

Inoculum sources for *Monilinia fructicola* in Ontario peach orchards

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Sources of *Monilinia fructicola* inoculum in peach orchards were studied at five sites in 1984. Apothecia were found in 1983 in a noncultivated peach orchard. In 1984 no apothecia were found although conidia were produced on mummies which had overwintered on the ground or in the tree, and on cankers, fruit peduncles, and blighted twigs. Sporulation occurred on blighted blossoms and associated twig cankers in late May, although blossom blight incidence was low in 1984 (< 1.0%). At the time of approaching fruit maturity, the principle sources of inoculum were thinned fruits on the ground (up to 14% infected) and nonabscised, aborted fruits in the tree (up to 32.5% infected). Thinning at or after pit hardening in a nonsprayed orchard resulted in 6.0 and 14.0% infection of thinned fruits on the ground, respectively. In the laboratory, inoculation of early-maturing peach cultivars resulted in greater numbers of conidia than on late-maturing cultivars, although late-maturing cultivars were colonized more rapidly. Early-maturing cultivars provided additional inoculum for infection of late-season cultivars.

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Les sources de l'inoculum de *Monilinia fructicola* dans des vergers de pêchers ont été étudiées dans cinq sites en 1984. Des apothécies ont été trouvées en 1983 dans un verger non cultivé. En 1984, aucune apothécie n'a été décelée, bien que des conidies se soient formées sur des fruits momifiés qui avaient hibernés sur le sol ou sur l'arbre; elles ont aussi été retrouvées sur des chancres, des pédoncules de fruits et des rameaux flétris. La sporulation se produit sur les fleurs flétries et les chancres des rameaux qui les accompagnent à la fin de mai, bien que l'incidence de la pourriture brune ait été faible en 1984 (1,0%). À l'approche de la maturité des fruits, les principales sources d'inoculum ont été les fruits éclaircis sur le sol (contamination atteignant jusqu'à 14%) et des fruits non excisés, avortés sur l'arbre (contamination allant jusqu'à 32,5%). Dans un verger non pulvérisé où l'éclaircissage est pratiqué au moment du durcissement du noyau ou après, les taux de contamination des fruits éclaircis sur le sol atteignent 6,0 et 14,0% respectivement. En laboratoire, l'inoculation de cultivars de pêchers précoces donne lieu à la formation d'un plus grand nombre de conidies qu'avec des variétés tardives, bien que ces dernières soient colonisées plus rapidement. Les cultivars précoces contribuent à augmenter les quantités d'inoculum qui infecteront les variétés tardives.

Brown rot caused by *Monilinia fructicola* (Wint.) Honey is one of the most important diseases of peach (*Prunus persica* (L.) Batsch.) in the Niagara region. Although numerous reports exist on inoculum sources, there is a notable absence of information on the disease as it occurs in Ontario. According to Byrde and Willetts (1), the fungus overwinters and produces primary inoculum in the spring from apothecia and from mycelia in previously infected plant parts (e.g. fruit mummies, peduncles, twig and branch cankers, leaf scars, and buds) that support sporulation if conditions are favorable. Secondary inoculum is produced on infected tissues when the moisture content is favorable. Roberts and Dunegan (10) discussed the contribution of inoculum from wild hosts adjacent to commercial orchards.

Current recommendations for brown rot control in Ontario emphasize chemical protection of the blossoms in spring followed by two or three cover sprays, a pre-pick spray, and a post-harvest treatment. Orchards are usually clean-cultivated to disrupt apothecium formation and to encourage decomposition of mummies removed from the trees during pruning in April or early May. However orchard management practices in Ontario are

changing in response to conditions imposed by new peach canker management schemes, winter killing of buds, and other economic constraints. Many growers are moving away from clean cultivation and toward strip cultivation and sod systems. The sod system is particularly useful in controlling erosion, reducing energy costs, and decreasing root damage; in addition, the sod system reduces peach canker incidence (3) and minimizes spread of soil-borne pathogens. Also many growers delay pruning until well into the blossom period to promote rapid wound closure, thus minimizing the risk of peach canker development, or to reduce the removal of surviving flower buds following a severe winter with high bud mortality. Such practices often result in mummies being left in the tree during the blossom period, thus increasing the risks of heavy blossom infection. The accepted strategy has been to increase protective fungicide applications, which increases the risk of developing fungicide resistance. For example, more than 80% of Ontario peach orchards harbour benomyl-resistant *M. fructicola* (J. Northover, unpublished data). The laboratory selection of isolates resistant to the dicarboximide fungicides iprodione, procymidone, and vinclozolin has been reported (5,8,9,11). Iprodione-

resistant *Botrytis cinerea* has been found in Ontario vineyards and greenhouses (7) after only two years of use.

A better understanding of the etiology of brown rot in Ontario is required to provide a basis for the management of fungicides to delay the development of resistance, to improve the timing of fungicide applications, and to allow for a re-evaluation of cultural practices used to reduce fungal inoculum. The objectives of this study were to examine sources of overwintering inoculum and to identify potential sources of secondary inoculum through to fruit maturity.

Materials and methods

Apothecium production. In 1983 and 1984, a 400 m² area of orchard floor beneath mature Redhaven trees was left noncultivated during the month of May. The peach trees were known to have had *Monilinia*-infected fruits the previous years. Weekly observations were made from four 30-cm-wide transects across the plot. In 1984, additional observations were made in two orchards with sod-herbicide strip systems, in a strawberry intercrop system, in two clean cultivation systems, and beneath wild *Prunus avium* and *P. serotina* adjacent to the Jordan Station Experimental Farm.

Asexual primary inoculum sources. Two sites were sampled intensively in May 1984 to determine the location of overwintered *M. fructicola* mycelia. An early-season (Candor), mid-season (Redhaven), and late-season (Cresthaven) cultivar was included at each site. Samples of 30 mummies that overwintered in the tree, 30 mummies that overwintered on the ground, and 10 samples each from peduncles, cankers, and necrotic twigs (buds and leaf scars) were collected weekly from each cultivar at each site and returned to the laboratory for incubation. Each plant part was placed on a quartered canned peach fruit (packed in syrup, rinsed in running tap water for 30 minutes) supported on a screen in a 23 × 30 cm aluminum baking tray covered with a clear polyethylene bag, and incubated for 48 h in the dark at 23°C. Samples were assessed for visible conidiophores and conidia of *M. fructicola* at the end of the incubation period.

Secondary inoculum sources. Blossoms — A survey of blighted blossoms was conducted in 1984 at four commercial orchards (sprayed) and one experimental orchard (unsprayed). No blossom infections were detected in May, so this potential source was not followed over the season.

Nonabscised, aborted fruit — From 20 June to 12 September 1984, 30 nonabscised, aborted fruits per cultivar (Candor, Redhaven, Cresthaven) were collected from each of four commercial orchards

and the one experimental orchard (Redhaven, only), brought to the laboratory, assessed for visible sporulation, and cultured on 2% potato dextrose agar (PDA) to determine if the fruits were infected. All fruits were surface sterilized by passage through 70% ethanol (60 sec), 0.5% sodium hypochlorite (60 sec), and sterile distilled water.

Thinned fruit — To examine the importance of thinned fruit on the orchard floor as a source of inoculum, an experimental orchard of 6-year-old Redhaven trees was thinned at weekly intervals, beginning 3 July 1984, to provide three classes of thinned fruit: pre-pit hardening, pit hardening, and post-pit hardening. Three replicates of one hundred fruit were examined in the orchard at weekly intervals, beginning 17 July and ending 21 August, for visible sporulation of *M. fructicola*. In addition, the thinning practices in the commercial orchards were monitored and sporulation on thinned fruit was assessed similarly.

Insect-injured fruit — Severe infestation of many Niagara peach orchards by an unidentified complex of fruit-wounding *Myrid* species provided conditions for sampling injured green fruits. During July, samples of injured fruit were taken weekly from two sites, 150 fruits per site, and the wounded tissues excised, surface sterilized, and placed on PDA.

Disease incidence ratings were taken at all five sites by taking three replicate samples of 100 fruit per cultivar per site at weekly intervals, beginning one week prior to the average commercial ripeness date for the cultivar Candor (30 July).

Peach cultivars — A laboratory inoculation experiment was conducted to examine the role of early-season cultivars as sources of inoculum for later-maturing cultivars. Three replicates of 10 fruit from 8 cultivars were collected at commercial ripeness (N. Miles, personal communication) from the experimental farm at the Horticultural Research Institute of Ontario. The fruits were stabilized with juice jar lids to prevent rolling, placed on 23 × 30 cm wooden boxes, wounded with a sterile scalpel (4 × 4 × 4 mm wound), and inoculated with 1 × 10⁵ conidia of *M. fructicola* isolate S5, a benomyl-sensitive isolate from peach. Fruits were incubated in the dark at 22°C and 98% RH, and lesion diameter was measured and recorded daily. The number of spores per fruit was determined by rinsing each fruit with 5 mL sterile distilled water followed by gentle brushing with a moistened No. 4 camel's-hair brush to dislodge remaining conidia. Spores were counted with a haemocytometer 7 days after inoculation on three fruits per replication for three replications. Three replicates of 10 wounded, noninoculated fruits were included for each cultivar

Table 1. Percentage of mummies overwintered in the tree or on the ground exhibiting sporulation of *M. fructicola* after 48 h incubation at 23°C

Date collected ^y	Site 1			Site 2		
	Candor	Redhaven	Cresthaven	Candor	Redhaven	Cresthaven
Ground mummies						
10 May	33.3	36.7	6.7	42.1	0.0	0.0
17 May	0.0	0.0	10.0	0.0	0.0	0.0
25 May	— ^z	—	25.0	0.0	8.3	8.3
30 May	—	—	—	0.0	0.0	4.0
Tree mummies						
10 May	66.7	76.7	50.0	81.8	100.0	90.0
17 May	75.0	86.9	55.0	100.0	—	100.0
25 May	46.7	43.3	66.7	77.8	88.9	83.3
30 May	76.7	56.7	60.0	55.0	78.6	80.0

^yMay 17 corresponds to the pink stage of flower development. Site 1 represents clean cultivation with a herbicide strip, site 2 represents a sod system with a herbicide strip.

^z— = mummies decomposed or not available.

to serve as a control to monitor natural background infection.

Results

Occurrence of apothecia. Apothecia of *M. fructicola* were found in May 1983 on mummified fruits in the noncultivated test orchard. Nine apothecia were found along 16 transects across the 400 m² plot, but none was observed in experimental and commercial orchards or under wild hosts in 1984.

Mummies. Data taken from three cultivars at each of two sites for percent *M. fructicola*-infected trees and ground mummies are presented in Table 1. Tree mummies were a significantly greater source of overwintering mycelium than were ground mummies. There were no apparent differences attributable to site for percent infection of overwintered tree mummies. However the influence of site was significant with regard to overwintered ground mummies, with site 2 (sod system) supporting 5.2% *M. fructicola*-infected mummies versus 9.3% for site 1 (clean cultivation) ($t = 1.42$, $p = 0.10$). Mummies could not be found following cultivation of site 1.

Peduncles, cankers, and twigs. Infected peduncles, cankers (on 1- and 2-year-old wood), and twigs (1-year-old) supported overwintering mycelium of *M. fructicola*. Induction of sporulation in the laboratory detected the highest percent infection (greater than 70%) for all three sources on 10 May. Subsequent weekly samples showed a steady decline in percent infection to less than 15% on 30 May. Woody tissues up to 2 years old continued to support sporulation of *M. fructicola*.

Nonabscised, aborted fruits. The percentage of nonabscised, aborted peach fruit exhibiting sporulation is presented in Table 2. The data are a composite of the data collected weekly from 20 June through 12 September from three cultivars at four

Table 2. Percentage of nonabscised, aborted peach fruit exhibiting sporulation of *Monilinia fructicola*

Cultivar	Location			
	Site 1	Site 2	Site 3	Site 4
Candor	12.1 a ^z	14.2 a	10.8 a	5.0 b
Redhaven	5.6 b	3.2 bc	2.8 bc	0.7 c
Cresthaven	6.1 b	4.2 bc	4.0 bc	0.7 c

^zMeans separated using orthogonal comparisons. Means bearing the same letter are not significantly different at $P = 0.05$.

commercial sites. There was a significant site × cultivar interaction in the percentage of nonabscised aborted fruit exhibiting sporulation. The cultivar Candor consistently supported a larger percentage of sporulating nonabscised, aborted fruit than Cresthaven or Redhaven on all sites, although fewer nonabscised, aborted fruits were present at site 4, especially when compared to site 1.

The data from weekly monitoring for sporulation on nonabscised, aborted fruit sampled from four commercial sites are presented in Fig. 1. Sporulating, nonabscised, aborted fruit were first detected on 20 June for the cultivar Cresthaven and on 26 June for the cultivars Candor and Redhaven. Percent sporulating, nonabscised, aborted fruit peaked on 11 July for the cultivars Candor and Redhaven and on 28 August for the cultivar Cresthaven.

Thinned fruit. Data on the influence of peach fruit development at thinning on the percentage of fruit exhibiting visible sporulation on the floor of a nonsprayed experimental orchard are presented in Table 3. Fruit thinned at pre-pit hardening showed virtually no visible sporulation of *M. fructicola* over the duration of the season, whereas fruit thinned at pit hardening or post-pit hardening showed maximum fruit infection of 6.0 and 14.0%, respectively, on 14 August, one week before har-

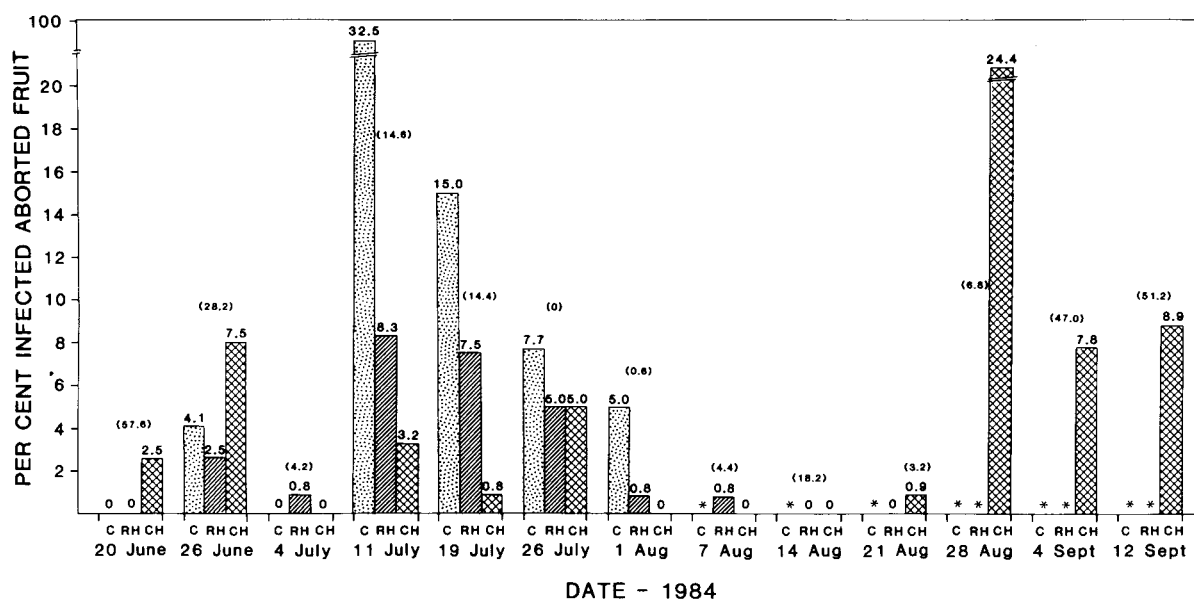


Figure 1. Percent infected, nonabscised, aborted fruit for three peach cultivars during the 1984 growing season. Data represent weekly means of observations from 30 fruit from each of four commercial orchards in the Niagara Peninsula. Numbers in parenthesis indicate mm rainfall the preceding week. C = Candor, RH = Redhaven, CH = Cresthaven, * = cultivar harvested.

vest. Fruit thinned at post-pit hardening displayed significantly greater infection than fruit thinned at earlier stages.

Commercial orchard thinning practices and percent sporulating thinned fruit for three cultivars at four sites are presented in Table 4. Thinning dates were variable from site to site, and, at three sites, cultivars were thinned according to their relative maturation time rather than stage of fruit development. Where thinned fruit exhibited sporulation, the percentage of fruit with visible sporulation of *M. fructicola* was greater for fruit thinned at pit hardening or later compared to fruit thinned at pre-pit hardening ($t = 1.82, p = 0.05$).

Peach cultivars. Data for lesion diameter, fungal colonization rate, number of spores per fruit, and maturity date for Vineland are presented in Table 5.

Table 3. Influence of peach fruit development at thinning on percent infection of thinned fruit by *Monilinia fructicola* in a nonsprayed Redhaven orchard

Assessment date	Fruit development stage ^z		
	Pre-pit hardening	Pit hardening	Post-pit hardening
24 July	1.0	0.0	0.0
31 July	0.0	1.0	0.0
7 August	0.0	4.0	6.0
14 August	0.0	6.0	14.0
21 August	0.0	2.0	7.0

^zMean percent infection of fruit thinned at post-pit hardening is significantly greater than means for pre-pit hardening or pit hardening using Duncan's Multiple Range Test ($P = 0.05$).

Lesion growth rate was negatively correlated with mean maturity date (Spearman's rank correlation, $r = -0.92, p = 0.01$), and spor number was positively correlated with maturity date (Spearman's rank correlation, $r = 0.67, p = 0.05$). Where early maturing cultivars supported slower colonization rates than later maturing cultivars, sporulation on early cultivars was relatively greater.

Discussion

Our results provide an assessment of inoculum sources in Ontario peach orchards. Apothecia were observed arising from mummified peach fruit beneath flowering trees; this is the first report of apothecia in Ontario peach orchards since 1947 (2), and, although apparently rare, their occurrence should be monitored on an annual basis to determine more accurately their contribution to primary inoculum. Conversion to sod-orchard-floor management systems, could favor apothecium formation relative to the traditional clean cultivation system.

The difference between mycelium survival in mummies which overwintered in the tree relative to those which overwintered on the ground suggests that removal of mummified fruit from trees in autumn could reduce considerably the primary inoculum from this source. Sporulation on fruit peduncles, twig cankers, and necrotic twigs was observed in the spring; thus these sites serve as sources of primary inoculum for infection of blossoms and of nonabscised, aborted fruit, and

Table 4. Effect of the date of thinning of three cultivars at four commercial sites in the Niagara region upon the percentage of sporulating thinned fruit on the orchard floor

Date	Site 1 ^w			Site 2			Site 3			Site 4		
	C 4/7	RH 4/7	CH 4/7	C 4/7	RH 14/8	CH 22/8	C 4/7	RH 16/7	CH 16/7	C 11/7	RH 17/7	CH 31/7
17 July	2.0	1.0	0	1.0	— ^y	—	2.0	0	0	7.0	0	—
24 July	0	0	0	1.0	—	—	3.0	1.0	0	5.0	1.0	—
31 July	1.0	0	0	2.0	—	—	* ^z	0	0	*	1.0	0
8 August	* ^z	0	0	*	—	—	*	0	0	*	1.0	2.0
14 August	*	1.0	0	*	4.0	—	*	0	0	*	2.0	6.0
22 August	*	*	0	*	7.0	—	*	*	0	*	1.0	1.0
28 August	*	*	0	*	*	—	*	*	0	*	*	0
4 September	*	*	0	*	*	—	*	*	0	*	*	2.0
13 September	*	*	0	*	*	—	*	*	0	*	*	2.0
Mean infection	1.0	0.4	0	1.3	5.5	—	2.5	0.2	0	6.0	1.0	1.9

^wCultivars: C = Candor, RH = Redhaven, CH = Crethaven; thinning dates: 4, 11, 16, 17, 31 July; 14 August.

4 July is pre-pit hardening for all cultivars on all sites, 11 July is pithardening for all cultivars on all sites, all dates after 11 July are considered post pit-hardening

^y— = fruit not thinned

^z* = fruit harvested

Table 5. Mean lesion diameter, lesion growth rate, mean number of spores per fruit, and mean maturity date (Vineland) for peach cultivars wound-inoculated in the laboratory with 1×10^5 conidia of *Monilinia fructicola*

Cultivar	Mean lesion diam (mm)	Lesion growth rate (mm/h)	Mean no. spores/fruit ($\times 10^6$)	Mean maturity date (Vineland)
Crethaven	44.4 a ^y	1.25 a	1.3 cd	Sept. 13
Babygold 7	42.8 b	1.18 a	1.6 c	Sept. 13
Babygold 5	34.0 c	0.88 b	1.0 d	Sept. 4
Loring	33.1 c	0.86 b	3.8 a	Sept. 3
Vivid	42.5 b	0.75 bc	1.6 c	Aug. 23
Veecling	30.5 d	0.83 b	2.9 b	Aug. 21
Redhaven	29.6 d	0.81 b	3.3 ab	Aug. 18
Harbelle	25.4 f	0.65 c	3.1 ab	Aug. 11
Candor	27.1 e	0.74 bc	— ^z	July 29

^yMeans followed by different letters are significantly different according to Duncan's Multiple Range Test, $P = 0.05$.

^zData not available.

thinned fruit on the orchard floor. However, because sporulation on infected twigs, blossoms, and peduncles was observed only in late May and early June, these inoculum sources probably do not contribute to fruit infections later in the season.

Field observations indicate that nonabscised, aborted fruits and thinned fruit on the orchard floor are potentially important sources of secondary inoculum as fruit approach maturity. However isolations from fruit injured by the tarnished plant bug and by other members of an unidentified myrid complex that severely injured fruit in many Niagara peach orchards in 1984 revealed no brown rot infection. In contrast, insect injuries appear to play an important role for fruit infection in Australia (4). Infection and sporulation of *M. fructicola* on nonabscised, aborted fruits is reported for the first time in Ontario. Occurrence of nonabscised,

aborted fruits has recently been reported for the first time in South Carolina where up to 3% of branches examined supported such fruit (6). In the present study, nonabscised, aborted fruit were extremely abundant, with approximately 5% exhibiting infection. Fruit abortion is thought to be related to several factors, including genetic predisposition, winter injury, or inadequate pollination. The cultivar Candor had more nonabscised, aborted fruits in 1984 than did the cultivars Redhaven and Crethaven.

Infections of thinned fruit on the orchard floor may provide a source of inoculum for mature fruit even in commercial orchards where fungicide sprays were applied. Landgraf and Zehr (6) have demonstrated the effectiveness of benomyl and captan on suppressing sporulation of thinned fruit where special sprays were directed to the orchard

floor. Whereas benomyl is not generally recommended for brown rot control in Ontario because of the widespread distribution of benomyl-tolerant *M. fructicola*, captan is still used and would probably be effective in controlling inoculum from this source. In the present study, where fruit were thinned by 4 July (pre-pit hardening) sporulation on thinned fruit was not observed, and therefore sprays directed towards the orchard floor would not be necessary.

Laboratory inoculations of peach cultivars showed correlations between mean maturity date, colonization rate, and spore production. These data show that the early maturing cultivars, although less rapidly colonized, induce more sporulation and thus provide inoculum for the more rapidly colonized late-maturing cultivars. This aspect of cultivar influence on survival of the pathogen could favour a brown rot epiphytotic under the appropriate environmental conditions. When new blocks of peaches are planted, the prevailing winds should dictate the downwind location of early-maturing cultivars, including brown-rot-susceptible sweet cherry, relative to late-maturing peach cultivars.

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