RELATIVE GEOGRAPHIC STABILITY OF RESISTANCE TO FUSIFORM RUST OF SELECTED SLASH PINE FAMILIES

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Abstract--Open pollinated progenies of 45 slash pine families which exhibited fusiform rust resistance in previous tests and four known rust susceptible families were established in nine potentially high rust incidence tests from Mississippi to Florida and Georgia. Rust frequency (percent of trees within a family with at least one rust gall) three years after planting was used to evaluate disease resistance.

Among locations average rust frequency varied from 11 to 64% for resistant families and from 15 to 82% for susceptible families. Significant variation in rust frequency was evident at each location, but discrimination of resistance among families increased as the mean rust frequency of the test increased. Some families exhibited high rust resistance in all locations although the family x location interaction was significant. Some of the most resistant families contributed greatly to this interaction as their relative disease frequency was lowest in high rust incidence locations. Of the 49 families tested, 25 possess very desirable levels of resistance over a large geographic area.

Additional keywords: Genetic variation, *Pinus elliottii*, *Cronartium fusiforme*, pest management, epidemiology.

The incidence, distribution and impact of fusiform rust, caused by *Cronartium fusiforme* Hedgc. & Hunt ex Cumm. have increased dramatically in much of the planted slash pine ecosystem since 1960 (Schmidt et al. 1974; Griggs and Schmidt, 1977; Dinus, 1974; Powers et al., 1974). Starting in 1969, increased emphasis was placed on genetic improvement of rust resistance by the University of Florida Cooperative Forest Genetics Program.

Although there is little or no evidence of pronounced provenance variation in rust resistance in slash pine (Snyder et al. 1967), early studies (Arnold and Goddard, 1965; Barber 1961; Jewell, 1961) indicated that rust resistant individuals existed throughout the species range and that this resistance was inherited. Preliminary analyses of artificial inoculation with C. *fusiforme* (Goddard and Schmidt, 1971) and general field progeny tests (Schmidt and Goddard, 1971) of previously selected families in the program indicated that: 1) population means in rust frequency did not differ between selected families and bulk lots; 2) some select families were resistant; 3) field progeny tests with low rust incidence were not useful to differentiate resistant and susceptible families.

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Consequently all families (approximately 1200) were screened for rust resistance through both artificial and natural inoculation. Artificial inoculationswere initially conducted at Gainesville and later at the USFS screening facility at Bent Creek, N.C. Natural inoculations were accomplished by establishing special progeny tests in high rust incidence areas (Sohn, Goddard and Schmidt, 1975). Families with potential rust resistance, as judged by their performance in one or all of the inoculations described, were established in nine progeny tests specially designed to further evaluate their rust resistance.

METHODS AND MATERIALS

Using preliminary data from one or more of the previously described screening procedures, open pollinated seed of potentially resistant families and susceptible check families were sown in the nursery in April, 1974. Resulting seedlings were distributed in January, 1975 to cooperators for establishment in nine specially selected rust hazardous locations in Florida, Georgia and Mississippi (Figure 1). At each location 10-tree row plots of each family were planted in five randomized blocks.

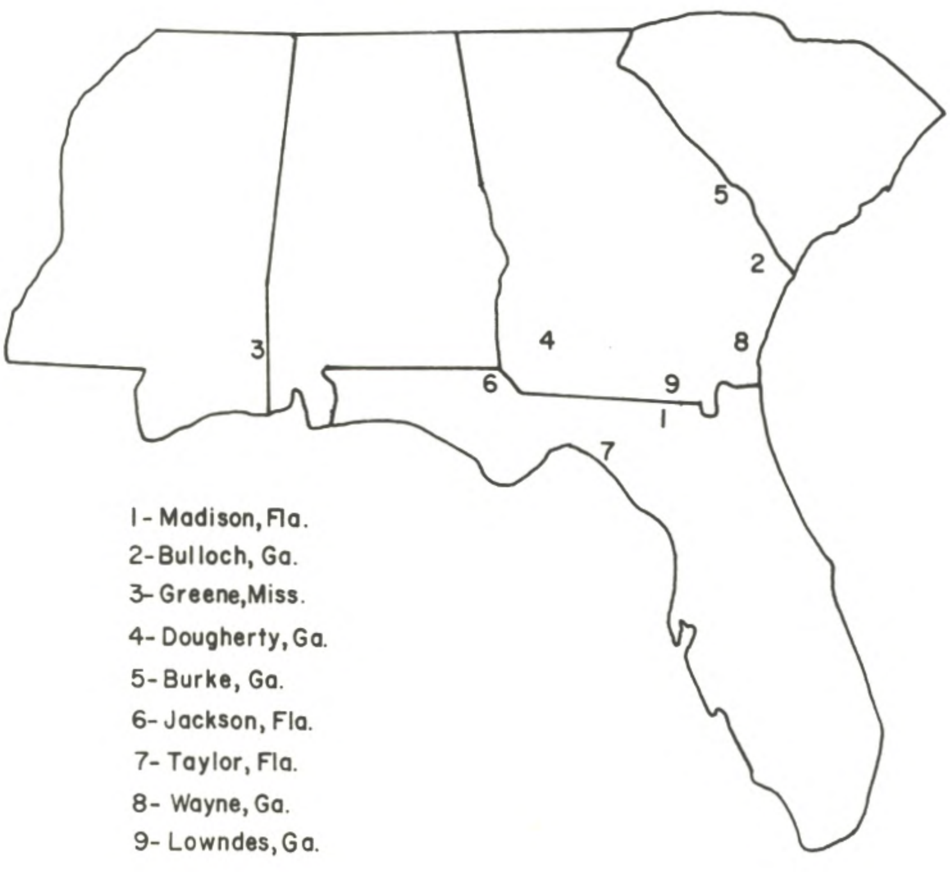

Fig. 1. Test locations on rust hazardous sites.

Rust frequency data (percent of trees in each plot with at least one rust gall) were recorded in January 1978, three years after planting. Family plot means (% rust) were analyzed since previous analyses (Sohn, 1977) indicated that these unadjusted data were sufficient to differentiate family resistance.

A separate analysis of variance was completed for each of the nine locations. Two combined analyses of variance: 1) 49 families common to three locations and 2) 24 families common to 8 locations provided estimates of the host geneotype x location interactions. In addition, regression analyses of individual family performance in the various locations were used to examine the nature of host genotype x location interactions.

RESULTS

Average rust frequencies for those families common to at least four locations are presented in Table 1. Location means varied from 11 to 64% for "resistant" families and 15 to 82% for susceptible check families. Family means varied from 19 to 56% for "resistant" families and from 44 to 58% for susceptible families. Within locations, individual family means varied from 0 to 94%.

Significant variation among families was evident at each location and differentiation of relative rust resistance among families, as indicated by the F ratio, increased as the mean rust frequency of the test (location) increased (Figure 2).

Combined analysis of 24 families common to eight locations and 49 families common to three locations (Table 2) indicated that there were significant differences among locations and families and that significant interactions between families and locations occurred.

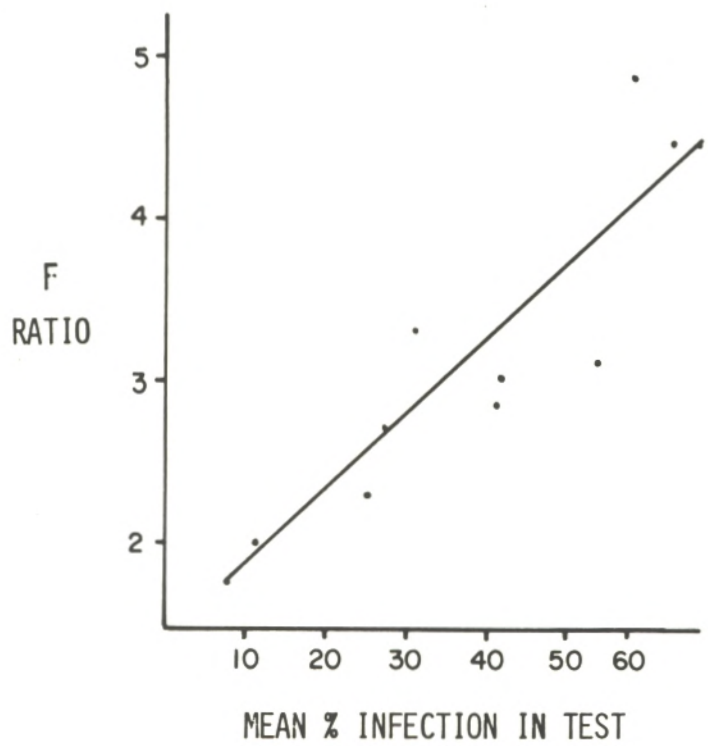

Fig. 2. The relationship between mean fusiform rust frequency and the F ratio (infection variance among families/error variance) for 9 progeny tests.

Table 1. Mean fusiform rust frequency of slash pine families established in nine locations.

Family #	Location # [1]									Mean
	1	2	3	4	5	6	7	8	9	
	%[2]									
potentially resistant										
6-56	13	0	14	38	57	25	33	15	41	26
C-129	27	25	7	27	40	29	24	10	39	25
B-210	17	20	9	42	62	29	30	26	36	30
119-56	20	22	13	40	57	40	34	30	63	35
79-56	25	45	11	31	48	38	35	36	64	37
257-56	22	23	23	49	60	47	41	21	62	39
246-55	26	27	6	48	66	39	36	25	64	37
123-61	23	17	10	64	67	33	36	14	80	38
7-56	25	26	10	61	56	45	41	24	67	39
286-56	34	41	14	55	61	36	33	22	57	39
B-617	32	33	7	69	77	31	51	26	54	42
M-724	48	30	8	72	60	47	51	29	58	45
215-56	34	26	8	55	70	34	54	12	74	41
261-56	45	21	12	64	61	37	42	25	44	39
164-58	25	15	10	70	68	61	46	28	85	45
310-56	28	39	4	56	82	60	37	29	66	45
27-58	38	26	15	58	57	42	58	36	58	43
451-55	40	32	9	69	87	60	54	46	87	54
62-56	32	32	8	74	84	56	55	56	92	54
110-56	62	40	8	72	74	65	55	26	86	54
311-56	37	43	18	77	72	56	56	24	94	53
316-56	24	6	16	29	45	19	9	14		20
28-60	20	9	4	39	31	23	27	16		21
179-55	19	19	6	43	30	23	23	20		23
16-59	25	16	14	54	35	48	18	13		28
187-57	22	28	20	50	62	58	40	22		34
186-57	48	48	24	80	94	77	40	31		55
165-57	10	13	4	39	58	29	41			28
205-55	23	16	6	51	38	39	16			27
57-57	22	29	13	38	45	41	35			32
293-55	23	22	0	59	42	37	41			32
106-56	16	18	10	64	67	39	47			37
74-61	57	28	32	55	77	50	52			50
C-135	20	2	2	33	29	29				19
70-56	19	13	4	34	41	22				22
8[illegible]-57	23	16	5	34	32	26				23
163-57	33	31	16	39	48	34				34
C-67	32	13	12	37	29	27				25
52-56	14	21	0	44	77					31
315-56	36	41	10	57	78					44
B-629	37	23	12	50						31
240-57	32	25	15	47						30
189-57	26	29	10	58						31
33-58	48	17	4	52						30
298-56	61	50	29	85						56
Mean	30	26	11	52	58	40	40	25	64	
susceptible										
262-55	33	29	9	81	92	70	69	50	78	57
121-56	57	64	12	67	84	48	65	35	90	58
30-62	49	38	29	80	84	67				58
UC	31	20	12	78	70	45	42	21	75	44
Mean	42	38	15	77	82	58	59	35	78	54
Test mean	31	27	11	54	60	42	41	26	66	40

Table 2. Analysis of variance of fusiform rust frequency of selected slash pine families.

Source of variation	49 families in 3 locations		24 families in 8 locations	
	Degrees of Freedom	Mean Square	Degrees of Freedom	Mean Square
Locations	2	57287**	7	34041**
Blocks (Locations)	12	892	32	417
Families	48	2063**	23	4172**
Loc. x Fam.	96	388*	161	383*
Fam. x Blocks (Loc.)	576	320	725	304

*, ** = Significant at 0.05 and 0.01 confidence levels, respectively.

Partitioning of the total family x location variance among the eight locations with 24 common families (Table 3) showed that this variance was not equally distributed among locations. Interaction variance appeared to be distributed in relation to neither the amount of rust nor geographic pattern.

Table 3. Fusiform rust frequency family x location interaction variance distribution among test locations.

Location	Fam. x Loc. % of Variance[1/]	Mean Rust Frequency %
Madison, FL	15.4	31
Bulloch, GA	19.9	27
Dougherty, GA	15.1	54
Burke, GA	8.3	60
Jackson, FL	9.3	42
Taylor, FL	6.2	41
Wayne, GA	13.1	26
Lowndes, GA	14.1	66

[1/] Proportions of variance per location were calculated from analysis of 24 families at 8 locations.

Partitioning the total family x location interaction variance among the 49 families common to three locations indicated that the interaction variance was not equally distributed among families. Family 79-56 accounted for 12% of the total interaction variance although, if the variance were distributed equally among families, each would have approximately 2%. Two of the susceptible check families accounted for a relatively high proportion of the interaction variance. Several resistant families showed little interaction. Family 6-56 accounted for only 0.17% of the interaction variance, or in other words, performed relatively the same at each location, always among the least infected families.

Relative consistency of performance is shown by regression of family means on test means (Fig. 3). For example, the rust frequency of family 6-56 closely paralleled average infection at each location, increasing as the test mean increased. In contrast, the rust frequency of C-129 was little lower than the test average in locations with low or moderate general infection but had substantially lower infection than average in locations with high mean frequency. C-129 was associated with a much larger portion of the family x location interaction. Very low and high contributions to interaction are illustrated by families 28-60 and 79-56. It is evident that 79-56 did not perform with high consistency in the various locations.

The 25 families with the lowest average rust frequency are listed in Table 4 along with results of regressions of the infection of these families on test means. Note that for all but two of the families, the correlation coefficient is significant, indicating that in most cases, infection of individual families is related to general incidence level at each location. Of particular interest is the slope of the regression. Slope values higher than 1.0 indicate a relative lower resistance in locations with high rust incidence. However, only three of the listed families have slopes greater than one and 14 have slopes indicating

Table 4. Regression of fusiform rust frequency per test of 25 rust resistant slash pine families on mean frequency per location.

Family	r[1]	slope[2]	Family	r	slope
C-129	.86*	.55	16-59	.74*	.74
6-56	.85*	.83	187-57	.89*	.95
B-210	.84*	.73	205-55	.85*	.82
119-56	.95*	.88	165-57	.93*	1.09
79-56	.75*	.63	57-57	.92*	.63
246-55	.98*	1.07	283-55	.92*	1.04
257-56	.94*	.88	C-135	.88*	.68
286-56	.92*	.82	70-56	.99*	.74
261-56	.83*	.81	89-57	.97*	.57
361-56	.69	.54	C-67	.77	.44
28-60	.93*	.67	163-57	.95*	.55
179-55	.88*	.58	240-57	.99*	.75
			B-629	.96*	.90

[1]Correlation coefficient. * = significant at 0.05 confidence level.

[2]Percent increase in frequency with each 1.0% increase in test mean.

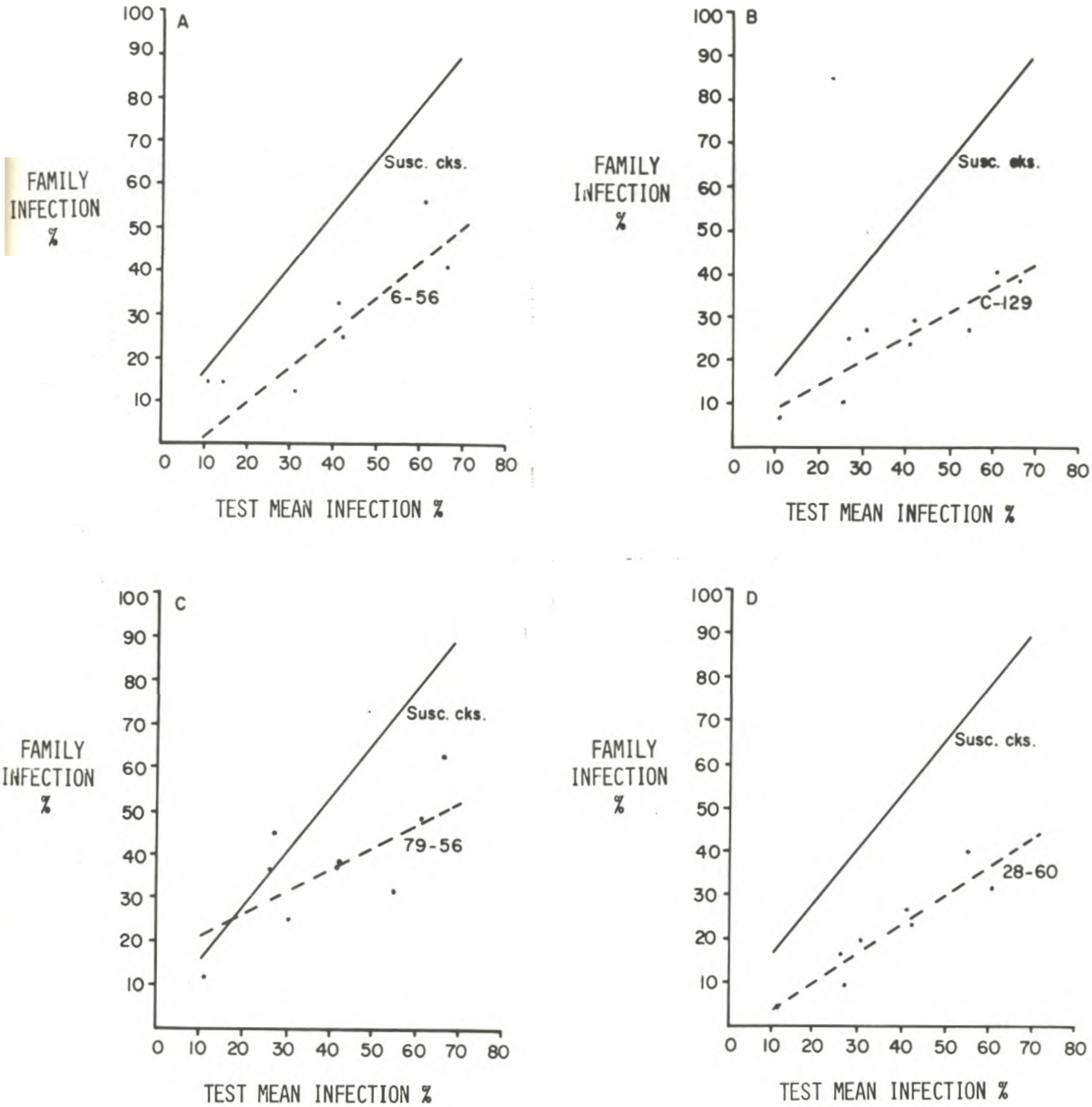

Fig. 3. Regression of individual slash pine family fusiform rust frequencies on test mean frequencies at 9 locations: A. Family frequency nearly parallel to test mean frequency. B. Increase in family frequency approximately 1/2 that of test mean increase. C. High family x location interaction. D. Low family x location interaction.

increase in frequency with increasing incidence at a rate less than 75% that of the average. Note also that the two families with lower than significant correlations with test means increase in infection at about half the normal rate.

DISCUSSION AND CONCLUSIONS

The trees established in this series of tests (with the exception of Test 3) were exposed to substantial amounts of natural fusiform rust inoculum although this is not fully evident from test means. Rust exposure is better indicated by the rust frequency of the susceptible check lots which ranged up to 92% and averaged 59%, omitting Test 3. Average frequency in families selected as resistant was consistently below that of the susceptible lots and this was particularly true for the 25 most resistant families.

However, the preliminary screening for resistance completed at the time choices were made for inclusion in these tests did not eliminate all susceptible families. At least 10 of the "resistant" families were as frequently infected as the control lots. It appears that limited simple tests will not thoroughly and reliably discriminate relative rust resistance in all cases.

With a few exceptions, the family x location interaction does not appear to be a serious problem. In fact, the interaction caused by increasing expression of resistance at higher disease incidence levels is beneficial. This type of performance shown by 14 of the families is more indicative of their relative resistance than their overall mean infection.

Data from these tests indicate little promise for fitting families with resistance to narrowly defined geographic locations. There was, for example, as much difference in relative ranking of families in Bullock and Burke County, Georgia tests which are in close geographic proximity as there was among rankings in tests more widely separated. The development of different rust resistant orchards for each specific location is not practical and the inclusion of clones in such an orchard which are resistant over a wide area seems more promising. However, the single test location in Mississippi in the western portion of the species range and the low exposure to rust inoculum in this location precludes conclusion that an East-West interaction does not exist.

Of the 45 families tested in 5 or more locations, 25 families showed very useful levels of resistance and 15 appear to be highly resistant in all eastern locations. Some families demonstrated stability of resistance over the entire geographic scope of the series of tests and, in so far as fusiform rust is concerned, would be useful for planting over the entire area. No implication of stability of resistance over time is implied by these tests. However, for the present, slash pine families such as these can provide substantial reductions in fusiform rust incidence on sites suitable for planting slash pine.

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