Powdery Mildew–resistant Pumpkin Inbred Lines

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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-Garcia 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 okeechobensis ssp. martinezii. The resistance trait was first transferred from C. okeechobensis 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 powdery mildew. ‘Spirit’ is an early-season, small pumpkin with short vines and is one of the most susceptible inbred lines. ‘PMR Bush Ebony’ is an acorn squash with powdery mildew resistance derived from an introgression with C. okeechobensis ssp. martinezii. The resistance trait was first transferred from C. okeechobensis ssp. martinezii to ‘Waltham’, a butternut squash (C. 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).
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.

| Name/cultivar | Source | Pedigree | Generation |
|---------------|--------|----------|------------|
| Howden        | Harris | Howden   | F₁         |
| Magic Lantern | Harris | Magic Lantern | F₁         |
| Racer         | Johnny's | Racer   | F₁         |
| Triple Treat  | Burpee | Triple Treat | F₁         |
| NY14-555      | Cornell | [(PMR-A') F₆ × Snackjack] F₁₁ | F₁₁ |
| NY14-556      | Cornell | [(PMR-A') F₁₀ × (PMR-B') F₉] F₉ | F₉ |
| NY14-557      | Cornell | (PMR-A') F₁₆ | F₁₆ |
| NY14-558      | Cornell | [(PMR-B') F₈ × (PMR-A') F₁₀] F₈ | F₈ |
| NY14-559      | Cornell | (PMR-A') F₁₅ | F₁₅ |
| NY14-560      | Cornell | [(PMR-A') F₂ OP] F₉ | F₉ |
| NY14-561      | Cornell | (PMR-A') F₁₄ | F₁₄ |
| NY14-562      | Cornell | [Brian Reeves OP × (PMR-A') F₄] F₅ × [(PMR-A') F₁₀] F₅ | F₅ |
| Patina        | Cornell | 'Patina' | F₅ |
| NY14-564      | Cornell | [(PMR-A') F₁₀ × (PMR-B') F₆] F₆ | F₆ |
| NY14-565      | Cornell | [(PMR-A') F₁₀ × (PMR-B') F₆] F₆ | F₆ |
| NY14-566      | Cornell | [(PMR-A') F₁₀ × (PMR-A') F₂ OP] F₇ | F₇ |
| NY14-567      | Cornell | [(PMR-B') F₆ × (PMR-A') F₁₀] F₇ | F₇ |
| NY14-568      | Cornell | [(PMR-B') F₆ × (PMR-A') F₁₀] F₇ | F₇ |
| NY14-569      | Cornell | [(Brian Reeves OP × (PMR-A') F₄)] F₇ × [(PMR-A') F₂ OP] F₇ | F₇ |
| NY14-570      | Cornell | [(Brian Reeves OP × (PMR-A') F₂)] F₇ × [(PMR-A') F₁₀] F₆ | F₆ |

PMR = powdery mildew resistant.

PMR-A and PMR-B represent independent selections from ([(Delicata × PMR Bush Ebony) F₂ × Spirit] × Spirit) × Howden F₁.
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                          | 8.32 a                           | 29 a           | 1.02 a        | 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 bcdf                          | 2.73 f                           | 17 g           | 0.88 bcd      | Long        | Medium   |
| NY14-555      | 2.3 abc                           | 1.42 gh                          | 14 h           | 0.86 bcd      | Short       | Early    |
| NY14-556      | 2.6 abc                           | 0.78 h                           | 11 i           | 0.93 b        | Medium      | Early    |
| NY14-557      | 0.9 cdef                          | 3.47 ef                          | 18 g           | 0.80 fg       | Short       | Late     |
| NY14-558      | 1.3 bcdf                          | 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 bcd      | Short       | Late     |
| NY14-562      | 0.6 def                           | 4.95 bcd                         | 21 def         | 0.91 bcd      | 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 bcd      | 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 abcd                          | 3.41 ef                          | 21 ef          | 0.93 b        | Long        | Late     |

PMR = powdery mildew resistant.
*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                                           | 100 a                                          | 72 a                             |
| 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 bcde                                        | 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 abcd                                        | 0 b                              |
| NY14-567      | 12 ef                                          | 17 e                                           | 0 b                              |
| NY14-569      | 12 ef                                          | 17 e                                           | 6 f                              |
| NY14-570      | 42 cd                                          | 50 abcd                                        | 0 b                              |
| NY14-570      | 28 def                                         | 28 cde                                         | 0 b                              |

PMR = powdery mildew resistant.
*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.

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