



Long Island Vegetable Pathology Program

2021 Annual Research Report

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Efficacy of Biopesticides for Managing Powdery Mildew in Pumpkin

The main objective was to evaluate recently developed biopesticides suitable for organic production. Not all are commercially available yet, but are expected to be in the near future. An organic copper fungicide, Kocide 3000-O, was included as the standard fungicide for organic disease management. A susceptible pumpkin variety, Gold Challenger, was used.

Methods. The field was moldboard plowed and urea fertilizer (46-0-0) was applied at 80 lb/A N on 8 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (cv. Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 7 Jun the mustard was flail chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as usually done, but the soil was moist. Pumpkins were planted with a vacuum seeder at approximately 24-in. plant spacing on 21 Jun after disking. Controlled-release fertilizer (N-P-K, 19-10-9) was used at 525 lb/A (101 lb/A N) and applied with the seeder in two bands about 2 in. to the side of the seed. Strategy 3 pt/A, Sandea 0.5 oz/A, and Curbit EC 1 pt/A were applied prior to seedling emergence for weed control on 21 Jun using a tractor-mounted sprayer. During the season, weeds were managed by cultivating and hand weeding as needed. Drip tape was laid along each row of pumpkin seedlings on 25 Jun. The following fungicides were applied throughout the season to manage Phytophthora blight: Omega 24 fl oz/A on 12 Jul, 23 Jul and 6 Aug, Presidio 4 fl oz/A on 16 Jul, Orondis Ultra 7 fl oz/A on 30 Jul, 20 Aug and 3 Sep, Revus 8 fl oz/A on 14 Aug, and Ranman 2.75 fl oz/A on 27 Aug. No foliar or fruit symptoms of Phytophthora blight were seen.

Plots were three 15-ft rows spaced 68 in. apart with a 15-ft in-row untreated area between plots. The 15-ft area between plots was also planted to pumpkin. A randomized complete block design with four replications was used. The primary source of initial inoculum for powdery mildew in this area is considered to be long-distance wind-dispersed spores from affected plants. Treatments were applied six times on a preventive schedule using a tractor-mounted boom sprayer equipped with twinjet (TJ60-11004VS) nozzles spaced 17 in. apart that delivered 72 gal/A at 50 psi and 2.3 mph. Plants were inspected for powdery mildew symptoms on upper and lower leaf surfaces. Initially only old leaves were examined: 20 in each plot on 26 Jul and 15 on 2 Aug. Old, mid-aged and young leaves (usually 5 of each selected based on leaf physiological appearance and position in the canopy) were examined in each plot on 10, 16, 25, and 30 Aug, and 8 Sep. Powdery mildew spots were counted; severity was assessed by visual estimation of percent leaf area affected when spots could not be counted accurately because they had coalesced and/or were too numerous. Colony counts were converted to severity values using the conversion factor of 30 spots/leaf = 1% severity. Average severity for the entire canopy was calculated from the individual leaf assessments. Area under disease progress curve (AUDPC) values were calculated from 26 Jul through 8 Sep. AUDPC is a summation measure of severity over time. Defoliation, which was mainly due to powdery mildew, was assessed on 8, 13, 21 and 27 Sep; and 4 Oct. Fruit quality was evaluated in terms of handle (peduncle) condition for mature fruit without rot on 21 Sep, 27 Sep and 4 Oct. Handles were considered good if they were green, solid, and not rotting.

Results. Powdery mildew was first observed in this experiment on 26 Jul in 1 of the 36 plots on only 1 of the 720 leaves examined (0.14%). Biopesticide treatment applications started 1 day later. The IPM action threshold recommended to growers for initiating fungicide applications is 1 out of 50 old leaves with symptoms (2%). Therefore, the first application in this experiment is considered a preventive application because it is before symptoms would be found

through routine scouting. On 2 Aug symptoms were found in 27 of the 36 plots on 50 of 540 leaves examined (9%). The fifth application scheduled for 24 Aug was delayed by 2 days because of extensive rainfall (2.6 in.) with Hurricane Henri on 22-23 Aug. The last application was applied early due to rain forecast with remnants of Hurricane Ida starting late on 1 Sep (3.3 in. total). It is possible efficacy of treatments was affected by the impact of these storms on application timing, product residues, and/or disease development. Severity was low throughout August especially on upper leaf surfaces, which may be partly due to some contact activity for powdery mildew of the pesticides applied for Phytophthora blight and insect pests. On 30 Aug, one day before the sixth and last application, severity in the untreated control plots averaged 0.3% on upper leaf surfaces and 33% on lower surfaces (data not shown). Severity increased substantially over the next week. All treatments suppressed powdery mildew on upper leaf surfaces (Table 1). Kocide 3000-O, the organic copper treatment included for comparison with the biopesticides, was the most effective treatment, providing 77% control based on 8 Sep severity and AUDPC values. It was only significantly better than Aviv + Timorex Act which provided 38% control. The other biopesticides provided 51 to 60% control. No treatment controlled powdery mildew on lower leaf surfaces, documenting these products have contact activity and are not able to move to the underside of leaves. Consequently, no treatment significantly reduced defoliation due to powdery mildew or improved fruit quality compared to the untreated control (Table 1). No phytotoxicity was observed.

Conclusions. The biopesticides controlled powdery mildew on upper leaf surfaces but not lower surfaces which documents that they have contact activity. All of the registered products tested are now allowed in organic production (OMRI-listed) or are expected to be. Theia, Tril-21, and MBI-121 are not commercially available yet.

Results from previous evaluations of biopesticides and other organic fungicides are posted at <https://blogs.cornell.edu/livepath/research/organic-disease-management/organic-management-of-powdery-mildew-in-cucurbit-crops/>.

Acknowledgements: Project was supported by the IR-4 Program.

Table 1. Efficacy of biopesticides for powdery mildew in pumpkins.

Treatment and rate (application dates) ^y	Powdery mildew severity (%) ^z						Defoliation (%) ^z		Fruit quality (% good handles) ^z		
	Upper leaf surface		Lower leaf surface				27 Sep	21 Sep	4 Oct		
	8 Sep	AUDPC	25 Aug	8 Sep	AUDPC						
Untreated control	58 a	267 a	10.5	73	639	88 ab	91	25	ab		
Howler 5 lb/A (1-6) ^x	28 bc	131 bc	5.8	62	548	92 ab	83	20	ab		
Theia 3 lb/A (1-6) ^x	23 bc	109 bc	10.3	71	637	85 ab	98	32	ab		
Howler 5 lb/A (1, 3, 5)											
Theia 3 lb/A (2, 4, 6) ^x	23 bc	110 bc	8.2	63	577	80 b	96	29	ab		
MBI-121 2 qt/A (1-6)	29 bc	130 bc	6.9	67	544	91 ab	94	13	b		
Tril-21 1% (1-6)	24 bc	111 bc	5.4	67	535	91 ab	92	20	ab		
Aviv 30 fl oz/100 gal +											
Timorex ACT 35 fl oz/A (1-6) ^x	36 b	164 b	8.3	69	595	95 a	94	36	a		
Aviv 30 fl oz/100 gal (1-6) ^x	20 bc	91 bc	9.6	60	603	86 ab	94	24	ab		
Kocide 3000-O 1.25 lb/A (1-6)	13 c	60 c	10.9	61	650	89 ab	92	18	ab		
<i>P-value (treatment)</i>	<0.0001	<0.0001	0.1397	0.2217	0.7796	0.0322	0.1279	0.0346			

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$). No transformations were needed before analysis.

^y Application dates were 1=27 Jul, 2=2 Aug, 3=10 Aug, 4=17 Aug, 5=26 Aug, and 6=31 Aug.

^x Treatment applied with the nonionic surfactant Dyne-Amic at 0.38% v/v.

Efficacy of Biopesticides Applied with Conventional Fungicides for Managing Powdery Mildew in Pumpkin

The objectives were to evaluate programs with biopesticides applied in place of conventional fungicides for some applications and to evaluate Cevya, a new FRAC code 3 fungicide. A susceptible pumpkin variety, Gold Challenger, was used.

Methods. The field was moldboard plowed and urea fertilizer (46-0-0) was applied at 80 lb/A N on 8 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (cv. Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 7 Jun the mustard was flail chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as usually done, but the soil was moist. Pumpkins were planted with a vacuum seeder at approximately 24-in. plant spacing on 21 Jun after disking. Controlled-release fertilizer (N-P-K, 19-10-9) was used at 525 lb/A (101 lb/A N) and applied with the seeder in two bands about 2 in. to the side of the seed. Strategy 3 pt/A, Sandea 0.5 oz/A, and Curbit EC 1 pt/A were applied prior to seedling emergence for weed control on 21 Jun using a tractor-mounted sprayer. During the season, weeds were managed by cultivating and hand weeding as needed. Drip tape was laid along each row of pumpkin seedlings on 25 Jun. The following fungicides were applied throughout the season to manage Phytophthora blight: Omega 24 fl oz/A on 12 Jul, 23 Jul and 6 Aug, Presidio 4 fl oz/A on 16 Jul, Orondis Ultra 7 fl oz/A on 30 Jul, 20 Aug and 3 Sep, Revus 8 fl oz/A on 14 Aug, and Ranman 2.75 fl oz/A on 27 Aug. No foliar or fruit symptoms of Phytophthora blight were seen.

Plots were three 15-ft rows spaced 68 in. apart with a 15-ft in-row untreated area between plots. The 15-ft area between plots was also planted to pumpkin. A randomized complete block design with four replications was used. The primary source of initial inoculum for powdery mildew in this area is considered to be long-distance wind-dispersed spores from affected plants. Treatments were applied six times on a preventive schedule using a tractor-mounted boom sprayer equipped with twinjet (TJ60-11004VS) nozzles spaced 17 in. apart that delivered 72 gal/A at 50 psi and 2.3 mph. Plants were inspected for powdery mildew symptoms on upper and lower leaf surfaces. Initially only old leaves were examined: 20 in each plot on 26 Jul and 15 on 2 Aug. Old, mid-aged and young leaves (usually 5 of each selected based on leaf physiological appearance and position in the canopy) were examined in each plot on 10, 16 and 30 Aug, and 7, 13 and 20 Sep. Powdery mildew spots were counted; severity was assessed by visual estimation of percent leaf area affected when spots could not be counted accurately because they had coalesced and/or were too numerous. Colony counts were converted to severity values using the conversion factor of 30 spots/leaf = 1% severity. Average severity for the entire canopy was calculated from the individual leaf assessments. Area under disease progress curve (AUDPC) values were calculated from 26 Jul through 13 Sep. AUDPC is a summation measure of severity over time. Defoliation, which was mainly due to powdery mildew, was assessed on 7, 13, 20 and 27 Sep; and 4 and 12 Oct. Quality of each fruit was evaluated in terms of handle (peduncle) condition for mature fruit without rot on 21 and 27 Sep; and 4 and 12 Oct. Handles were considered good if they were green, solid, and not rotting.

Results. Powdery mildew was first observed in this experiment on 26 Jul in 1 of the 36 plots on only 1 of the 720 leaves examined (0.14%). A biopesticide was applied 1 day later for the four treatments with biopesticides. This application was considered to be preventive because it was before symptoms would be found through routine scouting. The IPM action threshold recommended to growers for initiating fungicide applications is 1 out of 50 old leaves with

symptoms (2%). On 2 Aug symptoms were found in 31 of the 36 plots on 76 of 540 leaves examined (14%). The fifth application scheduled for 24 Aug was delayed by 2 days because of extensive rainfall (2.6 in.) with Hurricane Henri on 22-23 Aug. The last application was applied early due to rain forecast with remnants of Hurricane Ida starting late on 1 Sep (3.3 in. total). It is possible efficacy of treatments was affected by the impact of these storms on application timing, product residues, and/or disease development. Severity was low throughout August especially on upper leaf surfaces, which may be partly due to some contact activity for powdery mildew of the pesticides applied for Phytophthora blight and insect pests. On 30 Aug, one day before the sixth application, severity in the untreated control plots averaged 3% on upper leaf surfaces and 52% on lower surfaces (data not shown). Severity increased substantially over the next week reaching 51 and 66%, respectively, on 7 Sep. All four programs with biopesticides and conventional fungicides effectively suppressed powdery mildew on upper and lower leaf surfaces providing 98 to 100% and 84 to 90% control, respectively, based on AUDPC values. (Table 2). However, these treatments were not significantly better than the two parallel treatments with just the three applications of the conventional fungicides made on the same dates, documenting the excellent efficacy of Proline and Vivando. The grower standard conventional program with these fungicides applied weekly provided slightly but significantly better control than all other treatments based on AUDPC values for severity on lower leaf surfaces (99%). On 20 Sep, 2 wk after the last application, the grower standard was the only treatment still providing control on upper leaf surfaces (92%) and one of two providing control on lower surfaces (80%), documenting residual activity of Vivando (data not shown). Cevya was the least effective treatment for powdery mildew on lower leaf surfaces (67% control). All treatments had less defoliation than the control through 20 Sep; only the grower standard had significantly less through 12 Oct, 5 wks after the last application (not all data shown). All treatments had significantly better fruit quality on 27 Sep than the control; only the grower standard did on 12 Oct (Table 2). No phytotoxicity was observed.

Conclusions. This experiment documented that powdery mildew can be effectively managed with fungicide programs consisting of biopesticides applied in alternation with conventional fungicides thereby decreasing by half the number of applications of conventional fungicides; however, equally effective control was achieved with the two parallel treatments with just the three applications of the conventional fungicides made on the same dates, documenting the excellent efficacy of the two conventional fungicides used, Proline and Vivando. Two-week interval between applications of other conventional fungicides may not provide as good control, and there is concern about potential impact on selection of resistant strains of the pathogen.

This experiment also confirmed results from a similar experiment conducted in 2020 which also documented that Cevya, a new DMI (FRAC 3) fungicide is not as effective as anticipated based on its chemistry.

An additional finding is that powdery mildew can be controlled by the adjuvants in the fungicides for Phytophthora blight or insecticides that were being applied weekly to the planting. This is the most plausible explanation for limited development of powdery mildew on upper leaf surfaces during August when these products were being regularly applied. Efficacy of adjuvants for powdery mildew was documented through field experiments conducted previously in Arizona.

Acknowledgements: Project supported by registrants of products evaluated.

Table 2. Efficacy of biopesticides applied with conventional fungicides for powdery mildew in pumpkins.

Treatment and amount/A (application dates) ^y	Powdery mildew severity (%) ^z						Defoliation (%) ^z	Fruit quality (% good handles) ^z								
	Upper leaf surface		Lower leaf surface					20 Sep	27 Sep	12 Oct						
	13 Sep ^x	AUDPC ^x	7 Sep ^x	13 Sep	AUDPC ^x											
Untreated Control	61.6	a	575.6	a	65.5	a	73	a	1255.8	a	93	a	64	b	40	b
Sil-Matrix (1,3,5,7) Proline 5.7 fl oz (2,6) Vivando 15.4 fl oz (4)	0.7	cd	2.4	c	3.0	c	13	cd	121.0	c	18	bc	96	a	74	ab
Howler 5 lb (1,3,5,7) Proline 5.7 fl oz (2,6) Vivando 15.4 fl oz (4)	2.4	cd	7.4	c	3.8	c	19	cd	120.8	c	26	bc	97	a	67	ab
Theia 3 lb (1,3,5,7) Proline 5.7 fl oz (2,6) Vivando 15.4 fl oz (4)	2.6	cd	8.5	c	6.7	bc	20	cd	200.1	bc	28	bc	97	a	68	ab
Theia 3 lb (1,4,6,7) Proline 5.7 fl oz (2,5) Vivando 15.4 fl oz (3)	2.8	cd	10.5	bc	2.6	c	35	bc	172.6	c	33	bc	97	a	66	ab
Proline 5.7 fl oz (2,6) Vivando 15.4 fl oz (4)	3.8	bcd	12.0	bc	5.2	bc	14	cd	160.6	c	33	bc	97	a	69	ab
Proline 5.7 fl oz (2,5) Vivando 15.4 fl oz (3)	15.3	b	48.8	b	2.8	c	31	bc	136.6	c	38	bc	99	a	71	ab
Proline 5.7 fl oz (2,4,6) Vivando 15.4 fl oz (3,5,7)	0.0	d	0.2	c	0.7	c	1	d	14.1	d	10	c	100	a	92	a
Cevya 5 fl oz (2-7)	4.7	bc	17.1	bc	16.6	b	48	b	411.0	b	49	b	85	a	60	ab
<i>P-value (treatment)</i>	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.0146	

^zNumbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, P=0.05).

^yRate of formulated product/A. Application dates were 1=27 Jul, 2=3 Aug, 3=10 Aug, 4=17 Aug, 5=26 Aug, 6=31 Aug, and 7=7 Sep. All applied with Dyne-Amic at 0.38% v/v.

^xValues were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Fungicide Sensitivity of the Cucurbit Powdery Mildew Pathogen on Long Island

Fungicide resistance can be a major constraint to effectively managing powdery mildew in cucurbit crops. The most effective fungicides for this disease have mobility, enabling redistribution from deposition sites on upper leaf surfaces to the lower surfaces where powdery mildew develops best. They are more prone to the pathogen developing resistance because they have single-site modes of action. Resistance to FRAC code 1, 3, 7, 11, 13, and U6 fungicides has been documented in recent years on Long Island. In this study a seedling bioassay was used to obtain site-specific information about resistance in cucurbit powdery mildew pathogen populations.

Methods. Two bioassays were conducted in commercial and research plantings during the growing season. Pumpkin seeds were sown in 48-cell trays and kept in a growth chamber. Seedlings at about the cotyledon stage were transplanted individually to 4-in. pots and kept in a greenhouse. At approximately the 3-leaf stage, the growing tip with unexpanded leaves was removed, and then plants were sprayed to coverage with a fungicide dose. All fungicides were tested at their highest label rate, with some also tested at lower doses. Luna Privilege (FRAC code 7) was used rather than Luna Experience or Luna Sensation, which are labeled for cucurbit powdery mildew in upstate NY (none are permitted used on LI), because they contain a second active ingredient (FRAC code 3 and 11, respectively) which would confound results. Applications were made with a backpack sprayer using a TeeJet TP8004 flat fan nozzle delivering 50 gal/A operated at 55 psi. The next day the seedlings were organized into replications, each with one plant of each treatment plus two water-treated control plants. Each replication was placed in a different field location spot next to, but not touching leaves of, plants naturally affected by powdery mildew, with three to five replications in the same location.

In bioassay 1, treated on 10 Aug, four replications were put in a commercial spring planting of zucchini that had not been treated with any fungicides (Location A) and four replications were put in a research planting of zucchini that had not been treated with targeted fungicides for powdery mildew (Location B). In bioassay 2, treated on 13 Sep, five replications were put in two adjacent research plantings of pumpkin where biopesticides were tested alone and in programs with Proline and Vivando (Location C) and three replications were put in a commercial pumpkin planting that had been treated with Proline and Vivando (Location D). Locations A and D were different farms. Seedlings remained there for the rest of the day (6-8 hours) to be exposed to spores dispersed by wind, then the seedlings were returned to the greenhouse until symptoms developed. Seedlings regularly received water with 12-5-19 fertilizer applied to the top of the pot so leaves stayed dry and any new growth was removed. Severity of powdery mildew was assessed as percent coverage with symptoms on the upper surface of each leaf, 13 and 21 d after exposure to powdery mildew for bioassay 1 and 8 and 13 d after exposure to powdery mildew for bioassay 2. Values were averaged to obtain a single value per plant for analysis.

Results. Very few symptoms of powdery mildew developed on seedlings in bioassay 1, including on the water-treated control seedlings (Table 3), although symptoms were common on the plants at the locations used, in particular the commercial crop (Location A). The pathogen was likely suppressed by a period of hot weather during the first week after infection when temperatures in the greenhouse exceeded 100°F during the day. Results from bioassay 1 are somewhat similar to bioassay 2, suggesting when severity is very low some meaningful conclusions can be drawn but should not be considered definitive. In the late season bioassay (bioassay 2), Topsin M (FRAC code 1), Flint Extra (11), and Endura (7) were ineffective indicating a high frequency of resistance to these chemistries (Table 3). Resistance to these fungicides have been detected commonly in the past. Torino (U6) and Quintec (13) exhibited good efficacy at highest and below label rates (78-99% control). Resistance to these fungicides have been detected in the past associated with control failure. Resistance to Torino was detected

in the 2020 bioassay. These fungicides were not applied at any of the locations used. Rally (3), Luna Privilege (7), and Vivando (50) were very effective (96-100% control) at full and reduced doses, suggesting that applying Vivando and another FRAC 3 fungicide (Proline) at these locations did not result in selection for resistance to these chemistries. Luna Privilege and Vivando at all tested rates were more effective than Torino applied at labeled field rate based on 27 Aug assessments (13 days after field exposure).

Conclusions. Resistance was shown to remain common for FRAC code 1 and 11 fungicides, and also for the FRAC 7 active ingredient (AI) that is in Endura and Pristine. Luna fungicides (not permitted used on LI), which contain a FRAC 7 AI that binds differently to the target site in fungal pathogens, continue to be effective documenting that resistance impacting control has not been detected yet to this chemistry. Vivando (50) and Rally (3) were also highly effective. Other FRAC 3 (DMI) fungicides (Proline and Procure) are recommended because they have exhibited better control in season-long evaluations. While Quintec and Torino exhibited good efficacy, limited use is recommended due to resistance being detected in the past.

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Table 3. Fungicide sensitivity of the cucurbit powdery mildew pathogen on Long Island determined with a seedling bioassay.

Treatment and amount/A	Powdery mildew severity at 21, 8, and 13 days after field exposure (%) ^{z, y}									
	Bioassay 1				Bioassay 2					
	Location A		Location B		Location C				Location D	
	1 Sep		1 Sep		22 Sep		27 Sep		22 Sep	27 Sep
Water control	3.84	a	2.57	abc	49.5	a	82.71	a	15.96	44.67 a
Topsin M 8 oz	1.54	ab	4.09	a	59.6	a	88.89	a	20.99	53.27 a
Flint Extra 3.8 fl oz	1.10	ab	2.63	abc	51.7	a	82.28	a	18.56	38.19 a
Endura 6.5 oz	1.02	ab	3.51	ab	39.6	a	79.26	a	14.68	31.58 a
Endura 3.25 oz	0.98	ab	1.64	abcd	43.7	a	80.43	a	13.60	33.39 a
Torino 3.4 fl oz	0.40	b	1.04	abcd	3.8	b	18.04	b	2.05	7.92 b
Torino 1.7 fl oz	0.48	b	1.17	abcd						
Torino 0.85 fl oz	0.60	ab	0.61	abcd	2.6	b	10.35	bc	0.33	2.39 bc
Quintec 6 fl oz	0.21	b	0.36	abcd	1.0	b	7.70	bcd	0.09	1.56 bc
Quintec 3 fl oz	0.31	b	0.00	d						
Quintec 1.5 fl oz	0.17	b	0.20	bcd	3.0	b	15.84	b	0.25	1.81 bc
Quintec 0.75 fl oz	0.02	b	0.27	bcd						
Rally 5 oz	0.09	b	0.06	cd	0.5	b	1.17	de	0.67	0.98 bc
Rally 2.5 oz	0.10	b	0.47	abcd	0.6	b	2.96	cde	0.20	0.85 bc
Luna Privilege 6.84 fl oz					0.4	b	1.36	de	0.55	0.27 c
Luna Privilege 1.71 fl oz					0.2	b	1.18	de	0.00	0.48 c
Vivando 15.4 fl oz					0.5	b	0.66	e	0.00	0.04 c
Vivando 3.85 fl oz					0.6	b	0.69	e	0.07	0.03 c
<i>P-value (treatment)</i>	0.0003		<0.0001		<0.0001		<0.0001		<0.0001	<0.0001

^zNumbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Fungicide Sensitivity of Cucurbit Powdery Mildew Pathogen Isolates on LI in 2020

Fungicide resistance can be a major constraint to effectively managing powdery mildew in cucurbit crops. Fungicides that are most effective for managing powdery mildew (because they are mobile and thus can redistribute from where deposited on upper leaf surfaces to the lower surface where powdery mildew develops best) are also more prone to the pathogen developing resistance (because they typically have single site mode of action). The pathogen, has a long history of developing resistance, being the first pathogen to have been documented to have done so in the U.S. Resistance to Benlate (FRAC Code 1) was detected in 1967. Since then, resistance has been documented to Bayleton (first Code 3 fungicide), Quadris (11), Pristine and Endura (7), Quintec (13), and Torino (U6). Often occurrence of resistant isolates has been associated with control failure in fungicide evaluations conducted on field-grown plants. Also, newer FRAC 3 fungicides (e.g. Proline and Procure) are inherently more active than Bayleton.

The objective of this study was to determine fungicide sensitivity of pathogen isolates (i.e. individuals) by testing them in the laboratory on treated leaf disks. Isolates of the powdery mildew fungus were collected on 15 September 2020 from 2 commercial pumpkin fields in eastern NY north of Albany, on 25 September from 2 commercial pumpkin fields on Long Island, and on 28 September from 2 research fields of pumpkin and acorn squash at LIHREC. The pumpkin one was the fungicide efficacy experiment in the previous report. The squash one was the fungicide-treated acorn squash variety experiment in a report below. The isolates were collected near the end of the growing season after fungicides had been applied for powdery mildew. Isolates were maintained on leaf tissue on agar media in Petri dishes (culture plates) until tested in 2021. 57 isolates were tested.

Methods. For the leaf disk bioassay, pumpkin seedlings at the cotyledon leaf stage (about seven-days-old) were sprayed with various fungicide doses in a laboratory fume hood, after drying for about an hour the treated plants were returned to a growth chamber overnight, then disks were cut from the cotyledons and placed on water agar in sectioned Petri plates. Each plate has four sections thus there were three treatments per plate plus a nontreated control. Each plate was used to test one isolate. Five disks with the same treatment were placed in each section. Disks were inoculated by transferring spores from culture plates to each disk center. Then plates were kept in a growth chamber at 72F under constant light. Amount of pathogen growth on the disks was assessed after 10 and 14 days of incubation when the control treatment usually had good growth of the pathogen, with white sporulating pathogen growth covering an average of about 50% of leaf disk area by 14 days. The percent leaf disk area with symptoms of powdery mildew was recorded for each disk and averaged for each treatment. An isolate was considered insensitive (resistant) to a particular fungicide concentration if it was able to grow and produce spores on at least half of the disks. Due to limitations in the number of isolates and fungicide doses that can be done in each bioassay, the procedure was conducted multiple times over many weeks to obtain information on sensitivity to several fungicides.

Results. As in 2018 and 2019, there were isolates resistant to 3 chemistries: Endura (FRAC 7), Quintec (13), and Torino (U6)(Table 4). Notably, all isolates with resistance to Quintec were resistant to all 3 of these chemically different fungicides. They were from the two plantings where this fungicide was applied (10 isolates from a commercial planting in eastern NY and 1 from a research planting on LI) suggesting selection for resistance to Quintec from its use in these plantings and also that only multi-fungicide resistant isolates were present. There were isolates resistant only to Torino (23%) of these 3 chemistries and isolates resistant only to

Endura (21%), but no isolates resistant to both Torino and Endura or resistant only to Quintec. All but 1 of the 13 isolates determined to be resistant only to Torino were obtained from LI, while all but 1 of the 12 isolates determined to be resistant only to Endura were obtained from eastern NY, suggesting regional differences in the pathogen populations, perhaps reflecting local fungicide use although Torino was not applied in any of the LI plantings samples and no FRAC 7 fungicides were applied in the eastern NY commercial plantings. Control was poor to fair in these which is not surprising considering the frequency of resistant isolates. No resistance to Endura, Quintec, or Torino was found in the commercial field on LI where Vivando (50) and Proline (3) were applied to manage powdery mildew; control was excellent.

Resistance to QoI fungicides (FRAC 11) was detected in all isolates, similar to previous years. This trait is remaining in the pathogen population although these fungicides have not been recommended for many years. QoI resistance was first detected in NY in 2002.

38.6% of the 57 isolates were able to grow on leaf disks treated with 50 ppm Luna Privilege (re-named Velum Prime). This fungicide contains fluopyram, an SDHI (FRAC 7) fungicide that binds differently from boscalid, the active ingredient in Endura and Pristine, thus these fungicides do not exhibit full cross resistance. Luna Privilege is used in the bioassays because it contains only fluopyram whereas the fungicides with fluopyram that are labeled for cucurbit powdery mildew, Luna Experience and Luna Sensation, contain another active ingredient (FRAC 3 and 11, respectively). Isolates able to tolerate 50 ppm Luna Privilege are not considered resistant because this dose is well below the field rate and these isolates have not been associated with control failure in the field. Of the 22 isolates tolerating 50 ppm Luna Privilege, 16 were resistant to Endura and 6 were sensitive to Endura. 7 isolates resistant to Endura were sensitive to 50 ppm Luna Privilege. Some isolates collected in 2018 and 2019 were also able to tolerate 50 ppm Luna Privilege. These fungicides are registered in NY but not permitted used on LI.

All isolates were sensitive to Vivando (50 ppm).

Photographs of bioassay plates, a table with data from this study, and results from similar research conducted in previous years are posted at:

<https://blogs.cornell.edu/livepath/research/cucurbit-powdery-mildew-research/yearly-results-from-testing-isolates-for-fungicide-resistance-with-the-leaf-disk-bioassay/>

Conclusions. Detection of several isolates with resistance to Endura (FRAC 7), Quintec (13), and also Torino (U6) is alarming because applying any one of these fungicides will select for these multi-fungicide resistant isolates affecting efficacy of the other fungicides if applied subsequently. These isolates are likely also to be resistant to FRAC 1 and 11 fungicides considering how rare it has been to find an isolate sensitive to these (few isolates are now being tested because resistance has been detected very commonly for many years). Ability of the pathogen to develop resistance to multiple chemistries challenges the common resistance management strategy of applying different fungicides in alternation which is based on the premise that isolates cannot develop resistance to multiple fungicides and be fit.

Variation in frequency of resistance occurring among the plantings that reflects the fungicides that were used further documents that fungicide usage during a growing season can result in increased frequency of resistance in the pathogen population in a planting.

Acknowledgments: This project is partly supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch under NYC-153409.

Table 4. Occurrence of fungicide resistance in cucurbit powdery mildew isolates collected from commercial and research plantings in 2020.

Location	Powdery mildew fungicides used	# Isolates	Percent resistant isolates			
			Endura	Torino	Quintec	R to all ^z
Commercial pumpkin LI	Proline, Vivando, Proline + Vivando	7	0	0	0	0
Research field squash LI	Procure alt Vivando	11	0	36	0	0
Commercial pumpkin LI	Protectants only	8	13	63	0	0
Commercial pumpkin NY	Quintec	12	83	25	25	25
Commercial pumpkin NY	Quintec, Vivando, Quintec, Torino	12	92	67	58	58
Research field pumpkin LI	Fungicide evaluation (FRAC 3, 7, 13, 50) ^y	7	14	57	14	14
TOTAL		57	40.4	42.1	19.3	19.3

^z R = resistant.

^y Isolates collected from untreated plots and plots treated with Luna Privilege, Procure, Quintec, and/or Vivando

Evaluation of Powdery Mildew Resistant Varieties of Cantaloupe

The objective was to assess degree of resistance to powdery mildew of Edisto 47 and Trifecta by comparing them to a susceptible variety and two resistant varieties (Ambrosia and Sugar Rush) evaluated previously. Edisto 47 and Trifecta are also described as resistant to downy mildew, which was managed in the experiment by applying fungicides targeted to downy mildew to achieve focus on powdery mildew. A parallel experiment was conducted to assess their resistance to downy mildew (see following report).

Methods. The field was moldboard plowed on 6 Apr and urea fertilizer (46-0-0) was applied at 80 lb/A N on 7 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 14 Jun the mustard was flail-chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as is recommended, but the soil was moist. Controlled-release fertilizer (N-P-K, 19-10-9) at 525 lb/A (101 lb/A N) was broadcast over the bed area and incorporated on 30 Jun. Beds were formed with drip tape and covered with black plastic mulch on 30 Jun. Seeds were sown on 15 Jun in the greenhouse. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). Seedlings were placed outdoors to harden for a few days before transplanting on 6 Jul by hand into the holes in the beds. During the season, water was provided as needed via drip irrigation lines. Weeds were managed between the mulched beds by applying Strategy 3 pt/A, Sandea 0.5 oz/A, and Curbit EC 1 pt/A on 30 Jun with a tractor-sprayer and by hand weeding. Downy mildew and Phytophthora blight were managed by applying Presidio 4 fl oz/A on 16 Jul, Omega 24 fl oz/A on 23 Jul, Orondis Ultra 7 fl oz/A on 30 Jul, 20 Aug and 3 Sep, Revus 8 fl oz/A on 14 Aug, and Ranman 2.75 fl oz/A on 27 Aug.

Plots were three 8-ft rows spaced 68 in. apart with 9 plants per plot at 2-ft spacing. The plots were 4 ft apart within the row initially until plants began to vine, partly filling the area. Vines were moved as needed to maintain plot separation. A randomized complete block design with four replications was used. The primary source of initial inoculum of powdery mildew in this area is considered to be long-distance wind-dispersed spores from affected plants. Plots were inspected for powdery mildew symptoms on upper and lower leaf surfaces on 4, 12, 18, 26 and 31 Aug; and 8 Sep. For the first two assessments, 20 older leaves were rated in each plot starting with plots of the susceptible variety. These were the only plots examined on 4 Aug because no symptoms were found. For the remaining assessments, 5 leaves of young, mid-aged, and old leaves (selected based on leaf physiological appearance and position in the canopy) were rated for a total of 15 leaves in each plot. Powdery mildew spots were counted, or severity was assessed by visual estimation of percent leaf area affected when spots could not be counted accurately because they had coalesced and/or were too numerous. Colony counts were converted to severity values using the conversion factor of 10 spots/leaf = 1% severity. Average severity for the entire canopy was calculated from the individual leaf assessments. Area under disease progress curve (AUDPC) values were calculated from 12 Aug through 31 Aug. AUDPC is a summation measure of severity over time. Ripe fruit were harvested and rotten fruit were counted on 3, 8, and 14 Sep. Refractometer was used to measure sugar content (Brix) of one fruit per plot on 3 and 8 Sep. Fruit appearance, taste, texture, and marketability were rated by CCE and LIHREC staff plus Cornell Gardeners on a 1 (poor) to 5 (excellent) scale as interpreted by the rater. All remaining fruit were counted on 21 Sep.

Results. Powdery mildew was first observed on 12 Aug in three plots of Hales Best and a plot of Edisto 47; no symptoms were found on 4 Aug. Severity was low throughout August especially on upper leaf surfaces, which may be partly due to some contact activity for powdery mildew from the fungicides applied for downy mildew. Severity did not differ significantly among the four resistant varieties. Disease severity on Sugar Rush and Trifecta was significantly less than on the susceptible variety, Hales Best (Table 5). Ambrosia and Edisto 47 were substantially but not significantly less severely affected. Lack of significance is due to considerably more powdery mildew developing in plots of these varieties in replication one. All resistant varieties had significantly lower AUDPC values than Hales Best when the data was analyzed without replication one (0.24-0.98 vs 98.9; $P=<0.014$). Results from this study support the conclusion that Ambrosia is resistant to powdery mildew which was reached from results of the variety evaluation conducted in 2020 in which Ambrosia was used as the susceptible variety. There are differing claims for resistance for this variety among seed catalogues. Edisto 47 had the least defoliation on 8 Sep, but not significantly less than Ambrosia and Trifecta (Table 5). Ambrosia and Edisto 47 produced significantly larger (heavier) fruit than the other varieties (Table 5). Fruit of the resistant varieties all had significantly higher sugar content (Brix values) than Hales Best (Table 5). Trifecta rated highest (Table 6).

Conclusions. The cantaloupe varieties Trifecta and Edisto 47 exhibited excellent control of powdery mildew, yield, and fruit quality (sugar content); all similar to Sugar Rush, another powdery mildew resistant variety. Trifecta and Edisto 47 are also resistant to downy mildew (see following report). Size of their fruit were significantly different thereby fulfilling different market needs. Ambrosia was confirmed to be resistant.

An additional finding is that powdery mildew can be controlled by the adjuvants in the fungicides for downy mildew and Phytophthora blight or insecticides that were being applied weekly to the planting. This is the most plausible explanation for limited development of powdery mildew on upper leaf surfaces. Efficacy of adjuvants for powdery mildew was documented through field experiments conducted previously in Arizona.

Acknowledgements: Project funded by the Friends of Long Island Horticulture Grant Program and The National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch under NYC-153409.

Table 5. Ability to suppress powdery mildew, yield, and fruit quality of resistant varieties of cantaloupe.

Variety	Powdery mildew severity of leaves (%) ^z				Defoliation (%) ^z	Yield and fruit quality ^z		
	Upper surface	Lower leaf surface				# Fruit/plant	lb/fruit	Brix
	AUDPC	31 Aug ^y	AUDPC ^y	8 Sep ^x				
Hales Best (susceptible)	0.015	12.6 a	69.0 a	32	84 a	4.3 a	6.3 b	8.7 b
Ambrosia	0.000	1.2 ab	3.5 ab	10	34 b	4.2 a	9.3 a	12.5 a
Sugar Rush	0.000	0.1 b	0.6 b	--	92 a	3.3 b	6.5 b	13.1 a
Edisto 47	0.021	0.7 ab	3.1 ab	16	15 b	3.6 ab	9.6 a	13.2 a
Trifecta	0.000	0.4 ab	1.1 b	13	44 b	4.0 ab	6.8 b	12.9 a
<i>P-value (treatment)</i>	0.4099	0.025	0.0308	0.5772	<0.0001	0.0045	<0.0001	0.0085

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

^x All plots of Sugar Rush and two plots of Hales Best were omitted due to too few leaves being alive in these plots at this assessment.

Table 6. Average ratings for fruit of susceptible and resistant varieties of cantaloupe evaluated on a 1 (poor) to 5 (excellent) scale for several parameters by 11-31 people. Varieties are listed based on overall average and percentage of raters who indicated they would buy the variety. Comments made by the raters follow.

Variety	Size	Shape	Appearance		Taste	Texture	Average	Would you buy?	No. raters
			External	Internal					
Hales Best (susceptible)	3.7	3.4	3.3	3.2	2.8	3.2	3.3	47%	19
Edisto 47	4.6	4.2	4.3	3.6	3.1	3.2	3.8	36%	11
Sugar Rush	3.8	3.7	3.2	4.1	3.7	4.0	3.7	67%	26
Ambrosia	4.5	4.3	4.3	3.9	3.4	3.5	4.0	69%	28
Trifecta	3.7	4.1	3.8	4.7	4.2	4.2	4.1	83%	31

Variety	Comments ^z
Hales Best	wonderful smell, soft, not much flavor (2), not very sweet (3), good netting, pale orange flesh, internal rind light green, internal rind yellow, cavity too large, oblong
Edisto 47	favorite, notes of sugar snap pea, juicy, earthy taste (2), tastes like pumpkin, green rind, defined netting, wonderful smell, moderate cavity size, too orange
Sugar Rush	favorite (2), sweet, firm flesh (2), inside beautiful and delicious, 2nd favorite flavor, sweet, yum, not sweet, good orange flesh color, green rind edge inside, outside ugly with lots of issues, small cavity
Ambrosia	very good, sweet (2), good flavor (2), good taste, terrible taste, floral notes, wonderful smell, firm, softer, flesh isn't appealing, nice rind, pale orange flesh and light green rind, good appearance
Trifecta	best, good flavor, sweet, very good, far superior in taste + appearance + texture, not the best taste, not sweet, did not taste like cantaloupe, wonderful smell, ripe taste but unripe texture, firm flesh (3), hard texture, nice internal color, good sutures, perfectly round, good dark orange flesh and deep green rind, moderate sized cavity, rind thicker than others, too orange, small

^z Numbers in parentheses refer to number of raters who made the same comment.

Evaluation of Downy Mildew Resistant Varieties of Cantaloupe

The objective was to assess degree of resistance to downy mildew of Edisto 47 and Trifecta by comparing them to two susceptible varieties (Hales Best and Sugar Rush). Edisto 47 and Trifecta are also described as resistant to powdery mildew, which was managed in the experiment by applying fungicides targeted to powdery mildew to achieve focus on downy mildew. A parallel experiment was conducted to assess their resistance to powdery mildew (see previous report).

Methods. The field was moldboard plowed on 6 Apr and urea fertilizer (46-0-0) was applied at 80 lb/A N on 7 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 14 Jun the mustard was flail-chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as is recommended, but the soil was moist. Controlled-release fertilizer (N-P-K, 19-10-9) at 525 lb/A (101 lb/A N) was broadcast over the bed area and incorporated on 13 Jul. Beds were formed with drip tape and covered with black plastic mulch on 13 Jul. Seeds were sown on 28 Jun in the greenhouse. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). Seedlings were placed outdoors to harden for a few days before transplanting on 19 Jul by hand into the holes in the beds. During the season, water was provided as needed via drip irrigation lines. Weeds were managed between the mulched beds by applying Strategy 3 pt/A, Sandea 0.5 oz/A, and Curbit EC 1 pt/A on 14 Jul with a tractor-sprayer and by hand weeding. Powdery mildew was controlled by applying Procure 8 fl oz/A on 20 Aug and 7 Sep, and Vivando 15 fl oz/A on 27 Aug.

Plots were three 8-ft rows spaced 68 in. apart with 9 plants per plot at 2-ft spacing. The plots were 4 ft apart within the row initially until plants began to vine, partly filling the area. Vines were moved as needed to maintain plot separation. A randomized complete block design with four replications was used. The primary source of initial inoculum of downy mildew in this area is long-distance wind-dispersed spores from affected plants. Downy mildew severity was assessed weekly by estimating incidence of symptomatic leaves in each plot and rating severity on nine representative affected leaves. Canopy severity was calculated by multiplying incidence by average severity. Area under disease progress curve (AUDPC) values were calculated from 4 Aug through 8 Sep. AUDPC is a summation measure of severity over time. All fruit were counted on 21 Sep.

Results. Symptoms were first observed on 4 Aug, 16 days after transplanting. There were no significant differences in downy mildew incidence or severity between the two susceptible varieties. There were significant differences between the resistant and susceptible varieties starting with the third assessment on 20 Aug (Table 7). There was significantly less defoliation in plots of the resistant varieties than plots of the susceptible varieties on 8 Sep and plots of Hales Best on 22 Sep (data not shown). There were no significant differences between the resistant varieties. Control of downy mildew achieved was 47% for Edisto 47 and 52% for Trifecta based on AUDPC values for canopy severity relative to average value for the susceptible varieties. There were no significant differences among the four varieties in quantity of fruit produced indicating similar yielding ability (data not shown); however, the impact of downy mildew on foliage health can result in reduced fruit quality (not assessed). Yield and fruit quality were assessed in another experiment with these varieties (see previous report).

Conclusions. The cantaloupe varieties Trifecta and Edisto 47 exhibited good control of downy mildew. Trifecta and Edisto 47 are also resistant to powdery mildew (see previous report).

Acknowledgements: Project funded by the Friends of Long Island Horticulture Grant Program and The National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch under NYC-153409.

Table 7. Ability to suppress downy mildew of resistant varieties of cantaloupe.

Variety (reaction to downy mildew)	Downy mildew occurrence ^z						Defoliation (%) ^z
	Incidence of symptomatic leaves (%)			Canopy severity (%)			
	20 Aug	8 Sep	AUDPC	20 Aug	8 Sep	AUDPC ^y	
Hales Best (susceptible)	23.8 ab	93 a	1597 ab	4.9 ab	22 a	431 a	39 a
Sugar Rush (susceptible)	30.0 a	94 a	1652 a	6.9 a	23 a	446 a	28 a
Edisto 47 (resistant)	17.5 b	78 b	1309 c	2.7 b	9 b	230 b	6 b
Trifecta (resistant)	18.0 b	85 ab	1441 bc	3.0 b	11 b	211 b	1 b
<i>P-value (treatment)</i>	0.0243	0.0011	0.0003	0.0199	0.0003	<0.0001	<0.0001

^z Numbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Evaluation of Downy Mildew Resistant Varieties of Cucumber

The objective was to compare the new variety Brickyard and TSX-CU231AS, an experimental variety from Tokita, to Bristol and DMR401, both of which exhibited good suppression in previous variety evaluation, as well as to the susceptible variety Speedway.

Methods. The field was moldboard plowed on 6 Apr and urea fertilizer (46-0-0) was applied at 80 lb/A N on 7 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 14 Jun the mustard was flail chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as usually done, but the soil was moist. Controlled-release fertilizer (N-P-K, 19-10-9) at 525 lb/A (101 lb/A N) was broadcast over the bed area and incorporated on 13 Jul. Beds were formed with drip tape and covered with black plastic mulch on 13 Jul. Seeds were sown on 28 Jun in the greenhouse. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). Seedlings were placed outdoors to harden for a few days before transplanting on 19 Jul by hand into the holes in the beds. During the season, water was provided as needed via drip irrigation lines. Weeds were managed between the mulched beds by applying Strategy 3 pt/A, Sandea 0.5 oz/A, and Curbit EC 1 pt/A on 14 Jul with a tractor-sprayer and by hand weeding.

Plots were three 8-ft rows spaced 68 in. apart with 9 plants per plot at 2-ft spacing. The plots were 4 ft apart within the row initially until plants began to vine, partly filling the area. Vines were moved as needed to maintain plot separation. A randomized complete block design with four replications was used. No fungicides were applied. The primary source of initial inoculum of downy mildew in this area is long-distance wind-dispersed spores from affected plants. Downy mildew occurrence was assessed weekly by estimating incidence of symptomatic leaves in each plot and rating severity on nine representative affected leaves. Canopy severity was calculated by multiplying incidence by average severity. Area under disease progress curve (AUDPC) values were calculated from 30 Jul through 31 Aug. AUDPC is a summation measure of severity over time. Defoliation, which was mainly due to downy mildew, was assessed on 31 Aug and 8, 14, and 22 Sep. Fruit were harvested, counted and weighed on 13, 16, 24 and 31 Aug; and 10, 13 and 21 Sep. Mis-shaped fruit but not over-sized fruit were considered unmarketable.

Results. Downy mildew symptoms were first observed in one plot of the susceptible variety Speedway on 30 Jul, just 11 days after transplanting. All plots were found to be affected 4 days later at the next assessment. Downy mildew severity and incidence of affected leaves for the resistant varieties at all ratings were numerically lower, and usually significantly lower, than for Speedway (Table 8). TSX-CU231AS and DMR401 exhibited the best suppression of downy mildew throughout the season and least defoliation on 8 Sep. For some variables they were significantly better than both Bristol and Brickyard. Brickyard was better than Bristol based on AUDPC values and 20 Aug ratings (data not shown). Control of downy mildew achieved based on AUDPC values for canopy severity was 57% for Bristol, 76% for Brickyard, 87% for TSX-CU231AS, and 94% for DMR401. TSX-CU231AS and DMR401 produced more fruit than the other resistant varieties; all four produced more fruit than Speedway (Table 9). Fruit of TSX-CU231AS received the highest average for all ratings for fruit quality (Table 10).

Conclusions. All resistant varieties exhibited good to excellent control of downy mildew, especially considering how soon after transplanting the disease started to develop. The 3 newest varieties were better than Bristol. TSX-CU231AS and DMR401 yielded the most.

Acknowledgements: Project funded by the Friends of Long Island Horticulture Grant Program and The National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch under NYC-153409.

Table 8. Ability to suppress downy mildew of resistant varieties of cucumber.

Variety	Downy mildew occurrence ^z						
	Incidence of symptomatic leaves (%)			Canopy severity (%) ^y			
	4 Aug ^y	26 Aug	AUDPC ^y	4 Aug	12 Aug	26 Aug	AUDPC
Speedway (susceptible)	21.5 a	83 a	1611 a	2.16 a	18 a	58 a	867 a
Bristol	7.3 ab	39 b	1062 b	0.26 ab	13 ab	13 b	371 b
Brickyard	4.4 b	39 b	848 c	0.08 b	8 abc	9 bc	211 c
TSX-CU231AS (experimental)	3.9 b	24 c	457 d	0.06 b	6 bc	7 c	109 d
DMR 401	5.7 b	9 d	366 d	0.09 b	3 c	2 d	55 d
<i>P-value (treatment)</i>	0.005	<0.0001	<0.0001	0.0093	0.0005	<0.0001	<0.0001

^z Numbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Table 9. Impact of downy mildew suppression on defoliation and yield in cucumber resistant varieties.

Variety	Defoliation (%) ^z		Marketable fruit ^z			Fruit/plant ^z	
	31 Aug ^y	8 Sep	%	lb/plant ^x	oz/fruit	harvest 1 + 2	all harvests
Speedway (susceptible)	17.0 a	91 a	67 ab	2.3 c	7.6 b	2.0 ab	7.4 c
Bristol	4.3 b	71 a	70 ab	4.9 b	9.4 a	2.6 a	11.7 b
Brickyard	3.4 b	66 a	76 a	5.1 b	9.3 a	1.7 ab	11.6 b
TSX-CU231AS (experimental)	0.5 b	40 b	62 b	6.8 a	9.6 a	1.4 ab	18.4 a
DMR 401	1.2 b	31 b	63 b	7.1 a	8.8 ab	0.8 b	20.4 a
<i>P-value (treatment)</i>	0.0001	<0.0001	0.0141	<0.0001	0.017	0.0065	<0.0001

^z Numbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

^x Fruit that became over-sized because of extended time between harvests was not weighed. Yield per plant was estimated by multiplying average weight of marketable-sized fruit by number of fruit with marketable shape (straight and even).

Table 10. Average ratings for fruit of susceptible and downy mildew resistant varieties of cucumber evaluated on a 1 (poor) to 5 (excellent) scale for several parameters by 18 people. Varieties are listed based on overall average rating. Comments made by the raters follow.

Variety	Size	Shape	Appearance		Taste	Texture	Average	Would you buy?
			External	Internal				
Speedway (susceptible)	3.9	4.1	3.9	4.4	3.7	4.3	4.05	89%
Brickyard	4.2	4.2	3.8	4.5	3.6	4.1	4.06	61%
Bristol	4.3	4.1	4.1	4.0	3.8	4.3	4.11	83%
DMR401	4.4	4.5	4.1	4.2	3.7	4.1	4.17	78%
TSX-CU231AS	4.3	4.4	4.4	4.3	3.9	4.1	4.24	71%

Variety	Comments ^z
Speedway	most "cucumber-like" flavor, great but tart, a little sour (2), smaller seeds, sour, softest, very small
Brickyard	not as flavorful as #1, gross, hard on teeth, sour taste, mushy, very seedy, slightly bitter, big seeds
Bristol	really good crunch and taste, sweetest, too crunchy, bland, slightly bitter (2), big seeds, crunchy, sweeter, space throughout center, small seeds, curved, middle looks smaller
DMR401	best so far, most flavor, good crunch (2), good cucumber taste, good, tastes similar to Brickyard, smaller seeds, slightly bitter, bad texture, great color, very white inside
TSX-CU231AS	crunchiest, good crunch, most flavorful, a little sweet, loved it, sour taste, gross, looks weird, sweet but not in a good way, very seedy, a little bitter, space throughout center

^z Numbers in parentheses refer to number of raters who made the same comment.

Fungicide Sensitivity of the Cucurbit Downy Mildew Pathogen on Long Island

A seedling bioassay was used to examine fungicide sensitivity in the local cucurbit downy mildew pathogen population. The variety used was selected because of its resistance to powdery mildew and susceptibility to downy mildew.

Methods. Seeds were sown in 48-cell trays on 12 Jul, 29 Jul, and 13 Aug for three bioassays. They were kept in a growth chamber until 26 Jul, 6 Aug, and 24 Aug when they were moved to a greenhouse and the seedlings were transplanted to 4-in. pots. At approximately the 3-leaf stage, the seedlings were prepared for treatment by removing the growing tip with unexpanded leaves and then sprayed to coverage with one of 11 fungicides at full label rates on 10 Aug, 7 Sep, and 13 Sep. Technical grade zoxamide was used rather than one of the formulated products labeled for cucurbit downy mildew, Gavel and Zing!, because they contain a second active ingredient. Similarly, Orondis Gold 200 was used instead of Orondis Opti or Orondis Ultra to determine sensitivity to oxathiapiprolin. Rates used for zoxamide and Orondis Gold 200 were selected to apply the same amount of active ingredient as in the labeled products. Applications were made with a backpack sprayer using a TeeJet TP8004 flat fan nozzle delivering 50 gal/A operated at 55 psi. The next day the seedlings were organized into replications, each with one plant of each treatment plus two water-treated control plants. Each replication was placed in a different field location spot next to, but not touching the leaves of, plants naturally affected by downy mildew.

In bioassay 1, treated on 10 Aug, four replications of seedlings were put in a commercial planting that had not been treated with fungicides (Location A) and six replications were put in research plantings next to plants that were untreated (Location B). Seedlings for bioassays 2 and 3 were put in research plantings next to untreated plants (Location C, which was similar to B) and in an experiment where Orondis Ultra, Ranman, and Curzate had been applied (Location D). Seedlings were left there for 1-2 days for infection to occur, then the plants were moved into a greenhouse until symptoms developed. Severity was assessed three times at 5 or 6, 7 or 8, and 11 or 12 days after the first night-time infection period. Percent leaf coverage with visible symptoms was estimated for each leaf of each plant, and values were averaged to obtain a single value per plant for analysis.

Results. Water-treated control seedlings in bioassay 1 became substantially more severely affected by downy mildew than those in bioassays 2 and 3 (Table 11). Bioassay 2 seedlings were outside exposed to natural inoculum for only one day because of rain that was not forecast at the time the bioassay was started. However, weather station at the Long Island Horticultural Research and Extension Center recorded humid conditions all nights that plants were outside which should have provided favorable conditions for infection. Relative humidity was above 85%, and usually above 90%, for 12 and 9 hr for bioassay 1, 11 hr for bioassay 2 which was the only period that leaf wetness was also recorded, and 14 and 16 hr for bioassay 3. Results from bioassays 2 and 3 are somewhat similar to bioassay 1, suggesting when severity is very low some meaningful conclusions can be drawn but should not be considered definitive. Conclusions about efficacy were drawn from bioassay 1 results. They were similar for the three ratings. Severity was much lower at the first rating, 5 days after first infection period (data not shown), than at 7 and 11 days. Revus (FRAC code 40), Quadris (11), and Presidio (43) were deemed ineffective because for most ratings downy mildew severity was not significantly or substantially different from the control. Omega (29), Orondis Gold 200 (49), and Ranman (21) were the most effective (94-100% control based on

the 23 Aug rating). Zoxamide (22) was equally effective at location A but not B (95 and 86% control). Previcur Flex (28) was similar in efficacy to zoxamide but not as efficacious as the three most effective fungicides (86 and 88% control). Forum (40), Elumin (22), and Curzate (27) were moderately effective (48-78% control). Elumin is not registered for use in NY, but it is in other states participating in this project. In addition to results from bioassay 1 being more definitive than those from bioassays 2 and 3, they were also most useful being obtained at a time during the growing season that growers could use the results to decide what fungicides to use for subsequent applications. Results did not differ substantially from previous years (2017-2019). These results are posted at <https://blogs.cornell.edu/livepath/research/cucurbit-downy-mildew/#3>.

Conclusions. The bioassays have provided valuable information about efficacy of fungicides to guide recommendations to growers about what targeted conventional fungicides to use to control downy mildew. The most effective fungicides, which are also effective and labeled for Phytophthora blight, are Omega, Orondis Ultra, and Ranman. Another good choice is Gavel or Zing! when just managing downy mildew; these both have zoxamide but only Gavel is labeled for both diseases. While not quite as effective, Previcur Flex and Curzate could be included in a fungicide program when only downy mildew is occurring, especially when the program includes the most effective products; they are not labeled for Phytophthora blight. Similarly, Forum could be included in a program with the most effective products when also managing Phytophthora blight.

Revus and Presidio, which were not effective in the bioassay, likely will be effective for downy mildew on squashes and pumpkin. This is because the pathogen affecting these crops is different from the one affecting cantaloupe and cucumber, and resistant pathogen isolates have been detected on cucumber, which was the plant used in this bioassay.

Acknowledgements: Project funded by the USDA AMS Specialty Crop Multi-State Program.

Table 11. Fungicide sensitivity of the cucurbit downy mildew pathogen on Long Island determined with a seedling bioassay.

Treatment and rate	Downy mildew severity at 7, 11, 12, and 12 days after first nightly exposure (%) ^z										
	Bioassay 1				Bioassay 2 ^y				Bioassay 3 ^y		
	Location A ^y		Location B		Location C		Location D		Location C + D		
	19 Aug	23 Aug	19 Aug	23 Aug ^y	20 Sep	20 Sep	20 Sep	20 Sep	27 Sep		
Unsprayed control	49.5 a	59.9 a	53.7 a	47.7 a	3.04 a	1.04 ab			8.11 a		
Revus 8 fl oz/A	34.0 ab	43.9 ab	48.9 a	52.2 a	1.19 abc	0.01 c			2.29 bcd		
Quadris 15.5 fl oz/A	25.6 abc	34.6 b	37.1 abc	42.6 ab	1.98 ab	1.57 a			7.69 ab		
Presidio 4 fl oz/A	29.1 ab	36.5 ab	41.7 ab	36.1 abc	0.09 c	0.10 bc			5.11 abc		
Forum 6 fl oz/A	16.4 bcd	27.2 bc	27.7 bcd	24.8 bcd	0.72 bc	0.21 abc			2.06 bcd		
Elumin 8 fl oz/A	12.6 bcde	22.3 bcd	17.9 cde	19.8 cde	0.42 bc	0.01 c			1.61 cd		
Curzate 5 oz/A	7.3 cdef	12.9 cde	15.4 de	15.3 def	0.03 c	0.05 bc			0.15 d		
Previcur Flex 19.2 fl oz/A	6.1 def	8.5 de	3.8 e	5.9 fg	0.22 bc	0.23 abc			0.96 cd		
Zoxamide 400 ppm	1.0 fg	3.0 ef	3.1 e	6.8 ef	0.42 bc	0.25 abc			2.08 bcd		
Omega 24 fl oz/A	1.9 efg	3.9 ef	0.3 e	0.4 gh	0.04 c	0.01 c			0.17 d		
Orondis Gold 200 1.36 fl oz/A	0.2 fg	0.2 f	0.1 e	0.1 h	0.07 c	0.00 c			0.29 d		
Ranman 2.75 fl oz/A	0.0 g	0.0 f	0.0 e	0.0 h	0.06 c	0.23 abc			0.41 d		
<i>P-value (treatment)</i>	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			<0.0001		

^z Numbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Efficacy of Biopesticides for Managing Downy Mildew in Cucumber

The main objective was to evaluate recently developed biopesticides suitable for organic production.

Methods. The field was moldboard plowed on 6 Apr and urea fertilizer (46-0-0) was applied at 80 lb/A N on 7 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 14 Jun the mustard was flail chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as usually done, but the soil was moist. Controlled-release fertilizer (N-P-K, 19-10-9) at 525 lb/A (101 lb/A N) was broadcast over the bed area and incorporated on 13 Jul. Beds were formed with drip tape and covered with black plastic mulch on 13 Jul. Seeds were sown on 28 Jun in the greenhouse. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). All plants were placed outdoors to harden for a few days and then transplanted by hand into the holes in the beds on 15 Jul. During the season, water was provided as needed via drip irrigation lines. Weeds were managed between the mulched beds by covering the soil with landscape cloth and by hand weeding.

Plots were single 18-ft rows with 9 plants at 2-ft spacing. Rows were 4 ft apart. The plots were 6 ft apart within the row initially until plants began to vine partly filling the area. Vines were moved as needed to maintain plot separation. A randomized complete block design with four replications was used. Treatments were applied six times on a weekly schedule beginning on 28 Jul using a backpack boom sprayer equipped with one TwinJet (TJ60-8004VS) nozzle that delivered 31 gal/A at 55 psi and 2.2 mph. For the last three applications, two passes were made treating each plot side separately because plants had grown too large to obtain complete coverage with one pass. The primary source of initial inoculum of downy mildew in this area is long-distance wind-dispersed spores from affected plants. Downy mildew severity was assessed weekly by estimating incidence of symptomatic leaves in each plot and rating severity on nine representative affected leaves. Canopy severity was calculated by multiplying incidence by average severity. Area under disease progress curve (AUDPC) values were calculated from 30 Jul through 30 Aug. AUDPC is a summation measure of severity over time. Defoliation, which was due to downy mildew, was assessed on 24 and 30 Aug. Fruit were harvested and counted when time permitted (18 Aug, 24 Aug, and 27 Sep), rather than more frequently as fruit reached marketable size, because experiment focus was disease control. Misshaped fruit but not over-sized fruit were considered unmarketable.

Results. None of the treatments, including the grower standard copper fungicide (Kocide 3000-O), reduced the incidence of leaves with symptoms (data not shown), severity of symptoms on leaves (data not shown), canopy severity (not all data shown), or defoliation (Table 12). Lack of efficacy may be partly due to downy mildew having already started to develop in the experiment at the time of the first application, which is earlier than previous years. It was intended to have 1-2 preventive applications. Additionally, there was extensive rainfall (2.6 in.) with Hurricane Henri on 22-23 Aug. The last application was applied early due to rain forecast with remnants of Hurricane Ida starting late on 1 Sep (3.3 in. total). It is possible efficacy of treatments was affected by the impact of these storms on application timing, product residues, and/or disease development. No phytotoxicity was observed. There were few differences among treatments in yield. Number of fruit per plant was significantly greater in the Tril-21 treatment than the untreated control, Howler, and MBI-121 treatments, but not significantly

greater than the other treatments (Table 12). The Howler and Theia combination treatment resulted in the highest percentage of marketable fruit per plant, but was only significantly greater than Theia alone.

Conclusions. Inability to control downy mildew with any of the biopesticides tested and also copper documents how difficult it can be to control this disease, especially when it starts early in plant development, contact products are used, and conditions are very favorable.

Acknowledgements: Project was supported by the IR-4 Program.

Table 12. Efficacy of biopesticides for downy mildew in cucumber.

Treatment and rate (application dates) ^y	Canopy severity (%) ^z				Defoliation (%) ^z	Fruit/plant ^z			
	6 Aug ^x	17 Aug	30 Aug	AUDPC	30 Aug	No.	Marketable (%)		
Untreated Control	0.8	30	35	575	38	5.2	b	61	ab
Aviv 30 fl oz/100 gal (1-6) ^w	0.1	30	40	492	26	8.1	ab	66	ab
Aviv 30 fl oz/100 gal + Timorex ACT 35 fl oz/A (1-6) ^w	0.7	32	38	561	31	7.4	ab	67	ab
MBI-121 2 qt/A (1-6)	1.1	29	40	550	34	6.3	b	66	ab
Howler 5 lb/A (1-6) ^w	0.7	26	43	544	30	6.2	b	70	ab
Theia 3 lb/A (1-6) ^w	0.2	23	44	438	38	8.2	ab	56	b
Howler 5 lb/A (1, 3, 5) Theia 3 lb/A (2, 4, 6) ^w	1.5	27	46	536	28	7.6	ab	72	a
Tril-21 1% (1-6)	0.1	23	44	462	31	10.7	a	66	ab
Kocide 3000-O 1.25 lb/A (1-6)	0.1	25	34	445	33	8.2	ab	69	ab
<i>P-value (treatment)</i>	0.4475	0.4472	0.386	0.1617	0.6713	0.0026		0.057	

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Application dates were 1=28 Jul, 2=3 Aug, 3=11 Aug, 4=18 Aug, 5=25 Aug, and 6=31 Aug.

^x Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

^w Treatment applied with the nonionic surfactant Dyne-Amic at 0.38% v/v.

Efficacy of Biopesticides Applied with Conventional Fungicides for Managing Downy Mildew in Cucumber

The objective was to evaluate programs with biopesticides applied with or in place of conventional fungicides for some applications.

Methods. The field was moldboard plowed on 6 Apr and urea fertilizer (46-0-0) was applied at 80 lb/A N on 7 Apr. For management of Phytophthora blight, a mustard biofumigant cover crop (Rojo Caliente) was seeded at 10 lb/A by drilling on 9 Apr. On 14 Jun the mustard was flail chopped, immediately incorporated by disking, and followed by a cultipacker to seal the soil surface; the field could not be irrigated to initiate biofumigation as usually done, but soil was moist. Controlled-release fertilizer (N-P-K, 19-10-9) at 525 lb/A (101 lb/A N) was broadcast over the bed area and incorporated on 13 Jul. Beds were formed with drip tape and covered with black plastic mulch on 13 Jul. Seeds were sown on 28 Jun in the greenhouse. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). All plants were placed outdoors to harden for a few days and then transplanted by hand into the holes in the beds on 16 Jul. During the season, water was provided as needed via drip irrigation lines. Weeds were managed between the mulched beds by covering the soil with landscape cloth and by hand weeding.

Plots were single 18-ft rows with 9 plants at 2-ft spacing. Rows were 4 ft apart. The plots were 6 ft apart within the row initially until plants began to vine partly filling the area. Vines were moved as needed to maintain plot separation. A randomized complete block design with four replications was used. Treatments were applied seven times on a 7-day schedule beginning on 28 Jul using a backpack boom sprayer equipped with one TwinJet (TJ60-8004VS) nozzle that delivered 31 gal/A at 55 psi and 2.2 mph. For the last four applications, two passes were made treating each plot side separately because plants had grown too large to obtain complete coverage with one pass. The primary source of initial inoculum of downy mildew in this area is long-distance wind-dispersed spores from affected plants. Downy mildew severity was assessed weekly by estimating incidence of symptomatic leaves in each plot and rating severity on nine representative affected leaves. Canopy severity was calculated by multiplying incidence by average severity. Area under disease progress curve (AUDPC) values were calculated from 30 Jul through 7 Sep. AUDPC is a summation measure of severity over time. Defoliation, which was due to downy mildew, was assessed on 30 Aug, 7 Sep, and 22 Sep. Fruit were harvested and counted when time permitted (18 and 31 Aug; and 10 and 27 Sep), rather than more frequently as fruit reached marketable size, because experiment focus was disease control. Mis-shaped fruit but not over-sized fruit were considered unmarketable.

Results. Symptoms of downy mildew were first observed in this experiment in 2 of the 32 plots on 30 Jul, which was two days after the first application. All the treatments were effective based on canopy severity ratings and provided 69 – 95% control based on AUDPC values. Severity was numerically but not statistically lower for the programs with Howler or Theia applied in rotation with two conventional fungicides (Orondis Ultra and Ranman) on a 7-day schedule than similar programs with just these conventional fungicides applied on the same dates (14-day schedule) or with another conventional fungicide (Curzate) applied in place of the biopesticides (Table 13). Severity was numerically but not statistically lower for Ranman applied with the low rate of Timorex ACT than Ranman applied alone or with the high rate of Timorex ACT. All the treatments had numerically less defoliation than the control on 30 Aug, and most values were significantly lower. Impact of managing downy mildew on reducing

defoliation subsequently declined with only the Ranman alone and Ranman plus Timorex ACT treatments having significantly less defoliation than the control on 7 Sep and no significant differences on 22 Sep (data not shown). All treatments resulted in significantly more fruit per plant than the control and numerically more marketable fruit (Table 13). No phytotoxicity was observed.

Conclusions. While downy mildew was controlled with fungicide programs that included biopesticides applied in alternation with or combined with conventional fungicides, these treatments were not significantly better than treatments with just the conventional fungicides applied at the same time or the treatment consisting of a recommended conventional fungicide program with an alternation of products applied on a weekly schedule.

Acknowledgements: Project supported by registrants of products evaluated.

Table 13. Efficacy of biopesticides applied with conventional fungicides for downy mildew in cucumber.

Treatment and amount/A (application dates) ^y	Canopy severity (%) ^{z,x}				Defoliation (%) ^z	Fruit/plant ^z	
	17 Aug	30 Aug	7 Sep	AUDPC	30 Aug ^x	No.	Marketable (%)
Untreated control	30.7 a	45 a	38 a	846 a	39 a	8.2 c	66
Orondis Ultra 8 fl oz (1, 7)							
Howler 5 lb (2, 4, 6)							
Ranman 2.1 fl oz (3, 5)	1.2 b	14 bcd	12 bc	165 bcd	8 b	17.5 ab	75
Orondis Ultra 8 fl oz (1, 7)							
Theia 3 lb (2, 4, 6)							
Ranman 2.1 fl oz (3, 5)	0.4 b	12 bcd	11 bc	142 bcd	11 ab	16.0 ab	77
Orondis Ultra 8 fl oz (1, 7)							
Ranman 2.1 fl oz (3, 5)	1.6 b	21 ab	15 b	262 b	15 ab	15.0 b	74
Orondis Ultra 8 fl oz (1, 7)							
Ranman 2.1 fl oz (3, 5)							
Curzate 5 oz (2, 4, 6)	0.5 b	17 bc	16 b	199 bc	1 b	17.4 ab	73
Ranman 2.1 fl oz (1-7)	1.5 b	7 bcd	7 bc	104 bcd	5 b	20.5 a	75
Ranman 2.1 fl oz +							
Timorex ACT 13.5 fl oz (1-7)	0.7 b	3 d	3 c	41 d	2 b	19.5 ab	77
Ranman 2.1 fl oz +							
Timorex ACT 18 fl oz (1-7)	1.0 b	5 cd	6 bc	75 cd	2 b	20.8 a	72
<i>P-value (treatment)</i>	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	0.0834

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$)

^y Rate of formulated product/A. Application dates were 1=28 Jul, 2=3 Aug, 3=11 Aug, 4=18 Aug, 5=25 Aug, 6=31 Aug, and 7=7 Sep.
All applied with Dyne-Amic at 0.38% v/v.

^x Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Evaluation of an Experimental and Commercial Varieties of Sweet Basil Resistant to Downy Mildew

The objective was to evaluate ability to suppress downy mildew development of recently released resistant varieties of sweet basil, an experimental variety that has an additional novel gene for resistance, and two established resistant varieties that have been evaluated before. The new resistant varieties tested were bred to have the same resistance as varieties evaluated previously. There is concern about the pathogen's ability to evolve to be able to overcome resistance genes in these varieties.

Methods. The field was moldboard plowed on 29 May. Controlled-release fertilizer (N-P-K, 19-10-9) was broadcast at 525 lb/A (101 lb/A N) over the bed area and incorporated on 30 Jun. Beds were formed with drip tape and covered with black plastic mulch on 30 Jun. Weeds between mulched beds were managed by cultivating, covering the soil with landscape cloth, and by hand weeding. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). A late planting date was used for the experiment to increase the likelihood of downy mildew developing during the experiment. The primary source of initial inoculum in this area is considered to be sporangia dispersed by wind from infected plants potentially a long distance away. Basil for the experiment was seeded in trays in a greenhouse on 8 Jun. All plants were placed outdoors to harden for a few days and then transplanted in the field by hand on 7 Jul. No fungicides were applied.

A randomized complete block design with four replications was used. Each plot had 8 plants in 6-ft rows with 9-in. in-row plant spacing. The plots were 3 ft apart in the row. Downy mildew was assessed in all plots weekly from 13 Aug through 20 Sep, and then Prospera varieties only from 30 Sep through 15 Oct. Incidence of plants with symptoms (sporulation of the pathogen visible on the underside of leaves) was recorded and percentage of leaves per plant with symptoms was estimated for each plant in each plot. Area under disease progress curve (AUDPC) values were calculated from 13 Aug to 7 Sep. AUDPC is a summation measure of severity over time. Defoliation was assessed on 3 and 15 Sep for all plots, and 30 Sep, 5 Oct, and 15 Oct for Prospera varieties only. Results may have been impacted by storms, in particular remnants of Hurricane Henri on 22 Aug and Hurricane Ida on 2 Sep.

Results. Symptoms of downy mildew were first observed in this experiment on 13 Aug in 4 of the 36 plots; none were found on 23 Jul or 3 Aug. Very few leaves with downy mildew were observed on the Prospera varieties, Genesis 164 (an experimental variety related to Prospera with an additional gene for resistance), and Pesto Besto (Table 14). Similar results were obtained in 2020 with Prospera and Amazel, which was developed by the breeder of Pesto Besto. In contrast, although symptoms were first seen around the same time (17 Aug 2020), symptoms became more widespread on the Rutgers DMR varieties earlier in 2021 than in 2020, when incidence of affected leaves on 28 Aug was 89% on DiGenova and 0% on Rutgers Devotion DMR and also Rutgers Passion DMR. Symptoms did increase on the Rutgers varieties during Sep 2020. While incidence of affected leaves was high on these varieties in 2021, defoliation on 3 Sep was very low in contrast with the susceptible control reflecting differences in severity. However, a basil leaf with any amount of symptoms is unmarketable for fresh herbs. An integrated management program with fungicides applied to a Rutgers variety is expected to provide excellent control. Two major storms occurred: remnants of Hurricane Henri on 22-23 Aug (2.6 in. rain) and Hurricane Ida on 2 Sep (3.3 in.). Plant damage was evident on 3 Sep. Plants in some plots had too many broken branches to be able to rate the plot starting with the 15

Sep assessment (data not analyzed). The severely damaged plots were 3 of Prospera PS5, 2 of Pesto Besto and 1 of Prospera ILL2. The four Prospera varieties were examined on 30 Sep, 5 Oct, and 15 Oct to determine if more leaves would eventually become affected because there had been reports of downy mildew becoming severe on Prospera elsewhere in the northeast in 2021. No symptoms were found.

Conclusions. All of the resistant varieties tested provided control of downy mildew. The DMR Rutgers varieties were not as effective as in previous years suggesting the pathogen has evolved to partly overcome this resistance. There were a few reports of poor control with these in commercial plantings in 2021. There were also reports of downy mildew becoming severe on Prospera in a few commercial plantings in 2021. These varieties, and also Pesto Besto, exhibited excellent control as in past evaluations at LIHREC. A new pathogen strain has been detected in Israel able to overcome the single resistance gene in Prospera. Genesis 164 was tested because it has a newly discovered gene for resistance.

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Table 14. Evaluation of sweet basil varieties with resistance to downy mildew.

Variety	Downy mildew incidence (%) ^z								Defoliation (%) ^{z, y}
	Affected plants ^y				Affected leaves on affected plants				
	18 Aug	26 Aug	18 Aug ^y	26 Aug	7 Sep ^y	AUDPC ^y	3 Sep		
DiGenova (susceptible)	97 a	100 a	13.10 a	99.0 a	99.0 a	1679.4 a	94 a		
Rutgers Devotion DMR	23 ab	100 a	1.09 bc	64.7 b	43.4 b	907.3 b	4 b		
Rutgers Passion DMR	41 ab	100 a	6.22 ab	61.1 b	27.4 b	696.1 b	4 b		
Pesto Besto	8 b	1 b	0.23 bc	0.1 c	0.1 c	3.2 c	0 b		
Prospera ILL2	3 b	0 b	0.05 c	0.0 c	0.0 c	0.3 c	0 b		
Prospera CG1	1 b	0 b	0.03 c	0.0 c	0.0 c	0.2 c	0 b		
Prospera Compact PL4	1 b	0 b	0.03 c	0.0 c	0.0 c	0.2 c	0 b		
Prospera Compact PS5	3 b	2 b	0.04 c	0.1 c	0.3 c	1.3 c	0 b		
Genesis 164	2.3 b	0 b	0.03 c	0.0 c	0.0 c	2.3 c	0 b		
<i>P-value (variety)</i>	0.0007	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		

^zNumbers in each column with a letter in common are not significantly different from each other (Tukey's HSD, $P=0.05$).

^yValues were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

Evaluation of Biopesticides for Organic Management of Downy Mildew in Sweet Basil

The objective was to test biopesticides applied to a sweet basil variety bred to be resistant to downy mildew, forming integrated management programs. Organic products tested previously were ineffective when applied to susceptible and partially resistant varieties. Rutgers Passion DMR was selected because it exhibited good but not sufficient suppression of downy mildew in a variety evaluation in 2019, and some organic treatments tested on it in 2020 were effective. Biopesticides were tested individually and used in alternation with another biopesticide. All products tested are registered in NY and labeled for this use.

Methods. The field was moldboard plowed on 29 May. Controlled-release fertilizer (N-P-K, 19-10-9) was broadcast at 525 lb/A (101 lb/A N) over the bed area and incorporated on 30 Jun. Beds were formed with drip tape and covered with black plastic mulch on 30 Jun. Weeds between mulched beds were managed by cultivating, covering the soil with landscape cloth, and by hand weeding. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer (9-18-9). Basil for the experiment was seeded in trays in a greenhouse on 8 Jun. All plants were placed outdoors to harden for a few days and then transplanted in the field by hand on 7 Jul. A late planting date was used to increase the likelihood of downy mildew developing during the experiment. The primary source of initial inoculum in this area is considered to be sporangia dispersed by wind from infected plants potentially a long distance away.

A randomized complete block design with four replications was used. Each plot had 8 plants in 6-ft rows with 9-in. in-row plant spacing. The plots were 3 ft apart in the row. Fungicides were applied weekly over a 6-wk period, with a backpack CO₂-pressurized sprayer and hand-held boom with TJ60-8004EVS nozzle(s) operated at 55 psi and 2.3 mph. Applications 1-3 were made using a boom with a single nozzle delivering 32 gal/A. Starting with application 4, plants were large enough to use a boom with two drop nozzles directed to the side of plants as well as a nozzle delivering spray over the top of the plant that delivered 73 gal/A. Downy mildew was assessed in each plot weekly from 12 Aug through 14 Sep. Incidence of plants with symptoms (sporulation of the pathogen visible on the underside of leaves) was recorded and percentage of leaves per plant with symptoms was estimated for each plant in each plot. Area under disease progress curve (AUDPC) values were calculated from 12 Aug to 7 Sep.

Results. Symptoms of downy mildew were first observed at LIHREC on 3 Aug in an adjacent experiment and in this experiment on 12 Aug in 18 of the 24 plots. Three treatment applications had been made thus the planned preventive schedule was achieved. None of the treatments were effective. Based on AUDPC values, Rango and the program that included a copper fungicide had the lowest incidence of affected leaves, but these were not significantly different from other treatments including the control (Table 15). Lack of control was at least partly due to the fact the variety used did not suppress downy mildew as well in 2021 as in 2020 when incidence of leaves with symptoms in untreated control plots reached maximum of only 16% on 24 Sep and all treatments were effective, including the one with MBI-121 (containing the active ingredients in Regalia plus Stargus) alternated with EcoSwing plus Badge X2. Additionally, the fifth application scheduled for 25 Aug 2021 was delayed by 1 day because of extensive rainfall (2.6 in.) with Hurricane Henri on 22-23 Aug. And the last application was applied early due to rain forecast with remnants of Hurricane Ida starting late on 1 Sep (3.3 in. total). It is possible efficacy of treatments was affected by the impact of these storms on

application timing, product residues, and/or disease development. No phytotoxicity was observed.

Conclusions. Inability to control downy mildew with any of the biopesticide treatments tested likely is at least partly due to the resistant variety not providing the degree of suppression achieved in the past. Severity of downy mildew on leaves may have been reduced by these treatments. Only incidence of affected leaves was examined because there is no tolerance for any disease symptoms on basil being marketed for consumption as a fresh herb.

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Table 15. Efficacy of biopesticides for organic management of downy mildew in sweet basil.

Treatment and rate (application dates) ^y	Downy mildew incidence: affected leaves on affected plants (%) ^z					Defoliation (%) ^z	
	17 Aug ^x	25 Aug ^x	30 Aug	7 Sep	AUDPC	7 Sep	22 Sep
Untreated Control	4	23	62	45	767	2	39
MilStop 4 lb/100 gal (1-6)	5	25	65	48	810	1	40
MilStop 4 lb/100 gal (1,3,5) MilStop 3 lb/100 gal + Double Nickel 4 qt/100 gal (2,4,6)	6	28	60	40	799	2	36
Rango 1.25% v/v (1-6)	2	19	56	34	634	1	45
MBI-121 2 qt/A (1,3,5) EcoSwing 1 qt/A (2,4,6)	9	37	65	44	934	1	39
MBI-121 2 qt/A (1,3,5) EcoSwing 1 qt/A + Badge X2 0.75 lb/A (2,4,6) ^w	5	19	59	26	663	1	33
<i>P-value (treatment)</i>	0.3047	0.2839	0.6428	0.0747	0.07	0.7764	0.7037

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Application dates were 1=28 Jul, 2=4 Aug, 3=11 Aug, 4=18 Aug, 5=26 Aug, 6=31 Aug.

^x Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

^w In week 2, Cueva 1 gal/A was applied instead of Badge X2.

Evaluation of Conventional Fungicides for Downy Mildew in Sweet Basil

The main objective was to evaluate the efficacy and crop safety of a new fungicide, fluoxapiprolin, which is closely related to oxathiapiprolin, the active ingredient in Orondis fungicides. Both are classified as FRAC code 49. The work was done to support its registration for this use. It will be registered as a solo active ingredient in contrast with oxathiapiprolin, which is formulated with another active ingredient. This new fungicide will be labeled for field and greenhouse use and is anticipated to be available in 2025. A grower-recommended fungicide program with Orondis Ultra was also evaluated. A susceptible sweet basil variety, DiGenova, was used.

Methods. The field was moldboard plowed on 29 May. Controlled-release fertilizer (N-P-K, 19-10-9) was broadcast at 525 lb/A (101 lb/A N) over the bed area and incorporated on 30 Jun. Beds were formed with drip tape and covered with black plastic mulch on 30 Jun. Weeds between mulched beds were managed by cultivating, covering the soil with landscape cloth, and by hand weeding. A waterwheel transplanter was used to make planting holes in the beds and apply starter fertilizer. Basil for the experiment was seeded in trays in a greenhouse on 8 Jun. All plants were placed outdoors to harden for a few days and then transplanted in the field by hand on 7 Jul. A late planting date was used to increase the likelihood of downy mildew developing during the experiment. The primary source of initial inoculum in this area is considered to be spores dispersed by wind from infected plants potentially a long distance away.

A randomized complete block design with four replications was used. Each plot had 8 plants in 6-ft rows with 9-in. in-row plant spacing. The plots were 3 ft apart in the row. Fungicides were applied weekly over a 6-week period, with a backpack CO₂-pressurized sprayer and hand-held boom with TJ60-8004EVS nozzle(s) operated at 55 psi and 2.3 mph. Applications 1-3 were made using a boom with a single nozzle delivering 32 gal/A. Starting with application 4, plants were large enough to use a boom with two drop nozzles directed to the side of plants as well as a nozzle delivering spray over the top of the plant that delivered 73 gal/A. Downy mildew was assessed in each plot weekly from 10 Aug through 30 Sep. Incidence of plants with symptoms (sporulation of the pathogen visible on the underside of leaves) was recorded and percentage of leaves per plant with symptoms was estimated for each plant in each plot. Area under disease progress curve (AUDPC) values were calculated from 10 Aug to 8 Sep. AUDPC is a summation measure of severity over time.

Results. Fungicide treatments were started before symptoms were seen. Symptoms were first observed on 3 Aug in 3 control plots and 1 plot treated with Revus. On 10 Aug, 53-69% of plants in treated plots while 100% of the plants in untreated control plots had symptoms (no significant differences; data not shown). All plants had symptoms starting with the rating on 17 Aug. At all ratings, treated plants had numerically but not always significantly lower incidence of affected leaves compared to control plants (Table 16). Fluoxapiprolin had the lowest incidence starting with the 30 Aug rating. This treatment was significantly better than the others based on the 8 Sep rating. Based on AUDPC values, fluoxapiprolin provided 64% control versus 56% for the fungicide program and 43% for Revus. There was a plot of each treatment with substantially more downy mildew than other plots of these treatments in the north end of the experiment in two adjacent replications. Excluding these plots and also the control plot with high incidence in this area, control obtained with these treatments was 81, 66, and 51%, respectively (data not shown). Rating done on 16 Sep, 2 wks after the last application, documented no residual activity. Control of downy mildew achieved with fluoxapiprolin

resulted in less defoliation (Table 16). The fifth application scheduled for 25 Aug was delayed by 1 day because of extensive rainfall (2.6 in.) due to Hurricane Henri on 22-23 Aug. The last application was applied early due to rain forecast with remnants of Hurricane Ida starting late on 1 Sep (3.3 in. total). It is possible efficacy of treatments was affected by the impact of these storms on application timing, product residues, and/or disease development. No phytotoxicity was observed.

Conclusions. The new FRAC 49 fungicide, fluoxapiprolin, exhibited very good control of downy mildew and was more effective than Revus, the currently registered product included for comparison. Good control was obtained with a grower recommended conventional fungicide program consisting of an alternation of products labeled for this use. Fluoxapiprolin was more effective based on the 8 Sep rating.

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Table 16. Efficacy of conventional fungicides for downy mildew in sweet basil.

Treatment and amount/A (application dates) ^y	Downy mildew incidence: affected leaves on affected plants (%) ^z						Defoliation (%) ^z	
	10 Aug ^x	25 Aug	8 Sep	AUDPC	16 Sep		8 Sep	16 Sep
Untreated control	21	99 a	97 a	2538 a	99 a		55 a	99 a
Ranman 3 fl oz + K-Phite 1 qt (1, 4)								
Presidio 4 fl oz + K-Phite 1 qt (2, 5)								
Orondis Ultra 8 fl oz (3, 6)	5	23 b	69 b	1110 b	85 ab		29 b	63 bc
Revus 8 fl oz (1-6) ^w	7	54 ab	50 b	1442 ab	97 a		20 b	84 ab
Fluoxapiprolin 13.7 fl oz (1-6) ^w	5	26 b	24 c	918 b	77 b		14 b	36 c
<i>P-value (treatment)</i>	0.3785	0.0309	<0.0001	0.0145	0.0033		0.0004	0.001

^z Numbers in each column with a letter in common or no letters are not significantly different from each other (Tukey's HSD, $P=0.05$).

^y Application dates were 1= 28 Jul, 2=4 Aug, 3=11 Aug, 4=18 Aug, 5=26 Aug, and 6=31 Aug.

^x Values were square root transformed before analysis because raw data were not distributed normally. Table contains de-transformed values.

^w Treatment applied with the nonionic surfactant Induce at 0.125% v/v.