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Comparative Response of Red Raspberry Cultivars to Phytophthora Root Rot

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Abstract

Thirty red raspberry genotypes, including newly released cultivars and advanced selections from diverse breeding programs, were evaluated for response to Phytophthora root rot over three years on a natively infested field site. Plants were evaluated quantitatively and qualitatively for root rot symptoms and cane growth over three years and compared to known resistant and susceptible cultivars. Cultivars 'Cascade Bounty', 'Jaclyn', 'Newburgh', 'Cascade Delight', 'Prelude', 'Sumner', 'Moutere', 'Ukee', 'Josephine', and advanced selections WSU 1499 and WSU 1447 had root rot responses similar to 'Summit' and were identified as resistant to the disease.

Phytophthora root rot is an important disease of red raspberry (*Rubus idaeus* L.), affecting production areas worldwide. The major agent of the disease is an oomycete that spreads quickly under wet conditions, *Phytophthora rubi* (*P. rubi*), which has been previously reported as *P. erythroseptica* and *P. fragariae* var. *rubi* (7, 12, 14). Crown and root tissue affected by the disease may appear dark and necrotic, while above ground symptoms include yellowing foliage turning to bronzing, and wilting canes beginning at the tip, which can lead to yield reductions, cane collapse, and plant death (12). The use of resistant cultivars is a critical component of integrated management of the disease. Considerable variability in root rot resistance exists among cultivars, and resistance is a major goal of raspberry breeding programs (1, 3, 6, 9, 13). Multiple genes appear to control root rot resistance in red raspberry, which, considering the high levels of heterozygosity in parents, make it difficult to predict inheritance of the trait (10). 'Meeker' is the most widely grown cultivar in the Pacific Northwest, but is susceptible to the disease and does not thrive on heavily infested sites (1, 4, 6). By contrast, cultivars known to be highly resistant to the disease, such as 'Newburgh' and 'Summit' (1, 4, 6), have other horticultural traits that prevent them from being commercially important. Even when the root rot response of new cultivars is reported, variations in disease pressure and growing conditions make it difficult to compare resistance relative to existing cultivars. The goal of this study was to compare responses of new cultivars and advanced selections on a common site with cultivars with known responses.

Materials and Methods

The raspberry genotypes were tested at the Washington State University Puyallup Research and Extension Center in Puyallup, WA, on a site that has been previously planted to raspberry and naturally infested with *P. rubi*. The soil type is a Sultan silt loam. The presence of *P. rubi* was confirmed in soil and raspberry roots sampled from this site (Forge, pers. communication).

Prior to planting, the soil was tilled to a depth of 30 cm. Raised beds of 20-cm height were formed on 3-m centers. Thirty cultivars and advanced selections (Table 1) were planted in a randomized complete block design with six replicates. Newly released cultivars from other growing regions were included to assess their relative susceptibility to root rot pressure

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at our site. Tissue-culture propagated plants of each genotype were planted on 5 Sept 2007 in single-plant plots separated by 1.5 m within the row. Drip irrigation and fertigation were used to maintain soil moisture and fertility adequate to crop needs throughout the experiment. Annual rainfall was 812 mm in 2008, 991 mm in 2009, and 1016 mm in 2010. The previous year's primocane growth was removed during each dormant season. Plots were cultivated between rows as needed to control weed growth.

In July 2008, 2009, and 2010, each plot was assessed for the number of primocanes with root rot symptoms of tip wilting, cane lesions, and leaf yellowing, and for the number of healthy, symptomless primocanes. The sum of symptomatic and symptomless canes yielded the total number of canes per plot and was used to determine the percentage of healthy canes. Plants that succumbed to the disease over the course of the study after adequate establishment were considered to have 0% healthy canes. Plants that did not establish were treated as missing plots. Total primocane mass was determined for each plot during the dormant season in January 2010 and 2011 and percent change in cane mass was calculated. Plots were rated in October 2009 and October 2010 for plant appearance on a scale of 0 (dead plant) to 5 (vigorous plant with green leaves). Fruit was not harvested from the plots.

Statistical analysis

Field data were subjected to analysis of variance separately by year. Differences in overall and genotype means were tested at $P<0.05$. Pairwise comparisons of each genotype mean and the known resistant and susceptible cultivars 'Summit' and 'Cowichan', respectively, (4, 6, 9) were made at the $P = 0.01$ level with Dunnett's test. All data were examined for homogeneity of variance through diagnostic fit tests, and analyzed for normality using Kolmogorov-Smirnov's test. Variables that did not meet assumptions of normality and homogeneity of variance were transformed appropriately. Data that could not be transformed to meet assumptions of normality and homogeneity of variance were rank-transformed within blocks and analyzed by Friedman's test. Spearman's rank correlation was performed on response variables. Tables display arithmetic means. All statistical analyses were performed with SAS 9.2 software (SAS Institute, Cary, N.C.).

Results

This study was conducted on a site known for severe root rot pressure. As the experiment continued, differences between cultivars became more pronounced as susceptible plants succumbed to the disease. The known susceptible genotypes 'Malahat', WSU 1226, and 'Cowichan' showed between 37 and 47% affected canes in the establishment year, while known resistant cultivars 'Summit' and 'Cascade Bounty' had no apparent affected canes in the first year (data not shown). The susceptible standards exhibited a pattern of increasing biomass between the first and second years, then declining markedly between the second and third year. These genotypes had sparse canes of low vigor and their leaves had yellowish color by the third year. 'Summit' and 'Cascade Bounty', by contrast, increased in biomass each year, and had a profusion of vigorous, healthy green primocanes during the warm season of the third year.

To assess the resistance of the tested genotypes, measurement variables were compared with those of 'Summit' for percent change in total cane mass, percent healthy canes, and ratings in 2010, the final year of observation. Eleven genotypes differed from 'Cowichan' at the 1% significance level for all variables, but did not significantly differ from 'Summit' for any response variable: 'Jaclyn', 'Sumner', 'Prelude', 'Cascade Bounty', 'Newburgh', 'Cascade Delight', 'WSU 1447', 'Moutere', 'Josephine', WSU 1499, and 'Ukee' (Table 1). These cultivars were classified as resistant.

Three genotypes, 'Cascade Dawn', 'Chilliwack', and 'Chemainus' differed

Table 1. Percent change in cane mass and cane number from previous year, and percent healthy canes and plant rating in 2010, the third year on a root-rot infested site.

Genotype	N	Cane mass[z] (% change)		Healthy canes[z] (%)		Rating[z,y] (0-5)	
Summit	6	22	-	92	-	5.0	-
Jaclyn	6	80	r	94	r	4.8	r
Sumner	5	46	r	89	r	5.0	r
Prelude	6	9	r	91	r	5.0	r
Cascade Bounty	6	7	r	92	r	4.8	r
Newburgh	6	4	r	93	r	5.0	r
Cascade Delight	6	-2	r	87	r	5.0	r
WSU 1447	6	-3	r	88	r	4.5	r
Moutere	6	-7	r	80	r	4.7	r
Josephine	3	-9	r	84	r	4.0	r
WSU 1499	6	-14	r	90	r	5.0	r
Cascade Dawn	4	-19	r	77	s	3.2	i
Ukee	6	-22	r	80	r	4.7	r
Chilliwack	4	-29	r	70	s	2.8	s
Chemainus	6	-36	r	66	s	3.2	s
Willamette	6	-46	s	70	s	3.2	s
Anne	5	-48	s	60	s	2.8	s
WSU 1582	5	-55	s	52	s	1.3	s
ORUS 1142-1	3	-58	s	30	s	0.5	s
Meeker	5	-62	s	74	s	2.3	s
Tulameen	4	-63	s	71	s	1.8	s
Saanich	5	-70	s	54	s	1.5	s
WSU 1502	6	-70	s	35	s	1.0	s
Esquimalt	5	-70	s	43	s	1.6	s
Caroline	6	-79	s	46	s	2.0	s
Malahat	5	-84	s	27	s	1.2	s
Coho	5	-86	s	17	s	0.0	s
Cowichan	6	-88	-	28	-	1.0	-
Cascade Gold	6	-93	s	16	s	0.5	s
WSU 1226	3	-100	s	37	s	0.5	s

[z] Analyzed by Friedman's non-parametric test on ranked means. Arithmetic means displayed.
[y] Plants were rated on a scale from 0 to 5, where 0 = dead plant, 1 = few, short canes, foliage mostly yellow or brown; 2 = some canes, foliage green and yellow; 3 = several canes, foliage green with a little yellow; 4 = many canes, foliage mostly green, 5 = abundant canes, foliage almost all green.
[x] Letters indicate comparisons at $p = 0.01$ with resistant standard 'Summit' and susceptible standard 'Cowichan': r, non-significant difference from 'Summit' and significant difference from 'Cowichan'; i, significant difference from both 'Summit' and 'Cowichan'; s, significant difference from 'Summit' and non-significant difference from 'Cowichan'.

significantly from 'Summit' at the 1% significance level for percentage of healthy canes and rating, but not percent change in cane mass (Table 1). These three genotypes were designated as intermediate in susceptibility.

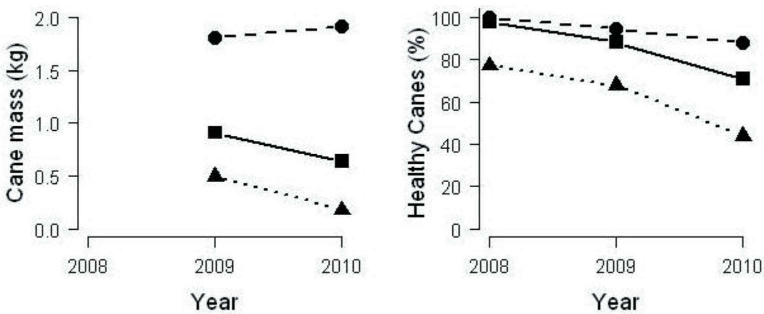
Fourteen genotypes were at least as susceptible to root rot as the susceptible standard 'Cowichan': 'Willamette', 'Anne', WSU 1582, ORUS 1142-1, 'Meeker', 'Tulameen', 'Saanich', WSU 1502, 'Esquimalt', 'Caroline', 'Malahat', 'Coho', 'Cascade Gold', and WSU 1226. These genotypes had no significant difference relative to 'Cowichan', but differed highly significantly from 'Summit' ($p = 0.01$) for all three response variables.

Discussion

This field assessment allowed evaluation of 30 genotypes over 3 years, a duration that has been previously identified as useful for classification of resistant and susceptible genotypes (4). Little correlation existed between first-year and third-year values of measurement variables, indicating that first-year data is not sufficient to compare root rot responses in the field (data not shown). The response of resistant, intermediate, and susceptible genotypes diverged considerably between the second and third year, especially for cane mass which increased for resistant genotypes as a group, but decreased for intermediate and susceptible groups (Fig. 1).

Correlation analysis revealed strong correlations among all the variables in 2010, the third year of the evaluation (Table 2). Subjective ratings may be a simple, rapid and effective way for breeding programs to screen root rot response in the field, although they are highly dependent on the observer. In this study, the subjective ratings tended to be bimodally distributed with high or low ratings being assigned to most of the plants with few intermediate ratings.

Genotypes in this study were evaluated based on primocane growth only, to make maintaining the plots and measuring cane mass easier, and also to minimize the variation



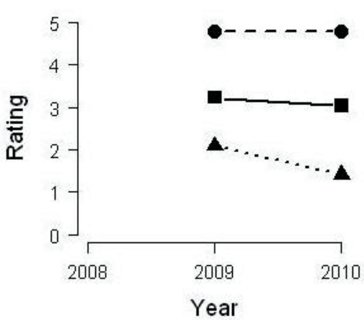


Figure 1. Year-over-year comparisons of resistant (●), intermediate (■), and susceptible (▲) group means for total cane mass, percent healthy canes, and plant rating.

Table 2. Spearman rank correlation coefficients and significance of three variables used to assess root rot response of 30 genotypes in 2010.

	Healthy canes (%)	Rating	Cane mass (% change)
Healthy canes (%)	1.00	**0.81**	**0.76**
Rating		1.00	**0.79**
Cane mass (% change)			1.00

Bold text indicates significance of $p < 0.0001$.

caused by fruiting differences among the cultivars. The stress of fruiting would possibly make root rot symptoms appear earlier in our study than we found with primocane growth only.

Previous results showing field resistance have been published for 'Summit', 'Sumner', 'Newburgh', and 'Cascade Delight' (1, 4, 13). In greenhouse studies, 'Cascade Bounty' and 'Prelude' were found to be highly resistant (4, 9). 'Moutere', 'Jaclyn', 'Ukee', WSU 1447, and WSU 1499 have no previous findings of root rot response, and appeared to have good field resistance when compared with 'Summit'. 'Josephine' was resistant according to our field study, which corresponds well with a previous report (9).

Among the highly susceptible genotypes included in our study, 'Malahat', 'Esquimalt', 'Cowichan', and WSU 1226 have been previously identified as such (4, 6, 9). Advanced selections WSU 1582 and WSU 1502, ORUS 1142-1, and newly released cultivars 'Saanich' and 'Cascade Gold' are highly susceptible genotypes that have not previously been tested. 'Coho' was extremely susceptible to root rot in our study, though its cultivar listing describes it as having "no particular susceptibility" to root rot (2). Both 'Anne' and 'Caroline' were reported to have moderate to high levels of resistance in a hydroponic study, but both were susceptible in our field evaluation, possibly the result of disease interaction with environmental conditions, or differences in disease pressure, plant size, and experiment duration (9).

The cultivars with intermediate root rot response in our study correspond well with previous observations. Both 'Cascade Dawn' and 'Chemainus' have been reported to have moderate susceptibility to the disease in field situations, slower to decline than 'Meeker' (4, 5). 'Chilliwack' was less susceptible to the disease under our field conditions than reported for a greenhouse test by Levesque and Daubeny (6).

Inheritance of root rot resistance is difficult to predict, as demonstrated in the comparative response of four progeny of the highly susceptible cultivar 'Qualicum' included in this study, two that are resistant, 'Moutere' and WSU 1447, and two that are highly susceptible, 'Cowichan' and WSU 1502. A dominant two-gene model of inheritance has been proposed for root rot resistance (10, 11). The high levels of heterozygosity possible in such a model explain how susceptible parents can produce resistant offspring. However, in field situations representing complex expression of root rot symptoms, some genotypes cannot be characterized as very susceptible or resistant even after several years of disease pressure. Such intermediate responses possibly support Nestby and Heiberg's view that both additive and non-additive genetic factors influence root rot resistance (8). Pattison et al. (10) explain this difference by emphasizing that the choice of assessment criteria influences whether the variation appears additive or non-additive. Further work will include elucidation of the genetic factors influencing the traits responsible for this variation.

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