trees. Development of these fruits had ceased for undetermined reasons, presumably lack of pollination. Profuse sporulation of *M. fructicola* was found on some of these nonabscised, aborted fruits in trees receiving minimal or no fungicidal sprays. Visible sporulation continued on these fruits until other fruits reached maturity. At fruit maturity, ~3% of the branches had sporulation on nonabscised, aborted fruit in each of the six orchards surveyed. Conidial viability was 95%.

In 1980, only 13 nonabscised, aborted fruits were found on 81 trees. A freeze in March killed many of the fruit buds, and consequently these trees only had approximately 70 fruits each.

Sporulation on thinned fruits. Infection and sporulation on thinned fruits on the orchard floor were observed on 31 May 1979 under trees that had received no fungicide sprays. Measurable rain fell on 15 of 22 days preceding this observation (Fig. 1). Redhaven and Blake trees thinned after pits began hardening averaged 12% (1 June) and 15% (11 June) fruits with sporulation, respectively. The maximum proportion of fruits with sporulation was 38%. Redskin trees thinned before pit-hardening averaged only 0.3% fruits with sporulation on 31 May. Most of these fruits decomposed rapidly, but spore viability was 85% or greater.

In 1980, only trace amounts of rain fell 2 wk before observation of thinned fruits (7 June). Sporulation was found on 3.3% of Redhaven fruits thinned on 31 May after pits began to harden. Sporulation was not found on more than 10% of the fruits of any individual tree. Fruits thinned before pit-hardening decomposed rapidly without sporulation; those thinned with pits in early stages of hardening dried and shriveled rapidly, also without sporulation.

Influence of fungicide cover sprays on sporulation on thinned fruits. In the 1979 test, captan and sulfur cover sprays significantly ($P = 0.05$) reduced the proportion of thinned fruits with sporulation compared with that of thinned fruits under unsprayed trees (Table 2). Applying the first two or three captan sprays was as effective as the full program of four cover sprays ($P = 0.05$), and was significantly better ($P = 0.05$) than applying the last two sprays only. Sporulation on fruits was highly variable when trees received sulfur cover sprays. There were no detectable sporulation differences ($P = 0.05$) among sulfur treatments; however, those sprayed with sulfur had less ($P = 0.05$) than the unsprayed controls.

In 1980, the number of sprayed and unsprayed thinned fruits with sporulation was lower than in 1979 (Tables 1 and 3). Benomyl suppressed sporulation ($P = 0.05$) on thinned fruits (Table 3). Among benomyl treatments there were no detectable differences ($P = 0.05$). The full captan program, the first three sprays, or the last two sprays were significantly better ($P = 0.05$) than applying the first two captan sprays only. There were no significant differences ($P = 0.05$) among sulfur treatments or between sulfur treatments and the unsprayed fruits.

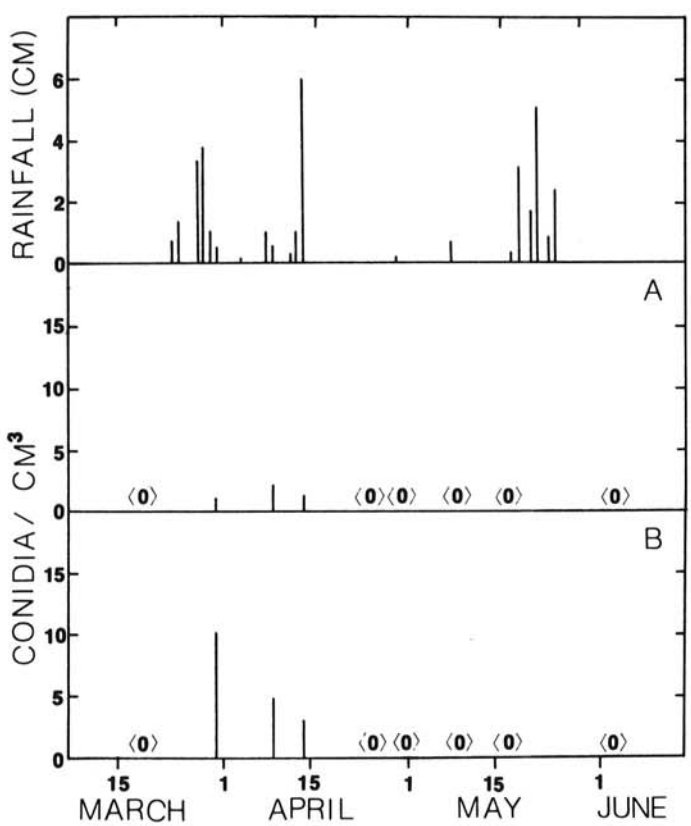


Fig. 5. Number of conidia per cubic centimeter of water recovered from washings of (**A**) fruit peduncles with cankers, and (**B**) mummified fruits hanging in the tree in 1980 compared with daily rainfall.

DISCUSSION

Results of this study help assess the relative importance of *M. fructicola* inoculum sources for South Carolina peach orchards and perhaps elsewhere in the southeastern USA. Apothecia were observed arising from both peach and wild plum mummified fruits beneath the trees; this occurrence in wild plum thickets is especially important because wild plums are abundant and brown rot in plum thickets is unchecked. Since conidial production on infected overwintered peach mummies, cankers, and fruit peduncles was light and infrequent, and sporulation occurs on mummified wild plums, ascospores and conidia from wild plums appear to be important primary inocula.

Blighted blossoms appear to be less important as a secondary inoculum source in the preharvest period than some other sources because sporulation on blighted blossoms declined as the season progressed and increased only slightly during rainy periods. Field observations indicate that nonabscised, aborted fruits; infected, injured green fruits; and thinned fruits on the orchard floor are

TABLE 1. Sporulation[a] of *Monilinia fructicola* on infected peach and wild plum tissues collected in South Carolina in 1980

Date	Peach			Wild plum
	Blighted blossoms	Fruit peduncle with canker	Mummified fruits	blighted blossoms
24 April	5/5	1/10	0/10	...
30 April	5/5	0/10	0/10	3/3
7 May	10/10	0/10	0/10	50/50
15 May	8/10	0/10	0/10	4/5
21 May	8/10	0/10	0/10	10/10
28 May	10/10	0/10	0/10	7/10
5 June	9/10	0/10	0/10	8/10
20 June	7/10			3/10
26 June	9/10			7/10

[a] Induced by incubation in a moist chamber at 25 C for 4 days.

TABLE 2. Influence of application time and number of captan or sulfur cover sprays on the sporulation of *Monilinia fructicola* on thinned Redhaven peach fruits in 1979

Fungicide	Treatment[a]	Sprays[b]	Thinned fruits with sporulation (%)[c]
Captan	A	#1,2	2.7
	B	#1,2,3	3.3
	C	#1,2,3,4	1.3
	D	#2,3	1.8
	E	#3	7.3
	F	#2	5.5
	G	#3,4	11.8
	H	#4	10.0
	I	#2,3,4	1.8
Sulfur	A	#1,2	7.0
	B	#1,2,3	3.3
	C	#1,2,3,4	8.0
	D	#2,3	9.0
	E	#3	8.5
	F	#2	14.3
	G	#3,4	10.0
	H	#4	4.8
	I	#2,3,4	8.5
Check			14.8

[a] Data were subjected to analysis of variance with the following contrasts: check vs all captan or sulfur treatments; A vs G; A vs B; A vs C; C vs I; A vs D; B vs all; B vs C; and I vs D. Standard deviation among captan treatments was 0.9683 with an error mean square of 0.938 and 37 corrected total degrees of freedom. Standard deviation among sulfur treatments was 1.085 with an error mean square of 1.1778 and 38 corrected total degrees of freedom. Means were based on data from four replicates.

[b] Cover sprays: 1, applied at calyx-split; 2, 10 days later; and 3 and 4 at 2-wk intervals.

[c] Differences between captan and unsprayed fruits are significant at $P = 0.002$. Differences between sulfur and unsprayed fruits were significant at $P = 0.07$. Omitting the first two sprays of the captan treatment significantly increased ($P = 0.05$) the percentage of fruits infected.

TABLE 3. Influence of application time and number of fungicide cover sprays with captan, sulfur, and benomyl on the frequency of brown rot sporulation of thinned Redhaven peach fruits in 1980

Fungicide	Treatment[a]	Sprays[b]	Thinned fruits with sporulation (%)[c]
Captan	A	#1,2,3,4	.7
	B	#1,2,3	.9
	C	#1,2	5.4
	D	#3,4	1.6
	E	#2,3,4	2.3
	F	#2,3	3.6
Sulfur	A	#1,2,3,4	5.0
	B	#1,2,3	1.6
	C	#1,2	4.6
	D	#3,4	2.8
	E	#2,3,4	2.5
	F	#2,3	2.7
Benomyl	A	#1,2,3,4	.7
	B	#1,2,3	.7
	C	#1,2	.8
	D	#3,4	1.8
	E	#2,3,4	1.1
	F	#2,3	2.0
Check			2.8

[a] Data subjected to analysis of variance with the following contrasts: Check vs others; C vs D; C vs F; A vs C; B vs C; and A vs D. Standard deviation was 0.6524 with an error mean square of 0.426 and 75 corrected total degrees of freedom. Means based on data from four replicates.

[b] Cover sprays: #1, at calyx-split; and #2, #3, and #4 at 2-wk intervals.

[c] Differences between benomyl and unsprayed fruits are significant at $P = 0.09$. Differences between sulfur and unsprayed fruits were not significant. Omitting spray #3 of the captan treatment significantly increased ($P = 0.05$) the percentage fruits infected.

potentially more important sources of secondary inoculum within the orchard.

Sporulation on fruit peduncles, twig cankers, and mummified fruits may not be epidemiologically important in South Carolina. Conditions suitable for inducing light sporulation on blighted blossoms during April, May, and June seldom stimulated production of conidia from these overwintering sources. Excellent control of brown rot in most South Carolina peach orchards minimizes the numbers of overwintering sources in peach trees.

Sporulation on infected, thinned fruits on the orchard floor appears to be a significant inoculum source. The later the fruits were thinned in the season, the higher the percentage with sporulation in the preharvest period. Early thinning of excess fruits and an effective spray program both help to minimize the importance of this inoculum source. Fungicide cover sprays may influence inoculum on thinned fruits by suppressing sporulation. Benomyl suppressed this inoculum source, whereas captan and sulfur were less effective or entirely ineffective.

The susceptibility of blossoms, maturing fruits, and injured green fruits is well documented (1,2,12,14). However, significant susceptibility of sound green fruits is under question. Both latent and quiescent infections have been reported on peach (5,8–10,16). In Australia, long-term latent and quiescent infections are reported to cause losses on <5% of the total sprayed crop (9). Jenkins and Reinganum (5) suggested that not all quiescent infections remain viable until fruit maturity. Latent contamination also has been reported (6). Other workers (5), however, question the ability of conidia to survive on fruit surfaces for long periods and to remain dormant during wet periods while fruit are immature. Latent and quiescent infections and latent contamination of fruits have not been investigated in the humid southeastern United States. Therefore, the importance of secondary inoculum between petal-fall and preharvest is uncertain except when fruit injuries are numerous.

Infections of nonabscised, aborted fruits have not been reported previously. These appear to be important reservoirs of inoculum in some orchards. Wild plum thickets are important inoculum reservoirs in the vicinity of peach orchards. Many wild plum thickets in commercial peach-growing areas may provide inoculum from apothecia; blighted blossoms; infected, injured immature fruits; and rotting mature fruits. Because insect pests are unchecked in plum thickets, fruit injury is often high, and subsequent brown rot infection and sporulation often occurs even during dry weather. Wild plums may provide a continuous inoculum supply. The distance of spore dissemination from wild plum thickets has not been determined.

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