HortScience 44(5):1484–1486. 2009.

Differential Resistance of Gordonieae Trees to *Phytophthora cinnamomi*

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Additional index words. host plant resistance, disease resistance, *Abies fraseri*, *Franklinia alatamaha*, *Gordonia lasianthus*, ×*Gordlinia grandiflora*, ×*Schimlinia floribunda*, *Schima wallichii*, *Schima khasiana*, *Phytophthora cinnamomi*

***Abstract*. Trees in the Theaceae tribe Gordonieae are valuable nursery crops, but some of these taxa are known to be highly susceptible to root rot caused by *Phytophthora cinnamomi* Rands. The objective of this study was to evaluate a collection of Gordonieae taxa for resistance to this pathogen. These taxa included *Franklinia alatamaha* Bart. Ex Marshall, *Gordonia lasianthus* (L.) Ellis, *Schima wallichii* Choisy, *S. khasiana* Dyer, ×*Schimlinia floribunda* Ranney & Fantz, and ×*Gordlinia grandiflora* Ranney & Fantz. *Abies fraseri* (Pursh) Poir. was also included in the study as a positive control. Container-grown trees were inoculated with three isolates of *P. cinnamomi* and symptoms were rated over an 84-day period during the summer of 2008. Disease symptom ratings from 1 (healthy) to 4 (dead) were collected twice weekly and area under the disease progress curve (AUDPC) values were calculated. None of the *S. khasiana* or *S. wallichii* exhibited any root rot symptoms or mortality, whereas the remaining species showed symptoms of infection at varying levels over time. Symptoms in *F. alatamaha* and *A. fraseri* were apparent before other taxa, and mortality for both species reached 100% by the end of the experiment. Comparison of AUDPC values indicated that *F. alatamaha* was the most susceptible followed by *A. fraseri*. There was no significant difference in AUDPC among the more resistant taxa, including *G. lasianthus*, both *Schima* species, and the intergeneric hybrids. Values for AUDPC in the hybrid taxa were similar to their more resistant parental genus, indicating that resistance to *P. cinnamomi* is a partially dominant trait in these plants. These results further suggest the potential to breed improved hybrids of Gordonieae trees with substantial resistance to *P. cinnamomi*.**

Franklinia alatamaha, a member of the Theaceae tribe Gordonieae, has both ornamental and historical significance. It was first discovered by John and William Bartram in 1765 but is now considered to be extinct in the wild and is only maintained in cultivation (Fry, 2000). *Franklinia*, with its large, white flowers that bloom in the fall and bright red fall foliage, makes a unique and desirable plant in the landscape. In addition to these characteristics, *Franklinia* is cold-hardy at temperatures as low as –38 °C (Dirr, 1998). Despite these appealing features, *Franklinia* remains a rarity in the landscape as a result of its susceptibility to root and crown rots caused by pathogens, including *P. cinnamomi* (Koslow and Peterson, 1980). *Franklinia* is a monotypic genus, and there is little genetic diversity within this species (Griffiths, 1994; Krüssman, 1986; Liberty Hyde Bailey Hortorium, 1976; Prince and Parks, 2001). This narrow diversity limits the potential for selecting or breeding disease-resistant cultivars within *F. alatamaha*.

Possibilities that do exist for breeding *Franklinia* include two closely allied genera in the tribe Gordonieae: *Gordonia* and *Schima*. Embryological and morphological studies showed these genera to be closely related to each other (Luna and Ochoterena, 2004; Tsou, 1997) and molecular studies have placed all three genera together in the same tribe of Theaceae (Prince and Parks, 2001; Yang et al., 2004). Some breeding work with genera *Franklinia*, *Gordonia*, and *Schima* has already been conducted. Successful crosses of *Franklinia* × *Schima* produced the intergeneric hybrid ×*Schimlinia* (Ranney et al., 2003) and crosses of *Franklinia* × *Gordonia* produced the intergeneric hybrid ×*Gordlinia* (Ranney and Fantz, 2006). However, little is known about the resistance of related species and potential parents to *P. cinnamomi*. The objective of this study was to evaluate a collection of species, clones, and hybrids of *Franklinia*, *Gordonia*, and *Schima* for resistance to *P. cinnamomi*.

Materials and Methods

During the summer of 2008, seven taxa of Gordonieae trees were inoculated with *P. cinnamomi* at the North Carolina State University Mountain Horticultural Crops Research Station in Mills River, NC. These taxa included *F. alatamaha*, *G. lasianthus*, *S. khasiana*, *S. wallichii*, ×*Gordlinia* H2004-024-008, ×*Schimlinia* H2002-022-083, and ×*Schimlinia* H2002-022-084. The plants of the selected Gordonieae taxa were 5-month-old rooted cuttings collected in early February of the same year. Two-year-old seedlings of *A. fraseri* were also included in the experiment as a positive control (Frampton and Benson, 2004). Plants of all taxa were grown in a 3:1 pine bark with peat (by volume) substrate amended with 1.8 $kg \cdot m^{-3}$ dolomitic limestone and 1.0 $kg \cdot m^{-3}$ micronutrients and top-dressed with 10 g of 15N–4P–10K controlled-release fertilizer (15-9-12 Osmocote® Plus 3–4 months; The Scott's Co., Marysville, OH) in 3.8-L containers. For the duration of the experiment, plants were kept on a gravel container pad in an open-ended structure covered with white polyethylene providing ≈40% shade. Plants were watered by drip irrigation once daily for 5 min.

Three isolates of *P. cinnamomi* were grown on sterile commercial rice grains in flasks in the dark at room temperature for 10 d. The isolate accessions used as well as their host, country of origin, and year of isolation were: 2378 (fraser fir, Avery Co., NC, 1993), 2399 [*Callitropsis* ×*leylandii* (A.B. Jacks. & Dallim.) D.P. Little, Ashe Co., 1999], and two Hundley (fraser fir, Avery Co., 2005). On 27 June 2008, 10 individuals (replicates) from each taxon were inoculated with *P. cinnamomi* in a completely randomized design. Three rice grains from each of the three isolates were placed 4 cm below the surface of the media on opposite sides of the plant for each of the inoculated individuals. Five additional noninoculated plants of each taxon were maintained in a separate, completely randomized block under the same environmental and cultural conditions as negative controls. To prevent the spread of the pathogen, the gravel floor of the study site was covered with polyethylene, and any water draining from the site was collected and sterilized with bleach before being discarded.

Plants were monitored for symptoms of root rot every other week until symptoms occurred and thereafter rated twice a week. A scale from 1 to 4, based on that described by Benson (1990), was used to rate the plants:

Received for publication 9 Mar. 2009. Accepted for publication 23 Apr. 2009.
This research was funded, in part, by the North Carolina Agricultural Research Service, Raleigh, NC.
Thanks are expressed to Joel Mowrey and Nathan Lynch for their technical assistance and to Dr. Anthony LeBude for assistance in propagating plants for this study.
This manuscript is from a thesis submitted by Elisabeth Meyer as partial fulfillment of the requirements for an MS degree.
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1 = healthy, 2 = initial symptoms (flagging of new growth, chlorosis), 3 = severe symptoms (wilting, necrotic leaves), 4 = dead. Plants were rated for 84 d, at which point all plants exhibiting symptoms had died and all remaining plants appeared healthy. During the course of the study, nine root and stem segments, ≈1.3 cm in length, were excised from at least one of the dead plants for each taxon, surface-sterilized, and placed on three separate plates of selective P_{10}ARP(H) media (Erwin and Ribeiro, 1996) to confirm the presence of the pathogen. This process was also performed on at least one inoculated plant of taxa that did not show any disease symptoms at the end of the study.

Area under the disease progress curve (AUDPC) values were calculated for each replicate in the experiment using the formula of Shaner and Finney (1977):

$$\mathrm{AUDPC} = \sum_{i=1}^{n} [(Y_{i+1}+Y_i)/2][X_{i+1}-X_i]$$

where Y_i = disease rating at the *i*th observation, X_i = days after inoculation at the *i*th observation, and *n* = the total number of observations. Disease ratings at specific dates and AUDPC values were subjected to analysis of variance and means separation using least significant difference (Proc GLM, SAS Version 9.1; SAS Institute, Cary, NC) to compare taxa.

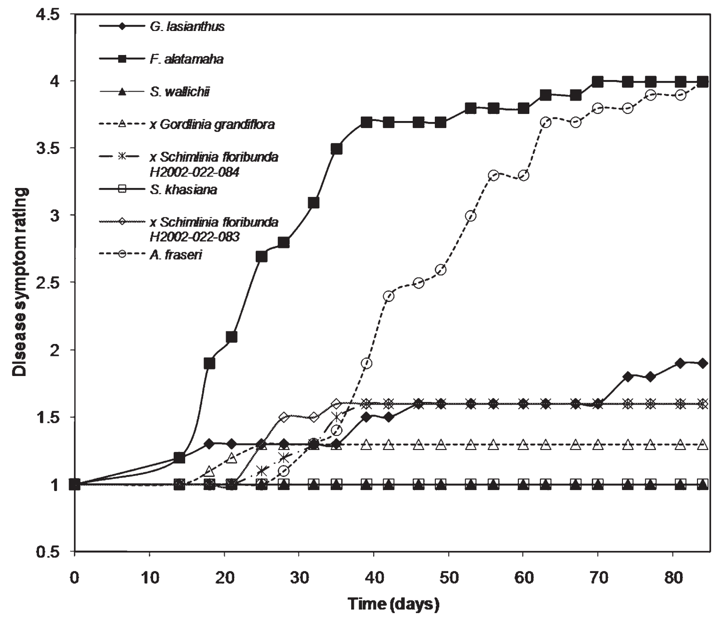

Fig. 1. Development of symptoms in *Abies fraseri* and selected taxa from the tribe Gordonieae after inoculation with *Phytophthora cinnamomi*.

Table 1. Disease symptom ratings and area under the disease progress curve (AUDPC) for *Abies fraseri* and selected taxa from the tribe Gordonieae after inoculation with *Phytophthora cinnamomi*.

	Disease symptom rating[z]							AUDPC[y]
Taxa	Day 0	Day 14	Day 28	Day 42	Day 56	Day 70	Day 84	(rating/d)
F. alatamaha	1.0[x] a	1.2 a	2.8 a	3.7 a	3.8 a	4.0 a	4.0 a	255.15 a
A. fraseri	1.0 a	1.0 a	1.1 b	2.4 b	3.3 a	3.8 a	4.0 a	192.10 b
G. lasianthus	1.0 a	1.2 a	1.3 b	1.5 c	1.6 b	1.6 b	1.9 b	122.50 c
×*Schimlinia* H2002-022-083	1.0 a	1.0 a	1.5 b	1.6 bc	1.6 b	1.6 b	1.6 bc	118.85 c
×*Schimlinia* H2002-022-084	1.0 a	1.0 a	1.2 b	1.6 bc	1.6 b	1.6 b	1.6 bc	116.05 c
×*Gordlinia* H2004-024-008	1.0 a	1.0 a	1.3 b	1.3 c	1.3 b	1.3 b	1.3 bc	103.35 c
S. wallichii	1.0 a	1.0 a	1.0 b	1.0 c	1.0 b	1.0 b	1.0 c	84.00 c
S. khasiana	1.0 a	1.0 a	1.0 b	1.0 c	1.0 b	1.0 b	1.0 c	84.00 c

[z]1 = healthy, 2 = initial symptoms (flagging of new growth, chlorosis), 3 = severe symptoms (wilting, necrotic leaves), 4 = dead.

[y]AUDPC calculated using all ratings taken twice a week over a period of 12 weeks.

[x]Values are mean, n = 10. Means followed by the same letter, within a column, are not significantly different, $P \leq 0.05$.

Results and Discussion

The noninoculated control plants did not exhibit symptoms of infection by *P. cinnamomi* throughout the duration of the study (data not shown). Among the inoculated plants, none of the *S. khasiana* or *S. wallichii* exhibited symptoms, whereas the remaining taxa showed varying levels of infection (Fig. 1; Table 1). Symptoms in *F. alatamaha* and the susceptible control, *A. fraseri*, were apparent 28 and 42 d after inoculation, respectively, and mortality for both reached 100% by the end of the experiment (84 d after inoculation). Symptoms in *Gordonia*, ×*Schimlinia,* and ×*Gordlinia* were generally delayed and less severe than in *Franklinia* and were not significantly different from the two species of *Schima*. When plant parts were harvested for reisolation of *P. cinnamomi*, roots of dead plants appeared brown and thinner in comparison with the white, fleshy roots of plants that did not exhibit any disease symptoms. *Phytophthora cinnamomi* was recovered from roots of inoculated plants in all taxa, including those taxa that appeared completely healthy at the end of the experiment, suggesting tolerance of the pathogen rather than total resistance.

The AUDPC, which reflects both rate of onset and severity of infection, also showed significant differences among taxa (Table 1). *Franklinia alatamaha* had the highest AUDPC followed by *A. fraseri*, a species known to be highly susceptible to *P. cinnamomi*. There was no significant difference among the AUDPC of *G. lasianthus*, both *Schima* species, and the hybrid taxa. Resistance in the hybrid taxa was similar to their more resistant parental genus, i.e., *Gordonia* or *Schima*.

Although *Franklinia*, *Gordonia*, *Schima*, and their hybrids are all closely related, it is not surprising that significant differences exist in their susceptibility to *P. cinnamomi.* Differences in susceptibility to *P. cinnamomi* among closely related species have been reported in *Rhododendron* L. (Benson, 1980; Hoitink and Schmitthenner, 1974; Krebs and Wilson, 2002), *Vaccinium* L. (Clark et al., 1986), *Banksia* L.f. (McCredie et al., 1985), and *Abies* Mill. (Benson et al., 1998; Hinseley et al., 2000). Even cultivars, clones, or provenances of the same species have shown significant differences in susceptibility, as in the case of *Pinus radiata* D.Don (Butcher et al., 1984), *Persea americana* Mill. (Gabor et al., 1990), *Abies fraseri* (Frampton and Benson, 2004), and *Eucalyptus marginata* Sm. (Stukely and Crane, 1994).

Previous studies have suggested that resistance to *P. cinnamomi* may be partially recessive (Clark et al., 1986) and controlled by multiple genes (Butcher, 1987; Stukely and Crane, 1994). Resistance to the pathogen in this experiment appears instead to be at least partially dominant, because all hybrid taxa expressed a level of resistance similar to that of the more resistant parent.

The results of this study show that sources of resistance to *P. cinnamomi* do exist in the tribe Gordonieae and that resistance can be successfully transmitted to hybrid progeny. This information will aid ongoing breeding efforts to combine the desirable ornamental traits of these taxa with a high level of resistance to *P. cinnamomi*. In addition, an effective protocol for the quick screening for *P. cinnamomi* resistance in this tribe has been established and can be applied to hybrids developed in the future.

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