Journal of the American Pomological Society 58(4):226-232 2004

Field Performance of Twenty-one Strawberry Cultivars in a Black Root Rot-Infested Site

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Abstract

Twenty-one commercial strawberry cultivars were planted into field soil naturally infested with the black root rot pathogens *Rhizoctonia fragariae, Pratylenchus penetrans* and *Pythium* spp. Plant growth and yield were evaluated for up to 3 years after planting. Root rot evaluations and pathogen isolations were also conducted. *R. fragariae, P. penetrans* and *Pythium* spp. were consistently isolated from all plots, and the gradual decline of cultivars in these soils over four years paralleled the development of disease typically observed in commercial strawberry production fields. Strawberry cultivars differed in root weight, shoot weight, and fruit yield over the length of the experiment. Plant shoot weights were highest in 2001 and 2003 and least in 2002 ($P \leq 0.0001$) and ranged from an average weight of over 200 g per plant over 3 years for 'Earliglow', 'Latestar' and 'Northeaster' to only 29.2 g for 'Tristar'. Root weights were higher in 2002 and 2003 than in 2001 ($P \leq 0.0001$), but root systems consisted of an increasing proportion of perennial roots each year. Root weights ranged from over 30 g per plant for 'Primetime', 'Latestar', 'Idea' and 'Earliglow' to under 10 g per plant for 'Tristar' and 'Marmolada'. There were no significant interactions among cultivars and years. Strawberry fruit yields ranged from over 800 g per plant ('Earliglow' and 'Latestar') to just over 100 g per plant for 'Marmolada' and 'Tristar'. Yields declined by only about 12% from 2002 to 2003, but were not significantly different. However, the yield of some cultivars increased by as much as 35% ('Latestar') while yields decreased for 14 of the 21 cultivars (by as much as 86% for 'Marmolada'). Our results indicate that selection for plant performance may best be conducted in infested soils over multiple years and that certain strawberry cultivars may be more tolerant of the black root rot complex under field conditions than others.

Introduction

Black root rot is a serious debilitating disease of perennial strawberry (*Fragaria ´ ananassa* Duchesne) production. Symptoms of the disease include a root rot of feeder roots as well as black cortical root lesions that may girdle roots and lead to a decline and loss of function in functional structural and perennial roots. Generally, the loss in plant vigor and increase in plant mortality occurs during harvest, especially under conditions of environmental stress. The disease typically increases in severity each year, leading to increased variability in plant vigor within a field and an eventual loss of productivity (15, 19, 24). The loss of a fruiting year and increased costs due to replanting have large economic impacts (5).

The binucleate fungus *Rhizoctonia fragariae* Husain and McKeen (9, 21, 22) has been the pathogen most often associated with black root rot. The lesion nematode, *Pratylenchus penetrans* (Cobb) Filip & Schur.Stek, has increased the severity of black root rot under field conditions (6, 7, 10, 11) and in controlled experiments (1, 13, 14). The mechanism by which *P. penetrans* increases black root rot appears to be a local effect within individual roots rather than a systemic effect within the plant and is due at least partially to the direct results of nematode feeding on cortical cells to cause tissue damage and cell death (13). Other factors that have been associated with increased black root rot include pathogens, such as *Pythium* spp., and environmental factors such as soil compaction, water-logging, or drought (15).

Other researchers have examined strawberry cultivars for resistance or at least

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The author thanks J. Canepa-Morrison and S. Lamoureux for technical assistance.

differential susceptibility to individual root pathogens in greenhouse screens (2) or first-year yield performance in fumigated and non-fumigated soils (8) or in soils with or without a history of strawberry production (23). The objective of this study was to evaluate the performance of commercially available locally adapted strawberry cultivars for growth, yield, and disease development under field conditions over several years.

Materials and Methods

Twenty-one strawberry cultivars were planted at the Connecticut Agricultural Experiment Station Valley Laboratory research farm in Windsor, CT into field plots with a history of over twenty years of strawberry production. Soils were naturally infested with *P. penetrans, R. fragariae* and *Pythium* spp. The soil type was a Merrimac sandy loam (73.4% sand, 22.3% silt, 4.3% clay, pH 5.9, 1.24% organic matter after sieving through a 2-mm screen). Commercially obtained crowns were transplanted into single row plots at five crowns per plot with 20 cm between plants within rows and 1 m between rows on 28 April 2000. A randomized complete block design with three blocks was used. The cultivars planted were: 'Allstar', 'Annapolis', 'Cavendish', 'Delmarvel', 'Earliglow', 'Honeoye', 'Idea', 'Jewel', 'Kent', 'Latestar', 'Lester', 'Marmolada', 'Mesabi', 'Mira', 'Northeaster', 'Primetime', 'Redchief', 'Seneca', 'Sparkle', 'Tristar', and 'Winona'. In separate greenhouse and laboratory studies, these same cultivars were evaluated for susceptibility to the black vine weevil, *Otiorhynchus sulcatus* (3).

Plots were maintained under standard commercial fertilization and pest control practices. Runners were removed at regular intervals to maintain only mother plants of known age over the length of the experiment. Plots were fertilized with 10-10-10 (N-P-K) at rates of 156 kg N per hectare annually, 40% applied in May and the remainder at renovation in July. Weeds were controlled by Dacthal applied at rates of 11.2 kg per hectare in May and July in the planting year and by Sinbar 80W (280 g per hectare) and Devrinol 50DF (4.5 kg per hectare) applied at renovation in 2001, 2002 and 2003 and again in November prior to mulching in all years.

The removal of all runners over the length of the experiment resulted in known numbers of crowns of similar age for each cultivar and allowed us to evaluate the changes in plant vigor and yield that occurred over time. If runners had not been removed, plants would have ranged from 1 to 4 years in age and different plant densities in plots would have resulted in different levels of plant to plant competition within plots. Because black root rot is a debilitating disease that increases in severity over a number of years (24), first year yields are usually not affected by this disease and were not measured in these experiments. Second and third year fruit yields were used as an indication of yield sustainability over time, especially in combination with plant vigor (weight) data from the same crowns.

One crown per plot was dug on 16 July in 2001, 17 July in 2002, and 31 July in 2003. Roots were washed free of soil, and root, shoot (leaves and petioles) and crown fresh weights were measured after blotting to remove excess water. The percent of the total root system with cortical rot was estimated visually by two persons in 2002 and 2003 and the independent ratings were averaged. Isolation of *R. fragariae* was attempted from ten 0.5-cm sections of surface sterilized structural and perennial roots in 2003. Roots were exposed to 0.5% NaOCl for 30 seconds, rinsed with sterile distilled water, and placed on acidified water agar for 96 hours. Percent root infection by *R. fragariae* was calculated from the number of infected root sections as a percent of the total. In 2001, 2002 and 2003, nematodes were extracted from 2 g of structural root tissue placed in a flask containing 50 ml water and shaken for 7 days using a wrist-action shaker, then counted. Fruit was harvested and weighed at 3 to 4 day intervals from 3 June 2002 to 28 June 2002 and from 12 June 2003 to 7 July 2003.

Results and Discussion

Cultivars differed in root weight, shoot weight, and fruit yield averaged over the length of the experiment (Table 1). *Plant* shoot weights were highest in 2001 and 2003 and least in 2002 and ranged from an average weight of over 200 g per plant over 3 years for 'Earliglow', 'Latestar' and 'Northeaster' to only 29.2 g for 'Tristar'. Root weights were higher in 2002 and 2003 than in 2001 but roots consisted of an increasing proportion of perennial roots each year. Roots ranged from over 30 g per plant for 'Primetime', 'Latestar', 'Idea' and 'Earliglow' to under 10 g per plant for 'Tristar' and 'Marmolada'. There were no significant interactions between cultivars and years.

Table 1. Plant growth and yield characteristics of 21 strawberry cultivars grown in black root rot-infested field soil, 2000-2003.

Cultivar	Shoot wt[z]	Root wt	Yield per crown	Yield change[y]
Allstar	75 ghi[x]	14 fghi	438 cdef	-20 cdef
Annapolis	160 cde	28 bcd	617 bc	3 abcd
Cavendish	123 defg	22 def	887 a	-31 cdefgh
Delmarvel	89 fghi	16 efghi	112 gh	-19 cdef
Earliglow	243 a	33 abc	481 bcde	-2 abcde
Honeoye	103 efgh	22 defg	523 bcde	-27 cdefg
Idea	170 bcd	36 ab	713 ab	23 ab
Jewel	101 efgh	18 efgh	525 bcde	-38 defgh
Kent	99 fgh	15 fghi	625 bc	7 abc
Latestar	226 ab	38 a	883 a	36 a
Lester	162 cd	29 bcd	602 bcd	7 abc
Marmolada	50 hi	10 hi	108 h	-87 i
Mesabi	33 i	13 ghi	214 efgh	-64 ghi
Mira	57 hi	15 fghi	175 fgh	-61 fghi
Northeaster	212 abc	25 cde	341 efgh	-25 cdefg
Primetime	175 bcd	39 a	687 abc	-10 bcde
Redchief	72 ghi	17 efghi	360 defg	-33 cdefgh
Seneca	79 ghi	16 efghi	165 gh	-68 hi
Sparkle	89 fghi	14 fghi	321 efgh	-41 efgh
Tristar	29 i	8 i	135 gh	23 ab
Winona	140 def	22 def	549 bcde	33 a
$P \leq$	0.0001	0.0001	0.0001	0.0001
Year				
2001	139 a	17 b	-	-
2002	85 b	25 a	480	-
2003	130 a	22 a	421	-
$P \leq$	0.0001	0.0001	ns	-

[z] Shoot, root and fruit yield expressed as g per crown average over 3, 3 and 2 years, respectively.
[y] Percent change in fruit yield from 2002 to 2003.
[x] Means within a column followed by a letter in common are not significantly different (Fisher's protected LSD test).

Table 2. Disease rating and pathogen isolation from roots of 21 strawberry cultivars grown in black root rot-infested field soil, 2002-2003.

Cultivar	Percent black root rot [z]	Percent root segments with *R. fragariae* [y]	*Pratylenchus* per g root [x]
Allstar	11	35	26
Annapolis	11	37	23
Cavendish	12	50	23
Delmarvel	11	43	6
Earliglow	10	23	20
Honeoye	11	30	22
Idea	7	40	11
Jewel	16	50	22
Kent	16	37	39
Latestar	10	23	2
Lester	6	57	12
Marmolada	138	33	21
Mesabi	9	53	41
Mira	14	48	35
Northeaster	12	10	11
Primetime	6	47	3
Redchief	8	36	14
Seneca	158	38	6
Sparkle	15	51	38
Tristar	11	39	26
Winona	11	68	6
$P \leq$	ns	ns	ns
Year			
2001	19	-	34
2002	4	-	18
2003	-	-	6
$P \leq$	0.0001	-	0.0001

[z] Percent of the total root system with cortical rot was estimated visually by two persons in 2002 and 2003 and the independent ratings were averaged.
[y] Isolation of *R. fragariae* was attempted from ten 0.5-cm sections of surface sterilized structural and perennial roots in 2003. Roots were exposed to 0.5% NaOCl for 30 seconds, rinsed with sterile distilled water, and placed on acidified water agar for 96 hours. Percent root infection was calculated from the number of infected root sections as a percent of the total.
[x] Nematodes were extracted from 2 g of structural root tissue placed in a flask containing 50 ml water and shaken for 7 days using a wrist-action shaker, then counted.

Strawberry fruit yields ranged from over 800 g per plant ('Latestar') to just over 100 g per plant for 'Marmolada' and 'Tristar'. Fruit yields averaged over all cultivars declined by an average of about 12% from 2002 to 2003. There were no significant differences among cultivars. However, the yield of some cultivars increased over that time by as much as 35% ('Latestar') while yields declined for 14 of the 21 cultivars from 2002 to 2003 (by as much as 86% for 'Marmolada').

Strawberry root rot was more visible on roots and was present in a greater percentage of root tissue in 2001 than 2002 (Table 2).

There were no differences among cultivars, in part due to an increasing percentage of black perennial roots over time. Diseased roots often are completely rotted or sufficiently damaged that they do not remain after washing roots free of soil. This appeared to be the case in 2003, as few structural or feeder roots were present on many of the cultivars and as a result, root rot ratings were not taken. Instead, *R. fragariae* was isolated from the structural roots present. Percent root infection by *R. fragariae*, which ranged from 10% to 68%, was not different among cultivars. Lesion nematode isolation from structural roots decreased over time as the root system changed from predominantly structural and feeder roots to predominantly perennial roots, and was also not different among cultivars. As obligate parasites, *P. penetrans* nematodes require healthy feeder or cortical root tissue upon which to feed. Root disease or the transition from structural to woody secondary perennial roots reduces the root mass available upon which lesion nematodes feed (12).

It may be unrealistic to try to select for resistance to the individual pathogens that may contribute to black root rot under different environmental conditions. Lesion nematode multiplication rates may vary among different strawberry cultivars and may be considered a measure of plant resistance, but complete resistance (immunity) has not been observed (4). The presence or absence of lesion nematodes may be more important in the development of black root rot than the number of nematodes per gram root tissue (13), so the low levels of resistance to *P. penetrans* present in some plants may not have significant impacts on black root rot development. While there are broad similarities within *R. fragariae* anastomosis groups, there are greater differences in virulence within groups (16) ranging from very virulent to mycorrhizal (17, 18). The *Pythium* spp. that attack strawberries have not been studied as extensively, but probably exhibit similar variation in pathogenicity and virulence. Greenhouse screens of individual *R. fragariae* and *R. solani* isolates (2) did not agree well with other studies and underscore the variation in virulence associated with these fungi. Field studies have been conducted in New York (23) and in Michigan (8), but in each case the evaluations were not continued past the first fruiting year.

Rhizoctonia fragariae, *P. penetrans* and *Pythium* spp. were consistently isolated from plant roots in all plots in our study and the gradual decline of cultivars in these soils over four years paralleled the development of disease typically observed in commercial strawberry production fields. Other diseases such as red stele root rot and Verticillium wilt were not detected, thus cultivars with resistance to these diseases were not at a competitive advantage. Our results indicate that certain strawberry cultivars, while also infected with black root rot pathogens, may be more tolerant of the black root rot complex under field conditions than others. 'Latestar' most consistently maintained vigorous root and shoot growth and was one of the top yielding cultivars tested. Other cultivars that were consistently vigorous and had superior yield were 'Idea', 'Lester' and 'Primetime'. 'Earliglow' had good plant vigor over the course of the experiment but yields were consistently lower than the top performing cultivars. 'Earliglow' is an early cultivar with many good characteristics but low yield potential (20). 'Cavendish' had the largest yields over the two years, but yields decreased 27.5% from 2002 to 2003. This may be a reflection of the lower root weight of 'Cavendish' and inability to maintain plant vigor over time. In fact, root weights were poor in 2002 or decreased between 2002 and 2003 for all cultivars tested with the exceptions of 'Earliglow', 'Latestar', 'Lester', 'Northeaster' and 'Winona'. Root weights decreased over that time period for 'Idea' and 'Primetime', but were still among the heaviest at over 30 g per plant in 2003. 'Idea', 'Lester' and 'Primetime' also exhibit non-preference to black vine weevil feeding (3) and may be of additional value in a breeding program.

Our results indicate that the day-neutral cultivar 'Tristar' performed poorly for both yield and plant vigor in black root rot soils in Connecticut after the first year of a four-year period. This cultivar was ranked as the most black root rot resistant cultivar evaluated by

Wing et al. (23) but was not evaluated beyond the first harvest. Wing et al. (23) also concluded those cultivar trials in black root rot infested soils to that time provided little evidence of resistance to black root rot and precluded both cultivar recommendations and effective screening by strawberry breeders. Hancock et al. (8) also evaluated the development of black root rot on different cultivars and native hybrids over a one-year time frame, but concluded that yield and vigor were sufficiently reduced in the first year to allow selection. They concluded that *F. virginiana* hybrids performed better in pathogen-infested soils than eastern US or California cultivars, suggesting that at least some resistance or tolerance to black root rot may exist in *F. virginiana*.

Despite the fact that we isolated pathogens from all cultivars, the longer-term favorable performance of certain locally adapted cultivars in our experiments suggest that some tolerance or field resistance to black root rot may exist in these cultivars and be expressed as a reduced rate of decline in yield and vigor due to the black root rot complex. The maintenance of plant root weight over time may be the best indicator of cultivar performance in black root rot-infested soils. Root weight was positively correlated with shoot weight ($P \leq 0.0001$, r = 0.87), fruit yield ($P \leq 0.0001$, r = 0.88), and negatively correlated with black root rot ($P \leq 0.0001$, r = 0.48).

The top-performing cultivars for plant vigor and yield in this study represent a range from early season fruiting cultivars such as 'Earliglow' to early-mid ('Cavendish' and 'Lester') to mid-season ('Primetime') to late-season fruiting cultivars such as 'Idea' and 'Latestar'. This range of cultivars may assist growers in the Northeast sustain yields over time in black root rot infested field soils and aid breeders in the development of new strawberry cultivars with some practical level of tolerance or field resistance.

In summary, greenhouse screens or single-year assessments have been inconsistent in evaluating strawberry cultivar response to black root rot. To accurately predict cultivar response within a particular region to a complex disease with multiple pathogens that interacts with environmental conditions, it may be necessary to evaluate performance of plants exposed to multiple pathogens under field conditions for a number of years in the same region. Our results indicate that the functional root mass remaining over a number of years may be the best indicator of yield performance and tolerance to black root rot.

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The Wilder Committee of the American Pomological Society (APS) invites nominations for the 2005 Wilder Silver Medal Award. All active members of APS are eligible to submit nominations. The award was established in 1873 in honor of Marshall P. Wilder, the founder and first president of APS. The award consists of a beautifully engraved medal which is presented to the recipient at the annual meeting of APS, held during the ASHS Annual Meeting.

The Wilder medal is presented to individuals or organizations that have rendered outstanding service to horticulture in the area of pomology. Special consideration is given to work relating to the origination and introduction of meritorious fruit cultivars. Individuals associated with either commercial concerns or professional organizations will be considered if their introductions are truly superior and have been widely planted. Significant contributions to the science and practice of pomology other than through fruit breeding will also be considered. Such contributions may relate to any important area of fruit production such as rootstock development and evaluation, anatomical and morphological studies, or noteworthy publications in any of the above subjects. Information about the award, past recipients, etc. can be found on the APS website at http://hortweb.cas.psu.edu/aps/wilder1.html

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Nominations must be submitted by 1 May 2005.