Evaluation of Delphinium Cultivars for Resistance to Powdery Mildew

Stephen N. Wegulo[1,2,3] and Miguel Vilchez[1]

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Summary. **Powdery mildew caused by *Erysiphe aquilegiae* var. *ranunculi* is one of the major diseases affecting field-grown delphiniums (*Delphinium* spp.). Two lath house and two field experiments were conducted in 2003 and 2004 to evaluate nine delphinium cultivars for resistance to the disease. 'Blue Bird', 'King Arthur', 'Cameliard', and 'Galahad' were consistently more resistant [0–1.1 disease severity (ds) on a 0–5 scale] than 'Casa Blanca', 'Blue Shadow', 'Belladona', and 'Bellamosum' (2.9–5.0 ds). 'Oriental Blue' was moderately resistant (0–3.3 ds). Spearman's coefficients of rank correlation were significant for all pairs of experiments ($0.70 \leq r_s \leq 0.98$; $P \leq 0.0354$) except for the 2003–04 field experiments ($r_s = 0.66$; $P = 0.0525$). Pearson correlation coefficients between experiments ($0.86 \leq r \leq 0.99$) were highly significant ($P \leq 0.0027$). Disease severity values from lath house evaluations were almost identical to those from field evaluations.**

Delphinium is a genus comprising three hundred or more distinct species belonging to the family Ranunculaceae (Bassett and Bassett, 2007). True delphiniums are herbaceous perennials. The common name, larkspur, is shared with a separate, closely related genus, *Consolida*, consisting of annual species. The two genera are distinguished by flower structure. Flowers of the true wild ancestors of species in the genus *Consolida* have a single petal and a single carpel (seedpod), whereas flowers of species in the genus *Delphinium* have two or four petals and three or more carpels (Basset and Basset, 2007; Mabberley, 1997). Delphiniums are native in the northern hemisphere, but a few species are found along the mountain ranges of tropical Africa. Delphiniums produce a range of beautiful flower colors, including blue, pink, purple, cream, and white. They contribute significantly to the aesthetic value of homes, gardens, and the landscape, and are grown commercially for cut flowers. In 2006, the wholesale value of larkspur (*Delphinium* spp. and *Consolida* spp.) as a cut flower in the United States for operations with sales worth $100,000 or more was $8 million, with California accounting for 80% of those sales (Jerardo, 2007).

Powdery mildew is one of the major diseases affecting field-grown delphiniums. The disease is caused by fungi in the genera *Erysiphe, Golovinomyces*, and *Podosphaera* (Horst, 2001). Growth of these fungi results in gray powdery masses of mycelium and conidia on the surface of leaves, stems, and flowers. In severe infections, young leaves and growing tips become curled and stunted, significantly lowering yield and quality. Ascocarps (sexual fruiting bodies) form on infected areas on the plant late in the growing season. The powdery mildews are obligate parasites. They overwinter as ascocarps on plant debris or as mycelia in dormant plant tissue. Conidia, ascocarps, and ascospores released from ascocarps are dispersed from infected plants or plant debris by wind (Jarvis et al., 2002).

Delphinium cultivars vary greatly in their resistance to powdery mildew (Pirone, 1978). Melquist (1941) screened 13 species of delphiniums native to California for resistance to powdery mildew caused by *Erysiphe polygoni*. The species varied widely in resistance ranging from highly susceptible [swamp larkspur (*Delphinium uliginosum*)] to highly resistant [sierra larkspur (*Delphinium scopulorum* var. *glaucum*)]. Since publication of Melquist's results in 1941, research has not been done in California to identify delphinium cultivars with resistance to powdery mildew. The use of resistant cultivars in combination with other disease management strategies such as cultural practices and fungicide application can reduce losses. The objective of this study was to evaluate delphinium cultivars for resistance to powdery mildew.

Materials and methods

In 2003 and 2004, nine delphinium cultivars were evaluated for resistance to powdery mildew caused by *Erysiphe aquilegiae* var. *ranunculi* in a lath house and in the field. *Erysiphe aquilegiae* var. *ranunculi* was identified on the basis of singly produced conidia and mycelioid appendages on ascocarps (Braun, 1995). The cultivars were Belladona, Bellamosum, Blue Bird, Blue Shadow, Cameliard, Casa Blanca, Galahad, King Arthur, and Oriental Blue. These cultivars were chosen because they comprised a significant proportion of seedling sales at a cooperating southern California nursery.

Lath house experiments. Lath house experiments were conducted on the University of California, Riverside campus. In the first experiment, seedlings with two to four true leaves were transplanted into 4-inch-diameter pots (1 plant/pot) on 27 Mar. 2003. Cultivars were arranged in a randomized complete block design with four replications (10 plants per replication) on two adjacent benches in the lath house. Infected 'Blue Shadow' delphinium plants raised in the lath house in 4-inch-diameter

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[1]Department of Plant Pathology, University of California, Riverside, CA 92521

[2]Current address: Department of Plant Pathology, University of Nebraska, Lincoln, NE 68583.

[3]Corresponding author. E-mail: swegulo2@unl.edu.

Units

To convert U.S. to SI, multiply by	U.S unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha^{-1}	0.1069
2.54	inch(es)	cm	0.3937

pots were placed around the benches at 24-inch intervals on the same day the cultivars were transplanted and served as a source of inoculum. Average disease severity on these plants at the time they were placed around the benches was 3 on a scale of 0 to 5 (0 = no symptoms; 1 = 1% to 20% of foliage covered with powdery mildew; 2 = 21% to 40% of foliage covered with powdery mildew; 3 = 41% to 60% of foliage covered with powdery mildew; 4 = 61% to 80% of foliage covered with powdery mildew; and 5 = 81% to 100% of foliage covered with powdery mildew) and was 5 on the disease assessment date. On 23 Apr. 2003, cultivars were further uniformly inoculated by dislodging conidia from infected, field-collected 'Blue Shadow' delphinium plants over the foliage with a brush. Plants were watered as needed and were fertilized once with 14N–6.1P–11.6K controlled-release fertilizer. Disease severity was visually evaluated (whole-plot rating) on 2 Jun. 2003 on a scale of 0 to 5 as defined above. Each replication with 10 plants was considered a plot. At the time of disease assessment, plant height varied with cultivar and ranged from 6 to 18 inches.

In the second experiment, seedlings of the same nine delphinium cultivars (two to four true leaves) were transplanted into 4-inch-diameter pots on 18 Oct. 2003. Cultivars were uniformly inoculated by dislodging conidia from infected, field-collected 'Blue Shadow' delphinium plants over the foliage with a brush just before transplanting. Experimental design was a randomized complete block with four replications (10 plants per replication). Watering and fertilization were as in the first experiment. Disease severity (0–5 scale) was visually evaluated as in the first experiment on 4 Mar. 2004. When disease was assessed, some cultivars were in bloom and others were starting to bloom. Plant height ranged from 30 to 72 inches.

FIELD EXPERIMENTS. Field experiments were conducted at the University of California South Coast Research and Extension Center (SCREC) in Irvine. In the first experiment, seedlings of the nine cultivars evaluated in the lath house were transplanted on 1 Apr. 2003 into 40-inch-wide, 100-ft-long beds in double rows per bed at SCREC. Seedlings had two to four true leaves at the time of transplanting. Spacing between plants in a row was 12 inches and spacing between rows on a bed was 10 inches. Cultivars were arranged in a randomized complete block design with four replications (one bed per replication). Plot length was 10 ft, with 1-ft-long gaps between plots. Each plot was planted with 20 plants of one cultivar, and there were nine plots representing nine cultivars in each block (a total of 180 plants per block). Cultivars were uniformly inoculated just before transplanting by dislodging conidia from infected, field-collected 'Blue Shadow' delphinium plants over the foliage with a brush. Inoculum was further provided by heavily infected 'Blue Shadow' delphinium plants from previous experiments growing in parallel beds on both sides of the experiment. Disease severity (0–5 scale) was visually evaluated (whole plot rating) on 27 Jun. 2003 during full bloom.

Beds were drip-irrigated as needed. Fertilizer was applied via drip and consisted of 760 lb/acre of 6N–8.7P–16.6K preplant, followed by two applications of 10 gal/acre of 32N–0P–0K at 7- and 14-d intervals. Weed control was achieved by applying 1.14 lb/acre of prodiamine preplant.

In the second experiment, seedlings of the same nine cultivars were transplanted into beds in double rows in the same field on 21 Oct. 2003. Bed length, plot length, seedling growth stage, inter and intrarow spacing, experimental design, irrigation, and fertilization were as in the first experiment. Infection was from natural inoculum (airborne spores). Disease severity (0–5 scale) was visually evaluated (whole plot rating) on 5 Mar. 2004 during full bloom.

DATA ANALYSIS. Data were analyzed by the general linear models procedure of SAS (version 8; SAS Institute, Cary, NC). The least significant difference test at $P = 0.05$ (Gomez and Gomez, 1984) was used to compare pairs of treatment means. Spearman's coefficients of rank correlation were used as a measure of correspondence between cultivar ranking in each pair of experiments. Pearson correlation coefficients were used as a measure of the strength of association of disease severity values between experiments.

Results and discussion

In all lath house and field experiments, there were significant differences ($P < 0.0001$) in disease severity among cultivars. 'King Arthur', 'Blue Bird', 'Galahad', and 'Cameliard' were consistently resistant in all four experiments. 'Oriental Blue' was moderately resistant, whereas 'Bellamosum', 'Blue Shadow', 'Belladona', and 'Casa Blanca' were consistently susceptible in all four experiments (Table 1).

There was wide variation in resistance to powdery mildew among

Table 1. Severity of powdery mildew on nine delphinium cultivars evaluated for resistance to the disease in a lath house on the University of California, Riverside campus (UCR) and in the field at the University of California South Coast Research and Extension Center, Irvine, California (SCREC).

	Powdery mildew severity (0–5 scale)[z]			
Cultivar	UCR lath house (2 June 2003)	UCR lath house (4 Mar. 2004)	SCREC field (27 June 2003)	SCREC field (5 Mar. 2004)
Bellamosum	3.8 a[y]	4.8 a	4.6 a	4.9 a
Blue Shadow	3.3 b	4.4 a	4.2 ab	4.6 a
Belladonna	3.0 b	4.6 a	4.5 a	4.6 a
Casa Blanca	2.9 b	4.6 a	3.8 bc	5.0 a
Cameliard	0.4 c	0.8 cd	0.1 d	0.1 b
Galahad	0.4 c	1.1 c	0.5 d	0.1 b
Blue Bird	0.3 c	0.0 d	0.1 d	0.1 b
Oriental Blue	0.2 c	2.2 b	3.3 c	0.0 b
King Arthur	0.2 c	0.9 c	0.3 d	0.0 b

[z]0 = no symptoms; 1 = 1% to 20% of foliage covered with powdery mildew; 2 = 21% to 40% of foliage covered with powdery mildew; 3 = 41% to 60% of foliage covered with powdery mildew; 4 = 61% to 80% of foliage covered with powdery mildew; and 5 = 81% to 100% of foliage covered with powdery mildew.
[y]Means within a column followed by the same letter are not significantly different at $P = 0.05$ according to the least significant difference test.

the nine cultivars tested in this study (Table 1). Melquist (1941) similarly demonstrated that 13 delphinium species native to California varied greatly in their resistance to powdery mildew caused by *E. polygoni*. In this study, the Pacific Hybrids 'Blue Bird', 'Cameliard', 'Galahad', and 'King Arthur' were more resistant to powdery mildew than the other cultivars, among which only 'Oriental Blue' was moderately resistant. Although the Pacific Hybrids were resistant to powdery mildew in this study, they are usually not as popular as the other cultivars because of their large size. Growers prefer cultivars that are smaller in size. However, because many of these cultivars are susceptible to powdery mildew, fungicides often are applied to control the disease. Several fungicide products are available for control of delphinium powdery mildew (Wegulo and Vilchez, 2006a, 2006b). An alternative approach to managing delphinium powdery mildew is to reduce the number of susceptible cultivars by introducing cultivars with resistance to the disease. It is imperative that delphinium breeders consider disease resistance a priority in their breeding efforts.

Although cultivar rankings (1 = most resistant; 9 = least resistant) varied somewhat between experiments, there was consistency in that the cultivars Bellamosum, Blue Shadow, Belladona, and Casa Blanca were in the worst four rankings in all experiments. 'Oriental Blue' ranked 1 and 2 in two experiments and 5 in the other two experiments. 'King Arthur', 'Blue Bird', 'Galahad', and 'Cameliard' fluctuated in their rankings from 1 to 5 (data not shown).

Inconsistency in cultivar reaction to pathogens in various pathosystems has been reported in previous studies. Wegulo and Vilchez (2007) found rankings of lisianthus (*Eustoma grandiflorum*) cultivars to fluctuate between evaluation methods when the cultivars were screened for resistance to *Botrytis cinerea*. In a separate study, Wegulo et al. (1998) similarly found rankings of soybean (*Glycine max*) cultivars to fluctuate between evaluation methods when screened for resistance to *Sclerotinia sclerotiorum*. Daubeny and Pepin (1973) observed inconsistencies in susceptibility of strawberry (*Fragaria* × *ananassa*) cultivars to postharvest fruit rot. Our study differs from the previous studies in that fluctuation in delphinium cultivar rankings between experiments was minimal, with Spearman's coefficients of rank correlation ranging from r_s = 0.66 to 0.98 (Table 2), whereas in the previous studies, fluctuation in rankings was considerable, for example $-0.44 \leq r_s \leq 0.55$ (Wegulo et al., 1998).

Pearson correlation coefficients, which measured the strength of association of disease severity values between experiments, were highly significant ($P \leq 0.0027$; Table 2). Except for the 2003 lath house/2003 field and 2003 field/2004 field experiments ($r = 0.86$), Pearson correlation coefficients between lath house and field experiments ranged from 0.94 to 0.99 (Table 2), indicating that disease evaluations in the lath house were almost identical to those in the field. Based on this finding, evaluation of delphinium cultivars for resistance to powdery mildew can be done in the lath house with accuracy similar to that in the field. Therefore, expensive field evaluations can be avoided by conducting evaluations in the lath house.

Table 2. Pearson correlation coefficients and Spearman's coefficients of rank correlation (n = 9) between experiments conducted to evaluate nine delphinium cultivars for resistance to powdery mildew. Experiments were conducted in 2003 and 2004 in a lath house on the University of California, Riverside, campus and in the field at the University of California South Coast Research and Extension Center, Irvine, California.

	Pearson correlation		Spearman correlation	
Experiments	Coefficient	$P > \|r\|$	Coefficient	$P > \|r\|$
2003 lath house/2003 field	0.86	0.0027	0.75	0.0191
2003 lath house/2004 field	0.99	<0.0001	0.87	0.0022
2004 lath house/2003 field	0.96	<0.0001	0.98	<0.0001
2004 lath house/2004 field	0.95	<0.0001	0.70	0.0354
2003 lath house/2004 lath house	0.94	<0.0001	0.73	0.0246
2003 field/2004 field	0.86	0.0027	0.66	0.0525

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