Proc. Second IUFRO Rusts of Forest Trees WP Conf., 19 - 23 Aug., 2002, Yangling, China
Forest Research 2003, 16(*Suppl.*): 101 - 112

Blister rust resistance of five-needle pines in Oregon and Washington

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Summary

Throughout much of western North America, populations of five-needle pines have been dramatically reduced in natural ecosystems by white pine blister rust, caused by an introduced pathogen, *Cronartium ribicola*. Land managers are reluctant to plant non-resistant western white pine (WWP) and sugar pine (SP), thus continuing the decline in these species. Genetic resistance to this disease offers land resource managers a valuable tool for restoring and sustaining these species. Several programs to develop rust resistance are active in North America.

In Oregon and Washington, the resistance program has evaluated progenies of over 4 900 WWP and 4 500 SP phenotypic selections since its inception in the late 1950's. Evaluation of whitebark pine (WBP) has recently begun. Rust screening has shown that progenies of most selected parents are susceptible, but that major gene resistance and forms of partial resistance are present. Resistance mechanisms occur at low frequencies, and at least one type, a hypersensitive reaction in the needles of WWP and SP, appears to be geographically restricted. Tests for major gene resistance in WBP have been negative for the first families tested; tests of partial resistance in WBP are just beginning. Another type of complete resistance (40% - 60% of half-sib seedlings from selected parents free of stem symptoms following artificial inoculation) may be present in WWP but at very low frequency (< 1%) among phenotypic selections. The underlying basis of this resistance (Mechanism 'X') is currently unknown; further work is needed to ascertain the relationship of this resistance to resistance(s) noted elsewhere in the species range. When inoculated with a mixture of rust from the Pacific Northwest, four progenies of eastern white pine (EWP) showed levels of bark reaction higher than that present in most progenies of phenotypic field selections of WWP, but few of the EWP survived. In the late 1980s WWP family 21105 - 052 was noted for its high bark reaction frequency; four separate tests in the 1990s have confirmed the high level of bark reaction (35% - 70%) initially observed.

Although an excellent inoculation and evaluation system is in place, only limited field validation results from these screenings are available. In a recent validation planting, SP has more trees with stem symptoms than WWP (85.5% vs. 43.2%) as well as much less variation among families in stem infection percentages. The mechanism 'X' family included at this site shows very low infection (12.3%). Long-term monitoring of these plantings will allow the first opportunity to closely evaluate several types of resistance in the field at the family level, to validate artificial inoculation results, and to monitor for changes in virulence in the rust population.

Orchards have been established for many breeding zones, and resistant seed is currently available for several of these zones. Many of the seedling selections from the first cycle of rust screening are at or near reproductive age, and breeding is underway. Further breeding will be needed to strengthen partial resistance traits, which may be the most valuable in the development of durable resistance.

Key words: *Pinus monticola*, *Pinus lambertiana*, *Cronartium ribicola*, resistance screening

1 Introduction

The introduced disease white pine blister rust, caused by *Cronartium ribicola* J. C. Fisch., has caused heavy mortality of five-needle pines in western North America. Resistance breeding programs for western white pine (*Pinus monticola* D. Don) and sugar pine (*P. lambertiana* Dougl.) have been underway since the 1950s and have supplied seed for restoration and reforestation efforts. More recently, evaluation of whitebark pine (*P. albicaulis* Engelmann) for blister rust resistance has also begun.

This paper provides an overview of some results from the operational blister rust resistance program for western white pine (WWP) and sugar pine (SP) in Oregon and Washington (Forest Service Region 6, see Figure 1 for maps of area covered); this program is based at Dorena Tree Improvement Center (Dorena). The Region 6 program is based upon previous resistance research on WWP and SP in Idaho and California (Bingham 1983, Hoff 1988, Hoff *et al*. 2001, Kinloch and Comstock 1980, Kinloch *et al*. 1999). Since the late 1950's, the Region 6 program has evaluated progeny of over 9 500 WWP and SP parent trees selected for blister rust resistance in the forest. Using results from several operational (nursery) tests, levels of resistance present in these two species are reviewed as well as field performance of WWP and SP in a 1996 trial. In addition, initial results from an inoculation of whitebark pine (WBP) and resistance information in four selected eastern white pine (*P. strobus* L.) families relative to WWP under conditions and rust strains present in Oregon and Washington are presented.

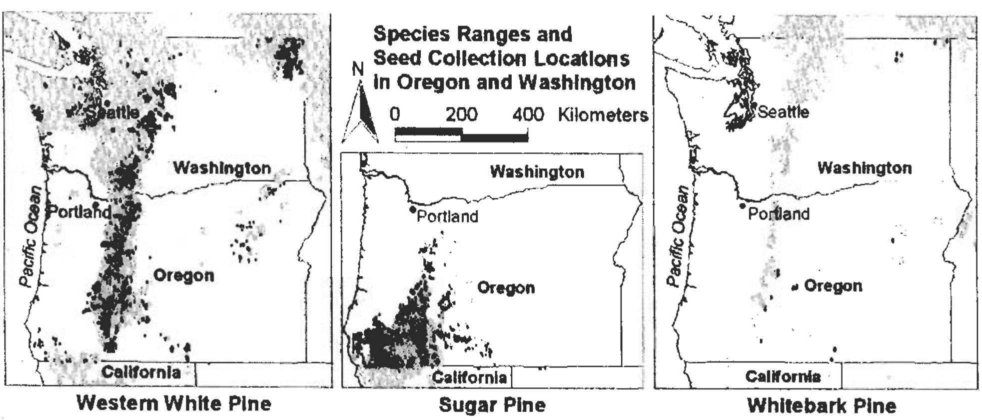

Figure 1. Species ranges (shaded areas) and location of phenotypic selections (small dots) for blister rust resistancefor western white pine, sugar pine, and whitebark pine in Oregon and Washington (USDA Forest Service Region 6).

2 Methodology

2.1 Operational Testing

Operational screening trials (also called 'runs') usually consist of 120 families in a randomized complete block design, with 10 trees per family in row plots in each of six replications. Each trial is identified by the year in which it is sown; more than one run can be sown in one year. Usually only a single species is represented in a run. The majority of families tested are open-pollinated half-sib progeny of phenotypic selections ('wild OP') from forested lands in Oregon and Washington. Dorena full-sib checklot families of SP and WWP known to possess major genes for a hypersensitive reaction (HR) in the needles are included as controls (Kinloch *et al*. 1999, and Kinloch and Dupper 2002 for discussion of HR). Several runs include full-sib families, half-sib validation families from previous runs, and full-sib checklot families from the Forest Service's Region 1 blister rust screening program in Idaho. The 1995 WWP run also includes four eastern white pine (EWP) half-sib progenies.

Seedlings are grown outside in boxes (0.9 m × 1.2 m) for two growing seasons. The seedlings are then moved into a large chamber (13.7 m × 10.1 m × 3.0 m) for inoculation. Temperature is maintained at around 16.7 ℃ (62 ℉), and relative humidity is at 100%. Naturally infected leaves of *Ribes* spp., the alternate host of *C. ribicola*, are collected from forests throughout Oregon and Washington and used for artificial inoculation. Dorena also maintains a '*Ribes* Garden' in which several species of *Ribes* (but primarily *R. nigrum* L.) are present; leaves from the ribes garden are another source of inoculum for many rust runs. *Ribes* leaves infected with *C. ribicola* at the telial stage are placed on wire frames above the seedlings, telial side down. Spore fall is monitored until the desired inoculum density is reached (approximately 6 000 spores/cm^2, 3 500 spores/cm^2, and unknown for SP, WWP, and WBP, respectively), then the *Ribes* leaves are removed. Seedlings are left in the inoculation chamber for approximately 48 hours to ensure spore germination; boxes are then returned to their previous outdoor location.

Seedlings are assessed six times during the five years following inoculation for the development of rust signs and symptoms. Seedlings are examined for the presence of needle lesions (or 'spots'), orange discoloration of stem tissue at the base of an infected needle, swollen stems (due to blister rust), cankers, and bark reactions. Seedlings are assigned to resistance categories based on presence, absence, and timing of appearance of rust signs and symptoms. Several traits examined are described below.

a. Height (cm).

b. Infection (INF): percentage seedlings that develop needle lesions and/or stem symptoms.

c. Needle Lesion class (NLclass): Each seedling is evaluated for number of needle lesions present on all secondary needles and is assigned to one of five needle lesion classes. Except for Class 0, which has no spots, the number of spots per needle lesion class varies by year and run. Generally, the scale is set up using a preliminary assessment of checklot families to have approximately 25% of the seedlings in each needle lesion class from 1 to 4.

d. Percent stem symptoms (SS%): the percentage of seedlings in a family that have stem symptoms (bark reactions, normal cankers, orange discoloration of bark, or swollen stem due to blister rust); SSfree% = 100 - SS%.

e. Percent bark reaction (BR%): the percentage of seedlings in a family that have a complete or partial bark reaction (see Hoff 1986 and Hoff 1988 for information on bark reactions).

f. Early stem symptoms (ESS%): the percentage of seedlings in a family that develop stem symptoms one year after inoculation relative to the total percentage that develop stem symptoms.

g. Stem symptom alive (SSA%): the percentages of seedlings alive with stem symptoms 3 years (SSA 3%) and 5 years (SSA 5%) after inoculationh. Rust survival (survival%): percentage of infected seedlings alive 5 years after inoculation.

Family means were computed for each trait using the means of the six replications.

A small, prototype inoculation of WBP in September 2001 used seedlings from a bulked cone collection from the Shoshone National Forest in Wyoming. Seedlings were grown for two years in Super Cells (3.8 cm diameter, 21 cm depth, 164 mL volume) at the Coeur d' Alene nursery in Idaho, moved to Dorena, and inoculated. Treatments were a factorial of inoculum level (1 000, 2 500, and 5 000 spores/cm^2) and *Ribes* source (central Oregon and southern Washington). After inoculation, seedlings were transplanted into 10 tree row plots in boxes (0.9 m × 1.2 m) and moved outside. Counts of total number of needle lesions per seedling were made in July 2002.

2.2 Testing for hypersensitive reaction (HR)

Seedlings of SP, WWP, and WBP at the cotyledon or primary needle stage are inoculated with *C. ribicola* and evaluated in a separate trial for the presence of hypersensitive reactions in the foliage (Kinloch *et al*. 1999, Kinloch and Comstock 1980, Kinloch and Dupper 2002 for details). Usually families with low to moderate levels of SS% are included in these tests.

2.3 Field testing

Replicated field validation trials of uninoculated seedlings of WWP and SP have been established in Oregon and California. Families included in these trials have undergone operational testing at Dorena. One of the first and largest of these trials was established at Happy Camp, in northern California (41°48′30″ N, 123°24′48″ W) in 1996. Twelve blocks were established with generally four trees per family (see Sniezko *et al*. 2000 and Sniezko *et al*., in prep., for more information). Height as well as number and type of stem symptoms (SS) were assessed in June 1999 and July 2000. A tree was recorded as having SS if therc was any sign or symptom of rust infection on the bole or branches, including small orange discoloration at the base of infected needles (the initial signs of stem infection), normal cankers or bark reactions in either 1999 or 2000. Percentage of trees with stem symptoms (SS%) was tabulated by family block and used for summaries and analyses.

3 Results and discussion

3.1 Major gene resistance (HR)

Testing for HR at Dorena has confirmed a small number WWP and SP parent trees with this resistance (Kinloch *et al*. 1999 and unpublished data). HR is controlled by different genes in WWP (Cr2) and SP (Cr1) (Kinloch and Dupper 2002). Current information indi-

cates that frequency of HR in both WWP and SP is very low (Kinloch 1992, Kinloch et al. 1999) and varies widely in the natural range of these species (Kinloch 1992 and unpublished data). Pathotypes of rust virulent to HR in SP and WWP are known (Kinloch *et al*. 1999, Kinloch and Dupper 2002). The durability of HR varies by site (unpublished data). The Region 6 program will use HR in conjunction with other types of resistance.

Identification of WWP and SP parents with HR allows separation of these trees from other resistant selections that show a high percentage of stem-symptom-free seedlings in testing. This allows more effective management of orchard and breeding populations. Identification of HR parents, particularly homozygous dominant parents, will provide materials to more easily monitor changes in pathogen virulence to this resistance mechanism.

Testing of WBP has only recently begun. As of 2001 HR has not been found in WBP at Dorena (unpublished data) or elsewhere (Kinloch and Dupper 2002), but many additional seedlots will be tested in 2002 and subsequent years.

3.2 Operational screening for resistance

Artificial inoculation at Dorena is very effective in infecting young seedlings; generally more than 95 percent develop needle lesions and/or stem infection (Tables 1, 4, and 5). The baseline level of resistance to blister rust is very low, with greater than 90% of seedlings getting stem infections and dying (SSA%, Table 1). Progeny of the majority of parent trees from wild populations of WWP and SP in Oregon and Washington have only a low level of resistance, but some families show levels well above the mean for the traits examined (Fig. 3 and Table 1). Bark reaction occurs at low frequency in both SP and WWP (usually < 8%), but some families have more than 25 percent of seedlings with bark reaction (see Table 1 for range in two SP tests). The majority of trees show stem infection within one year of inoculation (high ESS%), but there is often wide variation among families for ESS (see Table 1 for SP). ESS% can also vary widely from year to year, as can SSA% (see Table 1 for SP). However, by the fifth year after inoculation, less than 10 percent of trees with stem symptoms are still alive (see SSA5 in Table 1 for SP example). A few families stand out with SS < 70%, BR > 20%, or SSA5 > 20% (Tables 1, 4 and 5).

Table 1. Variation in family means for open-pollinated half-sib progeny of 104 sugar pine phenotypic field selections tested at Dorena in 1989 and 113 tested 1994.

Trait[a]	Sow Year 1989 Run 5		Sow Year 1989 Run 2	
	Mean	Range	Mean	Range
Height (cm)	39.0	30.3 - 47.3	47.8	33.2 - 66.9
NLclass	2.1	1.1 - 3.4	2.9	1.5 - 3.7
Infection (INF%)	95.9	77.1 - 100	99.7	91.7 - 100
Bark Reaction (BR%)	7.4	0.0 - 36.1	3.3	0.0 - 26.0
Stem Symptoms (SS%)	90.8	57.1 - 100	98.6	58.1 - 100
Early Stem Symptoms (ESS%)	56.2	28.2 - 89.4	84.4	60.0 - 100
Stem Symptoms Alive (SSA%)				
Through 4th inspection (3 years)(%)	71.2	26.1 - 94.0	1.8	0.0 - 14.8
Through 6th inspection (5 years)(%)	8.1	0.0 - 35.0	0.5	0.0 - 8.0
Rust Survival (Survival %)	13.0	0.0 - 51.9	1.6	0.0 - 28.6

[a] See methodology section for trait definitions.

The number of needle lesions varies by species and run, even when approximate spores loads of 3 500/cm^2 for WWP and 6 000/cm^2 for SP are achieved (Table 2). Some runs may have seedlings in the highest needle lesions class (Class 4) with six spots, while in other tests, six needle lesions may be in one of the lower classes (Table 2). In most runs, very few seedlings have no needle lesions. Family variation in needle lesion frequency is present, but further investigation is needed on its relation to field resistance. Early results are not encouraging; reduced spotting is not correlated with reduced percent stem infection in the field (Hunt 2002, Sniezko *et al.*, in prep.).

Table 2. Number of needle lesions per class for two sugar pine (SP) and four western white pine (WWP) blister rust screening trials at Dorena.

Sow Year	Run	Species	Inoculum density (spores/cm^2)	Needle lesion class				
				0	1	2	3	4
1989	1	WWP	3 470	0	1 – 2	3 – 5	6 – 10	11 +
1989	5	SP	5 233	0	1	2	3 – 5	6 +
1994	1	WWP	3 348	0	1 – 10	11 – 25	26 – 48	49 +
1994	2	SP	7 216	0	1 – 2	3 – 5	6 – 15	16 +
1995	1	WWP	3 653	0	1 – 3	4 – 9	10 – 20	21 +
1997	1	WWP	2 988	0	1 – 3	4 – 9	10 – 22	23 +

From the first small prototype inoculation of WBP at Dorena in September 2001, a large increase in number of needle lesions per seedling was observed at the highest inoculum (spore) density (5 000/cm^2) relative to the lower spore densities (Table 3). Preliminary examination of the data collected in July 2002 also showed evidence of differences in needle lesion frequency for the two sources of *Ribes* used (*R. bracteosum* Dougl. ex. Hook. from Mt. Adams area in southern Washington, and *R. hudsonianum* Richards. from Silver Lake area in central Oregon) (Table 3). Stem symptoms have begun to appear in August 2002. Assessments in the next few years will evaluate resistance responses.

Table 3. Number of needle lesion ('spots') observed on whitebark pine inoculated with blister rust spores from *Ribes* collected in central Oregon (Silver Lake) and southwestern Washington (Mt Adams).

Inoculum density (spores/cm^2)	# Seedlings		# Spots	
	Silver Lake	Mt Adams	Silver Lake	Mt Adams
1 000	47	46	8.0	6.8
2 500	49	49	7.7	4.8
5 000	37	28	29.7	12.1

There were low ($r < 0.4$) correlations of resistance traits with latitude or longitude in four rust runs at Dorena (involving 104 to 116 wild open-pollinated families) (unpublished data). In one of these runs, 1994 WWP, two northern Washington populations differed only slightly in SS% (95.3% for Quinault Indian Nation in western WA, 98.3% for Colville National Forest in eastern WA). The Quinault population had several families that were relatively low for SS% and had a wider range in family means than did the Colville population (Fig. 2). However, it is worth noting that the half-sib family (21105 – 052) with the lowest SS% in this run (a checklot not shown in Fig. 2) is from the Colville (first tested as 'Wild OP' in a

1988 run).

At Dorena the WWP full-sib checklots are usually among the highest SSfree%. However, these four checklots all have the Cr2 gene for HR, and when a strain of rust with known virulence to Cr2 (vcr2) is used, the checklots show little difference from 'Wild OP' families for SSfree (Fig. 3). The Idaho checklots and the Dorena BR checklot (not shown in Fig. 3) do not show increased SS% when rust strains with vcr2 are used (Fig. 3 and unpublished data).

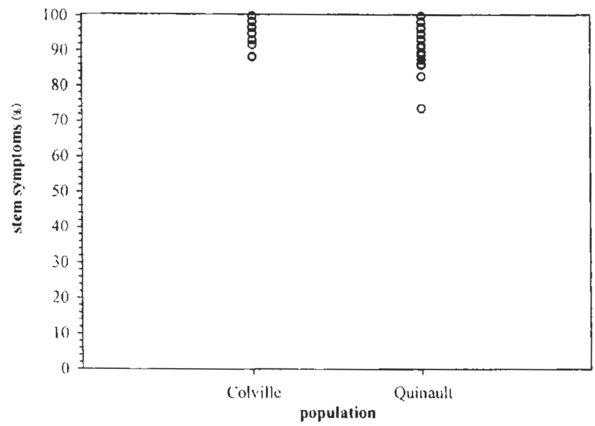

Figure 2. Family variation in percent stem symptoms of two sources of western white pine, Colville National Forest (eastern WA) and Quinault Indian Nation (western WA) in a 1994 rust run (57 Colville families, 42 Quinault families).

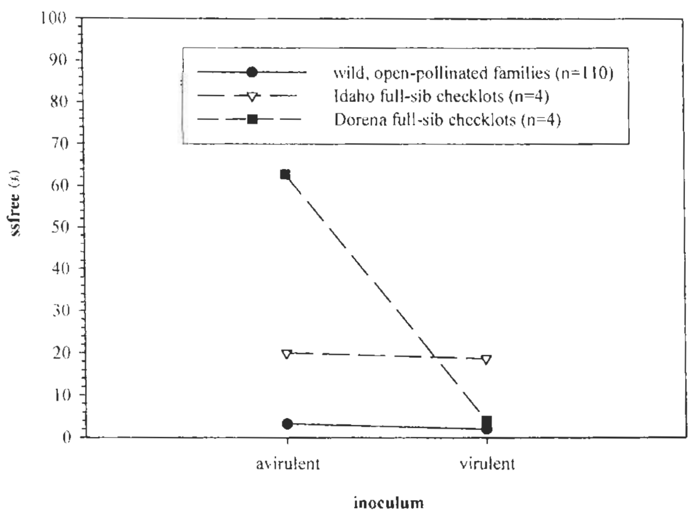

Figure 3. Percentage stem symptom free (ssfree) seedlings of several sources of western white pine in an operational blister rust screening trial (1995 inoculation) using strains of rust virulent and avirulent to Cr2.

Family 21105 – 052 was first inoculated in 1989 (sown in 1988) and was noticed for its relatively high level of bark reaction (BR) (Sally Long, personal communication). This family has been used in many recent runs as a BR checklot and it has continued to show high levels of BR (> 35%), even when vcr2 pathotypes of the rust are utilized (Fig. 4; also Sniezko and Kegley, in prep.).

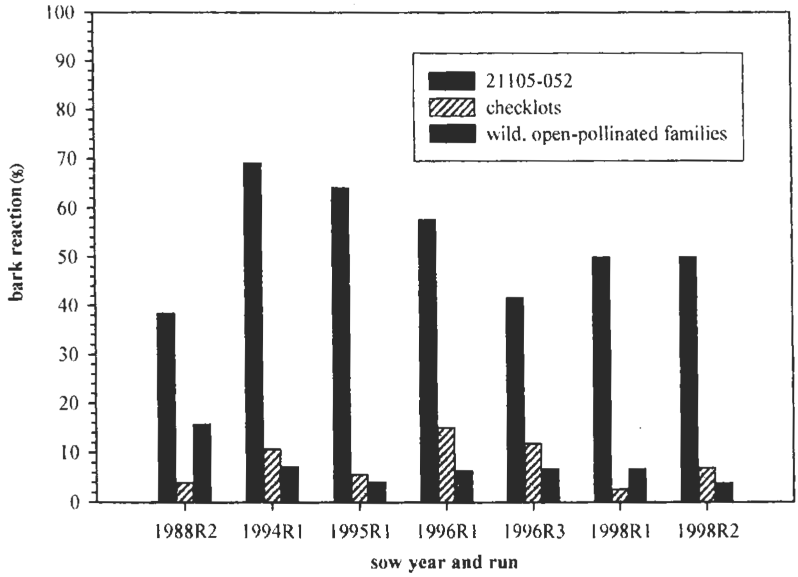

Figure 4. Performance of family 21105 – 052 (bark reaction checklot from the Colville National Forest), four Dorena HR checklots, and wind-pollinated progeny of phenotypic selections included in a series of operational blister rust screening trials of western white pine at Dorena.

Table 4. Family means for half-sib four eastern white pine (EWP) families, two outstanding western white pine (WWP) half-sib families, four WWP full-sib standard checklots, and 38 WWP half sib families (wild OP) inoculated in 1996 (sown in 1995).

Species	Family	Infected (%)	NL class	Bark reaction (%)	Stem symptoms(%)			Survival (%)
					Total	Early	Alive	
EWP	P – 312 – 5230A	100.0	2.1	26.0	94.3	92.0	2.0	6.9
EWP	P – 343 – 5232A	98.3	2.0	32.1	96.6	94.6	3.6	5.1
EWP	ONT – 500 – 7807	100.0	2.2	55.2	100.0	100.0	0.0	0.0
EWP	ONT – 4 – 3465A	100.0	3.2	39.2	100.0	100.0	0.0	0.0
WWP	05081 – 003	96.7	1.9	60.9	43.6	13.0	33.3	64.4
WWP	21105 – 052	100.0	2.8	64.2	91.4	60.4	28.3	33.9
WWP	checklots	100.0	2.5	5.6	80.4	66.0	5.4	23.4
WWP	wild OP	99.2	2.6	4.1	97.8	84.8	0.8	2.5

Molecular data has shown differences between races of rust from eastern and western North America (Hamelin *et al*. 2000), but little is known about whether strains from these two geographic areas vary in virulence or aggressiveness on their pine hosts. A recent test at Dorena (Table 4) included four half-sib families of EWP from phenotypically rust-resistant selections made many years ago in Wisconsin, Minnesota, and Ontario (Canada). These families show very high levels of SS% and low levels of survival similar to most WWP families at Dorena (see wild OP family means in Table 4). The EWP families generally show fewer needle lesions and more bark reactions than progeny of most WWP phenotypic selections (Table 4). However, the top WWP families in this trial such as 05081-003 and 21105-052 show more BR, fewer and later SS, and higher survival than the EWP families (Table

4). Despite relatively high levels of BR, few EWP seedlings survive under the Dorena test regime; further investigation is needed to ascertain more about the nature of BR on EWP or whether multiple stem infections (both BR and normal cankers) are present. Although the authors currently have no information on the performance of these four EWP families in testing programs in eastern North America, their performance in Dorena testing suggests that while they appear more susceptible at Dorena than the best WWP families, there may be potential for selection and breeding.

WWP Family 05081 – 003 shows relatively low SS% (45.6%) and ESS (13.0%), as well as high BR (60.9%) and SSA (33.3%) and is not adversely affected by a rust pathotype virulent to Cr2 (Table 2; note relatively poor SS% for checklots). The level of SS% (43.6% in 1995 WWP run) observed in this open-pollinated family is nearly half that reported in trials with the best first generation full-sib families elsewhere (Hoff 1988). This family is also outstanding for SS% in a field test (12.3%; Fig. 5). The underlying basis for this resistance (Mechanism 'X') and its inheritance is unknown, but it does not fit previously reported models for recessive single genes in WWP (Hoff 1988). Only a very small percentage (< 1%) of families tested show this low level of SS% and are non-Cr2. A group of these families have recently been sown in 2000 to confirm their performance.

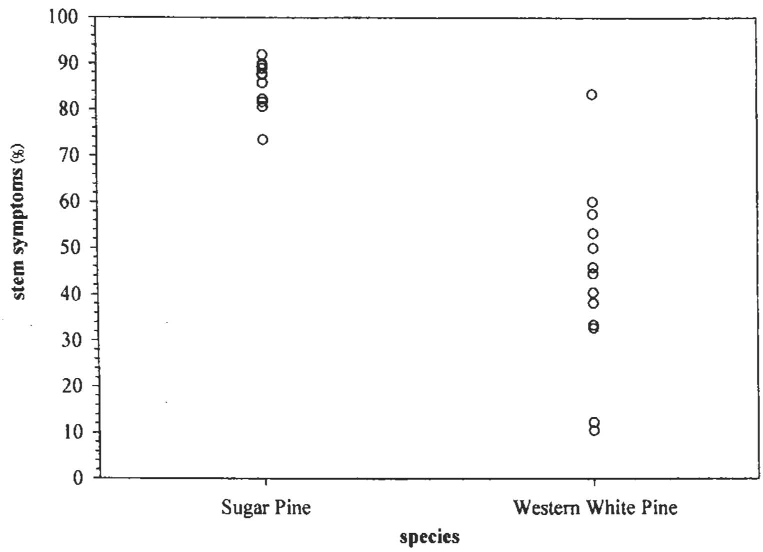

Figure.5 Range of family means for percent stem symptoms at Happy Camp for 12 sugar pine and 13 western white pine families (based on 1999 and 2000 assessments of a 1996 planting).

Some of the more resistant WWP families currently in the Region 6 program were included in a 1997 run. Table 5 shows a subset of the families in this run: three resistant full-sib families and a susceptible open-pollinated checklot. Although all four families show high infection, there is a wide separation between the susceptible checklot and the other three families for resistance traits (Table 5). All four grandparents of sow #7 are known to express HR, and this family has only 5.5% SS versus 100% for Sow #28. An effort was made to exclude inoculum with virulence to Cr2, but recent investigations indicate such pathotypes occur in low frequency in much of western Oregon (unpublished data). Incompatible stem infections have been noted in SP with HR (Kinloch and Comstock 1980). Sow # 1 and 2 share a common female parent, and both of these do well for all other resistance traits shown: NLclass, SS%, ESS%, SSA5%, and survival (Table 5). Except for HR, the nature and number of resistance mechanisms and their inter-relationships are unclear at this point.

Table 5. Family means for three full-sib families (Sow # 1, 2, and 7) and one low resistance half-sib family (Sow # 28) of western white pine tested in 1997 (results 3 years after inoculation).

Sow #	Family	Height (cm)	Infection (%)	NL mean	Bark reaction (%)	Stem symptoms(%) Total	Alive	Early	Survival (%)
1	(06024 - 506) x (504 x 511)	38.2	96.6	1.9	72.7	40.7	77.3	18.2	82.8
2	06024 - 506 x self	33.2	94.7	1.7	43.5	47.9	47.8	34.8	61.8
7	(15045 - 844 x 862) x (814 x 837)	51.5	100.0	2.4	0.0	5.5	66.7	33.3	91.5
28	03024 - 532 x w	43.7	100.0	2.7	0.0	100.0	8.9	69.6	8.3

3.3 Field testing

Through the 2000 assessment of a 1996 field test of 13 WWP and 12 SP families, the WWP families showed a much lower overall SS% (43.2% vs. 85.5%) as well as a wider range of family means (Fig. 5, also see Sniezko *et al.*, in prep.) and a lower number of stem infections per tree (unpublished data).

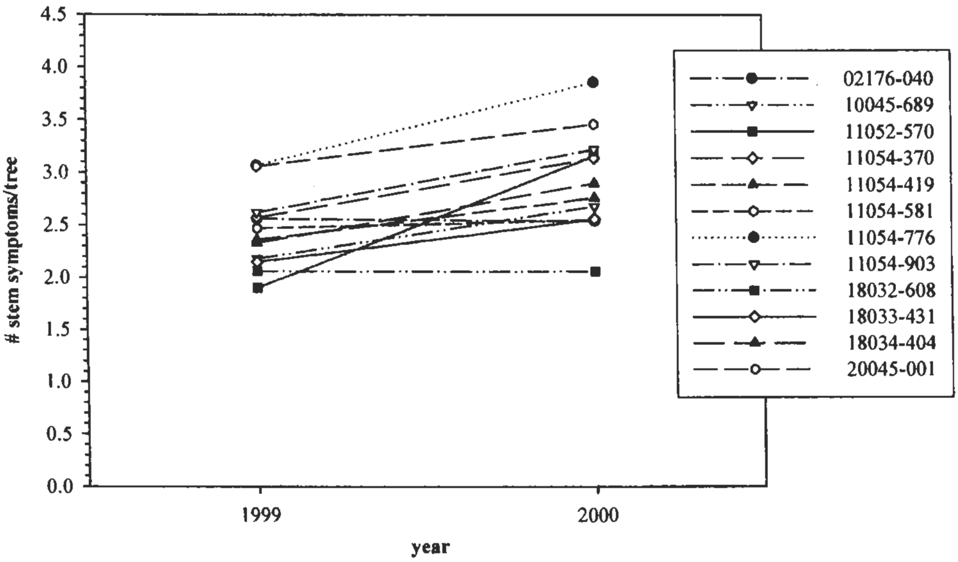

Figure 6. Number of stem symptoms per living tree at Happy Camp, CA field planting for 12 families of sugar pine planted in 1996 (family identifications are noted in the accompanying legend).

The range among families for number of stem infections in the field was relatively narrow for both SP (Fig. 6) and WWP (unpublished data). The number of stem infections increased slightly in most SP families from the 1999 to the 2000 assessment (Fig. 6). In two older tests, WWP full-sib families varied in SS%, number of cankers, and survival (Sniezko *et al.*, in preparation).

4 Conclusion

Most WWP and SP phenotypic selections show little resistance in testing at Dorena. The incidence of complete resistance, such as HR, in both WWP and SP is very low and varies geographically. On the highest rust hazard sites, it is likely that HR by itself will only serve as a temporary resistance, but on other sites it may be durable much longer. Several forms of partial resistance are also present in these species in Oregon and Washington but will generally need further breeding to enhance the relatively low levels. Many of the most outstanding families with non-Cr2 resistance have a relatively high frequency of BR and SSA and a relatively low frequency of ESS. The number of resistance mechanisms and their inter-relationships needs clarification to increase the efficiency of breeding and advanced generation selection.

Current efforts are concentrating on summarizing data from several decades of resistance screening and recently established field validation plantings and increasing levels of resistance by breeding selections made in resistance tests. Field plantings are necessary to confirm utility of resistances observed in operational screening. The Region 6 program will continue to provide seedlots with diverse array of resistance responses as well as a broad genetic base. With recent changes in management activities on federal lands the incidence of WWP, SP, and WBP will continue to decline, unless restoration and reforestation take advantage of genetic resistance present from breeding programs.

Seed orchards and breeding orchards have been established from selections of the best individuals in the best families for each resistance trait. In some cases parents of the best families are being used in orchards. Orchards have been established in many breeding zones in Region 6 using a diverse array of parents and several types of resistance. Many orchards are now flowering and breeding to increase resistance is underway.

It would be useful to examine a new subset of specific WWP and SP families in a number of sites beyond western North America to determine which type of resistances or combination of resistances might provide defenses to strains of blister rust from outside western North America.

Resistance work on WBP is just beginning, but genetic variation in resistance among families has been noted elsewhere (Hoff *et al* . 2001, Krebill and Hoff 1995). The rust screening protocols developed for WWP and SP will be used to start efforts with WBP. Evidence presented here suggests that species of *Ribes* or the geographic origin of inoculum has an influence on number of needle lesions in WBP.

Acknowledgements

The support of the United States Department of Agriculture Forest Service Region 6 Genetics Program and Forest Health Program and the USDI BLM Genetics program is gratefully acknowledged, as is the work of all cooperating groups and individuals who supplied seed from selected trees. The Forest Service's Region 1 Genetics Program provided seed of their full-sib checklots, Bill Sery (Region 9 Genetics Program) supplied seed of EWP, Melissa Jenkins facilitated the acquisition of seedlings of whitebark pine, and the Region 5 (California) Genetics Program provided the Happy Camp planting site and significant help in planning and assessing the field planting. A special thanks to Jude Danielson, Bob Danchok, Sally Long, the late Delbert Albin, and all or our co-workers at Dorena for the countless preparations, assessments, and compilation of these rust runs and subsequent discussions. Gayle Dupper, Annie Delfino-Mix and Dr. Bohun Kinloch, Jr. provided invaluable details on evaluating WWP and SP for HR.

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