HortScience 51(10):1297–1300. 2016. doi: 10.21273/HORTSCI10866-16

Powdery Mildew–resistant Pumpkin Inbred Lines

Kyle E. LaPlant, Lindsay E. Wyatt, George Moriarty, and Maryann Fink-Brodnicki
Department of Plant Breeding and Genetics, Cornell University, 248 Emerson Hall, Ithaca, NY 14853

Molly Jahn
Laboratory of Genetics and Department of Agronomy, University of Wisconsin-Madison, 3428 Genetics Biotechnology Center, 425 Henry Mall, Madison, WI 53706

Michael Mazourek[1]
Department of Plant Breeding and Genetics, Cornell University, 248 Emerson Hall, Ithaca, NY 14853

Additional index words. Cucurbita pepo, jack-o'-lantern, disease resistance, pumpkin breeding

Jack-o'-lantern pumpkin (*Cucurbita pepo* ssp. *pepo*) is an economically important crop grown for fall decoration in the United States, and they are traditionally carved and illuminated for display during the holiday of Halloween. In 2014, over 20,000 ha of pumpkins were planted in the United States, with a farm value of $145 million. The state of New York is one of the highest ranked states in value of production each year, often first in the nation. In 2014, the total farm value of the pumpkin crop in New York was $20.5 million, making jack-o'-lantern pumpkins a significant source of income for farmers (U.S. Dept. of Agriculture (USDA), National Agricultural Statistics Service, 2016). Because the crop has such high value, significant effort is put into controlling diseases that could decrease the value of the crop.

Powdery mildew, caused by *Podosphaera xanthii* and *Erysiphe cichoracearum*, is one of the major diseases that reduce the yield of susceptible pumpkins (McGrath and Thomas, 1996; Pérez-García et al., 2009). The pathogen is an obligate biotroph (Green et al., 2002) which overwinters in the southern United States on alternate hosts and on greenhouse-grown cucurbits. The pathogen is spread each year by airborne conidia, generally from the southern United States, where cucurbits are grown early in the season, to the northern United States. The disease is easily recognized by its white colonies that appear on the leaves of plants before spreading to the petioles and stems. Older leaves on mature plants are often infected first. Plants that have maturing fruit and plants grown in high-density plots are favorable for the pathogen (McGrath, 2011). Infection can cause the leaves to wither and senesce, which often leads to the death of the plant. This regularly results in shriveled and weakened peduncles ("handles" of the jack-o'-lanterns), reducing the marketability of the pumpkins (Zitter et al., 1996). Because of these factors, resistance to powdery mildew is an important trait for jack-o'-lantern pumpkins. The powdery mildew–resistant (PMR) pumpkin inbred lines we describe herein (Fig. 1) are the original source of powdery mildew resistance in many commercially available pumpkins. This study evaluates and compares the field performance characteristics of these PMR pumpkin inbred lines to commercially available cultivars (Table 1). Considered characteristics include yield, growth habit, size, maturity, and powdery mildew resistance.

Origin

Development of these PMR pumpkin lines began in the mid-1980s. The immediate source of their resistance was 'PMR Bush Ebony', an acorn squash with powdery mildew resistance derived from an introgression with *Cucurbita okeechobeensis* ssp. *martinezii*. The resistance trait was first transferred from *C. okeechobeensis* ssp. *martinezii* to 'Waltham', a butternut squash (*Cucurbita moschata*), as described by Contin (1978) and, with much effort, introgressed into *C. pepo* cultivars by crossing to Yankee Hybrid interspecific germplasm. To develop the PMR pumpkin inbred lines, a delicata squash (*C. pepo*) was first crossed to 'PMR Bush Ebony' in 1986 (Fig. 2). The resulting hybrid was crossed and then backcrossed to 'Spirit', a small jack-o'-lantern pumpkin. Selection for powdery mildew resistance occurred in every subsequent generation, beginning in 1990 after the first cross to 'Spirit'. The resulting progeny from the backcross were crossed with 'Howden', a large jack-o'-lantern pumpkin, and the progeny of this cross became the parents of all the PMR pumpkin lines. Several independent selections were made, resulting in multiple lineages. One of these lineages was crossed to Snackjack, a pumpkin cultivar with hull-less seeds, resulting in one hull-less PMR pumpkin line, NY14-555. In 1996, several reciprocal crosses were made between lines 96-937, 96-938, 96-941, and 96-944 (Fig. 2). Independent selections from the progeny of these crosses resulted in the remainder of the PMR pumpkin lines (see pedigrees in Table 1). 'Patina' was also evaluated in this trial. It is a small pumpkin that was identified in the USDA *C. pepo* collection and inbred for several generations to create a pure line. 'Patina' has a copper and bronze color pattern that makes it desirable for fall decorations (Fig. 1).

Description

A replicated trial was planted at the Homer C. Thompson Vegetable Research Farm in Freeville, NY. PMR pumpkin inbred lines were grown with the commercially available cultivars Howden, Magic Lantern, Racer, and Triple Treat as controls (Table 1). 'Howden' is a mid- to late-season, large pumpkin with long vines and is susceptible to powdery mildew. 'Magic Lantern' is an early-season, large pumpkin with medium-length vines and is reported to have intermediate resistance to powdery mildew. 'Racer' is an early-season, midsize pumpkin with medium-length vines and susceptibility to

Fig. 1. Pumpkins from the 20 lines that were evaluated in the trail. Top row (left to right): NY14-565, NY14-564, NY14-556, 'Patina', NY14-555, NY14-566, 'Triple Treat', and NY14-560. Middle row (left to right): NY14-559, NY14-561, NY14-567, NY14-562, and 'Racer'. Bottom row (left to right): NY14-557, NY14-568, NY14-558, 'Magic Lantern', NY14-569, and 'Howden'.

Received for publication 3 May 2016. Accepted for publication 5 July 2016.
Support for Kyle LaPlant was provided by the Calvin Noyes Keeney Endowment for Plant Breeding. Support for Lindsay Wyatt was provided by the Agriculture and Food Research Initiative Competitive Grant No. 2013-67011-21122 from the USDA National Institute of Food and Agriculture. Support for the project was provided by Hatch funding.
We thank Michael Glos, Lauren Brzozowski, and Christopher Hernandez for technical assistance; Jason Moore for the photographs; and Jess Lyga and Mary E. Kreitinger for photography assistance. We also give special thanks to Nancy Munger and Martha Munger for their contributions to Henry Munger's legacy at Cornell.
[1]Corresponding author. E-mail: mm284@cornell.edu.

Table 1. Seed sources, pedigrees, and generation of the PMR pumpkin lines and cultivars in the trial.

Name/cultivar	Source	Pedigree	Generation
Howden	Harris	Howden	
Magic Lantern	Harris	Magic Lantern	F_1
Racer	Johnny's	Racer	F_1
Triple Treat	Burpee	Triple Treat	
NY14-555	Cornell	[(PMR-A^z) F_6 × Snackjack] F_{11}	F_{11}
NY14-556	Cornell	[(PMR-A^z) F_{10} × (PMR-B^z) F_9] F_9	F_9
NY14-557	Cornell	(PMR-A^z) F_{16}	F_{16}
NY14-558	Cornell	[(PMR-B^z) F_9 × (PMR-A^z) F_{10}] F_8	F_8
NY14-559	Cornell	(PMR-A^z) F_{15}	F_{15}
NY14-560	Cornell	[(PMR-A^z) F_2 OP] F_9	F_9
NY14-561	Cornell	(PMR-A^z) F_{14}	F_{14}
NY14-562	Cornell	[Brian Reeves OP × (PMR-A^z) F_4] F_5 × {[(PMR-A^z) F_{10}] F_3 OP} F_5	F_5
Patina	Cornell	'Patina'	
NY14-564	Cornell	[(PMR-A^z) F_{10} × (PMR-B^z) F_9] F_6	F_6
NY14-565	Cornell	[(PMR-A^z) F_{10} × (PMR-B^z) F_9] F_6	F_6
NY14-566	Cornell	[(PMR-A^z) F_{10} × (PMR-A^z) F_2 OP) F_7] F_7	F_7
NY14-567	Cornell	[(PMR-B^z) F_9 × (PMR-A^z) F_{10}] F_7	F_7
NY14-568	Cornell	[(PMR-B^z) F_9 × (PMR-A^z) F_{10}] F_7	F_7
NY14-569	Cornell	({[Brian Reeves OP × (PMR-A^z) F_4]} F_5) × {[(PMR-A^z) F_2 OP] F_7} F_7	F_7
NY14-570	Cornell	[({Brian Reeves OP × [(PMR-A^z) F_4]) F_5} × [(PMR-A^z) F_{10}] F_6	F_6

PMR = powdery mildew resistant.
[z]PMR-A and PMR-B represent independent selections from ({[(Delicata × PMR Bush Ebony) F_2 × Spirit] × Spirit} × Howden) F_1.

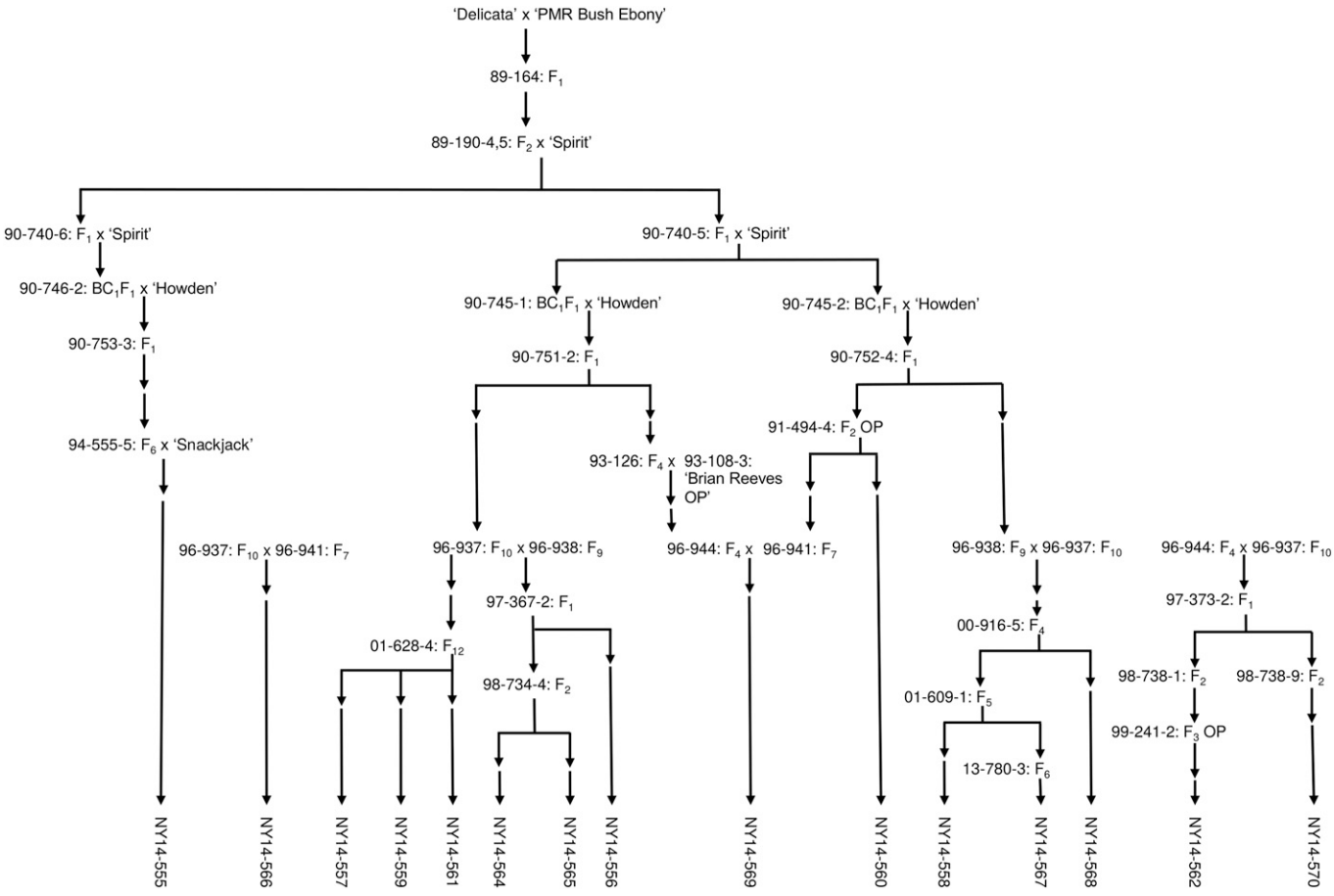

Fig. 2. Pedigree of powdery mildew–resistant (PMR) pumpkin lines. PMR pumpkin lines are identified with two or more numbers: the first is the year, the second is the plot, and the third, if present, is the plant within the plot. Two consecutive arrows indicate multiple generations of inbreeding. Selection for powdery mildew resistance occurred in every generation, beginning in 1990 after the first cross to 'Spirit'.

powdery mildew. 'Triple Treat' is a late-season, small pumpkin with long vines, susceptibility to powdery mildew, and hull-less seeds. The seeds of each trial entry were sown in the greenhouse on 19 May 2014. The seedlings were moved from the greenhouse to a coldframe on 30 May 2014, and were then transplanted on 11 June 2014 into 91-cm-wide raised beds covered with black plastic mulch. Drip irrigation was placed beneath the plastic to maintain adequate moisture. Three plots of 10 plants from each line or cultivar were planted in a replicated complete block design with plants spaced 91 cm apart in rows spaced 3.66 m apart. Before transplanting, 643 kg·ha^{-1} of 13N–5.7P–10.8K fertilizer was applied to the field. The plants were grown with standard horticultural practices, and irrigation was applied when necessary to achieve ≈1 inch of water each week.

Table 2. Means for the number of marketable fruit per plant, weight of marketable fruit, fruit height, fruit shape as measured by fruit height/width, vine length, and fruit maturity of the PMR pumpkin lines, and commercial varieties in the trial.

Name/cultivar	No. of marketable fruit per plant	Wt of marketable fruit (kg/fruit)	Fruit ht (cm)	Fruit ht/width	Vine length	Maturity
Howden	1.0 cdef[z]	8.32 a	29 a[z]	1.02 a[z]	Long	Medium
Magic Lantern	0.9 cdef	5.99 b	24 bc	0.91 bcd	Medium	Early
Racer	1.1 cdef	5.08 bc	21 ef	0.81 ef	Medium	Early
Triple Treat	1.3 bcdef	2.73 f	17 g	0.88 bcde	Long	Medium
NY14-555	2.3 abc	1.42 gh	14 h	0.86 bcdef	Short	Early
NY14-556	2.6 abc	0.78 h	11 i	0.93 b	Medium	Medium
NY14-557	0.9 cdef	3.47 ef	18 g	0.80 fg	Short	Late
NY14-558	1.3 bcdef	4.30 cde	22 de	0.93 b	Medium	Medium
NY14-559	0.5 ef	3.42 def	18 fg	0.81 cdefg	Short	Late
NY14-560	0.4 f	2.90 f	18 g	0.93 b	Short	Late
NY14-561	0.8 def	2.88 f	17 g	0.82 cdef	Short	Late
NY14-562	0.6 def	4.95 bcd	21 def	0.91 bcde	Long	Medium
Patina	3.0 a	1.31 h	10 ij	0.57 h	Medium	Medium
NY14-564	2.1 abcd	0.77 h	10 ij	0.80 f	Short	Late
NY14-565	2.9 a	0.74 h	9 j	0.72 g	Short	Medium
NY14-566	1.2 cdef	2.46 fg	17 g	0.87 bcdef	Short	Medium
NY14-567	1.2 cdef	4.98 bc	23 cd	0.93 b	Medium	Medium
NY14-568	1.2 cdef	5.17 bc	21 de	0.80 fg	Short	Medium
NY14-569	0.8 def	5.89 b	26 b	0.91 bcd	Medium	Late
NY14-570	1.8 abcde	3.41 ef	21 ef	0.93 b	Long	Late

PMR = powdery mildew resistant.
[z]Means in the same column followed by the same letter are not statistically different as determined by Tukey's honestly significant difference ($P = 0.05$).

Table 3. Means of powdery mildew severity on the adaxial leaf surfaces, abaxial leaf surfaces, and petioles of the PMR lines and commercial cultivars in the trial. The severity of powdery mildew coverage on the adaxial leaf surface was measured in percent coverage in 5% increments. The powdery mildew severity on the abaxial leaf surfaces and the petioles was measured in percent coverage in 15% increments.

Name/cultivar	Adaxial leaf surface powdery mildew severity (%)	Abaxial leaf surface powdery mildew severity (%)	Petiole powdery mildew severity (%)
Howden	92 a[z]	100 a[z]	72 a[z]
Magic Lantern	58 bc	89 ab	6 b
Racer	80 ab	83 abc	67 a
Triple Treat	95 a	100 a	78 a
NY14-555	10 ef	11 e	0 b
NY14-556	8 ef	28 cde	11 b
NY14-557	10 ef	33 bcde	0 b
NY14-558	7 ef	11 e	0 b
NY14-559	15 def	33 bcde	0 b
NY14-560	5 f	0 e	0 b
NY14-561	18 def	50 abcde	28 b
NY14-562	13 def	33 bcde	0 b
Patina	33 cde	78 abcd	89 a
NY14-564	8 ef	22 de	0 b
NY14-565	25 def	33 bcde	0 b
NY14-566	23 def	56 abcde	0 b
NY14-567	12 ef	17 e	0 b
NY14-568	12 ef	17 e	6 b
NY14-569	42 cd	50 abcde	0 b
NY14-570	28 def	28 cde	0 b

PMR = powdery mildew resistant.
[z]Means in the same column followed by the same letter are not statistically different as determined by Tukey's honestly significant difference ($P = 0.05$).

The fruit from all of the plants were harvested on 2 Sept. 2014, and the total number of marketable fruit per plot was counted. A sample of 10 marketable fruit from each plot was weighed, and height and width were measured on each fruit. The yield of the lines was expressed as the average number of marketable fruit per plant, and the average weight of the 10 marketable fruit per line was calculated (Table 2). As a general trend, there was an inverse relationship between fruit number and fruit size. The PMR pumpkin lines NY14-555, NY14-556, NY14-564, NY14-565, and 'Patina' all produced more than two marketable fruit per plant. These fruit were relatively small, with most less than 1 kg and ranged in height from 9 to 14 cm. The four commercially available cultivars produced about one marketable fruit per plant. Many of the PMR pumpkin lines yielded fewer marketable fruit per plant than the commercially available cultivars, and these lines also produced smaller fruit. 'Howden' produced significantly larger fruit by weight than all other entries in the trial. The PMR pumpkin lines exhibited a substantial range in the average fruit weights (Table 2). Several of the PMR pumpkin lines produced fruit that were not significantly different in weight from 'Magic Lantern' and 'Racer', and several produced fruit that weighed significantly less than these cultivars.

The overall shape of the fruit was determined by the ratio of height to width of the fruit. Generally, the fruit were quite round, except for 'Howden', which had the largest ratio, and 'Patina', which had the lowest. The PMR pumpkin lines range from 0.72 to 0.93, which was similar to the other cultivars, Magic Lantern, Racer, and Triple Treat (Table 2).

Vine lengths were evaluated on 28 Aug. 2014 as a measure of the appropriate planting density for each entry in the trial. The vine lengths were given as a rating of short (<2 m), medium (2 to 4 m), or long (>4 m). The maturity of the lines was also evaluated on 28 Aug. 2014. The rating was given as early, medium, or late ripening, as compared with the commercial checks. The PMR pumpkin lines expressed much variation for both vine length and maturity (Table 2).

The lines were screened for the presence of powdery mildew on 28 Aug. 2014. The percent powdery mildew coverage on the adaxial surface of the leaves was measured in 5% increments. There was strong disease pressure in the trial field, as indicated by the high levels of powdery mildew in the susceptible cultivars. 'Howden', 'Racer', and 'Triple Treat' each had an average of 80% or above powdery mildew coverage on the adaxial surface of their leaves. This was significantly greater than all of the PMR pumpkin lines, which had a dramatic reduction in powdery mildew severity as compared with the cultivars. 'Magic Lantern' had the least powdery mildew incidence of the cultivars, with an average of 58% powdery mildew coverage on the adaxial surface. All PMR pumpkin lines had significantly less powdery mildew on the adaxial surface than the cultivars, except for NY14-569, which was not

significantly different from 'Magic Lantern' (Table 3).

The percent powdery mildew coverage on the abaxial surface of the leaves was measured in 15% increments. There was a large range in the presence of powdery mildew on this portion of the plants. Overall, the highest presence of powdery mildew on leaf abaxial surfaces was found in the cultivars. The PMR pumpkin lines had lower levels of powdery mildew, many of which were significantly lower than the cultivars. The lowest levels of powdery mildew on the abaxial surface of the leaves were in NY14-555, NY14-558, NY14-560, NY14-567, and NY14-568 (Table 3).

The percent powdery mildew coverage on leaf petioles was also measured in 15% increments. The consensus of the petioles of fully expanded leaves was examined in each plot. There was a dramatic difference in this rating between the cultivars and the resistant lines. 'Howden', 'Racer', 'Triple Treat', and 'Patina' had significantly more powdery mildew present than any of the PMR pumpkin lines with over two-thirds coverage of powdery mildew on the leaf petioles. Many of the resistant lines had no measurable powdery mildew presence. However, 'Magic Lantern' was not significantly different from the PMR pumpkin lines (Table 3).

The PMR pumpkin lines described have been used widely in commercial pumpkin breeding and production. Increased resistance to powdery mildew generally results in increased yield, increased petiole strength, and decreased reliance on fungicide applications. The PMR pumpkin lines express substantial resistance to powdery mildew in all of the evaluated portions of the plant. The lines with the highest levels of resistance overall were NY14-555, NY14-556, NY14-557, NY14-558, NY15-560, NY14-564, NY14-567, and NY14-568. These lines also exhibited a wide range of variation in the other measured traits, including number of fruit per plant, fruit weight, fruit shape, plant growth habit, and maturity. The PMR pumpkin lines remain an important resource for the development of powdery mildew–resistant pumpkin cultivars and are well suited for pure line cultivar or hybrid development.

Availability

Seeds samples of the PMR pumpkin lines are available for distribution. Requests should be made to Michael Mazourek at mm284@cornell.edu.

Literature Cited

Contin, M.E. 1978. Interspecific transfer of powdery mildew resistance in the genus *Cucurbita*. Cornell Univ., Ithaca, PhD Diss.

Green, J.R., T.L.W. Carver, and S.J. Gurr. 2002. The formation and function of infection and feeding structures, p. 66–82. In: R.R. Bélanger, W.R. Bushnell, A.J. Dik, and T.L.W. Carver (eds.). The powdery mildews: A comprehensive treatise. The Amer. Phytopathol. Soc, St. Paul, MN.

Pérez-García, A., D. Romero, D. Fernández-Ortuño, F. López-Ruiz, A. De Vicente, and J.A. Torés. 2009. The powdery mildew fungus *Podosphaera fusca* (synonym *Podosphaera xanthii*), a constant threat to cucurbits. Mol. Plant Pathol. 10:153–160.

McGrath, M.T. 2011. Powdery mildew of cucurbits. 24 Feb. 2015. <http://vegetablemdonline.ppath.cornell.edu/factsheets/Cucurbits_PM.htm>.

McGrath, M.T. and C.E. Thomas. 1996. Powdery mildew. In: T.A. Zitter, D.L. Hopkins, and C.E. Thomas (eds.). Compendium of cucurbit diseases. The Amer. Phytopathol. Soc, St. Paul, MN.

U.S. Dept. of Agriculture, National Agricultural Statistics Service. 2016. Vegetables 2015 summary. 21 Sept. 2016. <http://usda.mannlib.cornell.edu/usda/current/VegeSumm/VegeSumm-02-04-2016.pdf>.