"Final Project Report to the NYS IPM Program, Agricultural IPM 2002–2003."

1. Title:

Developing a Management Program for Powdery Mildew in Winter Squashes with Resistant Varieties

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4. Type of grant:

Pest-resistant crops

5. Project location(s):

National application

6. Abstract:

Powdery mildew an important disease of winter squash and other cucurbit crops. It occurs throughout New York every year. Management is needed to avoid a reduction in yield. Application of fungicides has been the main practice. Several winter squash varieties with resistance to powdery mildew are now commercially available. Growers need to know how well these resistant varieties perform compared to horticulturally-similar, fungicide-treated susceptible varieties, and whether there are benefits to an integrated program with minimal fungicide inputs. Two experiments were conducted to evaluate acorn and butternut squashes. Growing varieties with resistance to powdery mildew was shown to be an effective and economic means to manage powdery mildew. Control of powdery mildew obtained with the resistant varieties was not improved significantly by applying fungicides. Although also not significant, there was a trend toward improved yield with fungicide treatment (more fruit, greater fruit weight, and higher sucrose content). Regardless of disease control benefit, an integrated program is recommended to reduce selection pressure for new races of the pathogen able to overcome the resistance in these varieties and for new strains of the pathogen that are able to tolerate the fungicides. A reduced-sprays fungicide program with a 14-day spray interval was as effective as the conventional program with a 7-day interval when applied to a resistant variety but not when applied to a susceptible variety.

7. Background and justification:

Powdery mildew is one of the most important diseases of cucurbit crops. It occurs throughout New York every year. Management practices must be implemented to avoid a reduction in yield. Application of fungicides is presently the principal practice for managing powdery mildew in most cucurbit crops, except for cucumber and muskmelon, for which there are

several commercially available varieties with resistance. A few varieties of summer squash and pumpkin with resistance are now available.

Several winter squash types with resistance to powdery mildew have very recently become commercially available. Three of these powdery mildew resistant (PMR) varieties were developed by Molly Jahn in Cornell's Department of Plant Breeding. There is a single gene source of resistance in squash and pumpkin that is codominant. Thus a higher level of resistance is obtained when both parents carry the resistance allele. There are also believed to be several modifier genes. Consequently, PMR varieties exhibit two levels of resistance, moderate and high, with some variation among varieties.

Evaluation of resistant varieties and implementing recommendations for these varieties are considered high priorities for research and implementation projects for cucurbits by the IPM Vegetable Working Group. Growers need to know how well these PMR varieties perform compared to horticulturally-similar varieties treated with fungicides, which is the current management program. They need to know if there are any benefits to using an integrated program with minimal fungicide inputs to these PMR varieties. In past experiments conducted by the project leader with PMR pumpkin, two commercially available varieties, Magic Lantern and Merlin, were shown to have a moderate level of resistance. Control of powdery mildew was improved by using an integrated program with these varieties. In contrast, advanced breeding lines with a high level of resistance benefited minimally from fungicide applications to improve powdery mildew control. A biocompatible fungicide program was as effective as the standard fungicide program when applied to these lines.

The goal of this project was to evaluate PMR varieties of butternut and acorn type winter squash with one allele (heterozygous) or two alleles (homozygous) for resistance . They were compared to a horticulturally-similar susceptible variety of each type that is sprayed with the recommended fungicide program for powdery mildew, Quadris alternated with Bravo + Nova on a 7-day schedule, to determine how genetic control compares to chemical control. Some PMR varieties were also treated with the 7-day fungicide program and/or this program applied on a 14-day schedule (reduced-sprays fungicide program) to assess the benefits of an integrated program with minimal fungicide inputs. All fungicide programs were started after powdery mildew reaches the IPM threshold.

Growing resistant varieties is expected to result in a reduction of fungicide inputs and thus a decrease in the potential for contamination of groundwater, thus this project could have an impact on water quality.

8. Objectives:

1. Evaluate PMR varieties of butternut and acorn type winter squash with moderate and high levels of resistance and determine if fungicide treatment is warranted.
2. Examine a PMR variety grown on three commercial farms.
3. Evaluate project results.

9. Procedures:

1. Two parallel experiments were conducted with butternut and acorn type winter squash at the Long Island Horticultural Research and Extension Center. Varieties and fungicide treatments evaluated are listed in Tables 1 and 2. For the butternut squash experiment, Bugle, a homozygous PMR variety developed by the Cornell Plant Breeding program was compared to the standard susceptible variety, Waltham Butternut. Four PMR acorn varieties were included in the second experiment, plus two susceptible varieties for comparison. Taybelle PM is heterozygous for PMR and is horticulturally similar to susceptible Taybelle. Autumn Delight is homozygous for PMR and compares to susceptible Table Ace. Seed of these four varieties were

obtained from Seminis Vegetable Seeds. Cornell PMR Acorn and Harlequin were obtained from the Cornell Plant Breeding program. Harlequin is a multicolored acorn; the others evaluated are dark green acorns.

Transplants for both experiments were seeded in the greenhouse on 28 May and planted into bare ground on 19 June. There were 9 plants per plot and 4 replications per treatment arranged in a randomized complete block design. Upper and lower (under) surfaces of 5 to 50 leaves in each plot were examined approximately weekly for powdery mildew from 31 July through 17 September. Initially, 50 older leaves were examined in each plot. As disease progressed, the number of leaves examined was adjusted based on the incidence of affected leaves in a plot. Beginning on 4 September, mid-aged and young leaves were also examined. Powdery mildew colonies were counted; severity was assessed when colonies could not be counted accurately because they had coalesced and/or were too numerous. Average severity for the entire canopy was calculated from the individual leaf assessments. Defoliation was assessed on 5, 12 and 19 September.

Symptoms of powdery mildew were first observed on the susceptible varieties (Waltham, Taybelle and Table Ace) on 12-13 August and on the resistant varieties on 20 August. Fungicide applications were started 1-2 days later. Application times were: 1=15 August, 2=21 August, 3=27 August, 4=6 September, and 5=13 September. Standard program for the susceptible varieties was Quadris (week 1,3,5) and Bravo + Nova (2,4) and for Bugle it was Quadris (week 2,4) and Bravo + Nova (3,5). Reduced-sprays fungicide program was Quadris (week 2) and Bravo + Nova (4). It was tested on the PMR varieties Taybelle PM, Autumn Delight, and Bugle, and also on susceptible Waltham. Applications were made with a tractor-mounted boom sprayer equipped with D5-45 hollow cone nozzles spaced 17 in. apart that delivered 100 gpa at 150 psi.

Ripe fruit were counted and a representative sample of about one-third of the fruit from each plot was weighed on 30 September. Percentage of sucrose was determined using a hand refractometer for two fruit per plot. To facilitate getting juice from the fruit for this measurement, a center section from each fruit was frozen and thawed. Fruit appearance and taste after cooking were evaluated by Joe Sieczka for two representative fruit of each variety from fungicide-treated plots when possible.

2. PMR winter squash varieties were not evaluated in grower fields as planned because there were insufficient funds available to fund the entire project when it was first approved and cooperator Molly Jahn felt this was the least important aspect of the project.

3. Project results were evaluated by statistically analyzing the data from the replicated experiment. Cost of controlling powdery mildew with the various variety/fungicide treatments was calculated. A Twilight meeting was held on 24 September so that growers could see the level of disease control at the end of the season and examine the fruit. Results will be presented at winter meetings: 2003 Long Island Agricultural Forum on 10 January and at the 2003 NYS Vegetable Conference on 13 February. A brief survey will be given to meeting attendees to assess how many growers would consider growing these varieties and to obtain an importance rating on this type of work. Results will be discussed with a few key growers following these presentations.

10. Results and discussion:

BUTTERNUT SQUASH

Compared to non-fungicide-treated Waltham, the resistant variety provided control of powdery mildew on upper leaf surfaces that was equivalent to that achieved with fungicides applied weekly to susceptible Waltham (86% and 92% control, respectively)(Table 1). Genetic control (non-treated Bugle) was superior to chemical control (fungicide-treated Waltham) for powdery mildew on lower leaf surfaces, providing 98% control versus 68%. Chemical control, however, may have been compromised by resistance to Quadris. Control of powdery mildew provided by genetic resistance with Bugle was not improved by applying fungicides. However, a reduced fungicide program could function to delay selection of a new pathogenic race able to overcome this resistance. Powdery mildew in the susceptible variety was not controlled on upper leaf surfaces with fungicides applied on a 14-day schedule (reduced fungicide program) as effectively as with a 7-day schedule (standard fungicide program)(45% vs 93% control).

Table 1. Powdery mildew severity, defoliation due to powdery mildew, and yield as affected by variety and fungicide treatment. Bugle is homozygous for resistance to powdery mildew.

	Powdery mildew severity (%coverage) [x]				Defoliation (%)	Mature fruit			
	Upper leaf surface		Lower leaf surface			Weight	Quantity	Sucrose	Split
Cultivar, Treatment [y]	12 Sep	AUDPC	12 Sep	AUDPC	5 Sep	(lb/fruit)	(#plant)	(% Brix)	(%)
Bugle, standard fungicide program	0.1 c [z]	0.6 c	0.2 c	3.3 c	1.5 b	2.7 b	5.9 a	9.0	2.2
Bugle, reduced fungicide program	0.3 c	7.8 c	1.0 c	5.1 c	1.0 b	2.6 b	5.8 a	9.6	2.8
Bugle, no fungicide	0.8 bc	19.8 c	0.8 c	7.1 c	1.3 b	2.5 b	5.9 a	8.9	3.3
Waltham, standard program	0.4 c	9.8 c	14.1 b	95.5 b	21.7 a	4.0 a	4.6 b	8.2	0.5
Waltham, reduced program	2.8 ab	75.1 b	16.0 b	135.8 b	28.8 a	3.9 a	4.4 b	8.4	1.8
Waltham, no fungicide	4.7 a	137.6 a	44.0 a	306.0 a	32.5 a	4.0 a	4.2 b	8.8	3.8
P-value	0.0051	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.4589	0.1127
Source of Variation for 2-factor ANOVA									
Cultivar	0.0036	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.1025	0.2199
Treatment	0.0214	0.0001	0.0001	0.0001	0.4788	0.7100	0.8222	0.7115	0.0258
Cultivar X Treatment interaction	0.1232	0.0001	0.0001	0.0001	0.4414	0.7551	0.6807	0.5604	0.3415

[x] Exact colony counts were made when possible and severity was estimated using the conversion factor of 10 colonies/leaf = 1%.

[y] Fungicide treatment was Quadris F (15.4 oz/A) applied in alternation with Nova 40W (5 oz/A) plus Bravo Ultrex 82.5WG (2.7 lb/A). Application times were: 1=15 Aug, 2=21 Aug, 3=27 Aug, 4=6 Sep, and 5=13 Sep. Standard program for Waltham was Quadris (week 1,3,5) and Bravo + Nova (2,4) and for Bugle it was Quadris (week 2,4) and Bravo + Nova (3,5). Reduced program was Quadris (week 2) and Bravo + Nova (4) for both Waltham and Bugle.

[z] Numbers in each column with a letter in common are not significantly different according to Fisher's Protected LSD (*P* = 0.05).

Powdery mildew causes leaves to senesce prematurely; thus, as a consequence of better suppression with genetic than chemical control, Bugle not treated with fungicides had significantly less defoliation on all assessment dates in September than Waltham receiving the standard fungicide program (1% vs 22% on 5 September). Fungicide treatment did not affect size, quantity, or sucrose content of fruit produced for either variety. Non-fungicide-treated Bugle produced smaller fruit than fungicide-treated Waltham (2.5 vs 4 lb) but more fruit (5.9 vs 4.6); however, this was not quite enough to compensate for the smaller fruit size (15 versus 18 lb mature fruit/plant). Sucrose content, a measure of fruit quality, was slightly higher for Bugle than Waltham, but this difference was not significant. There were no significant differences among treatments in the quantity of immature fruit present at harvest. A few fruit had long

splits that extended into the flesh. There was a trend toward fewer fruit having splits with increasing fungicide input for both varieties. Bugle was judged to have slightly better flavor than Waltham (Table 3).

Table 2. Powdery mildew severity, defoliation due to powdery mildew, and yield as affected by variety and fungicide treatment. Taybelle PM, Autumn Delight, Cornell PMR Acorn, and Harlequin have genetic resistance to powdery mildew.

	Powdery mildew severity (%coverage) [x]				Defoliation (%)	Mature fruit		
	Upper leaf surface		Lower leaf surface			Sucrose	Quantity	Weight
Variety, Treatment [y]	26 Aug	12 Sep	26 Aug	12 Sep	12 Sep	(% Brix)	(#/plant)	(lb/fruit)
Taybelle, No Fungicide	27.6 ab [z]	40.3 a	37.0 a	76.3 a	63 ab	8.5 cd	4.6	2.0 a
Taybelle, Fungicide	6.4 bc	3.1 d	15.3 bc	24.8 c	36 cde	10.2 b	5.0	2.0 a
Taybelle PM, No Fungicide	15.4abc	29.2 ab	7.2 c	9.7 d	49 bc	8.0 cde	4.9	1.9 a
Taybelle PM, Fungicide	8.0 bc	17.9 bc	5.0 c	8.9 d	25 de	9.6 bc	5.5	2.1 a
Table Ace, No Fungicide	29.3 a	30.3 ab	38.3 a	79.3 a	79 a	8.3 cde	4.9	1.5 bc
Table Ace, Fungicide	17.2 abc	1.1 d	24.6 ab	38.1 b	46 bcd	8.0 cde	5.7	1.6 b
Autumn Delight, No Fungicide	2.9 bc	5.7 cd	1.0 c	0.5 d	35 cde	6.7 e	4.6	2.0 a
Autumn Delight, Fungicide	1.8 c	4.3 cd	0.6 c	0.1 d	23 e	7.6 de	5.1	2.1 a
Cornell PMR Acorn, No Fungicide	2.2 bc	22.3 b	1.2 c	7.8 d	15 e	9.0 bcd	4.9	1.3 c
Harlequin, No Fungicide	13.5 abc	21.4 b	1.3 c	4.1 d	15 e	13.2 a	6.6	1.4 bc
P-value	0.0171	0.0001	0.0001	0.0001	0.0001	0.0001	0.0802	0.0001

[x] Exact colony counts were made when possible and severity was estimated using the conversion factor of 10 colonies/leaf = 1%.

[y] PMR=powdery mildew resistant. Fungicide treatment was Quadris F (15.4 oz/A) applied in alternation with Nova 40W (5 oz/A) plus Bravo Ultrex 82.5WG (2.7 lb/A). Application dates were: 1=15 Aug, 2=21 Aug, 3=27 Aug, 4=6 Sep, and 5=13 Sep. Taybelle and Table Ace were treated with Quadris at dates 1, 3,and 5 and Bravo + Nova at dates 2 and 4. Taybelle PM and Autumn Delight were treated with Quadris at date 2 and Bravo + Nova at date 4.

[z] Numbers in each column with a letter in common are not significantly different according to Fisher's Protected LSD ($P = 0.05$).

ACORN SQUASH

Host plant resistance provided good control of powdery mildew without the addition of fungicide treatment (Table 2). Taybelle PM provided control of powdery mildew on lower leaf surfaces statistically equivalent to that achieved with fungicides applied weekly to the susceptible variety Taybelle (80% vs 67% control, respectively); however, chemical control was more effective for powdery mildew on upper surfaces (28% vs 92% control for non-treated Taybelle PM and fungicide-treated Taybelle, respectively. Compared to fungicide-treated Table Ace, Autumn Delight provided better control on lower leaf surfaces (52% vs 98%, respectively) and equivalent control on upper surfaces (96% vs 81%). Chemical control, however, may have been compromised by resistance to Quadris. Autumn Delight, which has homozygous resistance, was less severely infected than Taybelle PM, which has heterozygous resistance, at all assessments. Powdery mildew severity on Cornell PMR Acorn and Harlequin did not differ significantly from the other two PMR varieties until 12 September when Autumn Delight was less severely infected on upper leaf surfaces. Control of powdery mildew provided by genetic resistance was not improved by applying fungicides twice based on powdery mildew severity; however, defoliation was significantly less in fungicide-treated plots of Taybelle PM. Additionally, a reduced fungicide program could function to delay selection of a new pathogenic race able to overcome this resistance. Fungicide treatment delayed senescence in addition to suppressing powdery mildew in Taybelle and Table Ace. Powdery mildew was the only foliar disease observed. Cornell PMR Acorn and Harlequin had the least defoliation when assessed in September (15% vs 79% for non-treated Table Ace on 12 September). Sucrose content was highest for Harlequin (13.2% Brix) and lowest for Autumn Delight (6.7% for non-

treated); it was 8% for non-treated Taybelle PM and 9% for Cornell PMR Acorn. Applying fungicides to Taybelle improved sucrose content (8.5% vs 10.2%); values were higher, but not significantly, for Taybelle PM and Autumn Delight treated with fungicides (9.6% and 7.6%). Fungicide treatment did not affect fruit size for any variety. Fruit of Table Ace, Cornell PMR, and Harlequin were smaller than others. Cornell PMR Acorn and Taybelle were rated best in fruit appearance and taste after cooking (Table 3).

Table 3. Comments from evaluation of fruit appearance and taste after cooking.

Taybelle ……..	Medium size cavity, slightly fibrous to dense flesh with excellent flavor, no need for adding sugar. One of the best.
Taybelle PMR ……	Seed cavity was large, but fruit was also large. Flesh was slightly fibrous. okay flavor but not sweet.
Table Ace ……......	Broad, relatively attractive, large seed cavity, fibrous, lacked flavor.
Autumn Delight ……	Small seed cavity, flesh was thick. Cooked flesh was free of fibers, smooth. Not much flavor but okay with brown sugar and butter.
Cornell PMR Acorn..	Very large seed cavity, broad "roundish" fruit, slightly fibrous, good sweet flavor without butter or sugar. One of the best.
Harlequin ……....	OK appearance. Small to medium size fruit with a large seed cavity. Flesh was very fibrous. Good flavor without sugar.
Bugle …….....	Relatively short, wide neck butternut. Small seed cavity, deep orange and smooth flesh, very nice flavor without butter or sugar but not very sweet. Yield of flesh to size of fruit is high.
Waltham……	Medium to large, moderately broad neck, relatively small seed cavity, deep orange flesh, relatively smooth flesh, not very sweet but it is edible without butter or sugar, although a little better with butter. Good yield.

ECONOMICS

Cost of seed for the resistant acorn squash varieties tested is only slightly more than that of comparable susceptible varieties. Cost of 1,000 seed from Siegers is $15.31 for Taybelle and $17.45 for Taybelle PM, an increase of $2.14 (= 14%), and $15.30 for Table Ace and $20.15 for Autumn Delight, an increase of $4.85 (= 32%). There is a greater disparity in seed prices for the butternut squashes: $15.15/lb for Waltham and $48.50/lb for Bugle from SeedWay. Cost to manage powdery mildew with a resistant variety plus a reduced-sprays fungicide program was less than using a standard fungicide program for the acorn squash varieties tested, but slightly more for the butternut squashes (Table 4). The fungicide program costs were calculated based on 2 applications to the PMR varieties and 5 applications to the susceptible varieties of Quadris alternated with Bravo + Nova and Bravo alone for the final application to the susceptible varieties. Fungicide prices were $3.85/oz for Nova 40W, $290/gal for Quadris, and $7.70/lb for Bravo Ultrex. Cost to make each application was estimated to be $7/A.

CONCLUSIONS

Growing varieties with resistance to powdery mildew is an effective and economic means to manage powdery mildew. Varieties with homozygous resistance (e.g. Autumn Delight) are more effective than those with heterozygous resistance (Taybelle PM). Control of powdery mildew provided by genetic resistance was not improved significantly by applying fungicides to Bugle, Taybelle PM, or Autumn Delight; however, leaf senescence was reduced significantly in Taybelle PM. Although not significant, there was a trend toward improved yield with fungicide treatment (more fruit, greater fruit weight, and higher sucrose content). Regardless of disease control benefit, an integrated program is recommended to reduce selection pressure for new races of the pathogen able to overcome the resistant variety and strains of the pathogen

that are resistant to the fungicides. The two fungicide applications made on a 14-day spray interval to the resistant varieties (Quadris followed by Bravo + Nova) cost $89/A versus $206/A for five applications to the susceptible varieties. Bugle produced smaller fruit and less total fruit weight per plant than Waltham in this experiment; it reportedly has yielded similarly in other trials. Fruit of Autumn Delight had lower brix values than fruit of Table Ace, Taybelle, or Taybelle PM in this experiment; but it had higher values than these varieties in an experiment conducted in California.

The integrated program is ready for implementation, however, additional research is warranted to confirm results and growers likely will want to test it before full implementation. All PMR varieties evaluated are commercially available. Seed of Bugle is available from Rupp Seed Co and SeedWay. Siegers and Stokes Seeds carry Taybelle PM and Autumn Delight. Seed of Harlequin is available from Rupp Seed Co, Territorial Seed Co and SeedWay. Turtle Tree Seeds plans to produce organic seed of Cornell PMR Acorn.

Table 4. Comparison of seed and fungicide costs for managing powdery mildew in PMR and susceptible winter squash varieties.

	Production costs ($/A)			
Variety	Seed	Fungicide program	Total cost	Variety comparison
Autumn Delight	$167.65	$88.93	$256.58	$76.37
Table Ace	$127.30	$205.65	$332.95	
Taybelle PM	$145.18	$88.93	$234.11	$98.92
Taybelle	$127.38	$205.65	$333.03	
Bugle	$194.00	$88.93	$282.93	-$16.68
Waltham	$60.60	$205.65	$266.25	

Seed cost/A calculated based on seeding at a rate of 4 lb/A or 15,000 seed/A.
See section on Economics for details on seed and fungicide prices.