Genetically Controlled Resistance to Discoloration and Decay in Wounded Trees of Yellow-Poplar

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Abstract

Estimates of single tree heritability (0.49) and family heritability (0.57) indicated that discoloration and decay resistance of yellow-poplar (*Liriodendron tulipifera* L.) was under moderately strong genetic control. The large amount of tree-to-tree and family variation and the moderately high single tree heritability estimate would allow the largest genetic gains to be made from a program of within-family selection.

Wood specific gravity, wood moisture content, total tree height and diameter at breast height were tested for their degree of correlation with individual tree resistance. None were found to be a useful indirect indicator of resistance. A significantly greater amount of discoloration and decay was found from wounds made at 0.91 m up the tree bole than at 1.82 m.

Key words: Liriodendron, heritability, correlation, discoloration, decay

Zusammenfassung

Schätzwerte für die Heritabilität von Einzelbäumen (0.49) und Familien (0.57) zeigen an, daß sich Verfärbung und Fäulnisresistenz von *Liriodendron tulipifera* L. unter mäßig starker genetischer Kontrolle befinden. Das große Ausmaß der Variation zwischen Einzelbäumen und Famlien und die mäßig hohen Heritabilitäts-Schätzwerte für den Einzelbaum würden einen größtmöglichen genetischen Gewinn bei einem Selektionsprogramm innerhalb von Familien ermöglichen

Die spezifische Holzdichte, der Feuchtigkeitsgehalt des Holzes, die Gesamthöhe und der Brusthöhendurchmesser wurden auf ihren Korrelationsgrad mit der Einzelbaumresistenz hin untersucht. Keines der Merkmale konnte jedoch als indirekter Indikator für Resistenz benutzt werden. Ein signifikant größeres Ausmaß an Verfärbung und Fäulnis als bei Wunden auf 1,82 m Stammhöhe wurde bei Wunden gefunden, die in 0,91 m Stammhöhe angebracht wurden.

Introduction

Hardwood forest trees are susceptible to injury and subsequent attack by various microorganisms. In the Southeast, the most destructive disease of hardwood trees is decay. The United States Forest Service (1976) estimated that 25 percent of hardwood resource in North Carolina is cull because of decay. To the natural resource manager, basic information on the processes of discoloration and decay and possible development of resistant varieties of trees is essential for the reduction of losses in amount and monetary value of our hardwood timber resources.

Before establishing a breeding program for resistance to discoloration and decay in hardwoods, knowledge of the natural variation and the degree to which resistance is transmitted from parent to progeny is essential. Breeding for resistance to discoloration and decay could be aimed at preventing infection by microorganisms; however, this approach would be ineffective since a breeding program must be developed for each of the many different modes of infection and microorganisms involved. Therefore a practical and effective breeding program should be aimed at limiting the spread of discoloration and decay within a tree once infection occurs (Schmitt, *et al.*, 1978). Many studies have demonstrated that tree-to-tree variation exists in discoloration and decay resistance (Shigo, *et al.*, 1977); however reference to only one study could be found on the heritability of the trait (Garrett, *et al.*, 1979).

A research program in forest genetics requires a large investment of time and effort to obtain meaningful results. Therefore an accurate and efficient selection method for determining resistance to discoloration and decay in trees is very important. The task is made difficult because discoloration and decay are internal processes with few external signs or symptoms of the disease. A knowledge of correlations between different characteristics may reveal that some easily measured character is an accurate predictor of the degree of the resistance within a tree.

Of the many hardwood species found in the Southeast, yellow-poplar (*Liriodendron tulipifera* L.) is one of the most economically important timber trees. Natural populations occur from upper New York to the Great Lakes, South to Louisiana and Florida. Yellow-poplar develops into a large tree on the best sites, (over 30 meters tall with a diameter of 1 to 2 meters)with a straight trunk usually free of side branches. Since discoloration and decay causes significant degrade of the wood, a study was initiated to determine whether variation in natural resistance to decay exists in this species and could be exploited in a breeding program.

The objectives of the study are: (1) to determine the heritability of discoloration and decay resistance, (2) to establish a selection method that would yield maximum genetic gain, (3) to determine if an indirect selection procedure can be developed using other easily measured characteristics of a tree and (4) to determine if discoloration and decay resistance varies with height in the tree bole.

Materials and Methods

The yellow-poplar trees selected for study were located on the Carl Alwin Schenck Memorial Forest, near Raleigh, N.C.. They were the result of a breeding study in which

[1]) Research conducted by the senior author for partial fulfillment of requirements for a Master of Science Degree

Table 1. — Structure of Experimental Population

	Female Family Group		
	1	10	11
Family[a]	1x3	10x1	11x1
	1x4	10x5	11x3
	1x5	10x7	11x6
	1x8	10x11	11x7

a Three individuals per family.

survival and growth of full-sib, half-sib and self-pollinated progeny of the species were grown on the same site for purposes of comparison. The trees were 18 years old, with an average height of 18.5 m and an average breast-height diameter (outside bark) of 20 cm.

Experimental Procedure

In May of 1978, 36 trees of three female family groups were artificially wounded. Each female group contained four full-sib families with three individuals per family *(Table 1)*. An electric drill with a bit diameter of 1.28 cm was used to inflict wounds in the tree boles at heights of 0.91 m and 1.82 m. At each wound height a horizontal whorl of four wounds, spaced at right angles to each other and drilled with an upward slope to a depth of 10.2 cm were inflicted on all 36 trees.

In the summer of 1979, all 36 trees were felled and dissected. Two bolts of 0.6 m length enclosing the centrally located whorl of wounds were taken from each tree. Each bolt was sectioned into disks approximately 6.35 cm thick.

Determination of the Volume of Discoloration and Decay

The area of discoloration and decay was measured on each disk using a 0.25 cm² dot grid. The total area of each disk was calculated using the area formula for a circle or ellipse depending on which shape the disk most closely approximated. The percent volume of discoloration and decay was then determined using the formula:

$$\text{Volume of discoloration and decay} = \frac{\text{Area of discoloration and decay times thickness of disk}}{\text{Area of disk times thickness of disk}} \times 100$$

The disk containing the centrally located whorl of wounds was analyzed to determine the degree of wound closure.

Determination of Specific Gravity and Moisture Content

Wood specific gravity of each tree was determined by the water displacement method as used by North Carolina Tree Improvement Cooperative. The wood sample was obtained from the 0.91 m height by taking a wedge of wood from the pith outward. The best possible wedge from each tree included clear wood and some discolored wood but no decayed wood. The green volume of each sample was determined by the maximum moisture content method.

The formula used to calculate wood specific gravity is:

$$\text{S.G.} = \frac{\text{ovendry weight of wood sample}}{\text{air weight of saturated wood minus submerged weight of wood}}$$

Wood moisture content for each tree was determined from the data obtained from the wood specific gravity determination. The formula used to determine moisture content is:

$$\text{M.C.} = 100 \times \frac{\text{air weight of wood minus ovendry weight of wood}}{\text{ovendry weight of wood}}$$

Estimation of Heritability

Family and individual heritability estimates were calculated on a half-sib basis using the formulae presented by Wright (1976) but modified to meet the sampling procedure of this study. The estimates of heritability are biased downward due to the relatedness of some families to each other (personal communication. — Dr. G. Namkoong)[1]). Narrow sense heritability (h^2) was estimated as the ratio of additive genetic variance to total phenotypic variance (Falconer, 1960). Single tree heritability was estimated as:

$$h^2_I = \frac{4V_{Fe}}{V_e + V_{I(Fe)} + V_{m(Fe)} + V_{Fe}}$$

where V_{Fe} = variance attributed to female family groups

$V_{m(Fe)}$ = variance attributed to males within female family groups

$V_{I(Fe)}$ = variance attributed to individual trees

V_e = variance attributed to error.

Family heritability was estimated as:

$$h^2_1 = \frac{V_{Fe}}{V_{e/HIM} + V_{I/IM} + V_{M(Fe)/M} + V_{Fe}}$$

where: I = number of individual trees per family

M = number of males within a female family group

Fe = number of female family groups

H = number of wound heights for tree

Results and Discussion

Variation in resistance to discoloration and decay among families and among trees within the same family were highly significant *(Table 2)*. Variation among individual trees accounted for 55 percent of the total phenotypic variation. Family means *(Figure 1)* exhibit a wide range of values. The ability of an individual tree to resist discoloration can be seen in *Figure 2*. Tree 25 from family 1×3 has weak resistance which is shown by extensive

Table 2. — One-way analysis of variance for discoloration and decay resistance in 18 year old *L. tulipifera* trees.

Source of Variation	DF	Mean Square[a]	Variance Components	Percent of Variation
Family	11	0.13482**	0.02128	35.00
female	2	0.25228NS	0.00598	
male(female)	9	0.10872**	0.00665	
Height	1	0.06596*	0.00162	3.00
Height*Family	11	0.00712NS	0.00150	3.00
Tree(Family)	24	0.06878**	0.03308	55.00
Height*Tree in family	24	0.00262	0.00262	4.00

a
* = Significant at 5% level
** = Significant at 1% level
NS = Not significant

[1]) Dr. G. Namkoong, Principal Plant Geneticist, Southern Forest Experiment Station, North Carolina State University, Raleigh, N. C.

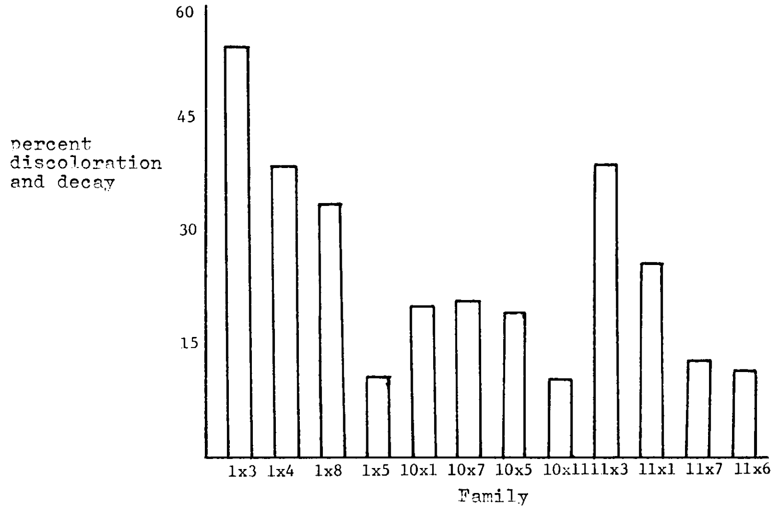
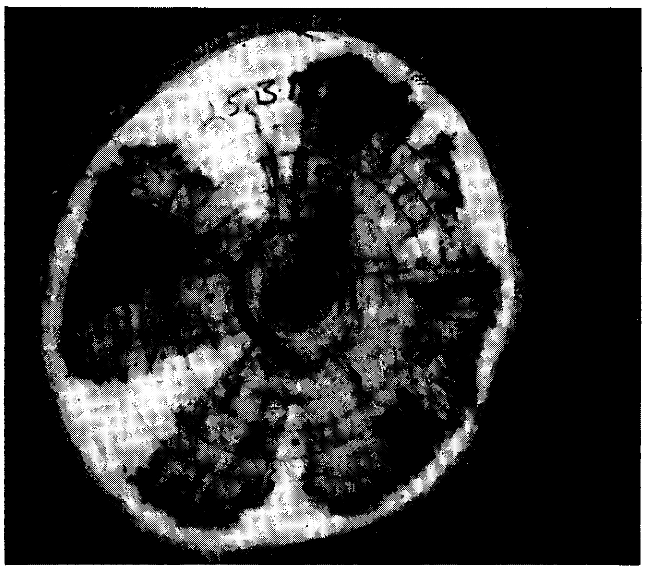
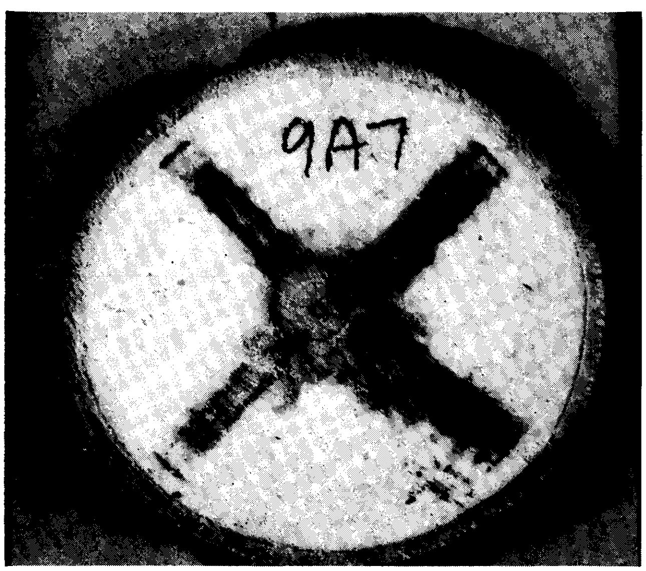


Figure 1. — Variation in resistance to discoloration and decay among families.



Tree 25 weakly resistant to spread of discoloration and decay.



Tree 9 strongly resistant to spread of discoloration and decay.

Figure 2. — Variation in resistance to discoloration and decay among individual trees.

discoloration spreading from the wounded area. Tree 9 from family 10×1 is strongly resistant, a small amount of discoloration is present only near the wound area. Male parent 3 when crossed with female parents 1 and 11 *(Figure 1)* contained a larger amount of discoloration and decay than any other cross. The majority of matings from female parent 1 are weakly resistant to discoloration and decay. In contrast all matings of female parent 10 are strongly resistant.

The estimates of heritability were 0.49 for single trees and 0.57 for families. These values show that discoloration and decay resistance is under moderately strong genetic control. These heritability estimates are consistent with the findings of GARRET, *et al.*, (1979) that discoloration and decay resistance is under strong genetic control in sweetgum (*Liquidambar stryricaiflua* L.) and eastern cottonwood (*Populus deltoides* BARTR.).

The large amount of variation among individual trees and families plus the high heritability estimates indicate that a program of within-family selection would yield substantial genetic gains. Within-family selection would allow the best individuals of the best families to be included in a breeding program.

Since discoloration and decay is an internal process there is only a limited number of methods that can be used to determine the degree of resistance. The method used in this study was effective in determining which trees possessed resistance; however, the method was also destructive since the tree had to be harvested to yield essential data. To determine whether, and if so to what extent, other characteristics are correlated with resistance to discoloration and decay of individual trees the following traits were investigated: (1) total height of tree, (2) diameter at breast height (DBH) of tree, (3) wood specific gravity and moisture content and (4) wound closure.

The height and diameter of individual trees were both significantly negatively correlated *(Table 3)* with discoloration and decay resistance. The statistical significance of these correlations does not imply biologic importance since the R^2 statistic of the correlations of height and diameter with resistance account for only a small portion of the total variation observed. If height and diameter are measures of tree vigor, then there is some evidence that vigor of

Table 3 .— Correlations (r) of selected characteristics with amount of discoloration and decay in individual trees.

	Characteristics[a]			
	M.C.	S.G.	T.H.	Dia.
Amount of Discoloration and Decay	0.060[NS] (0.004)[b]	-0.213[NS] (0.045)	-0.382* (0.145)	-0.390* (0.152)

where M.C. = Wood Moisture Content
S.G. = Wood Specific Gravity
T.H. = Total height of tree
Dia. = Diameter of tree

[a] * = Significant at 5% level
N.S. = Not significant

[b] Coefficient of Determination in parenthesis

Table 4. — Correlation (r) of wound closure with percent discoloration and decay of individual 18 year old *L. tulipifera* trees.

	Wound Closure[a]					
	Height B[b]			Height A		
	open	partial	closed	open	partial	closed
Percent* Disc. and Decay	-0.350[NS c]	0.094[NS]	0.264[NS]	-0.306[NS]	0.137[NS]	0.231[NS]

[a] open = wound did not heal
partial = incomplete callus formation did not close wound
closed = callus production completely closed wound hole

[b] wound height B is at 0.91m level
wound height A is at 1.82m level

[c] NS = not significant

* Percent Discoloration and Decay

the tree is related to discoloration and decay resistance. However, GARRETT, *et al.*, (1976) suggested that the ratio of tree growth and amount of discoloration did not appear correlated.

The degree of wound closure was not correlated *(Table 4)* with resistance. This result is consistent with the finding of SHIGO, *et al.*, (1977), that wound closure and resistance to discoloration and decay are two separate phenomena. The variation in extent of wound closure from tree-to-tree suggests that wound closure is under genetic control. Wound closure is under strong genetic control in sweetgum and eastern cottonwood (GARRETT, *et al.*, 1979).

Wood specific gravity and moisture content were not significantly correlated *(Table 3)* with resistance. Although anatomical features of the wood were not studied, ECKSTEIN, *et al.*, (1979) found that vessel size and number may be an indicator of a tree's ability to resist development of discoloration and decay.

There is a significant difference in the amount of discoloration between heights *(Table 2)* in the tree bole. Discoloration in the upper wound level was 27 percent; 21 percent of the total area was discolored in the lower wound level. Although only two heights were sampled, it appears discoloration and decay resistance decreases from bottom to top. A similar pattern of decreasing resistance with increasing height was found in black locust *(Robinia pseudoacacia* L.) (SCHEFFER and HOPP, 1944) and other species (SCHEFFER and COWLING, 1966).

Conclusion

Single tree heritability (0.49) and family heritability (0.57) for discoloration and decay resistance were moderately high. The moderately high single tree heritability and the large amount of tree-to-tree variation would allow the largest genetic gains to be made from a program of within-family selection where the best trees of the best families are designated for inclusion in a breeding program.

The processes of discoloration and decay occur internally with few external indications of the extent of spread within a tree. Since discoloration and decay resistant trees are difficult to measure, it is desirable to have a knowledge of how other characteristics are correlated with resistance. Vigor of the trees are measured by height and diameter, was the best indicator measured; larger trees were less affected by discoloration and decay than smaller trees.

References

ECKSTEIN, D., W. LIESE and A. L. SHIGO: Relationship of wood structure to compartmentalization of discolored wood in hybrid poplar. Can. J. For. Res. 9: 205—210 (1979). — FALCONER, D. S.: Introduction to Quantitative Genetics. The Ronald Press Company. New York. 365 pp. (1960). — GARRETT, P. W., A. L. SHIGO and J. CARTER: Variation in diameter of central columns of discoloration in six poplar clones. Can. J. For. Res. 6: 475—477 (1976). — GARRETT, P. W., W. K. RANDALL, A. L. SHIGO and W. C. SHORTLE: Inheritance of compartmentalization of wounds in sweetgum *(Liquidambar styraciflua* L.) and eastern cottonwood *(Populus deltoides* BARTR.). U. S. D. A. For. Serv. Res. Paper NE-443. (1979). — SCHEFFER, T. C. and H. HOPP: Decay resistance of black locust heartwood. U. S. D. A. Tech. Bull. 984. (1944). — SCHEFFER, T. C. and E. B. COWLING: Natural resistance of wood to microbial deterioration. Ann. Rev. Phytopathology 4: 147—170 (1966). — SCHMITT, D., P. W. GARRET and A. L. SHIGO: Decay resistant hardwoods? You bet! Northern Logger and Timber Processor 27 (3): 20—21, 30—31 (1978). — SHIGO, A. L., W. SHORTLE and P. W. GARRETT: Genetic control suggested in compartmentalization of discolored wood associated with tree wounds. For. Sci. 23: 179—182 (1977). — U. S. D. A. Forest Service: Incidence and impact of damage to the timber resource in North Carolina. U. S. D. A. For. Serv. Southeast Area State Priv. For. Rep. 77-1-5 14 pp. (1976). — WRIGHT, S. W.: Introduction to Forest Genetics. Academic Press, New York. 463 pp. 1976).