VARIATION IN HEARTWOOD AND SAPWOOD PROPERTIES AMONG 10-YEAR-OLD BLACK WALNUT TREES

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ABSTRACT

Ten-year-old black walnut trees from a half-sib progeny test were sampled for a study of heartwood and sapwood specific gravity in relation to color properties and total tree height. Average wood specific gravity for all 320 samples was 0.47. Sapwood specific gravity averaged 5 percent lower than heartwood specific gravity (0.46 and 0.48, respectively). Heritability of wood specific gravity was 0.35 for heartwood and 0.54 for sapwood, the lower heartwood value suggesting a greater environmental influence on heartwood formation. Heartwood specific gravity was negatively correlated with heartwood color and was positively correlated with total height. Sapwood specific gravity was not correlated with total height.

Keywords: Specific gravity, percent luminance, percent heartwood, narrow-sense heritability, *Juglans nigra* L.

INTRODUCTION

Specific gravity and heartwood color are important parameters of black walnut (*Juglans nigra* L.) wood quality. Specific gravity is an indicator of machining and mechanical properties (Schumann 1973), and color is important to producers of veneer and other products from black walnut wood (Phelps and McGinnes 1983).

Variability in wood properties is both a benefit to, and a problem for, the wood industry. For example, slight differences in heartwood color give the wood much of its character. However, excessive differences in wood color and other wood properties present problems to the user who prepares and tries to sell the material. Variability in wood is due to three naturally occurring influences: age or pith-to-bark variation, environmental influences, and genetic factors (Panshin and deZeeuw 1980). Several studies have examined variation in black walnut heartwood color due to geographic origin of trees and site (Moslemi 1967; Nelson et al. 1969; Phelps and McGinnes 1983). Rink (1987) studied the influence of genetic factors on black walnut heartwood color. Schumann (1973) did not observe any statistically significant differences in specific gravity associated with locality, site, or growth conditions. However, most of the above studies (except for Rink 1987) were conducted on wood samples from older, mature trees. Much needs to be learned about the properties of smaller and younger trees, as the use of this resource grows. The relative importance of certain wood properties will vary depending

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on the final product. However, such properties as specific gravity (as it influences processing) and appearance (e.g., color) will continue to be major determinants of the quality of high-value hardwoods.

Unfortunately, relationships among the properties of black walnut wood are not well understood even in mature trees. For example, Schumann (1973) found no correlation between specific gravity and total TAPPI extractive content, but Hiller et al. (1972) determined that specific gravity of fibrous tissue and extractive content were both related to color.

The present study quantified statistical relations primarily between heartwood and sapwood specific gravity, and estimated their heritability in 10-year-old black walnut trees in a half-sib progeny test for which wood color properties and tree height had previously been reported (Rink 1987).

METHODS

Trees used for this study were thinned from a 10-year-old black walnut half-sib progeny test in early 1983. Rink (1984) describes the establishment of the plantation and the site characteristics. When the trees were harvested, they averaged about 7 meters in height in some blocks and 3 meters in height in other blocks.

The progeny test was thinned by removing three of five trees in row-plots within each of the 10 blocks. The two remaining trees in the plot were the tallest, most vigorous, and/or best formed trees. Disks, 3 to 5 cm in cross section, were removed from a height of 30 cm above the ground level. The disks were collected from the six blocks with the largest trees; trees in the remaining four blocks were generally not large enough in diameter to contain sufficient quantities of heartwood and were not sampled.

Wood disks were evaluated for the following traits:

1. *Inside bark diameter*: This was determined by averaging two diameter measurements taken at the widest point and at a plane perpendicular to it. Branch scars were avoided in these measurements.

2. *Heartwood width*: This was determined by measuring the width along the same planes as the diameter measurements. Heartwood area was determined as the area of a circle ($A = \frac{1}{4}D^2$) using the mean heartwood diameter. The difference between total disk cross-sectional area and heartwood area was defined as sapwood area.

3. *Heartwood color*: This was determined after cutting disks along the longest axis, slightly off center to avoid the pith. This radial surface was lightly sanded and applied to a reflectance attachment on a Bausch and Lomb[1] Model 20 spectrophotometer to measure reflectance at 30-nm intervals in the visible spectrum (400 to 700 nm). The reflectance attachment was equipped with a "Type C" light source, representing average daylight (Moslemi 1967). Procedures outlined by Phelps and McGinnes (1983) were used to calculate luminance (lightness or brightness), dominant wavelength (hue), and purity (light saturation) for each disk.

4. *Heartwood and sapwood specific gravity*: The maximum moisture content method of Smith (1954) was used to determine the specific gravity of small

[1] Mention of trade names does not constitute endorsement of the products by USDA Forest Service.

TABLE 1. *Averages and ranges for properties of black walnut heartwood and sapwood and tree height.*

Characteristic*	Tree average	Range among trees
Height at age 10 (m)	4.6	2.2 to 8.2
Heartwood		
% Heartwood area	14.0	3.9 to 57.3
% Luminance	22.2	12.1 to 35.5
Dominant wavelength (nm)	591.4	583.5 to 601.6
Specific gravity	0.48	0.38 to 0.56
Sapwood		
Specific gravity	0.46	0.31 to 0.57

* % Heartwood area, % Luminance, and Dominant wavelength from Rink (1987).

unextracted samples (approximately 40 × 10 × 10 mm) of heartwood and sapwood cut from each disk. The samples were soaked in water, under vacuum for one week, to insure maximum moisture content weight.

Data were analyzed by analysis of variance (ANOVA) and Pearson's correlation analysis. The format of the ANOVA was a Type II General Linear Model, which used a two-way linear model (blocks and families) to compute the results on an individual tree basis (Barr et al. 1976). The method involved adjusting the sums of squares for blocks and families to compensate for unequal numbers of observations. Both effects in the model were assumed to be random. Although this method allowed for unbiased tests for these effects, data imbalance precluded unbiased tests of the block × family interaction.

Approximate narrow-sense heritabilities for each family were calculated using the method of Kung and Bey (1977) where $h^2 = (1 - 1/F)$. This method is used when the value of F (the calculated Fisher statistic used for testing significance) is found to be statistically significant among half-sib families. Narrow-sense heritability estimates that portion of inheritance of a metric trait which is predictably responsive to selection.

RESULTS AND DISCUSSION

Average values of total tree height, heartwood and sapwood specific gravity, and of heartwood color and area are presented in Table 1. The trees averaged 4.6 m in height and ranged from 2.2 to 8.2 m after 10 years of growth. The specific gravity of the disks averaged 0.47 for heartwood and sapwood, somewhat lower than the specific gravity value of 0.56 usually reported for black walnut (Panshin and deZeeuw 1980). The lower specific gravity in our analysis probably is a result of the young age of the trees.

Values for heartwood specific gravity averaged 5 percent greater than those for sapwood, although in a few trees the sapwood was slightly denser than the corresponding heartwood. Greater specific gravity values for heartwood may have resulted from accumulations of polyphenols and other extractives in the heartwood not normally found in sapwood (Hiller et al. 1972). Variation in walnut heartwood color and cross-sectional area has been reported before (Rink 1987).

Analyses of variance indicated significant differences for both block and family effects on heartwood and sapwood specific gravity (Table 2). Approximate narrow-sense heritabilities were 0.35 for heartwood and 0.54 for sapwood specific gravity,

TABLE 2. *Probabilities of obtaining larger* F-*values in analyses of variance and narrow-sense heritabilities for hardwood and sapwood specific gravity.*

Source of variation	Specific gravity Heartwood	Sapwood
Block	1.94×10^{-4}	1.27×10^{-3}
Half-sib family	0.02	2.30×10^{-4}
Error	—	—
Heritability	0.35	0.54

respectively. These heritabilities are similar to those obtained for wood specific gravity of *Platanus occidentalis* and other hardwood species (Dr. S. B. Land, Jr. personal communication, 26 October 1987).

Genetic control was greater over sapwood than over heartwood specific gravity, presumably reflecting a greater environmental effect over heartwood specific gravity (Table 2). Increased expression of environmental control reflected in lower heritability of heartwood specific gravity is consistent with the association between heartwood, formation of polyphenols, and ethylene production. Ethylene production, linked to the formation of polyphenols in heartwood, is thought to increase with greater environmental stress (Hillis 1975; Phelps and McGinnes 1983). Furthermore, no indication of genetic control over ethylene production has been observed (Nelson et al. 1981). Thus, environmental effects may mask the heritability of specific gravity, and a heritability of 0.35 for heartwood specific gravity may be higher than should be expected. The darkest heartwood (i.e., heartwood with the lowest percent luminance) had the greatest specific gravity, resulting in a statistically significant negative correlation ($r = -0.26$, $P < 0.01$). A similar correlation ($r = -0.20$, $P < 0.01$) was found between sapwood specific gravity and percent luminance. Heartwood color, expressed as percent luminance, has been shown to be significantly related to wood density and extractive content (Hiller et al. 1972).

Similarly, although the correlation between heartwood and sapwood specific gravity is significant ($r = 0.28$, $P < 0.01$), the magnitude of the correlation coefficient is lower than might be intuitively expected (Table 3). Presumably the correlation would be higher if it were not masked by environmental effects as-

TABLE 3. *Pearson's correlations and the probabilities* (P) *of obtaining greater values by chance among selected wood properties.*

	HT	HWA	LY	DWL	HSG	SSG
Total height at age 10 (HT)		−0.15	0.33	−0.09	0.17	−0.07
P		0.01	0.01	0.10	0.01	0.20
% Heartwood area (HWA)			−0.04	0.07	0.04	−0.08
P			0.50	0.17	0.51	0.17
% Luminance (LY)				−0.43	−0.26	−0.20
P				0.01	0.01	0.01
Dominant wavelength (DWL)					0.17	0.10
P					0.01	0.07
Heartwood specific gravity (HSG)						0.28
P						0.01
Sapwood specific gravity (SSG)						

sociated with heartwood formation; black walnut is known to be extremely sensitive to microenvironmental site differences (Rink and Clausen, in press). Perhaps this site sensitivity is also expressed in variation of heartwood parameters. In this study, variation in heartwood specific gravity significantly exceeded variation in sapwood specific gravity according to a matched-pair t-test of coefficients of variation of heartwood and sapwood specific gravity. Alternatively, use of extractive-free samples may have improved the correlation.

Wood specific gravity is one of the selection traits associated with many tree improvement programs whose primary objective is increased volume or biomass productivity. Such improvement programs deal primarily with coniferous tree species and aim at increasing pulp or lumber production. Specific gravity is important for both pulp and lumber because of its high positive correlation with pulp-yield and strength properties. When veneer is the desired end-product, as it would be with black walnut, specific gravity has an important impact on machining properties. Unfortunately, no simple noninjurious method is available for sampling heartwood specific gravity. Predicting heartwood specific gravity on the basis of sapwood specific gravity is not possible because of the low phenotypic correlation between them. However, black walnut heartwood specific gravity was positively correlated with 10-year total height. It is encouraging that heartwood specific gravity is not sacrificed when selecting walnut for tree height, the most common selection criterion in improvement programs. The existence of such a relation in older trees should be verified by additional research.

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