Development of Apple Scab on Fruit in the Orchard and During Cold Storage

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ABSTRACT

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Apple fruits were increasingly difficult to infect with *Venturia inaequalis* (anamorph *Spilocaea pomi*) under orchard conditions as the fruits matured. Fruits of the cultivar McIntosh developed more lesions than those of Jonathan and Golden Delicious. Scab lesions expanded on McIntosh fruits held in cold storage at 0.5, 2.8 C or a cycle of 2.8 and 0.5 C. The rate of lesion expansion was inversely related to the number of lesions on the fruit. Few new lesions developed on fruits free of visible lesions when stored, but new lesions developed on 18–47% of fruits that had visible lesions when stored. Scab-infected fruits stored at 2.8 C or a cycle of 2.8 and 0.5 C were more shriveled than fruits stored at 0.5 C. Shriveling was most severe on apples with numerous large lesions.

The duration of wetting required at various temperatures to establish infection by the apple scab pathogen *Venturia inaequalis* (Cke.) Wint. (anamorph *Spilocaea pomi* Fr.) has been fairly well characterized for apple foliage (3,4) but not for fruit. Bratley (1) reported that the duration of wetting required for infection of fruit during the summer months was significantly greater than that required for foliage infection, a finding substantiated by Schwabe (7).

Knowledge of the decline in susceptibility of maturing apple fruit to infection by *S. pomi* might allow midseason to late-season scab-control strategies that would require fewer fungicide applications than are currently practiced. This approach is particularly relevant to production areas such as Michigan, where scab is the major disease of economic importance on apple fruit.

This study was conducted to determine the relative susceptibility of apple fruits to infection by *S. pomi* during the growing season, the rate of lesion development on stored fruits, and the effect of scab infection on quality of stored fruits.

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MATERIALS AND METHODS

Field study. Successive groups of three 4-and 5-yr-old apple trees, one each of Golden Delicious, Jonathan, and McIntosh, were inoculated between 10 April and 10 August 1981 with a conidial suspension (about 2–5 × 10^5 viable conidia per milliliter) of *S. pomi*. Fifteen fruiting spurs were tagged and inoculated on each tree, except when a tree was missing, did not have 15 spurs with apples, or the apples were lost during the experiment.

Selected buds, flowers, or fruitlets were inoculated by spraying to runoff with a conidial suspension. Inoculated trees were enclosed in a topless inoculation chamber (5 m long × 3 m wide × 1.8 m high) constructed from aluminum tubing, plastic sheeting, and plastic pipe fitted with misting nozzles. After the inoculum was allowed to dry for 1–2 hr, the trees were misted, generally for the length of time necessary to constitute a severe Mills' infection period (4) for the average temperature during the wet period (Table 1).

Natural infection was controlled throughout the growing season by spraying uninoculated trees with etaconazole Vangard 10% W, CIBA-Geigy Corp., Greensboro, NC 27409) after a moderate or severe Mills' infection period (4). Fungicide was applied on 1 and 15 May and 11 and 17 June. Trees were inoculated with *S. pomi* no sooner than 2 wk after a fungicide treatment. Inoculated trees were not subsequently treated with fungicide.

Inoculated fruits were examined weekly for scab lesions. Scab infection per fruit was evaluated according to the following scale: 0 = no visible lesions, 1 = less than 10% fruit surface infected, 2 = 10–25% fruit surface infected, 3 = 25–50% fruit surface infected, and 4 = greater than 50% fruit surface infected. Fruits inoculated early in the season were examined daily, but the excessive handling caused some fruits to detach from the trees.

The trees used in these experiments were also used in a study on the latent period of *S. pomi* on leaf tissue (8). Beginning with the 18 June inoculation, conditions resulting in leaf infection observed in the foliage study were not sufficient to incite fruit infection. We attempted to increase the length of the wet period on the fruits by wrapping them in cheesecloth and aluminum foil and wetting the cheesecloth twice daily. This resulted in considerable fruit loss, possibly caused by increased temperature or ethylene concentration within the foil wrapping. Beginning with the 14 July inoculation, fruits were wrapped with cheesecloth before inoculation to impede wash-off of the conidia (6) and the trees were misted for 4 or 5 days.

Storage study. Mature McIntosh fruits were obtained in 1980 from a commercial orchard near Grand Rapids, MI (GR), and from a research orchard near East Lansing, MI (EL). The fruits from orchard EL were from trees in buffer rows between different treatments in a fungicide experiment. Scab lesions from late-season infections were evident on some of the fruits at storage. Fruits from each orchard were graded for scab severity, and individual fruits with 0,

1–10, 11–30, 31–70, and 71 or more lesions were assigned to classes 0, 1, 2, 3, and 4, respectively. Six lots of 50 such graded fruits from orchard GR were labeled and placed in each of six wooden fruit boxes. Three lots of 100 graded fruits from orchard EL were placed in each of three wooden fruit boxes. The remaining space in each box was filled with ungraded scabbed fruit from the respective location. The EL fruits were stored for 26 wk at 2.8 C. Two boxes each of GR fruits were stored for 26 wk at 0.5, 2.8 C, or alternately at 2.8 and 0.5 C at 6-wk intervals. Relative humidity within the storage rooms was approximately 80% as measured with a sling psychrometer.

Before storage, data were taken for each graded fruit; the diameter was measured, the number of lesions was counted, and diameters of isolated lesions on each fruit were measured. Similar data were collected approximately every 6 wk between 15 September 1980 and 15 March 1981.

Lesion and fruit diameter data were analyzed by analysis of variance. Data from the GR fruit were analyzed as a factorial experiment, using temperature and initial lesion class as factors. Data from EL fruit were analyzed with one-way analysis of variance.

RESULTS

Development of fruit scab in the orchard. In 1981, inoculations in April and May resulted in relatively heavy fruit scab, particularly on McIntosh (Table 1). Scab ratings of 3–4 were common on McIntosh and of 2–3 on Jonathan and Golden Delicious. As the fruits matured, both the frequency and severity of infection decreased. By 18 June (27 days after petal fall), conditions sufficient to establish foliage infection (8) were not sufficient to establish fruit scab.

We were able to infect maturing fruit by using extended wet periods and by taking precautions to impede loss of conidia from the fruit surface. The frequency and severity of late-season infection, however, were much less than those of early-season infection (Table 1). The fruits were apparently most susceptible to scab infection until 2 wk after petal fall, while the developing fruitlets were still pubescent. Infections that occurred late in the season were primarily on the stem ends of the fruits. Mature McIntosh fruits were more frequently infected by late-season scab than were Jonathan or Golden Delicious fruits.

Increase in diameters of lesions in storage. The increase in lesion diameters on GR fruits was significantly greater at 2.8 than at 0.5 C. Lesion diameters on fruits subjected to an alternating storage temperature did not differ from those held at either 2.8 or 0.5 C (Table 2). The interaction between temperature and lesion class was not significant.

The effect of lesion density, expressed by initial lesion class, was significant for GR fruits, but not for EL fruits (Table 2). With GR fruits lesion expansion was less at higher lesion densities.

Appearance of new lesions in storage. Development of new lesions on GR fruits was not significantly influenced by

Table 1. Development of apple scab on fruits of three cultivars in an orchard after inoculation with *Spilocaea pomi* conidia and artificial wetting in 1981

Inoculation date	Mean temperature (C) during wet period	Wet period duration (hr)	Severity of infection periods[a]	Tree growth stage	Relative fruit infection by cultivar (no. infected/no. inoculated [rating[b]])		
					McIntosh	Jonathan	Golden Delicious
10 April	15.6	20	S	1 cm green	13/13 (3)	10/12 (2)	10/11 (2)
20 April	2.2	30	NP	Tight cluster	11/11 (1)	10/10 (2)	13/15 (2)
22 April	11.1	30	S	Tight cluster	14/14 (3)	...[c]	10/11 (2)
27 April	12.8	30	S	Pink	15/15 (2)	...	12/14 (2)
1 May	6.7	20	L	Pink	13/13 (3)	14/14 (2)	12/12 (2)
8 May	14.4	48	S	Bloom	12/12 (3)	10/14 (3)	9/12 (2)
14 May	7.8	18	L	Bloom	12/13 (3)	9/10 (3)	10/12 (2)
18 May	11.1	23	M	Petal fall	14/14 (2)	12/14 (2)	12/13 (1)
20 May	15.6	21	S	Petal fall	13/13 (3)	...	9/9 (1)
22 May	21.1	21	S	Petal fall	15/15 (4)	...	...
25 May	18.9	25	S	3[d]	14/14 (4)	...	12/12 (3)
27 May	14.4	22	S	6	14/15 (4)	10/11 (2)	...
28 May	16.7	19	S	7	13/13 (4)	4/9 (3)	13/13 (1)
1 June	16.1	23	S	10	...	0/9 (0)	0/11 (0)
3 June	20.6	18	S	12	...	7/11 (1)	0/10 (0)
4 June	24.4	18	M	13	...	...	8/14 (1)
9 June	17.2	24	S	18	7/9 (3)	5/14 (1)	...
11 June	19.4	23	S	20	...	3/9 (1)	...
15 June	23.9	26	S	24	5/12 (2)	2/9 (1)	...
17 June	20.0	26	S	26	1/12 (1)	2/12 (1)	...
18 June	22.2	20	S	27	0/11 (0)	0/14 (0)	0/8 (0)
22 June	16.7	22	S	31	0/12 (0)	0/11 (0)	...
24 June	22.8	20	S	33	0/14 (0)	0/7 (0)	0/13 (0)
26 June	18.3	36	S	35	0/15 (0)	0/11 (0)	0/12 (0)
29 June[e]	27.8	18	NP	38	4/10 (1)	...	...
2 July[e]	22.2	36	S	41	10/14 (2)	0/9 (0)	0/8 (0)
6 July[e]	28.9	22	NP	45	0/12 (0)	0/9 (0)	0/11 (0)
8 July[e]	29.4	21	NP	47	0/7 (0)	6/10 (1)	0/10 (0)
9 July[e]	23.9	19	S	48	3/12 (1)	...	0/9 (0)
14 July[f]	25.0	120	S	53	5/9 (1)	1/10 (1)	0/11 (0)
20 July[f]	21.1	96	S	59	7/11 (2)	0/9 (0)	0/13 (0)
27 July[f]	24.4	120	S	66	3/12 (2)	0/12 (0)	0/12 (0)
4 August[f]	25.6	96	S	74	5/14 (1)	1/12 (1)	2/12 (1)
10 August[f]	...	120	...	80	3/14 (1)	1/10 (1)	2/14 (1)

[a] Mills' infection periods where S = severe, M = moderate, L = light, and NP = no predicition.
[b] Apple scab ratings where 0 = no lesions, 1 = less than 10% of fruit surface having scab, 2 = 10–25% of fruit surface having scab, 3 = 25–50% of fruit surface having scab, and 4 = more than 50% of fruit surface having scab.
[c] Not observed.
[d] Numerals are days after petal fall.
[e] Fruits were wrapped with cheesecloth, covered with aluminum foil, and wetted twice daily for 5 days after inoculation.
[f] Fruits were wrapped with cheesecloth during postinoculation wet period of 96–120 hr.

storage temperature (Table 2) nor was the interaction of temperature and lesion class significant. A direct relationship existed, however, between disease incidence at harvest and subsequent occurrence of new lesions during storage. The number of new lesions that appeared during storage was greatest on fruits initially graded in lesion class 3 (GR) or 4 (EL) (Table 2). None of the GR fruits and only 7% of the EL fruits that were apparently scabfree before storage developed new lesions during storage (Table 3). However, between 18 and 47% of the fruits initially in classes 1–3 advanced to a higher lesion class. Fruit usually advanced only one lesion class, although there were some exceptions among the GR fruits (Table 3). These observations indicate that scab severity can worsen on stored fruit even if the amount of scab at harvest is small.

Shriveling of fruit during storage. Shriveling of GR fruits was significantly influenced by temperature during storage. Fruits stored at 0.5 C shriveled less than fruits stored at 2.8 C or an alternating cycle of 2.8 and 0.5 C (Table 2). The interaction of temperature and lesion class did not significantly influence the decrease in fruit diameters.

The lesion class effect was not significant for GR fruits (Table 2), but loss in diameter on EL fruits was significantly lower on fruits initially graded in lesion class 0 or 1 than on those initially graded 3 or 4 (Table 2).

Table 2. Development of apple scab lesions on McIntosh fruits held in cold storage for 26 wk at three temperature regimes and the influence of scab incidence on final fruit diameter

Data	Lesion class[a]	Storage temperature (C)				
		GR fruit[b]				EL fruit
		2.8[c]	2.8/0.5[c]	0.5	Mean	2.8
Increase in lesion diam. (mm)	1	1.8	1.8	1.6	1.7 x[d]	1.0 x
	2	2.1	1.4	1.4	1.6 x	0.8 x
	3	1.4	1.4	1.1	1.3 y	1.0 x
	4	...[e]	...	...	...	1.0 x
	Mean[df]	1.8 q	1.5 qr	1.3 r	...	1.0
Number of new lesions per fruit	0	0.0	0.0	0.0	0 .0 x	0.1 x
	1	6.4	9.7	5.5	7.2 xy	2.2 x
	2	18.7	15.7	17.4	17.3 yz	5.4 xyz
	3	30.0	23.0	20.3	24.4 z	9.8 yz
	4	...	...	...	...	11.7 z
	Mean	13.8 q	12.1 q	10.8 q	...	4.4
Decrease in fruit diam. (mm)	0	3.6	2.7	1.7	2.7 x	2.0 x
	1	3.7	3.4	2.1	3.1 x	2.2 x
	2	4.5	3.3	2.6	3.5 x	3.1 xy
	3	2.8	3.7	2.3	2.9 x	3.8 y
	4	...	...	...	...	4.0 y
	Mean	3.6 q	3.3 q	2.2 r	...	2.8

[a] Fruit alternated between 2.8 and 0.5 C at 6-wk intervals.
[b] 0 = No visible lesions at time of storage, 1 = 1–10 lesions, 2 = 11–30 lesions, 3 = 31–70 lesions, and 4 = >70 lesions.
[c] GR fruit were from a commercial apple orchard near Grand Rapids, MI, where scab developed on the fruit shortly before harvest. EL fruit were from buffer rows in a research orchard near East Lansing, MI, where scab developed on the fruit throughout the season.
[d] Means followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.
[e] Not observed.
[f] Means calculated for classes 0–3 only to facilitate comparison with GR fruit stored at 2.8 C.

Table 3. Change in severity of apple scab on McIntosh fruits after cold storage for 26 wk. Data are the final proportions of fruit in the given lesion class for each initial lesion class

Initial lesion class	Proportion of fruit in final lesion class[a]									
	GR fruit[b]					EL fruit				
	0	1	2	3	4	0	1	2	3	4
0	1.00	0.00	0.00	0.00	0.00	0.93	0.07	0.00	0.00	0.00
1	...	0.66	0.23	0.23	0.01	...	0.82	0.18	0.00	0.00
2	...	...	0.53	0.41	0.06	...	...	0.86	0.14	0.00
3	...	...	...	0.62	0.38	...	...	...	0.60	0.40
4	...	...	...	...	...	...	...	...	...	1.00

[a] Initial lesion class was determined at time of storage; final lesion class was determined after 26 wk of storage. 0 = No visible scab lesions, 1 = 1–10 lesions, 2 = 11–30 lesions, 3 = 31–70 lesions, and 4 = >70 lesions.
[b] GR fruit were from a commercial orchard near Grand Rapids, MI; EL fruit were from a research orchard near East Lansing, MI.

DISCUSSION

Although inoculated trees were not treated with fungicide for 2 wk or more before inoculation, some of the fruit infections observed, particularly those supposedly incited by inoculations before petal fall, may have resulted from conidia from trees inoculated earlier in the study. We do not believe, however, that the level of inoculum present early in the season was sufficient to result in the levels of infection observed, particularly since Mills' infection periods of moderate or severe intensity were either preceded or followed by fungicide treatment. Moreover, natural primary infection of fruit was light in 1981 (A. L. Jones, *unpublished*). Fruit infection can occur as early as the green tip stage on the calyx end of the fruit (3,5). In our studies, infection on the sides of fruits was common until late summer.

The apparent decrease in susceptibility as the fruit matures may have an anatomical basis; the primary factors probably are loss of surface pubescence, changes in fruit shape, and cuticular development as the fruit matures (2). Like Schwabe (7), we were able to infect the more mature fruits by creating conditions favorable for conidial attachment and penetration.

We observed lesions developing in storage on a few fruits that were free of scab lesions at harvest, as did Bratley (1) (Tables 2 and 3). In 1980, infection periods of 45.5, 39, and 34 hr occurred in orchard EL on 26 July, 10 August, and 17 August, respectively. These infection periods may have been sufficiently severe to establish fruit infections that did not appear until after storage.

If fruits are stored with scab lesions, more lesions will probably develop, but it does not appear that the pathogen spreads from scabbed fruit to uninfected fruit. We observed, in contrast with Bratley's findings (1), that most of the existing lesions continued to expand. The differences between the EL and GR fruits in the amount of lesion expansion can probably be attributed to the fact that the lesions on the GR fruits appeared younger and thus more vigorous. By similar reasoning, the greater degree of fruit shriveling of the EL fruits can probably be attributed to the older, cracked lesions on those fruits.

Schwabe (6) found that treatments with curative fungicides long after infection but before storage did not adequately control storage scab and suggested that if a high probability of infection existed late in the season, the fruit should not be put into long-term storage (7). Until better techniques are developed for studying apple scab infection on fruit, this conservative approach offers the best strategy for handling fruit with light to moderate apple scab at harvest.

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