Frampton, J. 2004. *Exotic Conifer News.* 14(2): 5-8.

Exotic Fir Research in North Carolina

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In North Carolina, the Christmas tree industry is largely based on the production of Fraser fir (*Abies fraseri*) in the mountainous western portion of the state. This species accounts for approximately 98% of the $100^{+} million annual revenue from the state's industry. Since Fraser fir is widely accepted as a premier Christmas tree species, most of the state's Christmas tree growers have only a cursory interest in exotic conifers and most fir research conducted at North Carolina State University is focused on Fraser fir. Nevertheless, research investigating the potential of other true fir, or *Abies*, species is underway with the following goals: 1) to develop resistance to Phytophthora root rot, 2) to develop resistance to the balsam woolly adelgid, and 3) to identify fir species that are tolerant of low elevation sites for planting in the piedmont and coastal plain regions of the state.

Phytophthora Root Rot Resistance

Root rot caused by *Phytophthora cinnamomi* can be a devastating disease to Fraser fir. This pathogen is also likely to be a limiting factor for growing firs at lower elevations across the South where it will be even more favored by warmer temperatures. Through a series of artificial inoculations of greenhouse grown seedlings, we have been unable to find resistant seedlings from any of the six major provenances of Fraser fir.

So, in 2003, we conducted a large resistance screening trial which included 32 fir species. Over 6,600 seedlings were grown in a greenhouse for two or three years and then moved to an outdoor lath house. There, they were inoculated with rice grains colonized with *P. cinnamomi*. Disease developed rapidly resulting in 86% overall mortality after 16 weeks. Final species mortality ranged from 11% (*A. firma*) to 100% (several species). Statistical analyses were used to classify species into resistant, intermediate, and susceptible groups (Table 1). Resistant and intermediate species largely originated from Japan and central Asia.

Figure 1. ***Screening for Root Rot Resistance*** *Upper* - Rice grains colonized with *P. cinnamomi* are inserted into the medium of greenhouse grown fir seedlings. *Lower* – Most fir species are very susceptible, however, momi fir (*A. firma*) proved to be resistant.

We must be careful when drawing conclusions from these trials. First, some types of resistance may have been obscured since only very young trees were screened and severe disease conditions prevailed due to the confined root systems, high inoculum load, and continuously wet medium. In fact, we know that Canaan fir (*A. balsamea* var. *phanerolepis*) is killed under these inoculation conditions yet shows some useful resistance under certain field conditions. Another caveat to this research is the limited sampling of each species. Further screening of many provenances is needed to truly understand the variation of resistance within individual species.

Table 1. Of 32 fir species screened for root rot resistance, two were classified as resistant, nine as intermediate and the rest as susceptible (> 88% mortality).

Scientific Name	Common Name	Mortality (%)
	---------- Resistant ----------	
A. firma	Momi fir	11.3
A. pindrow	West Himalayan fir	30.0
	---------- Intermediate ----------	
A. bornmuelleriana	Turkish fir	61.3
A. cilicica	Cilician fir	63.2
A. siberica	Siberian fir	68.8
A. borisii-regis	King Boris fir	75.0
A. nordmanniana	Nordmann fir	77.0
A. cephalonica	Grecian fir	82.5
A. chensiensis	Shensi Fir	82.5
A. equi-trojani	Trojan horse fir	84.2
A. concolor	White fir	84.4

Despite these caveats, these results have helped us identify likely sources of *Abies* to be used as resistant rootstock or in developing a hybridization/backcrossing breeding program aimed at introducing resistance into Fraser fir.

In addition to greenhouse testing, field trials of various species have been established on Phytophthora infested sites. Both seedlings of exotic fir species, as well as Fraser fir grafted onto rootstock of exotic fir species, have been planted at some sites. These trials are too young to come to firm conclusions, but will be assessed yearly.

Balsam Woolly Adelgid Resistance

The balsam woolly adelgid (*Adelges piceae*) is an exotic insect that has decimated the natural stands of Fraser fir in the southern Appalachians. Human efforts to reduce the spread of the adelgid by cutting infested trees, applying various pesticides, and introducing adelgid predators have failed. Despite its use in the Christmas tree industry, *Fraser fir has a global rank of G2, indicating that it is imperiled and vulnerable to extinction*.

Figure 3. Fraser fir mortality at Mt. Mitchell State Park, North Carolina, caused by the introduced balsam woolly adelgid.

In addition to the aesthetic and ecological consequences of the balsam woolly adelgid, Fraser fir Christmas tree growers in North Carolina must scout and apply pesticides to control damage by this pest thus, increasing their production costs.

Field observations suggest large variation among fir species for resistance to balsam woolly adelgid infestation (Table 2). We have organized an Adelgid Research Team to better understand this variation in resistance by studying three species with widely different responses to attack: Fraser fir, European silver fir (*A. alba*), and Veitch fir (*A. veitchii*).

Table 2. Damage rating[1] of 18 fir species naturally infested with balsam woolly adelgid in the Pacific Northwest[2].

Scientific Name	Common Name	Damage Rating[1]
A. lasiocarpa	Subalpine fir	Severe
A. fraseri	Fraser fir	Severe
A. balsamea	Balsam fir	Severe
A. amabilis	Pacific silver fir	Severe
A. grandis	Grand fir	Moderate
A. lasiocarpa var. *arizonica*	Corkbark fir	Moderate
A. magnifica var. *shastensis*	Shasta red fir	Moderate
A. koreana	Korean fir	Moderate
A. sachalinensis	Sakhalin fir	Moderate
A. religiosa	Sacred fir	Slight
A. procera	Noble fir	Slight
A. concolor	White fir	Slight
A. alba	European silver fir	Nil
A. cephalonica	Grecian fir	Nil
A. pinsapo	Spanish fir	Nil
A. sibirica	Siberian fir	Nil
A. firma	Momi fir	Nil
A. veitchii	Veitch fir	Nil

[1] **Damage Rating:** Severe = trees often killed, gouting severe; Moderate = gouting moderate to severe, trees occasionally killed; Slight = gouting moderate to light, trees not observed killed; Nil = gouting not apparent; trees not killed.

[2]**From:** Mitchell, R.G. 1966. Infestation characteristics of the balsam woolly aphid in the Pacific Northwest. USDA Forest Service. Research Paper PNW-35. Pacific Northwest Forest & Range Experiment Station, Portland, OR. 18 p.

Fraser fir is one of the most susceptible species to the balsam woolly adelgid and almost all trees eventually die following attack. Interestingly, Fraser fir dies from a suicidal defense response run amuck. This defense system, presumably triggered by the contents of the adelgid's saliva, culminates in the formation of reddish wood called *rotholz*. Rotholz reduces water uptake so that infested trees eventually die with drought-like symptoms. Understanding the genetic control of this response may lead to methods of short-circuiting it and to the development of adelgid-tolerant Fraser fir.

European silver fir is one of the host species of balsam woolly adelgid in its native Eurasian range. Infested silver fir produces thick outer bark which is an unsuitable substrate for further adelgid development. Thus, this fir is very tolerant of attack by the balsam woolly adelgid showing little, if any growth loss.

The third species under investigation, Veitch fir, appears to be completely immune to adelgid infestation. Veitch fir trees growing in the North Carolina mountains alongside heavily infested Fraser fir have no, or only a few unhealthy, adelgids. Attempts to transfer healthy adelgids from Fraser fir to Veitch fir have always resulted in adelgid mortality. Our current hypothesis is that Veitch fir produces a substance in its bark that is toxic to the adelgid. If so, identification of this substance could help in the development of chemical control or host resistance.

Using grafts, seedlings, and field trees of these three species, our Adelgid Research Team is applying new technological approaches such as metabolic profiling and genetic microarray analyses to better understand different infestation responses. Although a long-term effort, we are hopeful that this knowledge will one day lead to restoration of the decimated natural Fraser fir stands as well as to the development of an adelgid tolerant or resistant variety of Fraser fir for use in the Christmas tree industry.

Tolerance of Low Elevation Sites

Generally, in North Carolina, Fraser fir cannot be grown at elevations below 3,000 feet restricting its production to the mountainous western portion of the state. Thus, Christmas tree growers in the piedmont and coastal areas of the state are interested in a fir adapted to their climate and sites.

We have tested six fir species in eastern and central North Carolina: Canaan (balsam), Fraser, Korean, Nordmann, momi and Turkish fir. Only a few trees of the first three species have survived in these trials (see Table 3 as an example). However, it is noteworthy that trials of Canaan fir in eastern Virginia have shown great promise for this species so that future testing in eastern and central North Carolina may be warranted.

Survival of Nordmann, Turkish, and momi fir in eastern and central North Carolina has been relatively higher (40-80%). However, Nordmann and Turkish fir growth has been extremely slow and abnormal including poor leader dominance. Momi fir growth has been faster, but in North Carolina, this species suffers from spring frost damage during most years and the harsh foliage makes is undesirable for many Christmas tree customers. Another strategy under investigation, is grafting Fraser fir scion unto the rootstock of

Table 3. Survival and growth of six fir species on a piedmont site in central North Carolina. For all grafts, Fraser fir was the scion material and the indicated species was rootstock.

Scientific Name	Common Name	Survival (%)		Height (inches)	
		Seedlings	Grafts	Seedlings	Grafts
A.balsamea var. phanerolepis	Canaan fir	4	4	28	.
A. fraseri	Fraser fir	0	0	.	.
A. koreana	Korean fir	4	0	16	.
A. firma	Momi fir	37	41	32	32
A. nordmanniana	Nordmann fir	55	70	17	35
A. bornmuelleriana	Turkish fir	48	51	16	32

exotic fir species. The survival of such grafts (41-70%) greatly exceeds that of Fraser fir seedlings (0%) (Table 3). Additionally, the growth and quality of the Fraser fir scion exceeds that of seedlings of the exotic species. However, more research is needed before this grafting strategy can become an economically sound option for eastern and central North Carolina growers.

While our research so far has not revealed an economically feasible fir for low elevation sites in North Carolina, we are not discouraged and believe that, with continued research efforts, we will eventually accomplish our goal. In particular, we know that there are tremendous differences among provenances of the most promising species; momi, Nordmann, and Turkish fir. We are gathering seed from as many provenances as possible of these species for future field testing. Additionally, we are testing, or will test, additional cultivation practices including irrigation, bud manipulation, and the use of partial shade for these species.

Conclusion

While it is anticipated that Fraser fir will continue to play the dominant role in North Carolina's Christmas tree industry, exotic fir research may enable us in the future to overcome some of the current problems limiting Fraser fir production. Further, the future is never certain and historically, the tastes of Christmas tree customers have undergone dramatic changes. Knowledge of exotic fir species can help in rapidly diversifying the state's industry, if necessary, in the future. In the meantime, knowledge of other fir species' performance in North Carolina can help interested growers develop niche products and increase their market shares.

Published as:

Frampton, J. 2005 Exotic fir research in North Carolina. *Nova Scotia Christmas Tree Journal*. 19(3):5,10.

Frampton, J. 2005. Exotic fir research in North Carolina. *Christmas Trees*. 32(1):36-40.

Frampton, J. 2004. Exotic fir research in North Carolina. *Exotic Conifer News*. 14(2): 5-8.