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Incidence of Diseases on Fruit of Nine Apple Genotypes as Influenced by Six Fungicide Treatments[1]

JOHN A. BARDEN AND RICHARD P. MARINI[2]

Abstract

Nine apple genotypes (three commercially important cultivars, three disease-resistant cultivars, and three disease-resistant selections) were sprayed with fungicides during the early- and/or late-season for two fruiting seasons to evaluate the occurrence of disease symptoms on the fruit. Apple scab, cedar-apple rust, quince rust, and powdery mildew symptoms were rare on all genotypes regardless of fungicide treatment. In general, fungicide applications from second cover spray through late Aug. controlled summer diseases more effectively than early-season treatments. Although there was some year-to-year variation, rot incidence was consistently lowest for NY 74828-12 and highest for 'York,' 'Golden Delicious,' and 'Liberty.' Flyspeck incidence was lowest on 'Redfree,' moderate on 'Freedom' and NY 74828-12, and greatest on 'Liberty' and NY 73334-35. 'Redfree' and NY 74828-12 consistently had the least sooty blotch. These results indicate that apple genotypes vary in their susceptibility to summer diseases, and that it may be possible to breed genotypes with improved summer disease resistance.

Introduction

Until recently mid-Atlantic apple growers relied on season-long use of ethylene bisdithiocarbamate (EBDC) fungicides for controlling summer diseases. With recent re-registration, these materials can be used only at half the former rate and applications must be discontinued 77 days before harvest (7). Because alternative fungicides are less effective and less residual than the EBDCs, control of summer diseases is not satisfactory in some seasons (11). Several apple breeding programs are selecting genotypes with resistance to early-season diseases, but none are consciously selecting genotypes with resistance to summer diseases. However, based on field observations, apple genotypes appear to possess varying degrees of susceptibility to summer diseases. The purpose of this study was to determine the susceptibility to summer diseases of nine apple genotypes, sprayed with different fungicide treatments. Disease symptoms on fruit are reported in this paper. Being a transition state between the hot, humid southeast, where all genotypes may develop severe symptoms, and the cooler, less humid northeast where symptoms may be absent, Virginia may be an ideal area to evaluate the relative susceptibility to summer diseases.

Materials and Methods

In May 1993, 270 trees on M.9 rootstock were planted at the Virginia Tech College of Agriculture and Life Sciences Kentland Farm near Blacksburg, VA. The factorial treatment structure consisted of nine genotypes and six fungicide treatments (Table 1) in a split-plot design. The field was divided into five replicates (whole-plots) and each replicate was further divided into six subplots. One tree per genotype was randomly assigned to a location within each subplot and the subplots were assigned randomly to one of the six fungicide treatments. Trees were supported to 2m with a wooden post and were trained as central leaders with minimal pruning. A 1.5m-wide herbicide strip was maintained under the trees. Trees

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[2]Professors, Department of Horticulture, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061-0327.

were allowed to fruit in 1995 and 1996; hand-thinning was required in 1996 to prevent some trees from overcropping. Insecticides (mostly Guthion, Imidan, and Lannate) were applied (to control insects on all trees) on the same dates as fungicides. All pesticides were applied to runoff with a single-nozzle backpack sprayer. To ensure disease pressure, cedar-apple rust galls, quince rust cankers, and dead apple twigs colonized with rot fungi, were placed in small cages attached to the tops of each post at about the tight cluster stage.

Air temperature and relative humidity were recorded continuously with a hygrothermograph in a weather shelter about 300m from the planting. Leaves were assumed to be wet when relative humidity was 100%. Daily precipitation was measured with a rain gauge. Because disease incidence may be related to harvest date, late-season genotypes were harvested about three weeks early, but early-season genotypes were harvested when about one third of the fruits had yellow-green ground color. Fruits were stored at about 0°C for 10 to 32 days, until each fruit was evaluated for disease symptoms. The percentage of fruits with symptoms of apple scab *(Venturia inaequalis)*, cedar-apple rust *(Gymnosporangium juniperi-virginianae)*, quince rust *(Gymnosporangium clavipes)*, sooty blotch (a fungal complex), flyspeck *(Zygophiala jamaicensis)*, and rots was recorded for each tree. The type of rot was not identified but, based on visual symptoms, the most common rot was likely bitter rot (*Colletotrichum* spp.).

Fungicide treatments were developed to provide varying levels of control against different diseases. Triadimefon was expected to provide moderate control of apple scab and to give good control of rusts and powdery mildew. Syllit was expected to give good control of apple scab, but poor control of rusts and powdery mildew. Late-season applications of captan plus benomyl were expected to provide good to moderate control of black rot, white rot, and bitter rot and good control of sooty blotch and fly speck. Because rots seemed to be the most difficult diseases to control, treatments were modified in 1996. Early-season sprays of myclobutamil plus mancozeb were expected to control all early-season diseases and possibly have some effect on rots. Late-season sprays of captan plus benomyl was expected to provide control similar to that obtained the previous year. Ziram was added to late-season sprays in an attempt to improve control of rots.

Data were analyzed with analysis of variance using SAS's Mixed Procedure (9). Genotypes and fungicide treatments were specified as fixed effects, and replicates and interactions containing replicates were specified as random effects. Least Square (LS) means are presented because there were missing observations caused by tree mortality and because some trees had no fruit. Satterthwaite's formula (10) was used to calculate approximate degrees of freedom by using the ddfm=satterth Option in the model statement (6). When the genotype x treatment interaction was significant ($P < 0.05$), the LS means for treatments within each cultivar and for cultivars within each treatment were compared with multiple t-tests using the slice option in the LS means statement. To control the experiment-wise error rate, the α-level for pairwise comparisons was adjusted as α = 0.05/no. of pair-wise comparisons (5).

Results and Discussion

In 1995 fruits per tree varied from 2 for NY 74840-1 to 17 for 'Freedom,' but in 1996 fruits per tree varied from 18 for 'Liberty' to 44 for 'York' (Table 2). Harvest dates are also presented in Table 2.

Fruits with no symptoms. In 1995 the percentage of fruits with no disease symptoms was greatest (68%) for Treatments 2 and 6 which received late-season applications of captan plus benomyl (Table 3). Trees which received early-season treatments of syllit and/or triadimefon and no late-season fungicides (Treatments 3, 4, 5) were similar to the nontreated control with less than 27% fruit with no symp-

Table 1. Dates of early- and late-season (cover sprays) fungicide treatments applied to nine apple genotypes for two seasons.

Treatment date	Time of season	Fungicide treatment[z] 1	2	3	4	5	6
		1995					
27 March; 10, 25 April	Early	None	None	T	S	T, S	T, S
15, 23 May; 5, 29 June; 12 July; 9, 25 Aug.	Late	None	C, B	None	None	None	C, B
		1996					
11, 25 April; 6 May	Early	None	None	None	M, P	M, P	M, P
14, 22, 30 May; 11, 26 June; 8, 23, 31 July; 14, 28 Aug.	Late	None	C, B	C, B, Z	None	C, B	C, B, Z

[z]Fungicides, AI/liter: captan (C), Captan 50W (0.6g/l); benomyl (B), Benlate 50W (0.11 g/l); triadimefon (T), Bayleton 50DF (0.037 g/l); syllit (S), Dodine G5W (0.4 g/l); myclobutanil (M), Nova 40W (0.06 g/l); mancozeb (P), Penncozeb 80W (0.96 g/l); ziram (Z), Ziram 76DF (0.91 g/l).

toms (Table 3). 'Redfree,' 'Delicious,' and NY 74828-12 had the greatest percentage of fruit with no infection, and 'York,' 'Liberty,' NY 74840-1, and NY 73334-35 had the lowest percentage with no infection (Table 3).

In 1996 the percentage of fruits with no symptoms was influenced by the interaction of genotype x treatment (Table 4). 'Redfree' had 100% fruit with no symptoms regardless of treatment. For non-sprayed trees of the other cultivars, only NY 74828-12 had more than 50% with no symptoms. Without late season fungicide application, early-season treatment (Treatment 4) was no better than the control. Late-season application of captan plus benomyl (Treatment 2) or captan plus benomyl plus ziram (Treatment 3) produced more than 50% fruit with no symptoms except for NY 74840-1 and 'York,' but the two late season treatments did not differ (P = 0.05). 'Delicious' was most responsive to late-season treatments; non-sprayed trees produced 0% fruit with no symptoms and late-season-sprayed trees (Treatments 2 and 3) produced > 90% clean fruit. Other genotypes produced 31 to 80% fruit with no symptoms.

In Vermont the percentage of non-treated fruit on which no disease symptoms were detected ranged from 52% on 'Nova Easygro' to 92% on 'Redfree' and 'Freedom' one year and 50% on 'Freedom' to 99% on 'Liberty' the following year (1).

Table 2. Harvest dates and LS means for fruit number on nine apple genotypes in 1995 and 1996.

Genotype	Harvest Date 1995	Harvest Date 1996	Fruit/tree 1995	Fruit/tree 1996
Delicious	Sept. 13	Sept. 8	3 de[z]	22 bc
Golden Del.	Sept. 13	Sept. 8	4 de	35 ab
York	Sept. 24	Sept. 15	8 cd	44 a
Freedom	Aug. 21	Aug. 18	17 a	31 ab
Liberty	Sept. 24	Sept. 5	12 bc	18 c
Redfree	Aug. 14	Aug. 29	13 ab	23 bc
NY 74840-1	Sept. 25	Sept. 8	2 e	38 a
NY 74828-12	Sept. 25	Aug. 29	14 ab	27 bc
NY 73334-35	Oct. 1	Sept. 5	7 d	19 c

[z]Mean separation within columns by multiple t-test (for pair-wise t-test $\alpha = 0.0014$). LS means of 30 trees per genotype.

Table 3. LS means for disease symptoms on fruits of nine apple genotypes treated with six fungicide programs, where the genotype x fungicide treatment is not significant at the 5% level.

			Fruit with symptoms (%)			
				1995		1996
Factor			No symptoms	Rots	Flyspeck	Sooty blotch
Treatment	*Early*	*Late*				
1	None	None	18b	14a	67a	5a[z]
2	None	C, B	68a	9a	22b	4a
3	T	None	26b	6a	65a	4a
4	S	None	19b	13a	67a	5a
5	T, S	None	24b	10a	63a	4a
6	T, S	C, B	68a	12a	20b	3a
Genotype						
Delicious			50ab	0c	62ab	1b
Golden Del.			30bc	4c	59ab	1b
York			18c	39a	40b	25a
Freedom			40bc	8c	47b	21a
Liberty			19c	4c	73a	1b
Redfree			67a	24b	3c	0b
NY 74840-1			25c	8c	58ab	1b
NY 74828-12			52ab	4c	44b	2b
NY 73334-35			24c	1c	72a	1b

[z]Fungicide treatments are listed in Table 1.
[y]Mean separation within columns and factors by multiple t-test (for pair-wise t-test $\alpha = 0.0038$ or 0.0014, respectively for fungicide treatment and genotype). Values are LS means of 45 or 30 trees per fungicide treatment and genotype, respectively.

Apple scab and rust – During the two seasons of this study, no fruits were observed with apple scab lesions, three 'Golden Delicious' fruits were infected with cedar-apple rust, and two 'Delicious' fruits were infected with quince rust (data not shown). Levels of apple scab inoculum are likely very low in this orchard because low incidence of the disease was observed on leaves of nonsprayed trees. This research orchard is at least 20 km from a commercial orchard. Scattered backyard trees are within one km. Although rust inoculum was placed above each tree, wetting periods during the early season were apparently too short to allow infection on fruits. Incidence of foliar rust infections were moderately low in this study. Nonsprayed trees of the susceptible cultivars 'York' and 'Golden Delicious' had less than 30% infected leaves.

Fruit rots. In 1995 the percentage of fruits with rot lesions varied from 6 to 14%, but was not influenced by fungicide treatment (Table 3). Genotypes did vary significantly, with 'York' and 'Redfree' being more susceptible than the others (Table 3). In 1996 the percentage of fruits with rot was influenced by the interaction of genotype and fungicide treatment (Table 5). In general, late-season fungicide application (Treatments 2, 3, 5, 6) reduced the incidence of rotten fruit, and adding ziram to the combination of captan plus benomyl (compare Treatments 3+6 to 2+5) improved control very little. In North Carolina, captan plus benomyl reduced the incidence of bitter rot, flyspeck and sooty blotch, but not Bot rot on 'Golden Delicious' fruit (12). In Virginia, early-season sprays of captan plus ziram provided moderate control of rots, but a full season program was much better (14). For nonsprayed trees (Treatment 1), only 'Redfree' and NY 74828-12 had less than 60% rotten fruit. Compared to no fungicide, early-season fungicide application (Treatment 4) substantially reduced the percentage of rotten fruits on NY 74840-1 and NY 73334-35, but the reduction was significant for only 'Freedom.' In the absence of early-season fungicides, late-sea-

Table 4. LS means for percentage of fruits with no disease symptoms for the interaction of nine apple genotypes treated with six fungicide treatments in 1996.

Genotype	Treatment Time Early / Late	Fungicide Program[z] 1 None None		2 None C, B		3 None C, B, Z		4 M, P None		5 M, P C, B		6 M, P C, B, Z	
Delicious		0b[y]	C	100a	A	94a	A	1b	C	92a	A	91a	A
Golden Del.		1b	C	80a	A	64a	AB	0b	C	63a	B	72a	AB
York		0c	C	31b	B	47ab	B	0c	C	37ab	BC	51a	AB
Freedom		27b	BC	73a	A	78a	AB	27b	BC	89a	A	77a	AB
Liberty		0b	C	58a	AB	55a	B	0b	C	69a	B	45a	AB
Redfree		100a	A	100a	A	100a	A	100a	A	100a	A	100a	A
NY 74840-1		19b	C	40ab	B	54a	B	31ab	BC	22b	C	38ab	B
NY 74828-12		59a	B	74a	A	80a	AB	62a	AB	79a	AB	66a	AB
NY 73334-35		1c	C	56a	AB	56a	B	1c	C	34b	C	47ab	AB

[z]Fungicide programs are listed in Table 1.
[y]Values are LS means of five trees per treatment combination. Mean separation across rows (lower case letters) by multiple t-test (α = 0.0033) and down columns (upper case letters) by multiple t-test (α = 0.0014).

son applications (Treatments 2 and 3) reduced the percentage of rotten fruit to < 35% for all genotypes, whereas only NY 73334-35, 'Golden Delicious,' and 'Liberty' had > 10% rotten fruit.

Seven disease-resistant cultivars and 'Delicious' and 'Golden Delicious' were evaluated for fruit rots in Pennsylvania (13); 'Redfree' was very susceptible to black rot and white rot and moderately susceptible to bitter rot. 'Freedom,' and 'Golden Delicious' were moderately susceptible to all three rots. 'Liberty' and 'Delicious' were moderately susceptible to black rot and white rot, and quite resistant to bitter rot.

Flyspeck. In 1995 the incidence of flyspeck was influenced by the main effects of genotype and fungicide treatment (Table 3), but there was not a significant genotype by treatment interaction. Late-season fungicide application (Treatments 2 and 6) reduced the percentage of fruit with flyspeck to < 23%, whereas all treatments without late-season fungicides had > 62% infection (Table 3). Only 'Redfree' had less than 5% infection; NY 74828-12, 'York,' and 'Freedom' had intermediate levels, and NY 73334-35 and 'Liberty'

Table 5. LS means for percentage of fruits with rot symptoms for the interaction of nine apple genotypes treated with six fungicide treatments in 1996.

Genotype	Treatment Time Early / Late	Fungicide Program[z] 1 None None		2 None C, B		3 None C, B, Z		4 M, P None		5 M, P C, B		6 M, P C, B, Z	
Delicious		90a[y]	AB	1b	B	2b	B	90a	A	6b	B	1b	A
Golden Del.		100a	A	16b	AB	34b	A	100a	A	30b	A	23b	A
York		98a	A	8b	AB	3b	B	100a	A	11b	AB	2b	A
Freedom		60a	B	0c	B	0c	B	24b	C	0c	B	5c	A
Liberty		100a	A	23b	A	12b	B	100a	A	11b	AB	10b	A
Redfree		0a	C	0a	B	0a	B	0a	C	0a	B	0a	A
NY 74840-1		71a	B	1b	B	5b	B	56a	B	3b	B	1b	A
NY 74828-12		4a	C	1a	B	1a	B	2a	C	0a	B	0a	A
NY 73334-35		98a	A	6b	AB	18b	AB	78a	AB	7b	B	1b	A

[z]Fungicide programs are listed in Table 1.
[y]Values are LS means of five trees per treatment combination. Mean separation across rows (lower case letters) by multiple t-test (α = 0.0033) and down columns (upper case letters) by multiple t-test (α = 0.0014).

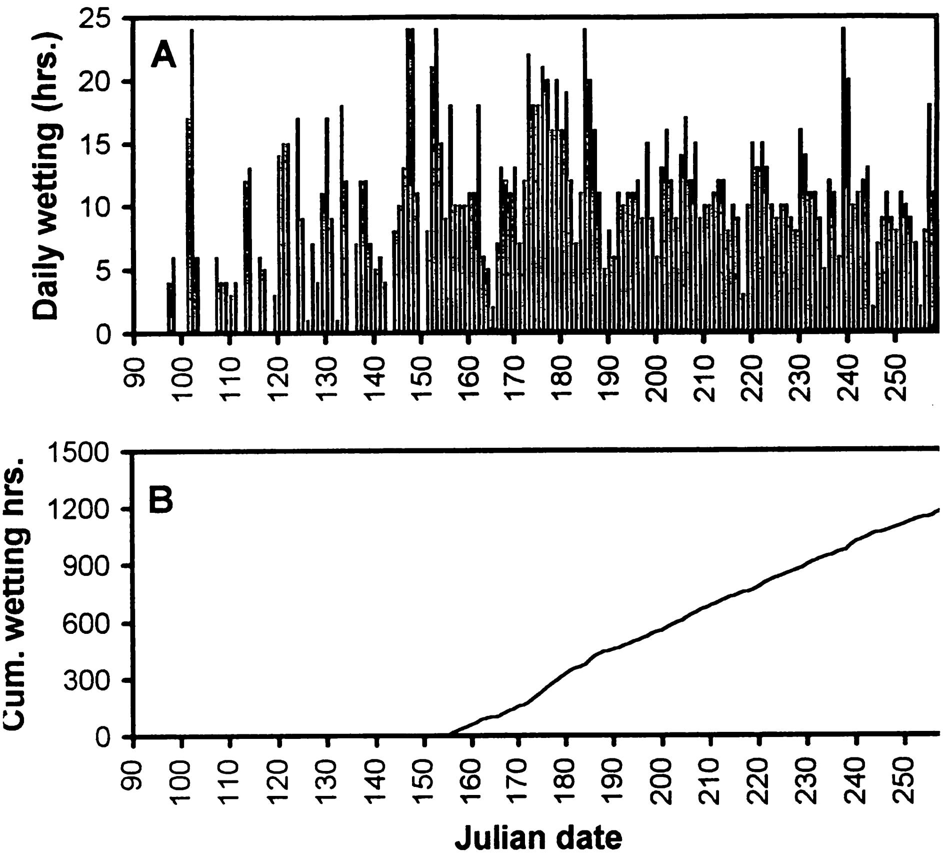

Figure 1. A. Daily wetting hours from 1 April 1995 (Julian date = 91) until Aug. 15 (Julian date = 227). B. Cumulative wetting hours starting 10 days after petal fall (May 15, Julian date = 156).

Table 6. LS means for percentage of fruit with flyspeck for the interaction of nine apple genotypes treated with six fungicide treatments in 1996.

Genotype	Treatment Time: Early / Late	Fungicide Program[z] 1: None / None		2: None / C, B		3: None / C, B, Z		4: M, P / None		5: M, P / C, B		6: M, P / C, B, Z	
Delicious		63a[y]	A	1b	B	4b	B	65a	B	2b	B	8b	BC
Golden Del.		40b	AB	2c	B	18c	B	99a	A	18c	B	9c	BC
York		89a	A	28b	AB	29b	AB	99a	A	30b	B	36b	B
Freedom		20ab	B	0b	B	0b	B	42a	B	1b	B	1b	C
Liberty		81a	A	32b	AB	45b	A	93a	A	28b	B	50b	AB
Redfree		0a	B	0a	B	0a	B	0a	C	0a	B	0a	C
NY 74840-1		55ab	A	57ab	A	39b	A	70a	AB	72a	A	62ab	A
NY 74828-12		26a	B	22a	B	14a	AB	38a	B	20a	B	32a	B
NY 73334-35		81a	A	44b	AB	26b	B	95a	A	63a	A	53ab	AB

[z]Fungicide programs are listed in Table 1.
[y]Values are LS means of five trees per treatment combination. Mean separation across rows (lower case letters) by multiple t-test ($\alpha = 0.0033$) and down columns (upper case letters) by multiple t-test ($\alpha = 0.0014$).

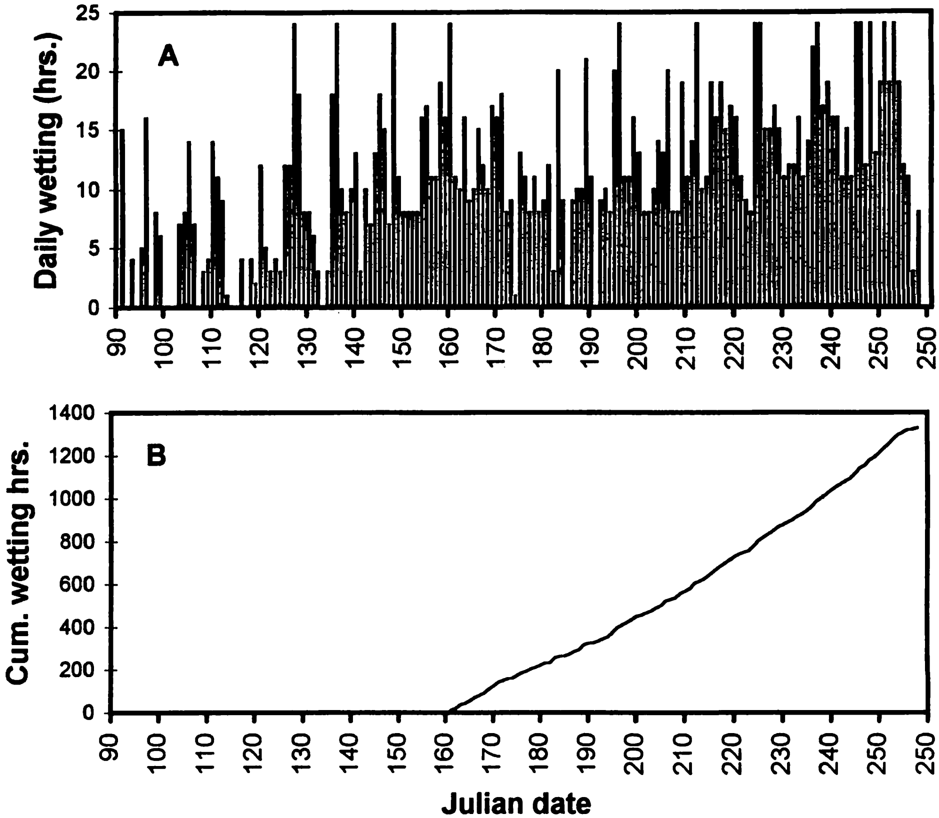

Figure 2. A. Daily wetting hours from 1 April 1996 (Julian date = 91) until Aug. 15 (Julian date = 227). B. Cumulative wetting hours starting 10 days after petal fall (May 10, Julian date = 161).

had the most flyspeck. In 1996 the percentage of fruit with flyspeck was influenced by the interaction of genotype and fungicide treatment (Table 6). Compared to nonsprayed controls, early- and late-season treatments reduced flyspeck on some, but not all genotypes. For nonsprayed trees, only 'Redfree' had no flyspeck. 'Freedom,' NY 74828-12, and 'Golden Delicious' had moderate levels; 'Liberty,' NY 73334-35, and 'York' had the highest incidence. In the absence of late-season treatment, early-season treatment (Treatment 4) did not reduce flyspeck. Adding ziram to the combination of captan plus benomyl did not improve flyspeck control. Late-season treatments (Treatment 2 & 3) substantially reduced flyspeck on NY 73334-35, 'Delicious,' 'Freedom,' 'Golden Delicious,' 'Liberty,' and 'York.' For the full-season programs (Treatments 5 & 6) genotypes with > 50% infection included NY 74840-1, NY 73334-35 and 'Liberty.'

Sooty Blotch. In 1995, the incidence of sooty blotch was affected by the interaction of genotype and treatment (data not shown). Early-season fungicide treatments were of little benefit, but late-season treatments reduced the percentage of fruits with sooty blotch to < 10% for all genotypes. For nonsprayed trees, 'Redfree' and NY 74828-12 had essentially no sooty blotch, 'Freedom' had moderate levels, and all other genotypes generally had > 60% infection. In 1996 sooty blotch was less severe than in 1995, and was affected by genotype (Table 3). 'York' and 'Freedom' had > 20% infection, whereas other genotypes had < 5% infection.

Most disease-resistant cultivars have not been evaluated for sooty blotch and flyspeck. Depending on the year in New York, nonsprayed 'Liberty' had 29 to 79% flyspeck and trees sprayed monthly with a benzimidazole plus captan had 2 to 45% flyspeck (8). Summer disease pressure was likely quite high in our study because inoculum for rots was placed above each tree and trees were less than 2 m tall. Fruits close to the ground tend to have higher incidence of sooty blotch (8). Sooty blotch and flyspeck infection can occur soon after petal fall in North Carolina, but symptoms can develop any time from early-June to mid-July (2). In areas with warm humid summers, these diseases require protectant fungicide programs at 10 to 14 day intervals, throughout the summer for control. The amount of sooty blotch in Pennsylvania orchards in a given year was proportional to the amount of rainfall occurring in July and, to a lesser extent, in August and September (4). Brown and Sutton (3) found that cumulative hours of leaf wetness of 4 hours duration or greater, starting at the first rain occurring 10 days after petal fall, provided the best measure of the time of symptom appearance. Symptoms appeared after an average of 273 (range 209 to 310) hours of wetting and temperature did not consistently affect the time of first symptom appearance. Petal fall for 'Delicious' occurred 15 May 1995 and 20 May 1996 in this study and in both years 270 cumulative hours of wetting starting 10 days after petal fall occurred by mid-June (Fig. 1 and 2). However, symptoms were not observed until early August (data not collected), possibly because temperatures are cooler in Blacksburg than in North Carolina. One explanation for this discrepancy may be that we assumed that fruit were wet when relative humidity was 100% and this assumption may be incorrect.

Differences in the incidence of disease symptoms in this study may not have been due entirely to genotype, but were likely also related to harvest date. Early maturing genotypes may be harvested before the incubation periods for flyspeck and sooty blotch are completed, and may escape disease without being resistant. The earliest maturing genotype, 'Redfree,' had few disease symptoms except rot in 1995. However, 'Freedom' was harvested only seven to 10 days after 'Redfree' in Aug. and had fairly high incidence of sooty blotch and flyspeck. By mid-Aug. flyspeck was obvious on 'Golden Delicious' and some 'York' fruits had rot lesions.

Certain fungicide treatments seem to control specific diseases on some genotypes better than on other genotypes. For example, flyspeck in 1996 was controlled fairly well with all late-season treatments on 'Delicious,' but no treatment controlled flyspeck on NY 74840-1. Therefore, as we better understand the interaction of genotype and fungicide treatment it may be possible to develop genotype-specific fungicide programs.

Although apple breeders are not intentionally selecting for resistance to summer diseases, the genotypes being selected apparently vary in susceptibility to summer diseases. 'Redfree' seems to be quite resistant to sooty blotch and flyspeck and can be grown without fungicides where rots are not serious. NY 74828-12 seems to possess considerable resistance to sooty blotch and flyspeck and 'Freedom' may have moderate resistance to flyspeck. These data indicate that certain apple genotypes could be grown in the mid-Atlantic region without fungicides and it is possible that breeders can select for genotypes possessing resistance to summer diseases.

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Incidence of Diseases on Foliage of Nine Apple Genotypes as Influenced by Six Fungicide Treatments

RICHARD P. MARINI AND JOHN A. BARDEN[2]

Abstract

Three commercially important apple cultivars ('Delicious,' 'Golden Delicious' and 'York'), three scab-immune cultivars ('Liberty,' 'Redfree,' and 'Freedom'), and three scab-immune numbered selections from New York were subjected to six different fungicide/timing treatments for three years to evaluate their effects on resulting foliar disease symptoms. Apple scab *(Venturia inaequalis)* infections occurred only on 'Delicious,' 'Golden Delicious' and 'York' and were prevented by early-season fungicide sprays. Leaf spot symptoms were not identified by cause and could include frogeye leaf spot *(Botryosphaeria obtusa)*, early symptoms of Alternaria blotch *(Alternaria mali)* or early phases of rust infections on resistant genotypes. Leaf spot symptoms were generally most severe on 'Redfree' and NY 74840-1 and least severe on 'Golden Delicious' and NY 74828-12. Necrotic leaf blotch was observed on 'Golden Delicious' each year. The percentage of leaves that had abscissed by late Aug. was greatest for 'Golden Delicious' (probably due to necrotic leaf blotch), 'Redfree,' and NY 73334-35 (possibly due to cedar apple rust or Alternaria blotch). These results indicate that foliage of scab-immune genotypes may possess varying susceptibility to other diseases.

Introduction

The apple industries in most developed countries are under pressure to produce high quality fruit while minimizing the use of agricultural chemicals. Apple breeders from North America and Europe have responded to this challenge by selecting genotypes with resistance to

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[2]Professors, Department of Horticulture, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061-0327.