Host Resistance Screening for Balsam Woolly Adelgid: A Comparison of Seedlings from 12 Fir Species

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Introduction

The balsam woolly adelgid, *Adelges piceae* (Hemiptera: Adelgidae) (BWA), first reported on Fraser fir, *Abies fraseri* (Pursh) Poiret, on Mount Mitchell in 1955 (Amman 1966, Boyce 1955), is a major pest in Christmas tree plantations and in native stands. Nearly all Fraser fir Christmas trees produced in North Carolina need to be treated one or more times during their 5- to 10-year rotation to prevent or lessen damage caused by this adelgid. These chemical treatments cost the industry over 1.5 million dollars per year (Potter et al. 2005) and may compromise the effectiveness of integrated pest management systems. The development of BWA-resistant Fraser fir trees would be a relatively inexpensive solution to a difficult pest problem and would minimize adverse effects from management strategies.

The balsam woolly adelgid, specific to the genus *Abies*, reproduces through parthenogenesis and completes two or more generations per year (Arthur and Hain 1984, Balch 1952). The early phase of the first instar (crawler) is the only motile stage. Feeding sites are chosen for accessibility to parenchyma cells (Balch 1952) and, once settled, the adelgid remains fairly sessile for the remainder of its life. Susceptibility to BWA varies among *Abies* species. Host responses include gouting (abnormal cell growth resembling a gall) at the feeding site, loss of apical dominance, and the production of abnormal xylem ('redwood' or 'rotholtz').

In the 100+ years that BWA has been in North America, studies on its biology and interaction with host trees have been conducted in the Pacific Northwest, Canada, and the Southern Appalachians on multiple fir species of different ages, utilizing various sources of the adelgid. Three subspecies of BWA have been identified in North America (Foottit and Mackauer 1983). Our long-term objective is to develop BWA-resistant Fraser fir trees for the Christmas tree industry and native stand restoration. Our objective for this study was to screen for resistance across multiple fir species utilizing trees of equal age, grown under the same conditions and infested with BWA from the same source, and to observe the reactions of both host and insect.

Methods

A BWA resistance screening trial was established in a greenhouse at the Upper Mountain Research Station in Ashe County, North Carolina in August 2007, utilizing 4-year-old seedlings. The study included 12 fir species, 9 representing the range of known susceptibility and 3 representing unknown susceptibilities. Susceptible species included Fraser fir (three seed sources: Roan Mountain, Richland Balsam, Mount Mitchell), balsam fir (*A. balsamea*), West Virginia Canaan fir (*A. balsamea* var. *phanerolepis*), corkbark fir (*A. lasiocarpa* var. *arizonica*), and Korean fir (*A. koreana*). Moderately resistant or tolerant species included European silver fir (*A. alba*) and white fir (*A. concolor*). Resistant species included Veitch fir (*A. veitchii*) and Momi fir (*A. firma*). Species representing unknown susceptibility included Turkish fir (*A. bornmuellariana*), Trojan fir (*A. equi-trojani*), and West Himalayan or Pindrow fir (*A. pindrow*). The greenhouse was divided into four blocks, each

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containing two treatment plots representing seasonal effect (August/September). There were 48 trees per species in each of the 8 treatment plots, for a total of 672 trees. Trees were exposed to BWA by suspending logs of BWA-infested Fraser fir over each treatment plot. This technique (Newton et al., 2011) mimics natural dispersal, allowing crawlers to drop onto the trees.

In December 2007 one-half of the study was dismantled and in May 2008 the remaining half was dismantled. Data collected from the first group of trees included the number and location of settled first instars (neosistentes). Data from the second group included presence/absence of settled instars, an assessment of infestation (yes/no), the number of BWA adults with eggs, the number of eggs, fecundity (mean number of eggs per adult), evidence of early BWA development (yes/no), and presence/absence of gouting. A subsampling technique was developed; the most predictive scheme was to take the first three branches from the top of the tree with secondary or tertiary branching (i.e., the bushiest branches from the second and third whorls). Data were collected from branches and boles, but we report here only branch responses. Because there was a significant difference in height between the species, infestation levels are expressed as counts per cm of branch.

Results

From the first group of trees (December 2007), there were no significant differences among species in the number of settled neosistentes per branch. Least squares means ranged from 0.03 (± 0.51) for *A. concolor* (white fir) to 2.09 (± 0.59) for *A. lasiocarpa* '*arizonica*' (corkbark fir). The susceptible species consistently ranked higher than the resistant and tolerant species. Crawlers settled at the base of the branches, at the nodes under old bud scales, at the base of leaves along the branch stem, and at the base of buds (both lateral and apical). They appeared to show a preference for the base of buds regardless of species.

From the second group of trees (May 2008), there were no differences among species in presence/absence of settled instars, with 81 to 100 percent of trees showing settled instars. Although one can consider trees with settled instars to be infested, here we consider 'infested' to mean that adults with egg clutches have developed on the tree. Differences in the proportion of infested trees (supporting adults with eggs) were highly significant ($p < .0001$) and, with few exceptions, the results were consistent with known susceptibility levels. Susceptible species generally showed higher proportions of infested trees than the tolerant or resistant species. Two of the unknowns, *A. equi-trojani* (Trojan fir) and *A. bornmuelleriana* (Turkish fir), were at opposite ends of this range, with almost all (0.99) of the Trojan fir trees becoming infested and only about one-third (0.34) of the Turkish fir trees. In the number of adults and eggs per cm branch, Trojan fir ranked significantly higher than Korean, Turkish, and white firs.

Mean fecundity levels reflected significant ($p = .0143$) differences among species, ranging from 4.4 eggs per adult in *A. pindrow* to 16.8 in *A. alba*. Trojan fir ranked high, along with corkbark fir, Fraser fir, and balsam fir, species known to be very susceptible to BWA. Early BWA development was evident on approximately half of the trees from most species. Turkish fir appeared least likely to exhibit early development (0.16) and Trojan fir the most likely (0.63). Fraser fir (Roan Mountain) exhibited the highest proportion of trees with gouting. Gouting responses were highly significant ($p < .0001$) with susceptible species ranking highest, tolerant and resistant species lowest, and the unknowns in the middle – one notable exception is Korean fir, which showed the least amount of gouting (0.18).

Discussion

Data collected from the first group of trees, harvested before winter dormancy, provide evidence that the trees were exposed to a sufficient number of crawlers to complete development to the next generation. Although the differences among species were not statistically significant, the rankings were consistent with a priori resistance classifications – susceptible species ranked higher than

resistant or tolerant species. This may reflect some constitutive defense that inhibits settling by the crawler. The preference for buds exhibited by the crawlers may indicate the presence of higher nutritive values in that region.

The second group of trees, when harvested, had gone through winter dormancy and entered into the growing season (although budbreak had not yet begun). Most trees from all species exhibited the presence of settled instars. At least some trees from each species were able to support the development of adults with eggs, but the differences in the proportion of trees that became fully infested suggest that this parameter alone (adults with eggs) may not be adequate for assessing resistance. Complete development took place on 89 percent of the *A. firma* fir trees, a species that exhibits resistance to BWA when mature (Mitchell 1966). One of the most interesting results revolves around the differences between two of the 'unknown' species, *A. equi-trojani* (Trojan fir) and *A. bornmuelleriana* (Turkish fir). Both are from the same global region, but here Trojan fir consistently suggests high susceptibility to BWA and Turkish fir consistently suggests resistance. This is observed in the proportion of trees that became fully infested, the numbers of adults with eggs, the number of eggs in general, the ability of BWA to complete development very early in the season, and, to a certain extent, fecundity. One important factor in the 'susceptibility status' of Trojan fir relates to the gouting response, generally considered detrimental to the health of the tree. While European silver fir can become infested with BWA, it suffers very little from BWA attack and here exhibited the highest fecundity levels (16.8 eggs per adult), but comparatively little gouting response (27 percent of the trees). Trojan fir appears to be highly susceptible, but it ranked with European silver fir in both fecundity levels and gouting responses. The other 'unknown,' Pindrow fir, generally ranked near the resistant and tolerant species. *Abies veitchii* (Veitch fir) consistently exhibited resistance and Fraser fir and the balsam firs consistently exhibited susceptibility. *Abies koreana* (Korean fir) is considered to be susceptible to BWA (Mitchell 1966); however, here its responses suggest resistance in the seedling class.

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