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Genetic Variation in Disease Resistance of *Juniperus virginiana* and *J. scopulorum* Grown in Eastern Nebraska

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(Received 6th May 1996)

Summary

Juniperus trees were examined in a plantation located in Horning State Farm, near Plattsmouth in eastern Nebraska, USA. Trees were grown from seeds collected from 131 open-pollinated families within 39 seed-zones in eastern redcedar (*J. virginiana* L.) and 25 open-pollinated families within 14 seed-zones in Rocky Mountain juniper (*J. scopulorum* SARG.) from their native ranges in the Great Plains of USA. The plantation was established in spring 1980 to examine genetic variation among genotypes for resistance to Cercospora blight caused by *Pseudocerospora juniperi* (ELLIS and EVERH.) SUTTON and HODGES, *comb. nov.* (formerly *Cercospora sequoiae* var. *juniperi*), a major disease that threatens juniper survival east of the Rocky Mountains. All plantation plots were inoculated with *P. juniperi* in 1982, 1984, 1985, and 1986. Infection was scored in 1987. Kabatina tip blight caused by *Kabatina juniperi* SCHNEIDER and v. ARX, which occurred naturally, was scored also. Between the two juniper species, we found significant differences in survival and resistance to both diseases (P<0.05). All traits differed among seed-zones and among families within seed-zones of eastern redcedar (P<0.01). With Rocky Mountain juniper, variation was significant among seed-zones for survival (P<0.01), and among families within seed-zones for Cercospora blight and survival in 1994 (P<0.05). Heritabilities and genetic correlations were high for both disease resistance traits in eastern redcedar. Geographic patterns of genetic variation were identified; seed sources from southeastern collection sites of lower elevations tended to exhibit higher resistance to both diseases than seed sources from northwestern collection sites of higher elevations. Disease resistance traits were not correlated with height growth (|r|<0.20, P>0.05) for either species. The relationship between Cercospora blight resistance and survival in 1994 was significant (r = 0.59, P<0.05). Results indicate that Cercospora blight resistance in eastern redcedar can be improved by selecting resistant seed sources or families for direct reforestation programs or future breeding programs in eastern Nebraska. Additionally, Kabatina tip blight levels were lower on genotypes selected for resistance to Cercospora blight. Moreover, because resistance to Cercospora and Kabatina blights can be selected independently of height growth and survival, there is apparently no need to sacrifice growth and survival characteristics.

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Key words: progeny test, disease resistance, *Pseudocercospora juniperi, Kabatina juniperi*, Cercospora blight, Kabatina tip blight, genetic parameters, selection, geographic variation, Great Plains.

FDC: 1232.11; 181.4; 165.3; 165.4; 165.5; 443; 172.8 *Pseudocercospora juniperi*; 172.8 *Kabatina juniperi*; 174.7 *Juniperus*; (782).

Introduction

Genetic improvement of any forest tree species requires a long-term commitment to a well designed selection and breeding program. With eastern redcedar (*Juniperus virginiana* L.) and Rocky Mountain juniper (*J. scopulorum* SARG.), this commitment is especially critical because, unlike many other coniferous species in which the selection programs are primarily focused on productivity, these species are used in urban and rural environmental plantings, such as shelterbelts, windbreaks, wildlife habitats, and landscapes (CUNNINGHAM, 1993). Therefore, sustainability is paramount when selecting adaptive provenances or families for environmental purposes. Assuring sustainability in stressful regions requires long-term studies on tree performance.

Although eastern redcedar and Rocky Mountain juniper can survive and grow in widely ranging climatic, edaphic, and topographic situations, 2 blights caused by *Pseudocercospora juniperi* (ELLIS and EVERH.) SUTTON and HODGES, *comb. nov.* (formerly *Cercospora sequoiae* var. *juniperi*) and *Kabatina juniperi* SCHNEIDER and v. ARX are considered the greatest threats to long-term survival of these species in the Great Plains (PETERSON, 1981). In eastern Nebraska, for example, successive seasons of severe Cercospora blight can cause mortality within 3 years for 15- to 20-year-old trees (PETERSON, 1977).

Selection of genetic materials that resist these diseases is the primary approach to improve the sustainability of juniper plantings. In a shelterbelt containing a row of both juniper species, damage by Cercospora blight was much heavier in Rocky Mountain juniper than in eastern redcedar (PETERSON, 1981; PETERSON and WYSONG, 1968). However, specific genetic information is lacking for the disease resistance in these species, and general information on other characteristics is limited to a few studies. Working on multiple populations grown at various locations within the Great Plains of the USA, van HAVERBEKE and KING (1990) reported that differentiation among populations was subtle, and genotype by environment interaction was significant in survival and height growth at age 5. Variation in volatile oil composition differed among 106 populations (COMER et al., 1982). Populations also differed in survival rate when seedlings were grown under severe drought stress (TAUER et al., 1987). Because the aforementioned studies were conducted only in juvenile stages, continuation of such trends must be verified as the trees mature. Furthermore, breeding programs for these species require information from progeny tests; no report has yet examined family variation within these species.

In this report, we analyze data collected from a plantation progeny test over a 15-year period. We address the following questions: 1) Are there differences in disease resistance, survival, and height among seed-zones and among families within a seed-zone? 2) If so, what is the magnitude of genetic and environmental variance in these traits? 3) How do these traits relate to one another and are there geographic patterns in these traits? and 4) Based on heritability estimates, are these traits heritable?

Materials and Methods

Seeds from 131 eastern redcedar and 25 Rocky Mountain juniper trees (open-pollinated families) were collected during 1973 to 1976 by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station (VAN HAVERBEKE and KING, 1990). Trees displaying desirable windbreak characteristics were selected from 39 and 14 seed-zones (CUNNINGHAM, 1975) for eastern redcedar and Rocky Mountain juniper, respectively (*Figure 1*). Seedlings were raised following standard nursery procedures.

In March 1980, 2-year-old seedlings were transplanted to the University of Nebraska's Horning State Farm near Plattsmouth, eastern Nebraska, USA (41°00'N. Latitude, 95°54'W. Longitude, 335 m elevation) (*Figure 1*). Soil at the site is composed of silty loam derived from loess. The growing season averages 170 days (April to September), with a mean annual precipitation of 760 mm. The experimental design was a randomized, complete block with 5 blocks and 4-tree-row plots. Trees were planted 2 m apart within a row and 4 m apart between rows. Competing vegetation was controlled by mowing between rows until 1986. In early spring of the initial year after planting, herbicide was applied between trees within rows.

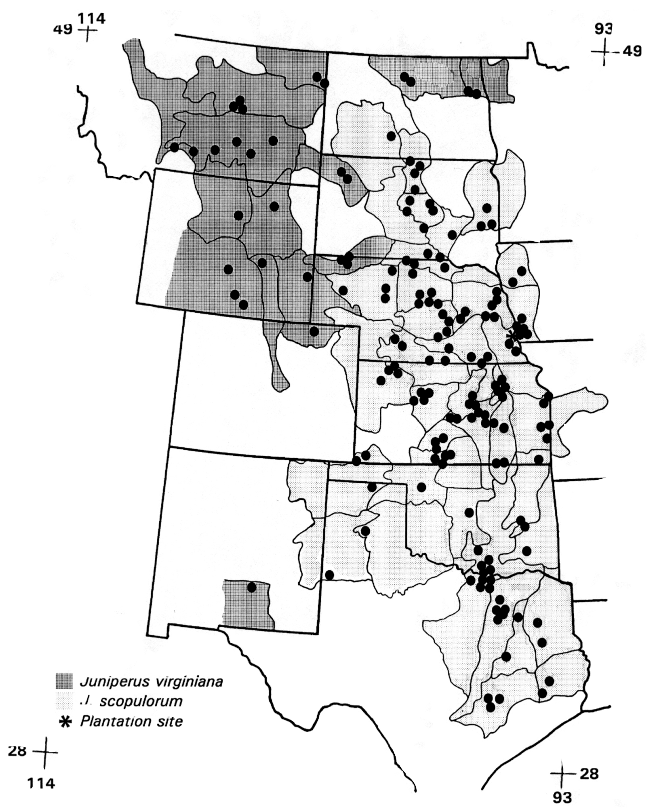


Figure 1. – Seed collection zones in the Great Plains of USA, and ranges where seeds were collected in *Juniperus virginiana* and *J. scopulorum* grown at plantation size (*) in Horning State Farm, Plattsmouth, Nebraska, USA.

Because the plantation was designed to select disease-resistant genotypes, *Pseudocerospora juniperi* was introduced into the plantation using infected foliage from eastern redcedar growing adjacent to the planting site. In late July and early August of 1982, 1 tree in each 4-tree plot was inoculated by attaching an infected branchlet to the upper part of trees. Additional inoculations were made in 1984, 1985, and 1986 to 1 tree in each 4-tree plot. In eastern Nebraska, *P. juniperi* typically infects junipers in early to late summer, with symptoms developing within 2 to 3 weeks. Early symptoms are bronzing of leaf tips on spur shoots, leaves subsequently become entirely bronzed, then necrotic by early autumn (PETERSON and WYSONG, 1986). Typically, foliage at the base of branches in the lower crown becomes infected first (PETERSON and WYSONG, 1986). Infected branches often display only a tuft of healthy foliage that remains on the terminal shoots. Thus, disease evaluations were confined to the lower half of tree crowns. The evaluation was conducted in 1987, and was based in the percentage of necrotic foliage according to the following rating scale: 0 = absent, 1 = very light (1% to 3%), 2 = light (4% to 10%), 3 = moderate (11% to 20%), 4 = moderate heavy (21% to 40%), and 5 = heavy (more than 40%). In addition, infection by *Kabatina juniperi* occurred naturally in 1985 and was scored in March, 1987 after the disease had spread throughout the plantation. Symptoms of Kabatina blight are first evident in spring when infected foliage on branch tips turns yellow-brown instead of becoming green (OSTROFSKY and PETERSON, 1986). Limited dieback from Kabatina blight occurs from the tip, thereby presenting symptoms that are quite distinct from Cercospora blight (OSTROFSKY and PETERSON, 1986). The same 6 categories of infection severity were used for *K. juniperi* infection as for *P. Juniperi*.

Height growth (HT) was measured nine times, annually from 1980 to 1986 with subsequent measurements in 1989 and 1994. Because survival rates were high (>97%) in the early stages, we only present survival data from 1989 and 1994.

We conducted data analyses in several stages. First, species comparison for all variables was performed by SAS GLM with a type III estimable function using following model:

$$Y_{ijk}=\mu+S_i+B_j+E_{ij}+W_{ijk} \qquad (1)$$

where Y_{ijk} is an observation of seedling k from species i in block j; μ is the overall mean; S and B are the effects of species and block, respectively; E_{ij} is the experiment-wise error; and W_{ijk} is the sampling error. Second, seed-zone, family within seed-zone, and interactions were analyzed by following model:

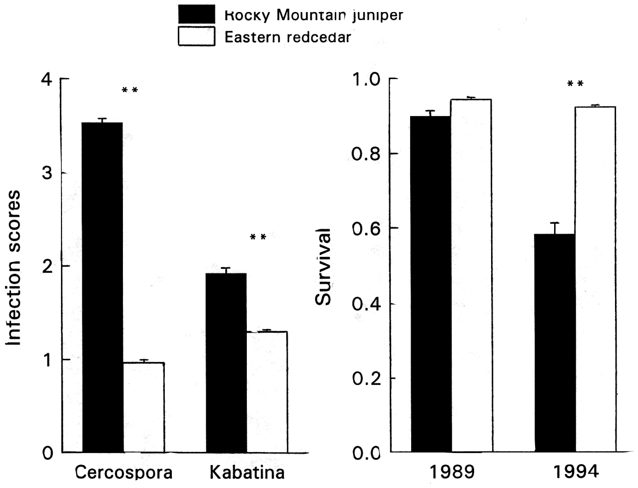
$$Y_{ijkl}=\mu+P_i+B_j+BP_{ij}+F_{k(i)}+BF_{jk(i)}+E_{ijkl} \qquad (2)$$

where Y_{ijkl} is an observation of seedling l from family k within seed-zone i in block j; μ is the overall mean; P and B are the seed-zone and block effects, respectively; F is the family within seed-zone effect; BP and BF are the interactions between block and seed-zone and between block and family within seed-zone, respectively; and E is the residual. We grouped within-plot effect into the residual because its variance is small and nonsignificant relative to the residual. For consecutive measures of height growth, we also used GLM MANOVA to test year effects and interactions among years and other variables.

We used SAS VARCOMP to estimate the variance component from model 2. Individual and family heritabilities were estimated for all traits with the assumption that inbreeding within open-pollinated families of natural populations is 10% (REHFELDT, 1992). The standard errors for heritabilities were calculated as described by BECKER (1992). Genetic correlations between traits were also estimated (FALCONER, 1989).

Results

Eastern redcedar had significantly higher resistance to Cercospora and Kabatina blights than Rocky Mountain juniper (*Figure 2*). Based on the rating scales, the disease severity rating of Cercospora blight was 3 times higher on Rocky Mountain juniper than on eastern redcedar. Survival was also different between 2 species in 1989 (P<0.05) and 1994 (P<0.01) (*Figure 2*). Similarly, species differed in height growth (P<0.01), although this difference was smaller early in the study, and greater as the trees matured (*Figure 3*).



*) p < 0.05; **) p < 0.01

Figure 2. – Species means and standard error for disease ratings of Cercospora blight and Kabatina tip blight in 1987 and survival in 1989 and 1994 in *Juniperus virginiana* (hollow bar) and *J. scopulorum* (filled bar) grown in eastern Nebraska, USA.

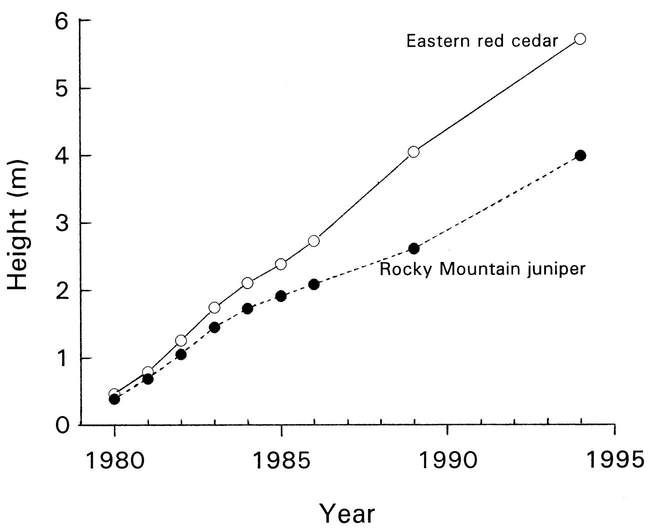


Figure 3. – Consecutive height in *Juniperus virginiana* and *J. scopulorum* grown in eastern Nebraska, USA. Each point is mean ± 1SE; error bars are too small to appear.

Variation was significant for all variables (disease severity, survival, and height) among seed-zones and among families within seed-zones of eastern redcedar (*Table 1*). In Rocky Mountain juniper, seed-zones differed for survival and most height measurements, while family within seed-zones differences were only significant for Cercospora blight severity in 1987, survival in 1994, and height in 1986 and 1989 (*Table 1*). The effects of year and interactions among year and other dependent variables on height were significant in both species (0.46<PILLAI's trace <2.5, P<0.008).

Genetic variation among seed-zones was significantly (at α = 0.01) correlated with latitude (r = 0.61 vs. 0.56 for Cercospora blight and Kabatina tip blight, respectively), longitude (r = 0.76 vs. 0.58, respectively), and elevation (r = 0.62 vs. 0.51, respectively) of the seed sources. Seed sources from southeastern and lower elevation sites showed much less infection by Cercospora blight than seed sources from northwestern and higher elevation sites (*Figure 4*). The similar trend was also found for the infection of Kabatina tip blight.

Variance components were estimated for the most important terms from the statistical model 2 that assumes all terms are random (*Table 1*). Heritabilities were estimated from variance components. Generally, heritabilities were higher and standard errors were smaller with eastern redcedar than with Rocky Mountain juniper except for survival in 1994 (*Table 2*). Family-mean heritabilities were higher than individual ones for both species. With height growth, heritabilities were high and relatively stable across years in eastern redcedar (*Figure 5*), but Rocky Mountain juniper varied in h_i^2 and standard errors for h_f^2 were too large to support conclusions for these variables.

Age-age phenotypic correlations were high in eastern redcedar ($0.65 \leqslant r \leqslant 1.00$, P<0.01) for all height variables, and in Rocky Mountains juniper ($0.64 \leqslant r \leqslant 0.99$, P<0.01) for all but height in 1994 ($r \approx 0.00$). Similarly, genetic correlations in height variables were 0.51 to 0.99 in eastern redcedar and 0.13 to 1.00 in Rocky Mountain juniper. Because the latter species suffered significantly from diseases and other environmental stresses through 1989 (*Figure 2*), lack of height correlations between 1994 and other years is probably attributable to the 40% mortality of trees that were not measured in 1994 as before.

Traits for disease severity were significantly intercorrelated in eastern redcedar (*Table 3*); as was survival (r = 0.93, P<0.01). In Rocky Mountain juniper, similar trends were detected; a correlation of 0.61 (P<0.05) was observed between survival in 1989 and survival in 1994 (*Table 4*). Cercospora blight severity in Rocky Mountain juniper was significantly correlated with survival in 1994. Genetic correlations yielded similar trends as phenotypic correlations. Cercospora blight, Kabatina tip blight, and survival had relatively high genetic correlations (*Tables 3* and *4*). Because of high mortality in Rocky Mountain juniper, the genetic parameters estimated in this species must be used with caution.

Discussion

The goal of this study was to select sources of families that exhibit high resistance to foliage blight diseases that are endemic in the Great Plains. The results show significant differences in disease resistance among seed-zones or families within seed-zones of 2 *Juniperus* species, thereby indicating that these species can be genetically improved through selection. Because heritabilities were relatively high (*Table 2*) and genetic and phenotypic correlations were relatively high and positive for 2 variables measuring resistance (*Tables 3* and *4*),

Table 1. – Variance components and significance levels for traits in eastern redcedar and Rocky Mountain juniper grown in eastern Nebraska.

Trait	Source of variation			
	Seed-zone (σ^2_P)	Fam(sz) ($\sigma^2_{f(P)}$)	Blk*Fam(sz)($\sigma^2_{b*f(P)}$)	Error (σ^2_e)
J. virginiana				
Cercospora blight (1987)	0.1360**	0.1818**	0.3096**	0.7630
Kabatina tip blight (1987)	0.0757**	0.0995**	0.1099**	0.4137
Survival (1989)	0.0109**	0.0014**	0.0053**	0.0336
Survival (1994)	0.0185**	0.0027**	0.0039**	0.0465
Height (1980)	0.1048**	0.2464**	0.1719**	0.9972
Height (1981)	1.5350**	0.8808**	0.2694**	2.9166
Height (1982)	3.1579**	1.3373**	0.8773**	6.4746
Height (1983)	5.7637**	2.2428**	1.0432**	7.9196
Height (1984)	8.6235**	2.8432**	1.7809**	10.5669
Height (1985)	8.7603**	3.1451**	2.3469**	12.4956
Height (1986)	10.4459**	4.1994**	3.0782**	18.6171
Height (1989)	17.1489**	7.2622**	4.7690**	34.2947
Height (1994)	21.6393**	9.9477**	9.6135**	54.4289
J. scopulorum				
Cercospora blight (1987)	<0^{ns}	0.0954*	0.1073*	0.7827
Kabatina tip blight (1987)	0.0135^{ns}	<0^{ns}	0.5516**	0.6213
Survival (1989)	0.0053**	0.0011^{ns}	<0^{ns}	0.0813
Survival (1994)	0.0371**	0.0256**	0.0056^{ns}	0.1596
Height (1980)	0.2344**	0.1903^{ns}	0.1530**	0.5230
Height (1981)	0.3277**	0.3889^{ns}	0.2554**	1.8269
Height (1982)	0.8361**	0.6899^{ns}	0.4234*	3.7783
Height (1983)	1.6937**	0.9783^{ns}	0.6060^{ns}	6.2420
Height (1984)	2.8692**	1.2669^{ns}	0.9747*	8.5977
Height (1985)	3.6833**	2.0162^{ns}	0.7355^{ns}	10.4287
Height (1986)	5.0439**	2.7361*	1.7170*	12.6581
Height (1989)	10.7674**	4.4767**	7.7190**	23.9853
Height (1994)	<0^{ns}	6.3570^{ns}	1.1736^{ns}	80.7940

^{ns}) $P < 0.05$; *) $P < 0.05$; **) $P < 0.01$

we can exercise selection for the most resistant seed sources or families to achieve resistance to both diseases. For example, if we estimate correlated responses through direct and indirect selection (FALCONER, 1989), and if we select the best 20% of families within seed-zone in eastern redcedar for the next generation to grow in eastern Nebraska, we can theoretically obtain 100% and 76% correlated response (genetic gains) in resistance to Cercospora blight and Kabatina tip blight, respectively. Moreover, when we achieve 100% gain in the former variable, we simultaneously obtain 53% gain through an indirect selection in the latter one.

Practical questions remain about where seed sources should be selected for current plantings and which families should be selected for a future breeding program. If we use "the best 20% of families" for Cercospora blight resistance as a standard, we select 1 or 2 families from 5 seed sources from southeast Texas, 13 seed sources from Kansas and Oklahoma, 4 from eastern Nebraska and western Iowa, and 2 other sources from South Dakota (*Figure 6*). When we select seed sources using the infection levels determined by family-mean selection, we yield to select 5 populations; 3 are from Kansas, 2 are from across border between Kansas and Oklahoma (*Figure 6*). If conducting simultaneous selection for Kabatina tip blight, we can select approximately 14 families from 11 seed sources based on a family-mean figure or 2 seed sources from eastern Oklahoma based on the seed-zone mean. Because Kabatina tip blight typically causes less severe damage to juniper than Cercospora blight in the central Great Plains (PETERSON, 1981), we suggest reducing selection intensity to minimize risks associated with limiting biological diversity of breeding population.

Does selecting the best seed sources or families for disease resistance sacrifice growth or survival characteristics? It does not, based on the results from this study; there were no significant correlations among disease variables and height growth or survival rate in eastern redcedar (*Table 3*). In Rocky Mountain juniper, survival can be increased by selecting superior genotypes for disease resistance. For example, if we select the 20% families of eastern redcedar mentioned above, the family mean of selected families for height in 1994 was 5.63 m, slightly higher than the overall family mean of 5.60 m. Similarly, the selected seed source mean (5.60 m) was the same as the overall mean (5.60 m) in eastern redcedar. Because of its higher susceptibility to diseases, lower survival, and slower height growth than eastern redcedar, Rocky Mountain juniper is not recommended for planting in eastern Nebraska. This result is similar to that of a previous study, in which VAN HAVERBEKE and KING (1990) found that both species were maladaptive as exemplified by moving eastern redcedar to the northern Great Plains or moving Rocky Mountain juniper to the central or southern Great Plains.

Although height growth may not contribute directly to disease resistance, it is a good indicator of tree vigor. With

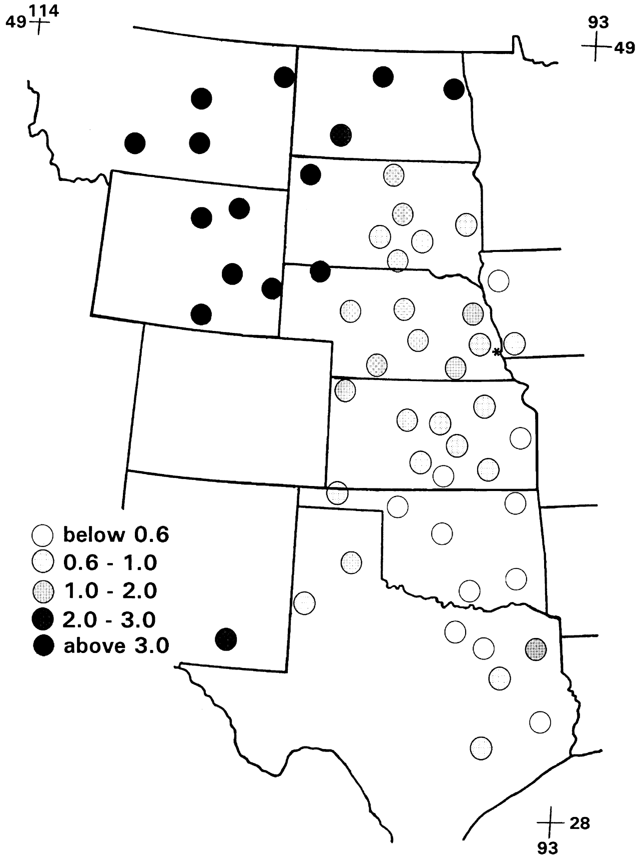


Figure 4. – Geographic variation in Cerospora blight severity in *Juniperus virginiana* and *J. scopulorum* grown in eastern Nebraska, USA. Each circle represents 1 seed-zone. The rating scales are: 0 = absent, 1 = very light (0% to 3%), 2 = light (4% to 10%), 3 = moderate (11% to 20%), 4 = moderate heavy (21% to 40%) and 5 = heavy (more than 40%). Seed-zones from southeastern New Mexico and southwestern North Dakota exhibited disease ratings of 2.0 to 3.0.

Table 2. – Estimated individual (h_i^2) and family mean (h_f^2) heritabilities and the corresponding standard errors (SE) for traits measured in eastern redcedar and Rocky Mountain juniper grown in eastern Nebraska, USA.

Trait	h_i^2 ±SE	h_f^2 ±SE
J. virginiana		
Cercospora blight (1987)	0.52 (0.03)	0.64 (0.15)
Kabatina tip blight (1987)	0.57 (0.03)	0.69 (0.15)
Survival (1989)	0.12 (0.02)	0.32 (0.16)
Survival (1994)	0.18 (0.02)	0.44 (0.15)
J. scopulorum		
Cercospora blight (1987)	0.35 (0.06)	0.59 (0.39)
Kabatina tip blight (1987)	0.00 (0.05)	0.00 (0.47)
Survival (1989)	0.05 (0.03)	0.19 (0.41)
Survival (1994)	0.48 (0.09)	0.59 (0.39)

eastern redcedar, strong age-age correlations and their genetic counterpart suggest that indirect selection for 15-year height can be performed as early as age 1, after only 1 year's growth in the field. Due to heavy mortality of Rocky Mountain juniper in 1994, height selection is only effective for growth up to 9 years.

Because of the complex nature of disease resistance (ZOBEL and TALBERT, 1984), the genetic gains calculated above may differ from real gains. Therefore, several caveats must be considered. First, data in current study was collected only from a

Table 3. – Phenotypic (lower triangle) and genetic (bolded in upper triangle) correlations among the characteristics of disease-severity and survival rate in eastern redcedar grown in eastern Nebraska, USA.

Trait[a]	CB1987	KTB1987	Surv1989	Surv1994
Cercospora blight (1987)		**0.72**	**-0.33**	**-0.21**
Kabatina tip blight (1987)	0.70**		**-0.16**	**-0.12**
Survival (1989)	0.10	0.24		**0.79**
Survival (1994)	0.13	0.26	0.93**	

*) $P < 0.05$; **) $P < 0.01$; The experiment-wise error rate for pair-wise correlations was controlled by BONFERRONI adjustment. The same as in *table 4*.

[a]) CB = Cercospora blight; KTB = Kabatina tip blight; Surv = survival.

Table 4. – Phenotypic (lower triangle) and genetic (bolded in upper triangle) correlations among the characteristics of disease-severity and survival rate in Rocky Mountain juniper grown in eastern Nebraska, USA.

Trait[a]	CB1987	KTB1987	Surv1989	Surv1994
Cercospora blight (1987)		**1.00**	**1.00**	**-0.65**
Kabatina tip blight (1987)	0.50		**-0.33**	**-0.43**
Survival (1989)	-0.31	-0.43		**-0.51**
Survival (1994)	-0.59*	-0.48	0.61*	

*) $P < 0.05$; **) $P < 0.01$

[a]) Traits codes explained in *table 3*

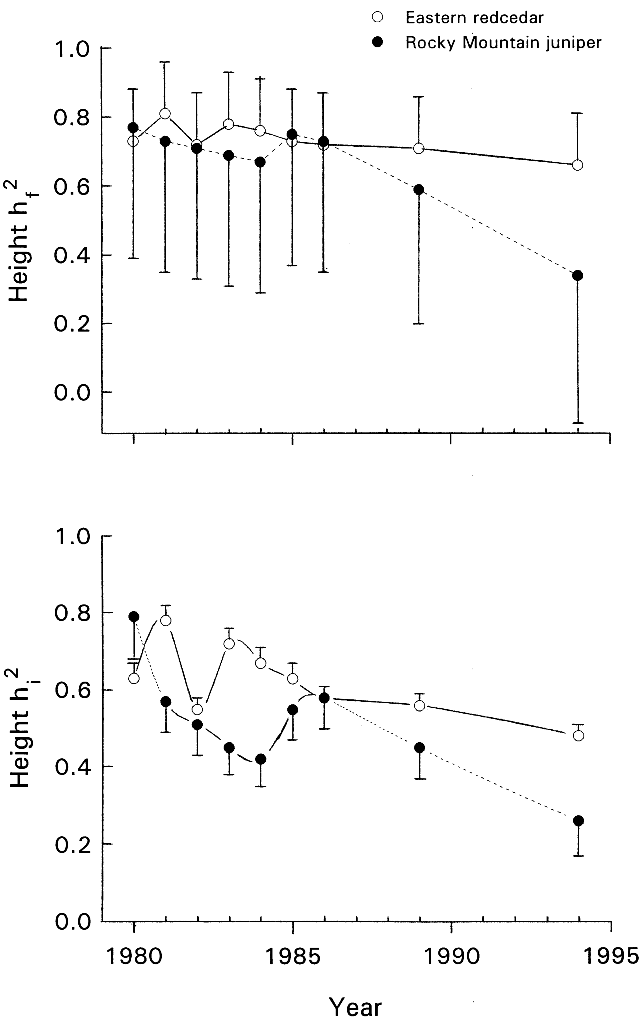


Figure 5. – Family-mean and individual heritabilities and their corresponding standard errors for height growth in *Juniperus virginiana* and *J. scopulorum* grown in eastern Nebraska, USA.

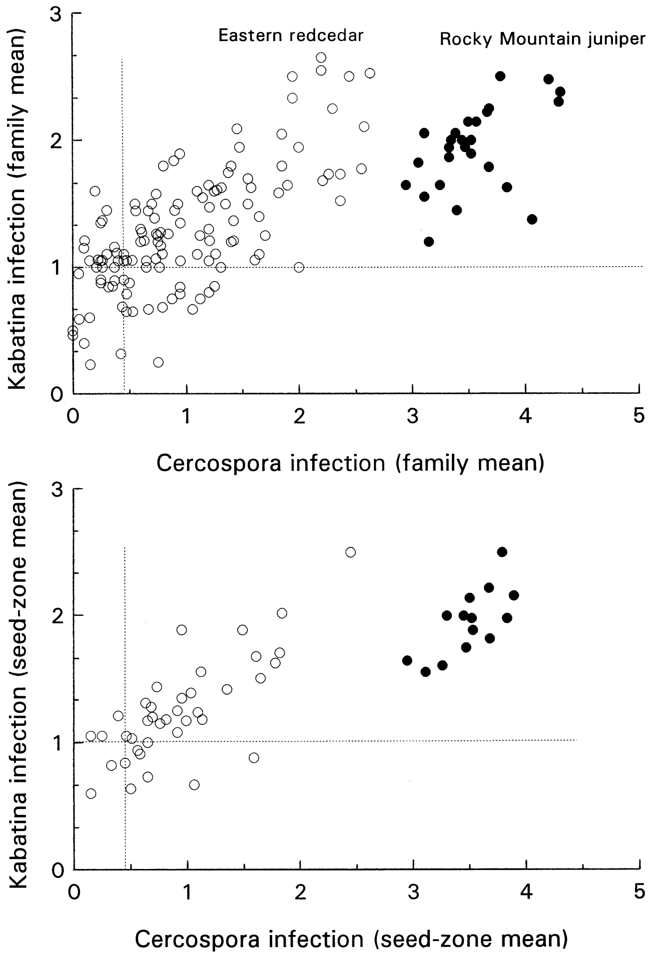


Figure 6. – The relationships between susceptibility to Cercospora blight and Kabatina tip blight based on family means (top) and seed-zone means (bottom) of *Juniperus virginiana* and *J. scopulorum* grown in eastern Nebraska, USA. Dashed lines (top) are demonstrations of selection for the top 20% of families in regard to disease resistance, while dashed lines (bottom) are adopted from dash lines (top).

single site; genetic parameters, especially heritabilities should strictly apply only to the progeny test site or similar environments. Second, our statistics would over-estimate heritabilities if applied over a wider area because we did not account for family by site interaction. Third, because of heavy mortality of Rocky Mountain juniper after 1989, the statistical estimates for this species must be used cautiously. Last, genetic variation in adaptive traits including the disease resistance are often correlated with environmental factors (REHFELDT, 1992). Because these trees were examined at only a single site, we cannot quantify the phenotypic plasticity of these trees in response to environmental changes.

Geographic patterns of genetic variation can also provide the guidelines for seed transfer in the reforestation program. Seed sources of the highest resistance to both diseases tend to occur in those environments at low elevations, low latitudes, and low longitudes within the seed collection region (*Figure 4*). In environments of the southeastern collection region of *Juniperus virginiana*, both temperature and relative humidity are much higher than in northwestern collection region. Because *P. juniperi* and *K. juniperi* apparently flourish under warm and humid conditions, trees from these habitats are likely derived from an intensive and long-term natural selection for resistance to environmentally adapted pathogens. As a result, these trees appear to effectively resist both diseases in eastern Nebraska. In contrast, trees from the northwestern collection region likely had little previous exposure to either disease before they were planted in the study site. Thus, severe disease is perhaps expected with these trees.

In summary, significant genetic variation in Cercospora blight resistance documented in this study indicates that we can improve performance of eastern redcedar by selecting resistant seed sources or families for eastern Nebraska. Because Cercospora blight was strongly correlated with Kabatina tip blight, damage by Kabatina tip blight declined tremendously when we selected genotypes for resistance to Cercospora blight. Moreover, because selection for blight resistance can be independent of height growth and survival, there is potentially no need to sacrifice growth or survival characteristics.

Acknowledgments

Authors gratefully thank MICHAEL KUHL and TED HOVLAND for the excellent technical assistance and Drs. MARY ELLEN DIX and MARK O. HARRELL for thoughtful review of an early draft. Use of trade names in this paper does not constitute endorsement by the USDA Forest Service.

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