

RELATIONSHIPS IN BLACK WALNUT HEARTWOOD BETWEEN COLOR AND OTHER PHYSICAL AND ANATOMICAL CHARACTERISTICS

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ABSTRACT

Relationships in black walnut heartwood between color and specific gravity, extractive content, and anatomical characteristics were explored. Per cent luminance, color brightness, was significantly related to extractive content and to the combination of extractive content and some of the measures of wood density. It was found that trees from Indiana compared with those from Missouri differed significantly in the following wood characteristics: lower extractive content, higher proportion of fibrous tissue with thinner cell walls, and smaller vessel lumens.²

Black walnut (*Juglans nigra* L.) is one of the most valuable cabinet woods because of pronounced color, beautiful wood figure, and other desirable physical properties as well as good machining and finishing properties.

The preference of some buyers for black walnut trees from particular areas within certain states indicates that environmental factors may affect the quality of wood. For this reason Nelson et al. (1969) investigated by spectrophotometry the color of black walnut heartwood from Indiana and Missouri, states from which the black walnut is, respectively, high and low on a buyer's preference list. They investigated trees that represent two site and two growth-rate classes within each state. Their results suggest that soil properties affect wood color—defined by luminance (lightness or brightness), dominant wavelength (directly related to hue), and purity (richness of hue). Furthermore, they found a statistically significant difference in the luminance of the wood from the two states; the wood of the Indiana trees showed a higher percentage of luminance.

This study is based on the wood specimens used by Nelson et al. (1969). The objective here was to determine whether the differences in color observed by Nelson et al. could be related to specific gravity, structure, or extractive content of the wood. Because Nelson's sampling procedure included site and growth-rate class for the two states, a second objective was to determine whether these factors affected physical and anatomical characteristics of black walnut. Little appears in the literature on these effects (Boyce et al. 1970; Funk 1966). However, the inverse relationship of shrinkage to extractive content is well known. The following structural features were examined: percentage of area occupied by vessel lumens, and normal and gelatinous fibers; the average number and size of vessels per square millimeter of wood cross-sectional surface; and the cross-sectional dimensions of the fibers expressed as number per square millimeter and average cell-wall thickness.

SELECTION OF SAMPLE MATERIAL

The procedures for selecting sample trees, boards, and test specimens were described by Nelson et al. (1969), and will be briefly summarized.

A system of classification was used for trees from each state, Indiana and Missouri, to represent fast- and slow-growth rate

¹ Maintained at Madison, Wis. 53705, in cooperation with the University of Wisconsin.

² Mention of specific instruments or trade names is made for identification purposes only, and does not imply any endorsement by the U. S. Department of Agriculture.

TABLE 1. *Bolt characteristics for black walnut trees from Indiana and Missouri^a*

Site class	Growth class	Diameter inside bark (inches)	Heartwood diameter (inches)	Sapwood width ^b (inches)	Ring count (number)	Rings per inch (number)
INDIANA						
Good	Fast	13.0	10.6	2.4	45	7.2
	Slow	10.9	9.4	1.5	70	12.9
Poor	Fast	15.2	12.2	2.6	52	7.2
	Slow	12.0	10.4	1.6	63	10.5
MISSOURI						
Good	Fast	13.7	12.0	1.7	55	8.3
	Slow	11.6	9.8	1.8	62	10.6
Poor	Fast	12.7	11.1	1.6	57	9.1
	Slow	11.0	9.5	1.5	58	10.6

^a Each value is the average of four trees.^b Measured on the diameter.

on typically good and poor sites for black walnut. Personnel of the North Central Forest Experiment Station selected four trees at random within each site and each growth rate, or subclass, to provide a total of 16 trees from each state. The high value of walnut logs precluded the use of increment borers; consequently, growth-rate classification was based on external characteristics of the trees.

Between 8 and 13 feet above ground, a 5-foot-long bolt was cut from each tree, and the age of the tree (bolt) and the diameter-growth rate were determined on both ends of each bolt. Values of bolt characteristics, each the average for four trees by site and growth subclass, are given in Table 1. Each bolt was flat-sawed into boards 1 inch thick by 4 inches wide; eight of the boards were selected at random to represent each bolt. One 6-inch-long piece was randomly selected from each board, and one 1- by $\frac{3}{4}$ - by $\frac{5}{16}$ -inch test specimen was randomly selected from each face of each piece. Thus 16 test specimens were obtained from each tree: they were used for determining color and wood structure. End-matched pieces of the same dimensions were used to determine specific gravity and extractive content.

After the color determinations were completed, the specimens were saturated in water. Three microtomed cross-sectional

surfaces were prepared for each specimen: two, one at each end, and a third, at the center. From 10 randomly selected fields per surface examined, percentage of area occupied by normal and gelatinous fibrous tissue was determined. A Zeiss Integrating Eyepiece (Henning 1958) that uses a test-point sampling procedure was used for the determinations. Measurements were at a magnification of 110 $\times$, which was too low for segregating fibers from axial and ray parenchyma by the test-point procedure. Therefore, either "normal" or "gelatinous" fibrous tissue refers to combinations of fibers and parenchyma. To discriminate between normal and gelatinous fibrous tissue a procedure described by Aufsess et al. (1968) was used that employs fluorescent light and acridin-orange stain. In addition, both the number of vessel lumens per calibrated field and the number of fibers per calibrated distance between two points of the eyepiece were counted. For counting fibers, a higher magnification was used than for counting the lumens, and the tissue traversed contained only fibers, whether they were gelatinous or normal.

The amount of extractives based on the matched specific gravity specimens was determined by the TAPPI standard method (1959) and expressed as a percentage of the extractive-free weight of the wood. Extractions were on solid wood pieces; data

for extractives content are also based on these pieces. Specific gravity was determined from the extractive-free oven-dry weight of the specimen, and volume was computed from the measured water-saturated dimensions of the specimen.

The average cell-wall thickness of fibrous tissue was calculated according to Smith (1967), in which the model is a cell circular in cross section with a water-saturated wall density of 1.0 g/cc³. The formula used in the calculation is:

$$W = (D/2)[1 - \sqrt{1 - (4/\pi)G_m}],$$

where W is the average single wall thickness, D , the average fiber diameter; and G_m , the specific gravity of a fibrous tissue on an extractive-free green volume basis. Thus the estimate of W incorporates a slight discrepancy from the assumption that the fibrous tissue is entirely fibers of a given average diameter.

The values for G_m are obtained by:

$$G_m = G/(1 - x/100),$$

where G is the original specific gravity of the wood and x is the percentage of volume occupied by vessel lumens. This is on the assumption that per cent vessel lumen volume is numerically equivalent to per cent vessel lumen area.

Average vessel diameter was calculated from per cent vessel lumen area per calibrated field and the number of vessels counted in that field.

All of the data were averaged to provide single representative values for each board and for each bolt (tree).

RESULTS AND DISCUSSION

Single and multiple linear regression analyses were used to determine the relationships between color indices (dominant wavelength, per cent luminance, and per cent purity) and anatomical features, specific gravity, and extractive content of the heartwood. The independent variables used in the analyses were the following:

- X_1 per cent normal fibrous tissue
- X_2 per cent gelatinous fibrous tissue

- X_3 number of vessels per square millimeter
- X_4 average vessel lumen area (mm²)
- X_5 average fiber diameter (microns)
- X_6 average wall thickness of fibrous tissue (microns)
- X_7 extractive-free specific gravity of wood
- X_8 specific gravity of fibrous tissue
- X_9 per cent extractives
- X_{10} ring width

It should be noted that per cent of vessels was not included as an independent variable because it is simply a linear function of variables X_1 and X_2 (per cent vessels = 100 - X_1 - X_2).

Separate analyses were made for each of the following dependent variables:

- Y_1 dominant wavelength
- Y_2 per cent purity
- Y_3 per cent luminance

Results of analyses based on values for individual test specimens and on average values for bolts were essentially the same. Dominant wavelength (Y_1) was not significantly related to any single independent variable or to any combination of these variables. Similarly, no significant relationships were found between per cent purity (Y_2) and the independent variables. However, there was some suggestion that both dependent variables Y_1 and Y_2 might be related to some of the measures of wood density. Thus, for wavelength (Y_1), wood specific gravity (X_7), number of vessels per mm² (X_3), specific gravity of fibrous tissue (X_8), and average vessel lumen area (X_4) were involved in the "best" regressions at each level of fitting. For per cent purity (Y_2), average vessel lumen area (X_4), and specific gravity of fibrous tissue (X_8) were almost as good as number of vessel lumens per mm² (X_3) and wood specific gravity (X_7). Since either of these combinations is close to a significant relationship, it is possible that some sort of curvilinear function of wood density would be reasonably related to per cent purity (Y_2). However, no attempt was made to explore these relationships further.

TABLE 2. Mean values of wood characteristics of black walnut by state of origin and site and growth-rate class

Source of materials	Vessels (%)	Gelatinous fibrous tissue (%)	Fibers ^a per mm ² (number)	Vessels per mm ² (number)	Average vessel lumen area (mm ²)	Single fiber wall thickness ^b (μ)	Specific gravity (extractive-free)	Extractive content (%)	Color luminance ^c (%)
State:									
Indiana	16.5	15.9	2,869	5.25	0.032	4.95	0.506	5.3	25.999
Missouri	19.4	12.0	2,697	5.54	0.036	5.33	0.500	6.6	24.573
Difference	2.9*	3.9	172	0.29	0.004**	0.38*	0.006	1.3*	1.426**
Site class:									
Good	17.7	17.2	2,821	5.53	0.033	5.21	0.511	5.5	25.797
Poor	18.1	10.8	2,744	5.27	0.035	5.07	0.495	6.5	24.775
Difference	0.4	6.4	77	0.26	0.002	0.14	0.016	1.0	1.022
Growth-rate class:									
Fast	17.3	11.5	2,778	5.26	0.034	5.13	0.505	6.2	25.539
Slow	18.5	16.4	2,787	5.54	0.034	5.15	0.501	5.7	25.033
Difference	1.2	4.9**	9	0.28	0.000	0.02	0.004	0.5	0.506

^a Based on actual fibers (excluding vessels and parenchyma).^b Based on fibrous tissue (including fibers and parenchyma).^c From N. D. Nelson, R. R. Maeglin, and H. E. Wahlgren, *Wood and Fiber* 1(1): 32, Table 3 (1969).

* Difference is significant at the 0.05 level.

** Difference is significant at the 0.01 level.

The third dependent variable, per cent luminance (Y_3), was significantly related to per cent extractives (X_9), and to the specific gravity of the fibrous tissue (X_8). When combinations of variables were considered, the addition of some measure of density to per cent extractives (X_9) produced the greatest reduction in residual sums of squares. These measures of density were either cell-wall thickness (X_6), wood specific gravity (X_7), or specific gravity of fibrous tissue (X_8); the fibrous tissues specific gravity, however, made the greatest improvement. In this case

$$Y_3 = 43.6 - 23.0X_8 - 0.697X_9; \quad s_{y.x} = 1.369$$

Additional variables made no significant reduction in residuals until a six-variable equation was fitted. The best six-variable regression involved the following independent variables: number of vessels per mm², average vessel lumen area, wood specific gravity, specific gravity of fibrous tissue, per cent extractives, and ring width. This jump from a two- to a six-variable equation seldom occurs in regression analyses, and is difficult to explain or interpret.

In accord with the factorial experimental design, the average values for wood structure, specific gravity, and per cent extractives are given in Table 2 by states, site classes, and growth-rate classes.

Nelson et al. (1969) found per cent luminance was the only color characteristic associated with state of origin, and the value of this characteristic was higher for the black walnut from Indiana than that from Missouri (Table 2). However, they found no association between per cent luminance and either site class or growth-rate class.

In this study, it has been shown that per cent luminance is significantly related to per cent extractives and to the combination of per cent extractives with some of the measures of wood density. Analysis of variance indicated a significant difference between states for per cent extractives although not for specific gravity *per se*. The results, which indicate that wood from Indiana had a lower per cent of extractives than that from Missouri, are consistent with the regression analyses in which per cent luminance was negatively related to per cent extractives.

In summary the following differences in wood characteristics between states were found: trees from Indiana had significantly thinner cell walls, lower per cent cross-sectional area occupied by vessel lumens, and vessels with smaller average lumen areas than those from Missouri.

Wood from the two states did not differ significantly in percentage of gelatinous fibers nor did the regression analyses show any relationship between this characteristic and the color of the wood. It is interesting that for both states, the wood from the "good" site class had significantly more gelatinous fibers than that from the "poor." The trends for growth-rate class were not consistent within states, but if the state of origin was disregarded (Table 2), the slow-growing trees had a significantly higher per cent of gelatinous fibers than did the fast-growing trees.

Although the results here are of a small exploratory study, they offer additional information on the effect of site and growth-rate class on the anatomy of black walnut wood. In evaluating these data, it has been shown that of the wood characteristics examined, per cent extractives is most closely related to the color of wood. Since the TAPPI (1959) standard method of extraction was used, the values for extractive content include water- and alcohol-soluble and benzene-soluble components. It may be profitable by modifying the extraction procedure to ascertain which of these components is most closely associated with the luminance of the wood and, if possible, to go a step further and try to isolate the active constituents.

Since Nelson et al. (1969) found a relationship between color of the wood and some soil properties, it is rather intriguing to speculate that these properties might also affect the extractive content of the wood. Of the properties, color and extractive content, extractive content may be more important than color for the industry since it is negatively related to the shrinkage of the wood. It may be possible in the future to control not only the color but also the shrinkage characteristics of wood by manipulating forest management practices.

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