Successful Management of Powdery Mildew in Pumpkin with Disease Threshold-based Fungicide Programs

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ABSTRACT

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Triadimefon applications initiated after disease detection (integrated pest management [IPM] schedule) controlled powdery mildew as well as a preventive schedule in four field experiments (1989 to 1992) and in four commercial pumpkin fields (1992). Yield and fruit quality were similar among IPM and preventive schedules. The action threshold used to initiate the IPM schedule was at least one leaf with powdery mildew symptoms per 50 old leaves examined. For both the IPM and preventive schedules, the systemic fungicide triadimefon was applied every 14 days combined with a protectant fungicide, chlorothalonil, applied every 7 days. Symptoms were observed in all experiments 6 to 12 days before the threshold was reached in each plot. When the threshold was reached, actual disease level ranged from an average of four to 50 colonies on the 50 leaves examined per plot. The first application under the IPM schedule was made 2 to 4 days after the threshold was reached. Thus with the decision criterion used there is time for detection and management response. However, triadimefon applications initiated 1 week later were not always as effective.

Additional keywords: cucurbits, disease threshold, *Sphaerotheca fuliginea*

Powdery mildew is a common disease of cucurbits under field and greenhouse conditions in most areas of the world (23). *Sphaerotheca fuliginea* (Schlechtend.:Fr.) Pollacci, the primary causal agent, produces white, talcumlike conidia and mycelia on both leaf surfaces, petioles, and stems. Management practices usually are required to avoid a yield reduction. Yield can be reduced by a decrease in the size or number of fruit (3,7,9,10,30). Premature senescence of infected leaves can result in reduced market quality because fruit sunburn or ripen prematurely or incompletely. Such fruit have low soluble solids and consequent poor flavor (4,25). In addition, powdery mildew infection predisposes plants to gummy stem blight (*Didymella bryoniae* (Auersw.) Rehm) (2). Fungicides are currently the only commercially available management tool for pumpkin (*Cucurbita pepo* L. and *C. maxima* Duchesne) and winter squash (*C. pepo* and *C. moschata* (Duchesne) Duchesne ex Poir.).

Reducing fungicide inputs needed for profitable agriculture is desirable, where feasible, because of societal concerns about possible impacts of pesticides on the environment. In addition, reducing the number of applications of systemic fungicides is a resistance management strategy. Some diseases may be controllable with the integrated pest management (IPM) approach of applying fungicides only after reaching a critical disease severity or incidence level. The objective of this project was to determine if this approach would be effective for powdery mildew in research plots and commercial fields of pumpkin (*C. pepo*). Triadimefon was selected because it was the main systemic fungicide being used for powdery mildew of cucurbits in the United States in 1989 when this study was started. Several programs were evaluated to determine if the most effective program was triadimefon applied every 14 days combined with chlorothalonil applied every 7 days beginning after symptoms were detected on at least one of 50 old leaves. Preliminary reports of part of this work have been made (15–18,20,21).

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MATERIALS AND METHODS

Cultural practices. Field experiments were conducted on Haven loam soil and Riverhead sandy loam soil at the Long Island Horticultural Research Laboratory (LIHRL) in Riverhead, New York. Fertilizer (10-20-20 N-P-K) was preplant broadcast, then incorporated at a rate of 1,120 kg/ha. The semi-bush pumpkin cultivar Spirit was direct-seeded on 29 June 1989, 22 June 1990, 25 June 1991, and 22 June 1992. Plots were 7 × 13.7 m and contained 80 plants in four rows. There were four replications in a randomized block design. Insect pests and weeds were managed as needed by applying insecticides and herbicides, mechanically cultivating, and handweeding (16–18,21). The fields were overhead irrigated as needed (16–18,21).

Fungicide treatments. Treatments listed in Table 1 were applied to plots. The principal fungicide program evaluated was triadimefon (formulated as Bayleton 50DF, Bayer Corporation, Kansas City, MO) applied at 0.14 kg a.i./ha on a 14-day schedule plus chlorothalonil (formulated as Bravo 720, ISK Biosciences Corporation, Mentor, OH) applied at 2.81 kg a.i./ha on a 7-day schedule [C (7) + T (14) in Table 1]. Triadimefon was tank mixed with chlorothalonil. In the first two experiments (1989 and 1990), timing of triadimefon applications was considered within the context of a general preventive fungicide program for other cucurbit diseases, thus other fungicides were applied before triadimefon. Efficacies of chlorothalonil and of triadimefon used alone were examined to determine the contribution of each of these fungicides to the program. Treatments with chlorothalonil alone were initiated before powdery mildew detection in 1989 and 1990 and after detection in 1991 and 1992. Two other treatments were triadimefon applied every 7 days at 0.07 kg a.i./ha with chlorothalonil [C (7) + T (7)] and benomyl (0.28 kg a.i./ha of Benlate 50DF, E. I. duPont de Nemours, Wilmington, DE) applied every 14 days with chlorothalonil in alternation with triadimefon plus chlorothalonil [C (7) + T (14) + B(14)]. A tractor-mounted boom sprayer that delivered 935 liters/ha at 2,413 kPa was used in 1989 and 1990. A sprayer that delivered 374 liters/ha at 469 kPa was used in 1991 and 1992. Treatments were applied on 5 dates in 1989 (2, 16, 22, and 29 August and 6 September), 8 dates in 1990 (16 and 26 July; 2, 9, 17, and 27 August; and 4 and 13 September), 8 dates in 1991 (23 and 31 July; 8, 16, 23, and 30 August; and 7 and 16 September), and 7 dates in 1992 (21 and 30 July; 6, 13, 21, and 27 August; and 5 September). Applications could not be made on a fixed 7-day schedule in 1989 because of abnormally wet conditions during the growing season.

Preventive and IPM schedules were used for triadimefon applications (Table 1). The first application under the preventive schedule was made when plants were starting to produce runners and before powdery mildew was detected. The first application under each IPM schedule was

made when the threshold was reached in all replicate plots for that treatment. The action thresholds (decision criteria) used for the IPM schedules were as follows: threshold 1 = one leaf out of 50 old leaves with powdery mildew; threshold 2 = an average of one powdery mildew colony per sampled leaf; and threshold 3 = 1 week after treatment was initiated in response to threshold 1. Threshold 3 tests the impact of a slow response to threshold 1. Two treatments in 1989, fungicide programs 1 and 2, included additional fungicides (Table 1). This approach was taken because other diseases were anticipated to be important. Thresholds 1 and 2 were used to time triadimefon applications for fungicide programs 1 and 2, respectively.

Powdery mildew assessments. Individual leaves from throughout each plot were examined weekly. Powdery mildew colonies were counted or severity was visually estimated as percent leaf area covered by mildew on both adaxial and abaxial leaf surfaces. Initially, 50 old leaves were examined in each plot. Old leaves were selected because powdery mildew typically develops first on old leaves. The examined leaves were selected from the oldest third of the foliage based on leaf appearance and position in the canopy. Fewer leaves were examined when most leaves had colonies. Once powdery mildew had progressed to

Table 1. Effect of fungicide program and application schedule for triadimefon on powdery mildew development in pumpkin cultivar Spirit on Long Island, New York, in 1989 to 1992

			Powdery mildew severity (% leaf coverage)			
			Adaxial leaf surface[p]		Abaxial leaf surface[p]	
Year/fungicide (interval)[q]	Triadimefon schedule[r]	Application dates[s]	mid-Sept.[t]	AUDPC[u]	mid-Sept.[t]	AUDPC[u]
1989						
Nontreated			17.50 a[v]	265.6 a	13.75 ab	255.9 a
C (7)[w]		34,48,54,61,69	1.50 b	32.8 bc	16.25 a	320.6 a
C (7) + T (7)	Preventive	34,48,54,61,69	0.08 b	3.9 d	0.26 c	37.8 b
Fungicide program 1[x]	Threshold 1	34,48,54,61,69	0.10 b	9.6 cd	0.95 c	45.4 b
Fungicide program 2[y]	Threshold 2	34,48,54,61,69	0.88 b	41.2 b	5.75 b	223.2 a
Probability > *F*			0.0069	0.0003	0.0001	0.0028
1990						
Nontreated			36.2 a	865 a	38.8 a	858 a
C (7)[w]		24,34,41,48,56,66,74,83	4.2 bc	60 b	23.8 bc	313 cd
C (7) + T (14)	Preventive	24,34,41,48,56,66,74,83	4.2 bc	68 b	27.5 b	421 b
C (7) + T (14)	Threshold 1	24,34,41,48,56,66,74,83	2.2 d	44 b	17.5 d	278 d
C (7) + T (14)	Threshold 2	24,34,41,48,56,66,74,83	5.5 b	63 b	26.2 b	345 bcd
1991						
Nontreated			48.86 a	641.0 a	59.4 a	754 a
C (7)[w]		52,59,66,74,83	6.23 ab	79.5 ab	45.2 a	686 a
T (14)	Threshold 1	52,66,83	0.96 bc	22.0 bc	2.0 b	52 b
C (7) + T (14)	Preventive	28,36,44,52,59,66,74,83	0.01 def	0.5 f	0.6 bc	31 b
C (7) + T (14)	Threshold 1	52,59,66,74,83	0.03 de	4.0 cdef	0.6 bc	43 b
C (7) + T (14)	Threshold 3	59,66,74,83	0.24 bcd	8.5 bcde	1.1 bc	39 b
C (7) + T (14) + B (14)	Threshold 1	52,59,66,74,83	0.00 f	1.1 ef	0.3 c	20 b
C (7) + T (7)[z]	Threshold 1	52,59,66,74,83	0.01 ef	1.9 def	1.1 bc	46 b
1992						
Nontreated			72.6 a	727.78 a	83.5 a	562 a
C (7)[w]		45,52,60,66,75	0.5 c	21.01 b	69.4 a	369 a
T (14)	Threshold 1	45,60,75	9.4 ab	44.61 b	10.9 b	45 b
C (7) + T (14)	Preventive	29,38,45,52,60,66,75	0.00165 de	0.02 f	2.0 cd	15 bcd
C (7) + T (14)	Threshold 1	45,52,60,66,75	0.00140 de	0.07 ef	1.1 de	5 de
C (7) + T (14)	Threshold 3	52,60,66,75	0.00080 e	2.66 c	1.5 cde	16 bcd
C (7) + T (14) + B (14)	Threshold 1	45,52,60,66,75	0.00193 de	0.03 ef	0.7 e	3 e
C (7) + T (7)[z]	Threshold 1	45,52,60,66,75	0.01086 d	0.49 d	4.2 bc	20 bc

[p] Exact colony counts made when there were less than about 50 colonies per leaf. Thereafter, severity was estimated with the conversion factor of 30 colonies/leaf = 1%. A logarithmic transformation was used to stabilize variance for severity values and for area under the disease progress curve (AUDPC) for upper leaf surfaces. This table contains de-transformed means.

[q] Fungicides tested included chlorothalonil (C) applied as Bravo 720 at 2.81 kg a.i./ha, triadimefon (T) applied as Bayleton 50DF at 0.14 kg a.i./ha, and benomyl (B) applied as Benlate 50DF at 0.28 kg a.i./ha. Spray intervals were 7 or 14 days.

[r] Triadimefon applications were initiated before disease detection (preventive) or after various action thresholds were reached. Threshold 1 = one of 50 old leaves with symptoms. Threshold 2 = average of one powdery mildew colony per sampled leaf. Threshold 3 = 1 week after treatment was initiated in response to threshold 1. In 1989 and 1990, timing of triadimefon applications was considered within context of a general preventive fungicide program for other cucurbit diseases, thus other fungicides were applied before triadimefon.

[s] Days after planting. Triadimefon applied on days underlined. Pumpkins direct-seeded: 29 June 1989, 22 June 1990, 25 June 1991, and 22 June 1992.

[t] Severity assessments made on 7 September 1989, 12 September 1990, 12 September 1991, and 9 September 1992, i.e., 70, 82, 79, and 79 days after planting, respectively.

[u] AUDPC calculated for severity from 14 August through 22 September 1989, from 31 July through 18 September 1990, from 14 August through 19 September 1991, and from 28 July through 9 September 1992.

[v] For each year, numbers in a column with a letter in common are not significantly different according to Fisher's protected least significant difference ($P = 0.05$). Probability > F was 0.0001 for all dependent variables in 1990, 1991, and 1992.

[w] The chlorothalonil treatment was initiated on a preventive basis in 1989 and 1990 and according to threshold 1 in 1991 and 1992.

[x] The following formulated fungicides were applied: 0.28 kg a.i./ha of Benlate 50DF + 2.81 kg a.i./ha of Bravo 720 on 2 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 16 August, 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 22 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 29 August, and 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 6 September.

[y] The following formulated fungicides were applied: 0.28 kg a.i./ha of Benlate 50DF + 2.81 kg a.i./ha of Bravo 720 on 2 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 16 August, 2.81 kg a.i./ha of Bravo 720 on 22 August, 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 29 August, and 1.8 kg a.i./ha of Ridomil/Bravo 81W on 6 September.

[z] Triadimefon was applied every 7 days as Bayleton 50DF at 0.07 kg a.i./ha.

young and mid-aged leaves, these also were examined. An equal number of leaves (7 to 10) from three age-classes of leaves (old, mid-aged, and young) in each plot were examined (24 to 30 leaves total). Data from all three age classes of leaves were averaged together to calculate an average severity value for each leaf surface for each plot. In 1989, rather than recording individual leaf values and calculating an average, whole plot estimates were made while examining leaves in the field. Colony counts were converted to severity values by using a conversion factor of 30 colonies = 1%. Area under the disease progress curve (AUDPC) was calculated for severity from 14 August through 22 September 1989, from 31 July through 18 September 1990, from 14 August through 19 September 1991, and from 28 July through 9 September 1992. A total of five to eight assessment dates per year were included.

Yield measurements. Fruit were cut from the vines and weighed during late September to early October when a majority of fruit were ripe. Each fruit was classed by color (orange, green, or mixed), and the amount of rot in each fruit handle (peduncle) was recorded (none, partial, or completely rotten). Yellow was added as a color rating in 1991. Yield was not measured in 1992 because Phytophthora fruit rot developed at the end of the experiment.

Commercial field evaluation. IPM tactics were implemented in four commercial pumpkin crops on Long Island in 1992. These fields were scouted every 7 to 14 days beginning in mid-July after powdery mildew was found in early plantings of summer squash on Long Island. The scouting procedure entailed traversing a field once or twice and selecting at least 10 sites spaced uniformly through the field. Adaxial and abaxial surfaces of five older leaves were examined at each site. The grower cooperators applied Bayleton 50DF with a protectant fungicide after threshold 1 was reached.

Statistical analysis. A randomized complete block design with four replications was used. Severity data and AUDPC values were transformed by natural log transformation where necessary to obtain constant variance based on scattergrams of residuals versus fitted *Y* before analysis of variance. Severity values of zero for a plot were assigned a value of 0.0022% because log of 0 is undefined. This corresponds to approximately one colony on 50 leaves. Only severity data collected near the end of the experiment were analyzed. Fisher's protected least significant difference was used to compare treatments. SuperANOVA version 1.1 for Macintosh computer (Abacus Concepts, Berkeley, CA) was used.

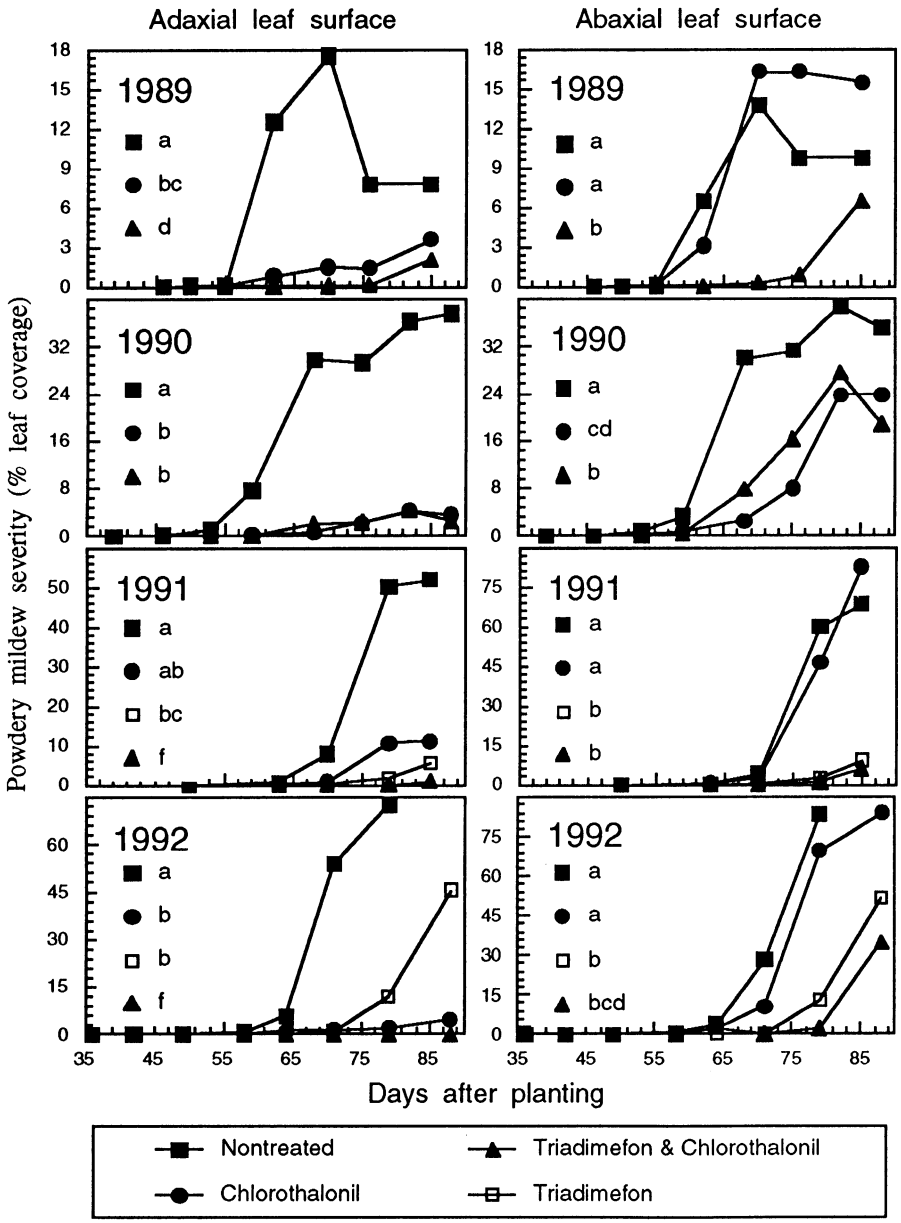

Fig. 1. Effect of fungicide program on powdery mildew development in pumpkin (application dates listed in Table 1). Most programs were initiated before symptoms were found, with the exception of chlorothalonil applied alone and triadimefon applied alone in 1991 and 1992. These programs were initiated after powdery mildew reached the threshold of one of 50 old leaves with symptoms. Scale varies among graphs. Symbols followed by the same letter within a graph denote area under the disease progress curve values that do not differ significantly (see Table 1).

RESULTS AND DISCUSSION

Fungicide program efficacy. The fungicides triadimefon plus chlorothalonil effectively controlled powdery mildew on pumpkin when applied on a preventive schedule, thus documenting that this was a good fungicide program to evaluate under an IPM schedule. With this fungicide program, powdery mildew was much less severe on both leaf surfaces compared with nontreated control plants (Fig. 1 and Table 1). Both fungicides were needed to obtain satisfactory disease suppression. It is difficult to deliver spray material to abaxial leaf surfaces with a conventional boom sprayer; as a result, chlorothalonil, a contact fungicide, was ineffective on abaxial leaf surfaces (Fig. 1 and Table 1). Consequently, leaves on plants treated with chlorothalonil alone turned yellow and died prematurely. The level of control on abaxial leaf surfaces achieved with chlorothalonil alone was better in 1990 than in 1991 and 1992, most likely because the sprayer used in 1990 was operated at much higher pressure and volume than the sprayer used in 1991 and 1992. The systemic fungicide triadimefon was effective on abaxial leaf surfaces; however, when applied alone, it was not as effective as triadimefon plus chlorothalonil in 1992. Reduced efficacy of triadimefon evident in September 1992 probably was due to selection of triadimefon-resistant strains that occurred in this field (19).

Threshold 1 IPM schedule. Powdery mildew was suppressed effectively with triadimefon plus chlorothalonil applied under the IPM schedule of initiating treat-

ment after reaching threshold 1, which was one of 50 old leaves with symptoms. The degree of control achieved with this IPM fungicide program was at least as good as a preventive program (Fig. 2 and Table 1). Triadimefon plus chlorothalonil applied after reaching threshold 1 in 1990 was the only treatment providing significantly better control than chlorothalonil alone, based upon mildew severity on 12 September (Table 1). In 1990, the preventive schedule was not as effective as the threshold 1 IPM schedule, most likely because triadimefon inadvertently was not applied on 9 August as planned for the preventive schedule, causing a 22-day lapse between applications. Similar control of powdery mildew was obtained in 1993 with preventive and threshold 1 IPM schedules (22). Elmer and Stoner also controlled powdery mildew effectively when they timed their first triadimefon application using the threshold 1 IPM schedule developed through the present study (5).

Vine growth was sufficient to close the canopy between rows and first fruit were enlarging when threshold 1 was reached in all experiments. First application under the preventive schedule was made 28 to 34 days after planting when plants were starting to produce runners and before female flowers had opened.

A disease threshold-based fungicide program has a greater chance for success in a commercial setting if there is some latitude for disease detection and management response. The threshold 1 IPM schedule has these features. There is latitude for disease detection because onset of powdery mildew epidemics occurred several days before threshold 1 was reached in all four experimental fields. Powdery mildew was first observed on 8 August 1989, on 30 July 1990 in 15 of 36 plots, on 2 August 1991 on two of 1,000 leaves examined, and on 28 July 1992 112 powdery mildew colonies were observed on the 2,000 leaves examined. Threshold 1 was reached 6 to 12 days later (Table 2). The first triadimefon application was made 2 to 4 days after threshold was reached (Table 2). There is latitude for management response because effective control was obtained with threshold 1 even when the actual disease level was substantially above one of 50 old leaves with symptoms. On 7 August 1990 (46 days after planting [dap]) when threshold 1 was reached, average number of colonies per 50 leaves was 78 for nontreated plants, 4.3 for plants that had been sprayed three times with chlorothalonil, and 1.8 for plants sprayed three times with chlorothalonil and once with triadimefon on a preventive schedule. In 1991, plants that received the threshold 1 triadimefon application schedule were actually at threshold 2 when the first spray was made. An average of one colony per leaf was found on these plants on 14 August 1991 (50 dap), while only 2 colonies were found

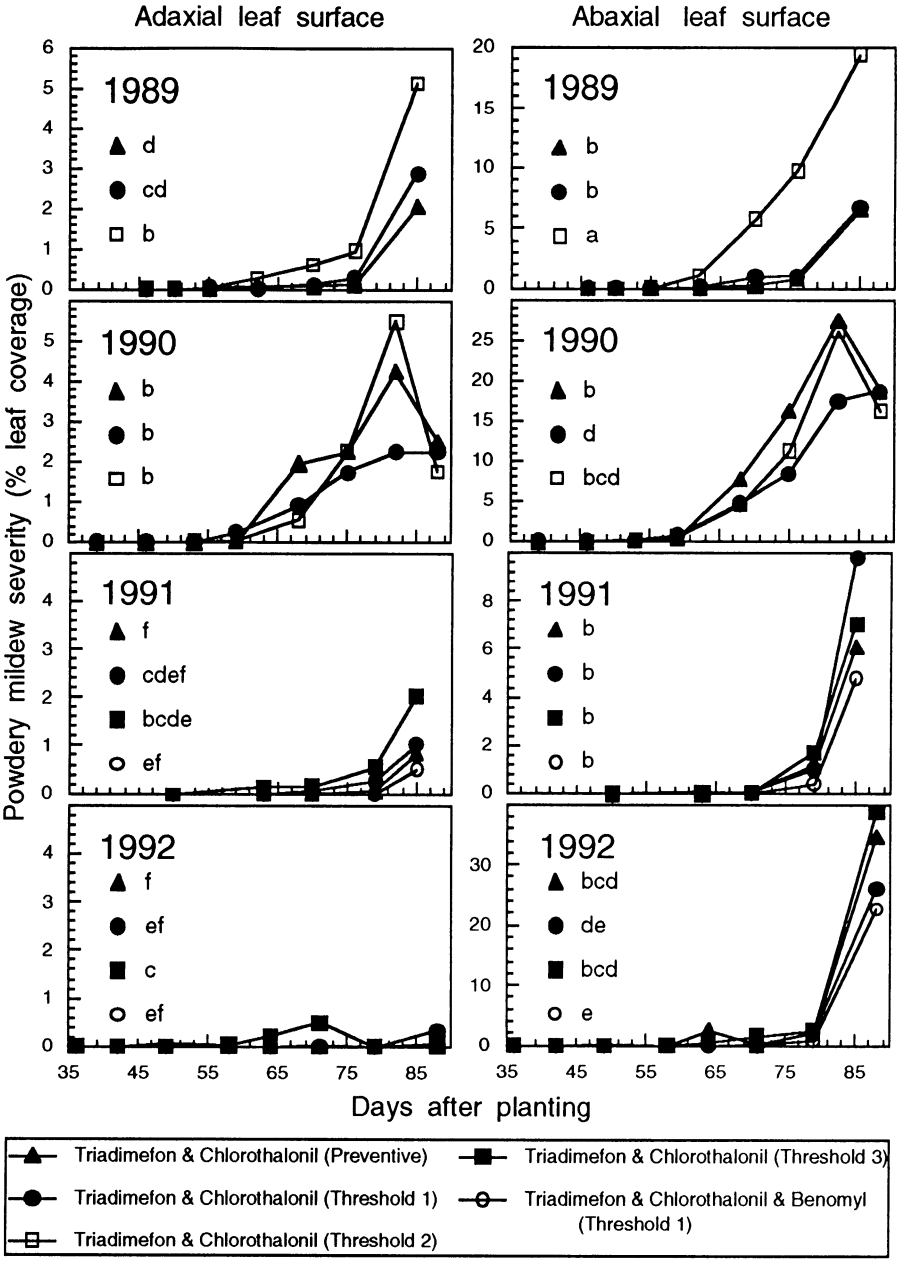

Fig. 2. Effect of application schedule for triadimefon on powdery mildew development in pumpkin (application dates listed in Table 1). Triadimefon applications were initiated before disease detection (preventive) or after various action thresholds were reached. Threshold 1 = one of 50 old leaves with symptoms. Threshold 2 = average of one powdery mildew colony per sampled leaf. Threshold 3 = 1 week after treatment was initiated in response to threshold 1. Benomyl was applied on a 14-day schedule in alternation with triadimefon. Scale varies among graphs. Symbols followed by the same letter within a graph denote area under the disease progress curve values that do not differ significantly (see Table 1).

Table 2. Dates powdery mildew was first observed, thresholds were reached, and triadimefon was first applied to research plots of pumpkin cultivar Spirit on Long Island, New York, in 1989 to 1992

Year	Symptoms first observed	Threshold 1[w] Reached	Threshold 1[w] Sprayed	Threshold 2[x] Reached	Threshold 2[x] Sprayed	Threshold 3[y] Sprayed
1989	8 August	18 August	22 August	29 August	29 August	...[z]
1990	30 July	7 August	9 August	14 August	17 August	...
1991	2 August	14 August	16 August	...[z]	...	23 August
1992	28 July	3 August	6 August	...	...	13 August

[w] Threshold 1 = one of 50 old leaves with symptoms.
[x] Threshold 2 = average of one powdery mildew colony per sampled leaf.
[y] Threshold 3 = 1 week after treatment was initiated in response to threshold 1.
[z] Not tested.

on 200 leaves of plants sprayed twice with triadimefon 6 and 22 days earlier (preventive schedule). Actual disease level was close to the threshold 1 level when this threshold was reached in 1992: an average of four colonies (one to four leaves) per 50 leaves were found on 3 August (42 dap).

Powdery mildew development at the start of the epidemic in 1989 in the fungicide program 1 and 2 treatments may have been suppressed by benomyl applied for black rot on 2 August, which was 6 days before symptoms of powdery mildew were first seen. In addition, an extensive period of rain in August 1989 provided favorable conditions for downy mildew and unfavorable conditions for powdery mildew; consequently, powdery mildew was not as severe as in subsequent years. Between 6 and 15 August a total of 20.1 cm of rain fell over 6 days in 1989, 6.3 cm of rain fell over 5 days in 1990, 5.9 cm of rain fell over 3 days in 1991, and 7.9 cm of rain fell over 5 days in 1992.

Threshold 2 and 3 IPM schedules. While threshold 1 was consistently effective, adequate control was not always obtained with threshold 2. Compared with pumpkins treated according to threshold 1 or preventive schedules in 1989, there was significantly more powdery mildew on pumpkins that were not sprayed with triadimefon until after threshold 2 was reached, especially on abaxial leaf surfaces (Fig. 1 and Table 1). The level of control obtained when threshold 2 or 3 was used in 1990, 1991, and 1992 was not substantially different from the level of control obtained when either the preventive schedule or threshold 1 was used; however, there were significant differences in some of the severity variables analyzed (Table 1). When threshold 2 was reached on 14 August 1990, average number of colonies per leaf was 70 for nontreated plants, 8.4 for plants to be sprayed with triadimefon (threshold 2), 9.7 for plants sprayed once with triadimefon 5 days earlier (threshold 1), and 2 for plants sprayed once with triadimefon 19 days earlier (preventive schedule). Powdery mildew may have been suppressed by the rain associated with the hurricane that occurred on 19 August 1991, 3 days after the first threshold 1 application, thereby obscuring any treatment differences that might have occurred. In 1992, average number of colonies per 50 leaves found on nontreated plants increased from four on 3 August 1992 to 19 on 10 August 1992 during the week between when applications were initiated according to thresholds 1 and 3. Therefore, threshold 2 (average of one colony per leaf) had not been reached when applications were initiated for threshold 3 (1 week after finding symptoms on at least one of 50 old leaves). In 1993, there was significantly more powdery mildew on plants sprayed with triadimefon plus chlorothalonil beginning 1 or 2 weeks after the first threshold 1 application was made (22). However, "threshold 1" plants were actually above threshold 2 when the first spray was made in 1993: there was an average of 7.7 colonies per leaf and 33 of 50 leaves with symptoms. Elmer and Stoner found that using threshold 2 to time the first triadimefon application was not as effective as threshold 1 (5). Powdery mildew in cucumber was controlled effectively with four applications of triarimol started when the first few detectable spots were found under the leaf surface (1). Recommendations in the 1940s to commercial cantaloupe growers in California included applying the first fungicide spray when one to five colonies per leaf were found on the lower surfaces of the crown leaves (24). Others also have found that fungicide treatment begun early in disease development was more effective than treatments initiated later (12,13).

Efficacy of other fungicide programs. The standard fungicide program (chlorothalonil plus triadimefon applied at full labeled rates every 7 and 14 days, respectively) was compared with other programs that used the threshold 1 IPM schedule in 1990, 1991, and 1992. Disease control was not improved by applying triadimefon every 7 days at 0.07 kg a.i./ha or by applying benomyl with chlorothalonil in alternation with triadimefon plus chlorothalonil (Table 1). Effective control also was achieved with two formulations of a prepackaged mixture of triadimefon and chlorothalonil (17,18,21).

Fungicide resistance. Late in the growing season, powdery mildew was not suppressed effectively on abaxial leaf surfaces with the IPM fungicide program in 1990 and 1992 compared with 1989 and 1991 (Fig. 2). Severity of powdery mildew on abaxial leaf surfaces was high (18 to 28%) on 12 September 1990 (Table 1). In 1992, all fungicide programs with triadimefon plus chlorothalonil controlled powdery mildew on both leaf surfaces at least through 9 September. By 18 September, powdery mildew severity had increased substantially on abaxial leaf surfaces (average severity of 26 to 39%), but not on adaxial leaf surfaces (<1%), of plants treated with triadimefon plus chlorothalonil. Nontreated control plots did not have enough foliage to be evaluated on 18 September. Powdery mildew severity may have increased because of development of fungicide resistance. Isolates insensitive to 200 µg of triadimefon per ml were found in this experimental field in 1990 (19). Frequency of triadimefon-resistant isolates in 1992 increased from 3% on 14 August to 100% on 17 September in the plots treated with triadimefon plus chlorothalonil on a preventive schedule (19).

Yield. The primary impact of managing powdery mildew was on fruit quality rather than quantity during this study (Table 3). At least 50% of fruit from nontreated plants had partially to completely rotten handles, compared with 20 to 21% for the C (7) + T (14) threshold 1 treatments (Table 3). An intact, solid handle is an important characteristic for ornamental pumpkins. Color was yellow-orange for 20% of fruit from nontreated plants in 1991. Color was also poor in other years. Fruit quality was affected because leaves on nontreated plants died before fruit had fully matured and vines rotted before harvest time. Pumpkins treated with triadimefon plus chlorothalonil in 1989 produced 29 to 38% more fruit (ton/ha) than nontreated plants (Table 3). In 1990 and 1991 there were no significant differences among treatments in number or total weight of fruit; however, both number and weight of orange and green fruit combined and of orange fruit alone were lower for the nontreated control compared with triadimefon plus chlorothalonil treatments (Table 3). These yield parameters in 1991 also were lower for triadimefon alone and for chlorothalonil alone compared with triadimefon plus chlorothalonil. Potential yield benefits of managing powdery mildew with fungicides in pumpkin and winter squash have been documented in other studies. Compared with nontreated pumpkins, number of fruit was increased 32 (32), 63 (11), and 84% (33). Total fruit weight was increased 19 (29), 46 (26), 58 (34), 79 (11), and 98% (33). These increases were all significant.

Commercial fields. Powdery mildew also was suppressed effectively in commercial fields when the threshold 1 IPM schedule was used. As was the case in the research fields, powdery mildew often was observed before threshold 1 was reached and powdery mildew severity increased substantially by mid-September. In field #1, one colony was found on one of 105 leaves examined on 16 July and five colonies were found on five of 55 leaves examined on 28 July. Powdery mildew was not found on any of the 80 leaves examined on 28 July in field #2, which was at an earlier stage of development. In field #3, powdery mildew was not found on any of the 135 leaves examined on 13 July. Symptoms were observed at the second of 10 sites on 27 July. In field #4, one colony was found on one of 150 leaves examined on 23 July. The canopy was closing and small fruit were observed when threshold 1 had been reached in these fields (on 28 July, 27 July, and 6 August in fields 1, 3, and 4, respectively). Average powdery mildew severity was as follows on adaxial and on abaxial leaf surfaces: 0.23 and 0.16% on 19 August in field #1, respectively; 0.01 and 0.07% on 19 August and 4 and 9% on 9 September in field #2, respectively; and 0.0 and 0.2% on 25 August and 5 and 13.3% on 9 September in field #4, respectively. Although disease severity increased substantially by mid-September, the level of control achieved was considered commercially acceptable because this

increase occurred late enough in the growing season that yield and fruit quality probably were not affected.

Other diseases and threshold-based programs. Cucurbit powdery mildew can be managed successfully using the IPM approach of timing fungicide treatment based on disease occurrence because the initial disease level is low and initial disease development is not rapid. In contrast, powdery mildew of apple (*Podosphaera leucotricha* (Ellis & Everh.) E. S. Salmon on *Malus* sp.) and grape (*Uncinula necator* (Schwein.) Burrill on *Vitis* sp.) most likely cannot be effectively managed with fungicide applications initiated after disease detection because the source of initial inoculum is local overwintering cleistothecia, thus the initial level of infection is high. Wind-blown conidia from other fields is the initial inoculum for powdery mildew in cucurbit crops. Downy mildew (*Pseudoperonospora cubensis* (Berk. & M. A. Curtis) Rostovzev) and target leafspot (*Corynespora cassiicola* (Berk. & M. A. Curtis) C. T. Wei) of cucurbits and late blight (*Phytophthora infestans* (Mont.] de Bary) of tomato (*Lycopersicon esculentum* Mill.) cannot be managed effectively with fungicide applications initiated after disease detection because initial disease development is too rapid (8). Anthracnose (*Colletotrichum orbiculare* (Berk. & Mont.) Arx) cannot be controlled successfully on susceptible cucumber (*Cucumis sativus* L.) cultivars; however, if disease progress is slowed by the use of a resistant cultivar, then control can be achieved with fungicide applications initiated after an action threshold of 1% diseased leaf tissue is reached (31).

Other diseases have been controlled successfully with fungicide applications initiated after initial disease development. The threshold for Botrytis leaf blight (*Botrytis squamosa* J. C. Walker) of onion (*Allium cepa* L.) is an average of one lesion per 10 leaves (27). Early blight (*Alternaria solani* Sorauer) can be managed effectively with spray schedules initiated after symptoms are first detected in tomato (14). Effective control of early blight in potato (*Solanum tuberosum* L.) can be obtained when initial spray applications are made after detecting either initial symptoms or an increase in number of trapped spores from secondary spread (6). Preventive spray schedules are not more effective (6).

Benefits. Potential benefits of managing powdery mildew by using an IPM approach to time fungicide applications include reduced fungicide inputs, effective disease control, and management of fungicide resistance. At the time of this study, some local growers were making as many as 13 fungicide applications on a weekly, preventive schedule to their pumpkin crops, whereas some of the growers who waited until they saw symptoms were not satisfied with the level of control achieved. Control probably was poor because powdery mildew is more severe than threshold 2 when readily seen. Tactics for managing fungicide resistance include limiting the number of applications of resistance-prone fungicides, applying them only when justified, and applying them when the pathogen population is small (28). Use of an IPM approach facilitates achieving these goals by ensuring fungicides are applied at the critical time when they will make the greatest contribution to disease suppression. This eliminates unnecessary preventive applications and reduces the need for subsequent applications. When triadimefon-resistant strains are present in the pathogen population at the start of an epidemic, waiting to apply this fungicide until just before the population reaches an uncontrollable size delays the occurrence of the consequential increase in the frequency of the resistant strains. This shift can occur rapidly (19).

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Table 3. Effect of fungicide program for powdery mildew on yield of pumpkin cultivar Spirit on Long Island, New York, in 1989 to 1991

Year/ fungicide (interval)[s]	Triadimefon schedule[t]	No./ha	Ton/ha	Rotting handle (%)[u]	Yellow color (%)[v]
1989					
Nontreated		10,110 b[w]	32.5 c	54.4 a	
C (7)		11,591 ab	38.6 bc	17.9 b	
C (7) + T (7)	Preventive	12,760 a	44.8 a	7.6 b	
Fungicide program 1[x]	Threshold 1	11,513 ab	41.8 ab	1.2 b	
Fungicide program 2[y]	Threshold 2	12,137 a	43.6 ab	6.8 b	
Probability > *F*		0.0774	0.0082	0.0009	
1990					
Nontreated		12,189	41.6	55.8 a	
C (7)		13,592	52.1	19.5 b	
C (7) + T (14)	Preventive	12,708	48.4	22.2 b	
C (7) + T (14)	Threshold 1	13,644	51.5	19.9 b	
C (7) + T (14)	Threshold 2	13,124	49.6	17.6 b	
Probability > *F*		0.4489	0.2379	0.0001	
1991					
Nontreated		9,919	39.2	50.8 c	19.7 a
C (7)		10,367	42.0	23.0 a	4.1 b
T (14)	Threshold 1	10,367	41.7	35.8 b	1.4 b
C (7) + T (14)	Preventive	11,950	49.3	16.8 a	1.5 b
C (7) + T (14)	Threshold 1	11,027	47.1	20.8 a	3.2 b
C (7) + T (14)	Threshold 2	10,974	46.7	20.8 a	1.0 b
C (7) + T (14) + B (14)	Threshold 1	11,159	46.7	20.7 a	1.1 b
C (7) + T (7)[z]	Threshold 1	10,394	44.6	17.1 a	1.8 b
Probability > *F*		0.2167	0.1347	0.0010	0.0116

[s] Fungicides tested included chlorothalonil (C) applied as Bravo 720 at 2.81 kg a.i./ha, triadimefon (T) applied as Bayleton 50DF at 0.14 kg a.i./ha, and benomyl (B) applied as Benlate 50DF at 0.28 kg a.i./ha. Spray intervals were 7 or 14 days.

[t] Triadimefon applications were initiated before disease detection (preventive) or after various action thresholds were reached. Threshold 1 = one of 50 old leaves with symptoms. Threshold 2 = average of one powdery mildew colony per sampled leaf. Threshold 3 = 1 week after treatment was initiated in response to threshold 1. In 1989 and 1990, timing of triadimefon applications was considered within context of a general preventive fungicide program for other cucurbit diseases, thus other fungicides were applied before triadimefon.

[u] Proportion of fruit with a partially to completely rotten handle (peduncle).

[v] Proportion of fruit that had an undesirable yellow-orange color.

[w] For each year, numbers in a column with a letter in common are not significantly different according to Fisher's protected least significant difference ($P = 0.05$).

[x] The following formulated fungicides were applied: 0.28 kg a.i./ha of Benlate 50DF + 2.81 kg a.i./ha of Bravo 720 on 2 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 16 August, 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 22 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 29 August, and 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 6 September.

[y] The following formulated fungicides were applied: 0.28 kg a.i./ha of Benlate 50DF + 2.81 kg a.i./ha of Bravo 720 on 2 August, 1.8 kg a.i./ha of Ridomil/Bravo 81W on 16 August, 2.81 kg a.i./ha of Bravo 720 on 22 August, 0.14 kg a.i./ha of Bayleton 50DF + 2.81 kg a.i./ha of Bravo 720 on 29 August, and 1.8 kg a.i./ha of Ridomil/Bravo 81W on 6 September.

[z] Triadimefon was applied every 7 days as Bayleton 50DF at 0.07 kg a.i./ha.

LITERATURE CITED

1. Banihashemi, Z., Rafii, Z., and Azad, H. R. 1972. Field evaluation of a systemic and a nonsystemic fungicide for control of *Sphaerotheca fuliginea* on cucumber. Plant Dis. Rep. 56:206-209.
2. Bergstrom, G. C., Knavel, D. E., and Kúc, J. 1982. Role of insect injury and powdery mildew in the epidemiology of the gummy stem blight disease of cucurbits. Plant Dis. 66:683-686.
3. Cohoon, D. F. 1965. Control of powdery mildew and Alternaria leaf blight in cantaloupe. Fungic. Nematicide Tests 20:58-59.
4. Dougherty, D. E. 1980. Fungicide evaluation for powdery mildew control on honeydew, 1979. Fungic. Nematicide Tests 35:71.
5. Elmer, W. H., and Stoner, K. A. 1993. Comparison of two action thresholds for powdery mildew management in pumpkins, 1992. Fungic. Nematicide Tests 48:170.
6. Harrison, M. D., Livingston, C. H., and Oshima, N. 1965. Control of potato early blight in Colorado. I. Fungicidal spray schedules in relation to the epidemiology of the disease. Am. Pot. J. 42:319-327.
7. Johnston, S. A. 1987. Evaluation of fungicides for powdery mildew control in cucumber, 1986. Fungic. Nematicide Tests 42:63.
8. Jones, J. P. 1978. Disease thresholds for downy mildew and target leafspot of cucurbits and late blight of tomato. Plant Dis. Rep. 62:798-802.
9. Kantzes, J. G. 1974. Control of powdery mildew in cantaloupe. Fungic. Nematicide Tests 29:55.
10. Lambe, R. C., and Price, P. L. 1983. Control of powdery mildew of squash, 1982. Fungic. Nematicide Tests 38:107.
11. Latin, R. X. 1987. Control of powdery mildew on pumpkin, 1986. Fungic. Nematicide Tests 42:75.
12. Latin, R. X. 1991. Evaluation of fungicides and application schedules for control of muskmelon powdery mildew, 1990. Fungic. Nematicide Tests 46:136.
13. Lewis, G. D. 1974. Control of powdery mildew in cucumber. Fungic. Nematicide Tests 29:60.
14. MacNab, A. A. 1993. Bravo 720 initiation-time treatments for control of tomato early blight on a fresh market tomato variety, 1992. Fungic. Nematicide Tests 48:199.
15. McGrath, M. T. 1990. An action threshold for management of pumpkin powdery mildew. (Abstr.). Phytopathology 80:971.
16. McGrath, M. T. 1990. Effect of timing of Bayleton application(s) on control of pumpkin powdery mildew, 1989. Fungic. Nematicide Tests 45:130.
17. McGrath, M. T. 1991. Evaluation of fungicides and effect of timing of Bayleton applications on control of pumpkin powdery mildew, 1990. Fungic. Nematicide Tests 46:164.
18. McGrath, M. T. 1992. Efficacy of fungicides applied preventatively or based on disease occurrence for managing powdery mildew of pumpkin, 1991. Fungic. Nematicide Tests 47: 124.
19. McGrath, M. T. 1996. Increased resistance to triadimefon and to benomyl in *Sphaerotheca fuliginea* populations following fungicide usage over one season. Plant Dis. 80:633-639.
20. McGrath, M. T., and Ghemawat, M. S. 1992. Effective management of powdery mildew in pumpkin with triadimefon despite development of fungicide resistance following treatment. (Abstr.). Phytopathology 82:1157.
21. McGrath, M. T., Ghemawat, M. S., and Staniszewska, H. 1993. Efficacy of fungicides applied preventively or following disease detection for managing powdery mildew of pumpkin, 1992. Fungic. Nematicide Tests 48: 173.
22. McGrath, M. T., and Staniszewska, H. 1994. Efficacy of fungicides applied preventively or following disease detection for managing powdery mildew of pumpkin, 1993. Fungic. Nematicide Tests 49:142.
23. McGrath, M. T., and Thomas, C. E. 1996. Powdery mildew. Pages 28-30 in: Compendium of Cucurbit Diseases. T. A. Zitter, D. L. Hopkins, and C. E. Thomas, eds. American Phytopathological Society, St. Paul, MN.
24. Middelton, J. T., and Yarwood, C. E. 1946. Fungicidal control of cantaloupe powdery mildew. Calif. Agric. Exp. Stn. Bull. 697:1-8.
25. Paulus, A. O., Nelson, J., Shibuya, F., Whitaker, T. W., House, J., Meister, H., and Bohn, G. W. 1972. Fungicides and methods of application for the control of cantaloupe powdery mildew. Plant Dis. Rep. 56:935-938.
26. Potter, H. S. 1981. Evaluation of fungicides for powdery mildew control on acorn squash and pumpkin, 1977. Fungic. Nematicide Tests 36:76-77.
27. Shoemaker, P. B., and Lorbeer, J. W. 1977. Timing initial fungicide application to control Botrytis leaf blight epidemics on onions. Phytopathology 67:409-414.
28. Staub, T. 1991. Fungicide resistance: Practical experience with antiresistance strategies and the role of integrated use. Annu. Rev. Phytopathol. 29:421-442.
29. Stephens, C. T., Stebbins, T. C., and Kwantes, M. 1986. Fungicidal control of powdery mildew of pumpkin, 1985. Fungic. Nematicide Tests 41:63.
30. Thayer, P. L., and Dohner, L. D. 1970. Control of powdery mildew in squash. Fungic. Nematicide Tests 25:82.
31. Thompson, D. C., and Jenkins, S. F. 1985. Influence of cultivar resistance, initial disease, environment and fungicide concentration and timing on anthracnose development and yield loss in picking cucumbers. Phytopathology 75:1422-1427.
32. Tisserat, N., Marr, C., and Schaplowsky, T. 1989. Control of powdery mildew of pumpkin, 1988. Fungic. Nematicide Tests 44:130.
33. Tisserat, N., Marr, C., and Schaplowsky, T. 1990. Control of powdery mildew of pumpkin, 1989. Fungic. Nematicide Tests 45:133.
34. Zitter, T. A., and Hsu, L. W. 1992. Evaluation of fungicides for control of powdery mildew of pumpkin, 1991. Fungic. Nematicide Tests 47:126.