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Resistance to Powdery Mildew from Some Small-fruited *Malus* Cultivars

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Abstract. Progenies from 48 small-fruited *Malus* species and cultivars were tested for heritable, high-level resistance to powdery mildew [*Podosphaera leucotricha* (Ell. & Ev.) Salm.] Six-week-old seedlings from controlled crosses and open pollination were inoculated by dusting with conidia in the greenhouse. 'David', 'White Angel', *M. × robusta* (Robusta 5), *M. × robusta* 'Korea', and an unnamed selection *M. × robusta* (24-7-7,8) all produced some seedlings in their progenies that remained free of infection after inoculation. The mode of inheritance of resistance was not clear.

Heritable high-level powdery mildew resistance has been reported both as the result of a deliberate search through *Malus* species and hybrids (5, 6), and as serendipitous discoveries in open-pollinated progenies (4, 10). The annual surveys of Nichols (7) suggested that many ornamental crabapple cultivars also might prove to be useful sources of high-level powdery mildew resistance. Our work involved screening some of these ornamental crabapples for such resistance.

A single, dominant gene was chosen as the model for the type of resistance sought. Screening of young *Malus* seedlings in the greenhouse had been shown to be effective for some sources of powdery mildew resistance, such as 'White Angel' (Lamb and Aldwinckle, unpublished data), 'Mildew Immune Selection' ('MIS') (4), *M. × zumi* Rehd. and *M. × robusta* Rehd. (2), and the 'D-numbers' (11). Therefore, it was chosen as the testing method for this study. The number of seedlings to grow from each cultivar or species was determined following the logic of Knight and Alston (5), except that 20 seedlings from each cultivar were

used instead of 10 to provide an additional measure of confidence.

Controlled crosses were made in the field at Geneva, New York. Flower buds at the balloon stage were emasculated by removing the calyx, corolla, and stamens by hand in one operation. Pollen was applied with the fingertip after washing hands in 50% ethanol. Pollinated pistils were left naked with no bagging.

The seedlings were grown for 6 weeks before testing. Testing was done in greenhouses equipped to provide as close to 100% RH as possible. The conidia source had been maintained in the greenhouse on potted apple seedlings. Conidia were blown from infected plants and allowed to settle onto the leaves of the plants to be tested (9). Some seedlings were completely covered with powdery mildew after only 1 week. Only seedlings that had no visible mildew were rated as resistant. The number of resistant seedlings in a progeny tended to decrease over time, making it difficult to establish exactly the best time for seedling evaluation. Final evaluations were made at least 2 weeks after inoculation, and up to 26 days later in some instances.

Progenies of 48 *Malus* cultivars and species from either controlled crosses or open pollination were tested in 1980 and 1981 for segregation for a high level of powdery mildew resistance (Table 1). Seven of these, 'David', *M. × robusta* Robusta 5, *M. × robusta* 'Korea', *M. × robusta* (24-7-7,8), *M. prunifolia* Borkh. 'Sikora I', Spec 63-6 and

'White Angel' had a segregation that did not deviate significantly below 50%. The first 6 of these were used in 1981 as pollen parents in crosses with the mildew susceptible cultivar *M. × domestica* Borkh. 'Frimley Rome'. The 7th cultivar, 'White Angel', already had been used the previous year as a pollen parent in 3 crosses with 'Radiant', *M. × sublobata* 'Novole', and *M. × domestica* 'Liberty'. Five of these 7 transmitted a high level of mildew resistance to their progeny when used as pollen parents; *M. × robusta* Robusta 5, *M. × robusta* 'Korea', *M. × robusta* (24-7-7,8), 'David' and 'White Angel' (Table 2). Self pollinations of these cultivars were attempted in the field in 1982 using the technique described by Dayton (3) (Table 3).

The other 2 of the 7 cultivars, Spec 63-6 and *M. prunifolia* 'Sikora I', had few resistant seedlings in their progenies when used as pollen parents. 'Sikora I' is located 2 trees away from a tree of 'White Angel', so it is likely that the powdery mildew resistance in the open-pollinated progeny came from 'White Angel' pollen. We have not observed the neighbors of the tree of Spec 63-6, which is at the Morton Arboretum, but there may be some other source of powdery mildew resistance in close proximity.

The percentage of resistant seedlings in the selfed progenies was not markedly different from the results of previous years using the cultivars as pollen parents, with the exception of 'White Angel', which was slightly higher (Table 2). Therefore, it seems unlikely that the selfing was successful. Both cultivars used as mentor (killed) pollen were red-leaved crabs. The killed pollen was tested for germination before use, with negative results. Since there were no red-leaved seedlings in the 'David' and *M. × robusta* Robusta 5 selfed and the 'Frimley Rome' × killed NY 517 progenies, it is unlikely that the seeds were set by the mentor pollen (Table 3). There was too much variability in the progenies to consider apomixis as the source of the seeds. We therefore assume that the seeds resulting from the attempted selfs were set by open pollination.

Several of the progenies that were otherwise all susceptible had a small number of resistant plants with greatly shortened internodes, slow growth, and smaller leaves than normal plants. These "dwarf" plants were quite common in some progenies, but not all of them were resistant. These seedlings were especially common in *M. × robusta* 'Korea' and *M. × robusta* (24-7-7,8) progenies. Al-

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Table 1. Segregation of apple progenies resulting from open pollination and controlled crosses for resistance to powdery mildew (*Podosphaera leucotricha*) following greenhouse inoculation.

Progeny	No. of seedlings					
	Time of evaluation after initial inoculation (days)					
	7		14		26	
	R	S ^z	R	S	R	S
<i>October 1980 inoculation</i>						
<i>Open pollinated</i>						
Arrow	4	16	2	18		
Donald Wyman	4	109	1	111		
Frettingham	3	20	0	22		
Golden Hornet	7	97	0	101		
<i>M. baccata</i> 18-8-37	5	15	2	18		
<i>M. hupehensis</i>	1	0	1	0		
<i>M. × purpurea</i> Aldenhamensis	1	10	1	8 ^y		
<i>M. Sargentii</i>	4	15	0	18		
<i>M. yunnanensis</i> Vilmorin	3	18	2	18 ^y		
NA 40298	3	19	0	22		
NY 11902	2	19	0	20		
Royalty	0	9	---	---		
White Angel	35	33	32	36		
	34	36	34	36		
<i>April of 1981 inoculation</i>						
<i>Open pollinated</i>						
Albright	2	12	0	14	---	---
Ames White	2	13	1	14	1	14
Burtens Yellow Fruited	2	17	2	17	0	19
David	14	6	7	13	5	15
Golden Gem	0	17	---	---	---	---
Henningii	2	14	1	15	1	15
Henry Kohankie	1	16	1	14	0	15
Hybrid Clone 700-68	0	15	---	---	---	---
Hyslop	0	18	---	---	---	---
Kit Trio	0	14	---	---	---	---
<i>M. baccata</i> Columnaris	5	15	0	18	---	---
<i>M. brevipes</i>	1	16	0	17	---	---
<i>M. Halliana</i> Parkmanii	2	0	2	0	2	0 ^y
<i>M. kansuensis</i>	6	14	3	16	3	16
<i>M. prunifolia</i> Sikora I	3	17	3	15	3	15
<i>M. × robusta</i> 24-7-7,8	9	4	4	8	2	10
<i>M. × robusta</i> Korea	11	5	11	3	10	4
<i>M. toringoides</i>	1	13	1	13	1	13 ^y
Morden 19-27	4	16	2	18	2	18
Mount Arbor Special	0	4	---	---	---	---
Nipissing	0	18	---	---	---	---
Redflesh	0	13	---	---	---	---
Rodney	0	12	---	---	---	---
Sissipuk	1	8	---	---	---	---
Spec 63-6	9	11	9	11	9	11
Toshprince	1	14	0	15	---	---
Wies	4	12	1	15	0	16
<i>Crosses with Frimley Rome as seed parent</i>						
Arrow	1	12	0	13	---	---
Chestnut	0	17	---	---	---	---
Dolgo	0	19	---	---	---	---
<i>M. brevipes</i>	2	14	0	14	---	---
<i>M. floribunda</i>	0	15	---	---	---	---
<i>M. Halliana</i>	0	3	---	---	---	---
<i>M. Halliana</i> Parkmanii	0	7	---	---	---	---
<i>M. × sublobata</i> Novole	0	19	---	---	---	---
<i>M. × robusta</i> Robusta 5	7	13	6	14	4	16
Red Baron	0	16	---	---	---	---
September	0	20	---	---	---	---

^zR = resistant (free of visible infection); S = susceptible.

^yResistant plant(s) dwarf.

though not counted, their presence may have affected the percentage of resistant seedlings.

A few seedlings from all 5 cultivars have been planted in the field and evaluated for 2 growing seasons, and all seedlings but one

have remained free of mildew infection. One seedling from *M. × robusta* 'Korea' had one infected terminal leaf cluster out of a total of 31 shoots in the fall of 1983. There was no sign of infection on any of the other shoots of that seedling. There was no mildew on

that shoot or on any other shoot of that tree in the spring of 1984, possibly indicating that a new race of pathogen capable of overcoming the resistance of *M. × robusta* 'Korea' was present that season, or that the common form of the pathogen may be in-

Table 2. Percentage of powdery mildew resistant seedlings in progenies from 5 small-fruited *Malus* cultivars tested in the greenhouse.

Cultivar	Resistant seedlings (%)		
	Open pollinated	As a pollen parent ^z	Selfed ^y
<i>M. × robusta</i> Robusta 5	--- ---	20 (20) 16 (94)	22 (18)
<i>M. × robusta</i> 24-7-7,8	17 (12) ^x	59 (84)	55 (64)
<i>M. × robusta</i> Korea	69 (14)	69 (157)	63 (252)
David	25 (20)	41 (94)	45 (18)
White Angel	48 (71) 47 (68) 48 (70)	47 (298) 46 (39) 44 (305)	58 (149)
Spec 63-6	45 (20)	2 (86)	--- ---
<i>M. prunifolia</i> Sikora I	17 (18)	6 (63) ^w	--- ---

^zFrimley Rome used as seed parent, except for White Angel crosses, which have Radiant, *M. × sublobata* Novole and Liberty as the seed parents, respectively. Evaluated 2 weeks after inoculation.

^ySelfing not believed to be successful. See text.

^xNumbers in parentheses are numbers of seedlings in each progeny.

^wResistant plants dwarf.

Table 3. Numbers of powdery mildew resistant seedlings and percentage of red-leaved seedlings in progenies from 1982 *Malus* crosses tested in the greenhouse.

Progeny	No. of seedlings						Red leaved (%)
	Time of evaluation after initial inoculation						
	1 wk		2 wk		3 wk		
	R ^z	S	R	S	R	S	
Selfs^y							
White Angel	109	45	87	64	86	63	20
David	12	6	8	10	8	10	0
<i>M. × robusta</i> Robusta 5	9	10	4	14	4	14	0
<i>M. × robusta</i> Korea	230	42	186	74	159	93	4
<i>M. × robusta</i> 24-7-7,8	50	17	40	25	35	29	22
Crosses							
Frimley Rome x NY 517 (live)	---	---	0	42	0	42	26
Frimley Rome x NY 517 (killed)	---	---	1	15	1 ^x	15	0
Frimley Rome x Red Jacket (live)	---	---	0	17	0	17	35
Idared x David o.p. #5	5	5	4	6	4	6	0

^zR = resistant; S = susceptible.

^yNY 517 used as mentor pollen for White Angel and David; Red Jacket was used for the remaining 3.

^xResistant seedling dwarf.

fecting under unusually favorable conditions.

Only the mildew resistance of 'David' has been taken through more than one generation. One open-pollinated seedling from 'David' bloomed in the greenhouse in 1982, 1 year after germination; however, the seedling died of root rot soon afterwards. Pollen was collected from this seedling ('David' o.p.

#5) and used in a cross with *M. × domestica* 'Idared' (Table 3).

M. × robusta Robusta 5, *M. × robusta* 'Korea', *M. × robusta* (24-7-7,8), 'David' and 'White Angel' may hold promise as sources of easily detected, high-level powdery mildew resistance. Our data do not indicate clearly that resistance is controlled by a single dominant gene segregating with 50%

of the progeny free from infection. There may be a single gene modified by the polygenic background, as suggested by Alston (1) for the *M. × robusta* and *M. × zumi* sources of powdery mildew resistance and by Rousselle et al. (8) for the V_f gene for scab (*Venturia inaequalis* Wint.) resistance. The presence of dwarf seedlings and the instability of the percentage of resistance seedlings over time also may be confusing the ratios. The usefulness of any of these cultivars in apple breeding programs will be decided by the durability of their resistance and the ease and completeness of its transfer in more advanced generations.

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