Susceptibility of European Hazelnut Clones to Eastern Filbert Blight

J. N. PINKERTON, Research Plant Pathologist, USDA-ARS, Horticultural Crops Research Laboratory, Corvallis, OR 97330, and K. B. JOHNSON, Assistant Professor, Department of Botany and Plant Pathology, S. A. MEHLENBACHER, Associate Professor, Department of Horticulture, and J. W. PSCHEIDT, Assistant Professor, Department of Botany and Plant Pathology, Oregon State University, Corvallis 97331

ABSTRACT

Pinkerton, J. N., Johnson, K. B., Mehlenbacher, S. A., and Pscheidt, J. W. 1993. Susceptibility of European hazelnut clones to eastern filbert blight. Plant Dis. 77:261-266.

In the springs of 1989 and 1990, 2- to 3-yr-old hazelnut trees representing 19 cultivars were exposed to ascospores of *Anisogramma anomala,* which causes eastern filbert blight. The trees were potted and randomly arranged under wire mesh platforms elevated 1.8 m from the ground. Diseased hazelnut branches were placed on top of the platforms in low, medium, or high numbers to provide three levels of inoculum. During periods of rain, ascospores of the pathogen were released from the diseased branches and deposited on the potted trees. External disease symptoms developed at 16 and 28 mo after initial exposure to inoculum, at which times disease responses were evaluated. Cultivars differed significantly in disease incidence, mortality, number of cankers per tree, proportion of wood cankered, and proportion of dead wood. The cultivars Hall's Giant, Willamette, Casina, and Tonda di Giffoni had the lowest disease severities. Barcelona, Ennis, Butler, Daviana, and DuChilly, the predominant cultivars in Oregon, were rated as moderately to highly susceptible. Gasaway, an obsolete pollenizer, did not develop disease symptoms. Inoculum density did not affect the relative resistance rankings of the cultivars. In a second experiment beginning in 1990, 44 hazelnut clones (cultivars and selections) were exposed to a high dose of *A. anomala* ascospores. Five clones—Gasaway, Gem, Winkler, Giresun 54-21, and Giresun 54-56—failed to develop symptoms of eastern filbert blight. An additional 13 clones were more resistant than the widely grown cultivar Barcelona. The relative resistance rankings of the cultivars evaluated in both experiments were consistent between experiments.

Additional keywords: *Corylus americana, C. avellana*

Eastern filbert blight, caused by the ascomycete *Anisogramma anomala* (Peck) E. Müller in E. Müller & Arx, is an endemic disease of *Corylus americana* Marsh. in eastern North America (1,13). The disease was not reported west of the Rocky Mountains until 1973, when it was found in an orchard of European hazelnut, *C. avellana* L., in southwest Washington State (4). By 1979, eastern filbert blight had spread through the hazelnut-growing area of southwest Washington, and most diseased orchards in this area were subsequently removed (2,8). In 1986, the disease was found in the northeast Willamette Valley of Oregon, 25 km south of the Washington border (15). Subsequent surveys of orchards and unmanaged plantings in Oregon (15) have determined that the disease is established in the Willamette Valley, where 98% of the hazelnut production in the United States is located.

The disease cycle of eastern filbert blight is initiated in the spring when ascospores of *A. anomala* infect breaking vegetative buds and young vegetative shoots (16). The fungus systemically colonizes the cambial tissue of hazelnut branches, usually producing a canker 13–15 mo after first infection (6,7,16). The disease spreads by perennial expansion of cankers (8) and by release of ascospores from perithecia that are produced annually within cankers associated with living wood (6). Canker expansion eventually girdles branches and limbs, resulting in canopy dieback and death of trees in 4–10 yr (8). In Oregon, ascospores are released from perithecia during periods of rain from early winter to late spring (7,14).

Observations in the Pacific Northwest over the last 15 yr have shown that commonly grown European hazelnut cultivars are susceptible to eastern filbert blight (2,3,8,9). The cultivar Barcelona, which accounts for 80.6% of Oregon's production, was reported to have a moderate level of resistance (2). Other common cultivars, including Ennis, Daviana, Butler, Casina, and Hall's Giant, which account for 10.1, 4.6, 1.2, 0.4, and 0.3% of production, respectively, were reported to vary in susceptibility. The cultivars Royal and Ennis and the pollenizer cultivars Daviana and Butler were described as highly susceptible (2,3). One cultivar, Gasaway, is apparently immune but has an unmarketable nut (2,3,12).

The devastation caused by the eastern filbert blight epidemic in Oregon and Washington has demonstrated the need for greater disease resistance in both main crop and pollenizer cultivars (2,8). Most European hazelnut clones, however, have not been evaluated for their response to this disease. The objectives of this study were to develop a rapid and reproducible method for evaluating the level of resistance to eastern filbert blight in European hazelnut clones, to evaluate the effect of inoculum dose on the relative resistance responses of common European hazelnut cultivars, and to assess the resistance of additional hazelnut germ plasm to the disease.

MATERIALS AND METHODS

Plant material. In January of 1989 and 1990, dormant 2-yr-old hazelnut trees were obtained from commercial nurseries in Oregon and from the Oregon State University hazelnut breeding program (Table 1). The trees were pruned 1.0 m above the crown and planted in 7-L plastic pots in a soil mix containing 20% sandy loam, 20% peat, 20% sand, and 40% pumice by volume. Trees were potted in Corvallis, OR, then transported in mid-January to the Southwest Washington Experiment Station in Vancouver, WA.

Inoculation. Hazelnut trees were inoculated in a manner designed to resemble natural infection in an orchard. Potted trees were placed under wire mesh platforms that were topped with diseased hazelnut branches bearing perithecia of *A. anomala.* The diseased branches were collected in October of 1988 and 1989 from severely infected trees in a commercial orchard. Collection of diseased branches was timed to coincide with maturation of *A. anomala* ascospores (6) and to avoid loss of ascospores to discharge, which begins with the onset of the winter rainy season in November (14). At the time of collection, diseased branches were inspected for current-season perithecia, cut into 1-m lengths, and stored in a dry, unheated (−18 to 10 C) greenhouse until they were placed on the platforms.

Twelve (3.3 × 4.6 m) and three (3.3 × 5.5) inoculation platforms were erected in a grass-covered field at the Vancouver experiment station. Wire mesh fencing (36-cm^2 opening) was fastened over the wooden frames, and four wooden posts supported the corners of each platform

Technical paper 9905 of the Oregon Agricultural Experiment Station.

Accepted for publication 10 November 1992.

at a height 1.8 m above the ground. One steel fence post 2.5 m long supported the center of each platform. The distance between platforms was approximately 15 m.

During periods of rain, ascospores of *A. anomala* were released from perithecia in the diseased branches and were deposited on the potted plant material. To verify the release of ascospores, rainwater was collected in traps placed under each platform. Each trap was a semicircular gutter fabricated by longitudinal bisection of a polyvinyl chloride pipe 4.36 m long and 2 cm in diameter. One rain trap was positioned under each platform on a 20° incline to drain into a covered 16-L plastic container. These containers were changed monthly while diseased branches were on the platforms. To prevent ascospore germination and growth of other microbial contaminants, 50 ml of a 5% copper sulfate (w/w) solution was added to each container at the time of placement in the field. The collected rainwater was filtered, and the cellulose filter was microscopically examined to determine ascospore concentration in the samples (16).

Cultivar-inoculum density experiment. This experiment was arranged in a split-plot design with three replications. The whole-plot factor was inoculum density, with hazelnut cultivar as the subplot factor. To obtain low, medium, and high inoculum densities, 1.3, 3.9, and 11.8 1-m-long diseased branches per square meter, respectively, were uniformly positioned on platforms. Subplots comprised seven trees of each of 11 common hazelnut cultivars; in addition, eight less commonly grown cultivars and advanced selections (three or four per subplot) were exposed only to the high-inoculum treatment (Table 1).

The experiment began 24 January 1989, when stored inoculum branches were placed on the platforms (first inoculum period). On 20 April 1989, the exposed diseased branches were replaced with diseased branches that had been held in storage (second inoculum period). All diseased branches were removed from the platforms on 1 June 1989, but the potted trees remained under the platforms over the summer and fall of 1989. An automatic sprinkler system with six sprinkler heads per platform supplied water to the trees daily through October 1989. During the summer of 1989, the top and the south and west sides of each platform were covered with 47% shade cloth. In 1990, diseased branches were again placed above the trees on 9 February (first period) and were replaced on 6 April (second period) with diseased branches that had been protected from rain. On 1 June 1990, the potted trees were transplanted into a nearby field.

External symptoms of eastern filbert blight developed in June of 1990 and 1991, and disease evaluations were made shortly thereafter. Number of stromata-bearing cankers per tree, canker length (measured between distal stromata), disease incidence (percentage of trees with cankers), and percentage mortality were measured for each cultivar. As cankers expanded, infected branches distal to the canker died, so the total length of live and dead branches on trees was also measured. In 1991, many of the 2-yr-old cankers had expanded and coalesced, so the number of individual cankers per tree was not recorded.

Throughout the study, trees of the 11 common cultivars were maintained as controls in Corvallis, where eastern filbert blight was not known to occur (15).

Germ plasm evaluation. This experiment was arranged in a randomized block design with three replications (i.e., inoculation platforms). Forty-two hazelnut clones and two selections of the Barcelona clone (Table 1) were exposed to a high dose of inoculum (11 diseased branches per square meter) from 9 February 1990 through 31 May 1990. Diseased branches were replaced on 6 April. Among the clones evaluated were three Barcelona selections (Ben Doris, McGrew, and VanderBaum) that are propagated by commercial nurseries. Four to seven trees of each of 28 clones were placed under each inoculation platform. The number of trees of the remaining 16 clones ranged from one to

Table 1. Origin of clones and selections evaluated for eastern filbert blight resistance, source of experimental plants, and experiments in which each clone was evaluated

Clone	Origin	Plant source[a]	Experiments in which evaluated[b]
Barcelona[c]	Spain	N,O	I,G
Brixnut	United States	O	G
Bulgaria X1-8	Bulgaria	O	G
Butler	United States	N	I
Camponica	Italy	O	G
Casina	Spain	N,O	I,G
Cosford	England	O	G
Creswell	United States	O	G
Daviana	England	N,O	I,G
DuChilly	England	N,O	I,G
Ennis	United States	N,O	I,G
Fitzgerald	United States	N	I
Gasaway	United States	N,O	I,G
Gem	United States	O	G
Giresun 54-1	Turkey	O	G
Giresun 54-21	Turkey	O	G
Giresun 54-39	Turkey	O	G
Giresun 54-56	Turkey	O	G
Hall's Giant	Germany	N,O	I,G
Henneman #3	Unknown	O	G
Italian Red	Germany	O	G
Lansing	United States	N	I
Montebello	Italy	N,O	I,G
Morell	Spain	N	G
Negret	Spain	N,O	I,G
Neue Riesennuss	Germany	O	G
Nooksack	United States	O	G
OSU 14-19	United States	N	I
OSU 162-17	United States	O	G
OSU 166-34	United States	O	G
OSU 167-2	United States	O	G
OSU 23-17	United States	O	G
OSU 41-83	United States	O	G
OSU 49-73	United States	N	I
Pellicule Rouge	France	O	G
Redleaf #3	United States	O	G
Ribet	Spain	O	G
Riccia de Talanico	Italy	O	G
Rode Zeller	Netherlands	O	G
Segorbe	Spain	O	G
Tombul Ghiaghli	Turkey	O	G
Tonda di Giffoni	Italy	N,O	I,G
Tonda Gentile delle Langhe	Italy	N,O	I,G
Tonda Romana	Italy	N,O	I;G
USOR 7-71	United States	O	G
Willamette	United States	N,O	I,G
Winkler	United States	O	G

[a] N = commercial nursery, O = Oregon State University hazelnut breeding program.
[b] I = cultivar-inoculum density experiment, G = germ plasm evaluation experiment.
[c] Barcelona selection Ben Doris was used in the cultivar-inoculum density experiment; Barcelona selections Ben Doris, McGrew, and VanderBaum were used in the germ plasm evaluation experiment.

four per inoculation structure, depending on availability.

The potted clones were maintained over the summer under the platforms as described above. As part of a longer-term study, a duplicate set of the 44 hazelnut clones was interplanted among infectious hazelnut trees in a field at the Vancouver experiment station during February 1990. Because of the paucity of plant material, controls consisted of clonal trees in propagation beds maintained at Corvallis.

The clones in this experiment were not exposed to inoculum for a second spring because a severe freeze in December 1990 damaged the root systems of the potted trees. In response to the freeze, most of the trees produced small leaves in March and April of 1991, but no new growth. In late April, it was apparent that many trees would not survive the additional 1–2 mo until external symptoms of eastern filbert blight were expected to develop. Consequently, we decided to strip each tree of all bark to expose the cambium. Because the pathogen had infected and colonized trees the previous spring and summer (8–9 mo before the freeze), cankers were well developed in the cambial layer of infected trees and were revealed as distinct areas of chocolate brown discoloration in this tissue. At first, hand sections of the discolored tissue were carefully stained and microscopically examined (16) to verify the presence of hyphae of *A. anomala* in the discolored cambium. As our confidence in visual assessment of discolored cambial tissues increased, we limited microscopic verification of the pathogen to those cankers where the margin of the chocolate brown discoloration was not distinctly defined. Disease incidence, number of cankers per tree, canker length, and total trunk and branch length per tree were recorded. Trees that died before May had uniformly brown cambium and were not evaluated.

Data analyses. Measured responses in each experiment were subjected to analysis of variance (SPSS Inc., Chicago, IL). Before analysis of variance was performed, the proportion of wood cankered was calculated by dividing total canker length by total length of the trunk and branches (live and dead) on each tree. Similarly, the proportion of dead wood was computed for trees in the cultivar-inoculum density experiment. Clone means were compared with Fisher's protected least significant difference procedure ($P = 0.05$).

RESULTS

Inoculation. The inoculation technique of suspending diseased hazelnut branches over the experimental trees resulted in ascospore doses that were proportional to the number of diseased branches placed on a platform. The mean rate of ascospores captured in rainwater during 1989 and 1990 was 0.3, 1.2, and 2.9×10^6 spores per square meter of trap surface per day for the low, medium, and high inoculum treatments, respectively, during the first inoculum period, and 0.1, 0.7, and 2.7×10^6, respectively, during the second inoculum period (Fig. 1). Ascospore capture was less consistent, however, in the germ plasm experiment; 1.3 and 3.0×10^6 spores were trapped per square meter in the two periods (Fig. 1).

During the first inoculum period in 1989, rain fell on 48 days and totaled 255 mm. The second inoculum period that year had 17 days with rain, which totaled 93 mm. In contrast, the second inoculum period in 1990 received more rain (124 mm over 35 days) than the first (85 mm over 23 days).

Cultivar-inoculum density experiment. Analysis of variance indicated significant differences among hazelnut cultivars ($P < 0.05$) for all disease variables (Table 2). In addition, increasing inoculum density significantly ($P < 0.05$) increased disease incidence and proportion of wood cankered at both 16 and 28 mo after initial inoculum exposure and affected the proportion of dead wood when disease was first assessed in the summer of 1990. The cultivar by inoculum density interaction, however, was not significant ($P > 0.05$) in any of the analyses.

Sixteen months after initial exposure to *A. anomala,* the cultivar Barcelona had the highest disease incidence and number of cankers per tree at all inoculum densities (Table 2). Other common cultivars, such as Daviana, Ennis, and Butler, did not differ significantly ($P > 0.05$) from Barcelona in disease incidence, number of cankers, or proportion of wood with cankers. At each inoculum density, Hall's Giant, Willamette, and Casina consistently ranked as the most resistant of the 19 cultivars to eastern filbert blight for all disease variables measured. Of the eight cultivars and advanced selections that were tested only at the high inoculum level, Tonda di Giffoni and OSU 49-73 were among the most resistant, and Gasaway remained disease-free. Eastern filbert blight was not observed on any of the nonexposed trees used as controls in Corvallis.

The relative susceptibility rankings of the hazelnut cultivars after 28 mo of exposure to ascospores of *A. anomala* were similar to those after 16 mo (Table 2). Disease incidence after 16 mo exceeded 75% for all cultivars except Gasaway, Tonda di Giffoni, and OSU 49-73 exposed to the high ascospore dose and Willamette, Hall's Giant, and Casina exposed to the low ascospore dose. Tonda di Giffoni, Hall's Giant, and Willamette had the lowest proportion of

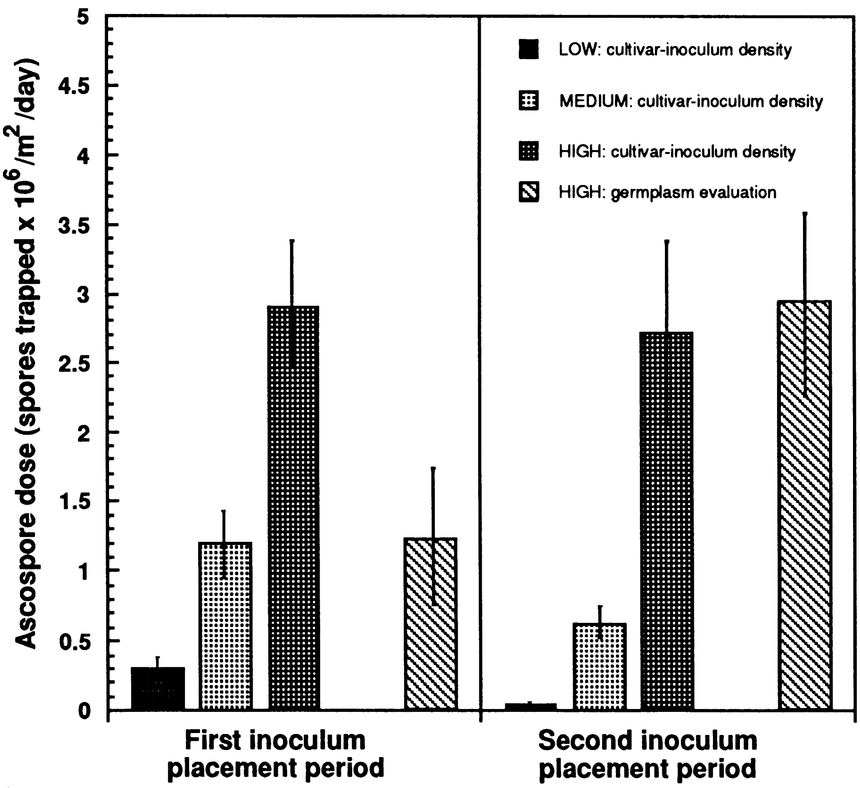

Fig. 1. Rate of collection of ascospores of *Anisogramma anomala* in rainwater for low, medium, and high inoculum treatments in the cultivar-inoculum density experiment during 1989–1990 and a high inoculum treatment in the germ plasm evaluation experiment in 1990. The first inoculum placement period extended from late winter before budbreak through mid-April, and the second from mid-April through 1 June. The vertical line on each bar represents the standard deviation in each period.

wood cankered (excluding Gasaway), and the proportion of dead wood on these cultivars averaged less than 14% for the high inoculum dose after 28 mo.

At low and medium inoculum doses, trees of the more resistant cultivars continued to produce vigorous new shoots and compensate for canker expansion; thus, the proportion of wood cankered or dead decreased the second season (Table 2). This was most evident with Barcelona, which ranked among the most susceptible cultivars after one season and intermediate the second season. At the high inoculum dose and with the most susceptible cultivars, tree vigor was poor the second year, little new growth was produced, and the proportion of cankered wood increased. Vigor was lowest for Daviana, DuChilly, Ennis, Tonda Gentile delle Langhe, Tonda Romana, and USOR 7-71, with 57% or greater mortality 28 mo after initial exposure to a high inoculum dose. No trees of Gasaway, Hall's Giant, Tonda di Giffoni, or Willamette and only 5% of Casina and Montebello trees exposed to a high dose had died after 28 mo. No symptoms of eastern filbert blight or dead branches were observed in Gasaway or in the nonexposed trees used as controls.

Germ plasm evaluation. Fourteen months after initial exposure to ascospores of *A. anomala,* the disease responses of the 44 hazelnut clones ranged from symptomless to 100% incidence of eastern filbert blight with multiple cankers per tree (Table 3). Trees in this experiment developed fewer cankers per tree than trees in the cultivar-inoculum density experiment. In 1990, lower rainfall during the early spring when susceptible tissue is most abundant (16) resulted in a lower inoculum dose and possibly less favorable conditions for infection than in the previous year. Rankings of relative cultivar resistance, however, were generally consistent between the experiments (Tables 2 and 3). Daviana, Tonda Romana, DuChilly, Tonda Gentile delle Langhe, Ennis, and USOR 7-71 were the most susceptible clones, with disease incidence of 75% or

Table 2. Effect of inoculum dose on development of eastern filbert blight on hazelnut clones 16 and 28 mo after exposure

Clone	Cankers per tree after 16 mo	Disease incidence (%)		Proportion of wood				Percentage of dead trees after 28 mo
				Cankered		Dead		
		16 mo	28 mo	16 mo	28 mo	16 mo	28 mo	
Low inoculum dose								
Barcelona (Ben Doris)	8.5	90.5	100.0	0.20	0.10	0.10	0.29	10.0
Butler	7.4	95.2	100.0	0.23	0.06	0.16	0.19	10.0
Casina	3.5	59.5	95.2	0.15	0.06	0.13	0.11	10.0
Daviana	6.3	85.7	90.5	0.18	0.17	0.31	0.48	24.0
DuChilly	5.3	81.0	90.5	0.16	0.12	0.12	0.23	10.0
Ennis	7.5	90.5	90.5	0.21	0.11	0.11	0.40	29.0
Hall's Giant	1.6	42.9	85.7	0.04	0.03	0.09	0.02	0.0
Montebello	4.8	81.0	90.7	0.18	0.12	0.07	0.09	0.0
Tonda Gentile delle Langhe	4.9	85.7	95.2	0.16	0.18	0.32	0.58	38.0
Tonda Romana	5.4	76.2	81.1	0.17	0.16	0.25	0.51	38.0
Willamette	1.0	42.9	47.6	0.02	0.03	0.17	0.05	0.0
LSD ($P = 0.05$)[a]	2.7	24.8	15.6	0.09	0.07	0.18	0.25	NS[b]
Medium inoculum dose								
Barcelona (Ben Doris)	11.5	100.0	100.0	0.26	0.12	0.02	0.33	14.0
Butler	6.7	95.3	100.0	0.30	0.14	0.12	0.18	5.0
Casina	3.7	52.3	100.0	0.12	0.08	0.05	0.16	5.0
Daviana	8.2	76.3	95.2	0.25	0.31	0.33	0.78	67.0
DuChilly	5.5	95.2	95.2	0.19	0.20	0.09	0.54	38.0
Ennis	6.7	94.3	100.0	0.17	0.12	0.18	0.42	29.0
Hall's Giant	2.4	71.3	90.5	0.06	0.07	0.13	0.02	0.0
Montebello	6.5	90.7	90.7	0.26	0.23	0.12	0.40	5.0
Tonda Gentile delle Langhe	4.9	73.6	100.0	0.23	0.25	0.40	0.80	62.0
Tonda Romana	11.1	93.3	95.2	0.34	0.27	0.26	0.70	52.0
Willamette	3.3	52.3	80.9	0.07	0.07	0.02	0.11	0.0
LSD ($P = 0.05$)	4.6	25.9	20.1	0.17	0.08	0.19	0.20	NS
High inoculum dose								
Barcelona (Ben Doris)	8.9	100.0	100.0	0.20	0.23	0.34	0.60	29.0
Butler	5.5	95.2	100.0	0.24	0.22	0.17	0.43	24.0
Casina	3.0	85.7	95.2	0.11	0.22	0.12	0.31	5.0
Daviana	6.4	100.0	100.0	0.15	0.30	0.49	0.92	81.0
DuChilly	5.2	100.0	100.0	0.18	0.34	0.20	0.72	62.0
Ennis	5.9	85.7	95.2	0.17	0.22	0.30	0.69	57.0
Fitzgerald	6.1	100.0	100.0	0.27	0.29	0.06	0.50	17.0
Gasaway	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.0
Hall's Giant	3.6	90.5	100.0	0.05	0.15	0.01	0.05	0.0
Lansing	5.4	100.0	100.0	0.30	0.22	0.18	0.66	36.0
Montebello	6.4	100.0	100.0	0.18	0.34	0.12	0.34	5.0
Negret	5.3	91.7	100.0	0.25	0.31	0.18	0.53	17.0
OSU 14-19	9.0	100.0	100.0	0.49	0.61	0.30	0.86	42.0
OSU 49-73	1.5	61.0	91.7	0.08	0.18	0.48	0.68	33.0
Tonda Gentile delle Langhe	3.8	85.7	100.0	0.16	0.26	0.49	0.87	71.0
Tonda di Giffoni	1.7	58.0	88.7	0.07	1.10	0.07	0.13	0.0
Tonda Romana	5.4	95.2	95.2	0.17	0.20	0.17	0.71	57.0
USOR 7-71	8.2	100.0	100.0	0.49	0.52	0.15	0.93	92.0
Willamette	2.6	76.2	100.0	0.02	0.19	0.02	0.09	0.0
LSD ($P = 0.05$)	3.5	21.5	10.7	0.12	0.22	0.18	0.22	65.0

[a] Fisher's protected least significant difference ($P = 0.05$).
[b] Not significant.

more and 18% or more of wood cankered, and Gasaway, Gem, Winkler, Giresun 54-21, and Giresun 54-56 were the most resistant clones, with no apparent symptoms. Disease response was not significantly different ($P > 0.05$) among the three strains of Barcelona. Eastern filbert blight was not detected in the nonexposed trees in Corvallis.

DISCUSSION

The inoculation method used in these studies resulted in predictable releases of *A. anomala* ascospores into rainwater, which in turn resulted in consistent levels of infection in the hazelnut clones exposed under the platforms. The time required to develop statistically significant and consistent rankings of eastern filbert blight susceptibility is likely 4–8 yr less with this inoculation method than with the duplicate set of hazelnut clones planted in 1990 and in a previous field study that relied on natural tree-to-tree spread of *A. anomala* (12). The ascospore concentrations in rain sampled under the medium-inoculum-dose platforms were similar to those measured in rain sampled under the canopies of severely diseased trees in natural epidemics during the spring of 1990 (J. Pinkerton, *unpublished*). To maximize the likelihood of disease development in future hazelnut screening, however, we recommend use of 10 or more inoculum branches per square meter. In addition, for experiments begun after the ones in this study, we installed an irrigation system on the inoculum platforms to mist the inoculum branches daily to reduce the variability in inoculum dose due to differences in rainfall patterns between inoculum periods and years.

Studies of hazelnut cultivars grown in the Pacific Northwest (2,10) have reported Barcelona to be more resistant than we observed in this study. The young age of our trees and the high inoculum dose under our platforms may account for the difference between our observations and results in previous studies in which inoculation depended on tree-to-tree spread in orchards. Nonetheless, Barcelona maintained its vigor and continued to produce new shoots and basal sprouts after infection, as did the relatively resistant cultivars Willamette, Hall's Giant, Casina, and Tonda di Giffoni, which had low incidences of mortality at the end of the experiments. In contrast, vigorous new shoots or basal sprouts were absent in infected trees of the susceptible cultivars Daviana, DuChilly, Tonda Romana, Tonda Gentile delle Langhe, and Ennis. Mortality in these cultivars exceeded 50% 28 mo after first exposure to the high inoculum treatment. The low mortality rate we observed for Barcelona compared to other susceptible cultivars, combined with its ability to continue to produce new growth after infection, may account for the lower rate of disease-induced decline reported for full-grown Barcelona trees in other studies.

In the germ plasm evaluation experiment, five clones—Gasaway, Gem, Winkler, Giresun 54-21, and Giresun 54-56—remained free of eastern filbert blight symptoms. It is possible that cankers did not develop in all infected trees because of freeze injury. To verify the disease reactions of the 44 clones, the duplicate set of clones planted in the field in 1990 will be evaluated over 4–5 yr. However, only 24 infected trees were found after 16 mo of exposure in the field (S. A. Mehlenbacher, *unpublished*).

The apparent immunity of Gasaway is a simply inherited trait for which cross-pollinated Gasaway seedlings segregate 1:1 for immunity and susceptibility (12). Four immune seedling selections of Gasaway have been released as pollenizers for Barcelona orchards, but, as with Gasaway, the yield and nut quality of these pollenizer selections are inferior to those of commercial cultivars (11). Gem, like Gasaway, is a minor cultivar first selected by a grower in Oregon, but its nut yield and quality are better than those of Gasaway. Although Gem also appeared to be immune in our study, several mature trees of this cultivar interplanted in a severely diseased commercial orchard have developed a few cankers (J. Pinkerton, *unpublished*).

A third source of resistance to eastern filbert blight appears to be present in the *C. americana* cultivar Winkler. Clones of *C. americana*, the natural host of *A. anomala* in eastern North America, are usually more resistant than clones of *C. avellana* but vary widely in their reactions to *A. anomala* (5,10). A *C. avellana* × *C. americana* hybrid, Bixby, remained disease-free when planted along the edge of an orchard in Oregon

Table 3. Effect of a high inoculum dose of *Anisogramma anomala* on development of eastern filbert blight on 44 *Corylus avellana* clones and one *C. americana* clone

Clone	Cankers per tree	Disease incidence (%)	Proportion of wood cankered
Barcelona (Ben Doris)	1.8	60.0	0.13
Barcelona (McGrew)	2.2	89.2	0.16
Barcelona (VanderBaum)	1.7	61.9	0.09
Brixnut	2.4	88.9	0.22
Bulgaria X1-8	0.3	25.0	0.02
Camponica	0.3	25.0	0.03
Casina	1.0	62.7	0.13
Cosford	2.0	83.3	0.11
Creswell	0.2	16.7	0.02
Daviana	3.7	85.7	0.40
DuChilly	1.6	75.0	0.30
Ennis	2.4	80.2	0.18
Gasaway	0.0	0.0	0.00
Gem	0.0	0.0	0.00
Giresun 54-1	0.9	66.7	0.09
Giresun 54-21	0.0	0.0	0.00
Giresun 54-39	0.4	44.4	0.04
Giresun 54-56	0.0	0.0	0.00
Hall's Giant	1.0	74.3	0.09
Henneman #3	0.7	66.7	0.13
Italian Red	0.5	41.7	0.06
Montebello	1.4	91.7	0.17
Morell	0.3	30.6	0.03
Negret	1.0	55.6	0.07
Neue Riesennuss	1.8	100.0	0.19
Nooksack	1.2	83.3	0.06
OSU 162-17	2.3	100.0	0.18
OSU 166-34	4.0	100.0	0.15
OSU 167-2	2.9	88.9	0.18
OSU 23-17	1.6	100.0	0.02
OSU 41-83	0.3	25.0	0.24
Pellicule Rouge	0.2	8.3	0.02
Redleaf #3	0.3	16.7	0.02
Ribet	0.6	41.7	0.04
Riccia di Talanico	0.9	77.8	0.11
Rode Zeller	2.2	91.7	0.26
Segorbe	0.7	55.6	0.05
Tombul Ghiaghli	1.8	75.0	0.22
Tonda di Giffoni	0.7	33.3	0.08
Tonda Gentile delle Langhe	2.8	100.0	0.34
Tonda Romana	3.0	100.0	0.38
USOR 7-71	3.4	91.7	0.40
Willamette	1.2	72.2	0.10
Winkler	0.0	0.0	0.00
LSD ($P = 0.05$)[a]	1.1	38.6	0.15

[a] Fisher's protected least significant difference ($P = 0.05$).

where most of the trees were severely diseased (J. Pinkerton, *unpublished*). The Turkish selections Giresun 54-21 and Giresun 54-56 are another potential source of resistant germ plasm. The diverse origins of the hazelnut clones and the wide range of disease reactions obtained in this study suggest that multiple resistance mechanisms may be present within *Corylus* spp.

This study has resulted in a recommendation to Oregon hazelnut growers that the horticulturally acceptable cultivars Casina, Willamette, and Tonda di Giffoni be planted in areas threatened by eastern filbert blight. The resistant cultivars Hall's Giant and Gem are recommended as pollenizers for the main crop cultivars. Many of the resistant clones and selections continue to be used as parents in Oregon State University's hazelnut breeding program.

ACKNOWLEDGMENTS

We thank Karen Theiling, Steve Cluskey, and Julie Jenkins for technical assistance.

LITERATURE CITED

1. Barss, H. P. 1921. The eastern filbert blight menace. Proc. West. Nut Growers Assoc. 4:31-33.
2. Cameron, H. R. 1976. Eastern filbert blight established in the Pacific Northwest. Plant Dis. Rep. 60:737-740.
3. Cameron, H. R. 1980. 1979–90 Progress report on eastern filbert blight. Proc. Nut Growers Soc. Ore. Wash. B.C. 65:113-115.
4. Davidson, A. D., and Davidson, R. M., Jr. 1973. Apioporthe and Monochaetia cankers reported in western Washington. Plant Dis. Rep. 57:522-523.
5. Fuller, A. S. 1910. Filbert or hazelnut. Pages 118-146 in: The Nut Culturist. Orange Judd, New York.
6. Gottwald, T. R., and Cameron, H. R. 1979. Morphology and life history of *Anisogramma anomala*. Mycologia 71:1107-1126.
7. Gottwald, T. R., and Cameron, H. R. 1980. Infection site, infection period, and latent period of canker caused by *Anisogramma anomala* in European filbert. Phytopathology 70:1083-1087.
8. Gottwald, T. R., and Cameron, H. R. 1980. Disease increase and the dynamics of spread of canker caused by *Anisogramma anomala* in European filbert in the Pacific Northwest. Phytopathology 70:1087-1092.
9. Lagerstedt, H. B. 1979. A review of observations and research on eastern filbert blight in the Pacific Northwest. Proc. North. Nut Growers Assoc. 70:22-30.
10. Mehlenbacher, S. A. 1991. Genetic resources of temperate fruit and nut crops: Hazelnuts (*Corylus*). Acta Hortic. 290:791-836.
11. Mehlenbacher, S. A., and Thompson, M. M. 1991. Four hazelnut pollenizers resistant to eastern filbert blight. HortScience 26:442-443.
12. Mehlenbacher, S. A., Thompson, M. M., and Cameron, H. R. 1991. Occurrence and inheritance of resistance to eastern filbert blight in Gasaway hazelnut. HortScience 26:410-411.
13. Peck, C. H. 1874. Report of the botanist. Rep. N.Y. State Mus. 28:31-88.
14. Pinkerton, J. N., Johnson, K. B., Stone, J. K., and Pscheidt, J. W. 1990. Ascospore discharge of *Anisogramma anomala* under field and controlled conditions. (Abstr.) Phytopathology 80:1031.
15. Pinkerton, J. N., Johnson, K. B., Theiling, K. M., and Griesbach, J. A. 1992. Distribution and characteristics of the eastern filbert blight epidemic in western Oregon. Plant Dis. 76:1179-1182.
16. Stone, J. K., Johnson, K. B., Pinkerton, J. N., and Pscheidt, J. W. 1992. Natural infection period and susceptibility of vegetative seedlings of European hazelnut to *Anisogramma anomala*. Plant Dis. 76:348-352.