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Original article

Variation in 15-year-old *Quercus robur* L and *Quercus alba* L heartwood luminance and specific gravity

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Summary — Average specific gravity of heartwood was greater than sapwood specific gravity for both *Quercus robur* and *Q alba* (0.55 *vs* 0.51 for *Q robur* and 0.57 *vs* 0.54 for *Q alba* heartwood and sapwood, respectively). Also, Pearson's correlations between specific gravity and tree height or diameter were highly negative for heartwood and sapwood of both species. Heritabilities of sapwood and heartwood specific gravities are high for both species (h^2 > 0.60). Although heartwood color variation (as indicated by variation in luminance) was much greater within species than between species, no evidence for genetic control of heartwood color was indicated.

heritability / progeny test / correlation / color / extractive

Résumé — Variabilité de la luminance du bois de cœur et de l'infradensité du bois chez des arbres de *Quercus robur* L et *Quercus alba* L âgés de 15 ans. *L'infradensité du bois de cœur était plus élevée que celle de l'aubier chez* Q robur *et* Q alba *(respectivement 0,55 et 0,51 chez* Q robur, *0,57 et 0,54 chez* Q alba*). Les infradensités (du bois de cœur et de l'aubier) sont corrélées négativement avec la hauteur et le diamètre de l'arbre. À l'intérieur de chaque espèce, les héritabilités des 2 infradensités sont élevées (h^2 > 0,60). Bien que la variabilité de la couleur du bois de cœur–mesurée par la luminance–fût plus variable à l'intérieur de chaque espèce, qu'entre les 2 espèces, nos résultats n'ont pas mis en évidence un contrôle génétique de ce caractère.*

héritabilité / test de descendances / corrélation / couleur / extrait du bois

The mention of trade names or herbicides does not constitute an endorsement by the USDA Forest Service.

INTRODUCTION

Three primary influences are responsible for naturally occurring variation in wood properties: environmental effects, genetic factors and age or pith-to-bark variation (Panshin and de Zeeuw, 1980). Although variability in wood properties gives wood much of its character, excessive differences in wood color and other properties present problems to secondary users and merchandisers. Several studies (Nelson 1975; Phelps and McGinnes, 1983; Phelps *et al*, 1983) have examined variation in color and other properties of black walnut, but very little information is available on wood property variation of oaks in the United States, particularly small and young oak trees; in Europe, several analyses of oak heartwood color have been published (Janin *et al*, 1990). This study was done to explore relationships between height, diameter, specific gravity of heartwood and sapwood, and heartwood color in oaks, and to estimate heritability of these traits.

MATERIALS AND METHODS

English oak (*Quercus robur* L) acorns were collected from 69 widely spaced mother trees of unknown provenance on the campus of Michigan State University, East Lansing, Michigan in fall 1974. In addition, acorns from 10 local, widely spaced white oak (*Q alba* L) trees near Carbondale in Jackson County, Illinois were collected in the same fall. Seedlings resulting from these collections were lifted in the fall of 1975, bundled and overwintered in cold storage until planting in March 1976. Seedling height and survival were measured at the end of each of the first 5 growing seasons. Results of analyses of these data, as well as outplanting design and site information, were published by Clausen (1983a, b).

Height and diameter at breast height (DBH) were remeasured at the end of the 15th growing season in the winter on 1989–1990, before the need for thinning was apparent. That same winter, 2 trees per 5-tree plot were removed; trees retained were the tallest and best formed. At the time, all thinned trees large enough so that a cross-sectional disk of wood 3–5-cm thick could be removed from the basal portion were so sampled. Ninety-four thinned English oak trees of 34 half-sib families and 24 white oak trees of all 10 families represented were large enough to be sampled. Disks were evaluated for the following traits.

Inside bark diameter. This was determined as the average of 2 diameter measurements taken at the widest point on the disk and at a plane perpendicular to it. Branch scars were avoided in these measurements.

Heartwood content. Using the mean heartwood diameter determined along the same plane as the average inside bark diameter determined above, heartwood content was estimated as the area of a circle (A = 0.7854 D^2). The difference between total disk cross-sectional area and heartwood area was defined as sapwood area.

Heartwood luminance. Heartwood luminance was estimated using a reflectance Colormet* spectrophotometer and associated computer software to convert surface reflectance values to luminance values; this instrument uses a D-76 light source with a standard observer at 10 degrees (Colormet, 1988). Luminance determinations were made on a knife-planed surface that simulated a quarter-sawn board to maximize the effect of the annual rings on color readings. Since it has been suggested that variability in luminance is the primary cause of heartwood color variability we use the terms color and luminance interchangeably (Phelps *et al*, 1983). Ten readings were made per surface and the average luminance value derived from these 10 readings was used in analyses.

Heartwood and sapwood specific gravity. The maximum moisture content method of Smith (1954) was used to determine the specific gravity of small unextracted samples of sapwood and heartwood cut from each disk.

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 for a 2-way linear model (blocks and families as random effects) to compute individual tree mean squares individually for each species.

Approximate narrow-sense heritabilities (h^2) for familly selection 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.

RESULTS AND DISCUSSION

In the winter of 1989–1990, 15 years after outplanting, survival of English oak trees was almost identical to that of white oaks. English oak survival averaged 65% and

Table I. Pearson's correlation coefficients and the probabilities of obtaining greater values by chance among selected English oak and white oak wood properties.

Parameter	*HT*	*D*	*HA*	*L*	*HSG*	*SSG*
English oak						
Total height (HT)		0.78	0.53	0.14	−0.46	−0.51
P		< 0.01	< 0.01	> 0.05	< 0.01	< 0.01
Diameter (D)			0.68	0.18	−0.36	−0.34
P			< 0.01	> 0.05	< 0.01	< 0.01
Heartwood area (HA)				0.24	−0.39	−0.43
P				< 0.05	< 0.01	< 0.01
Luminance (L)					−0.01	−0.24
P					> 0.50	< 0.05
Heartwood Sp Gr (HSG)						0.62
P						< 0.01
Sapwood Sp Gr (SSG)						
P						
White oak						
Total height (HT)		0.64	0.0	−0.17	−0.17	−0.06
P		< 0.01	–	> 0.50	> 0.50	> 0.50
Diameter (D)			0.35	−0.03	−0.38	−0.43
P			> 0.05	> 0.50	> 0.05	< 0.05
Heartwood area (HA)				0.05	−0.26	−0.52
P				> 0.50	> 0.05	< 0.01
Luminance (L)					0.13	0.15
P					> 0.50	> 0.50
Heartwood Sp Gr (HSG)						0.76
P						< 0.01
Sapwood Sp Gr (SSG)						
P						

Sp Gr: specific gravity.

white oak averaged 70%, only slightly lower than at age 5 years (Clausen 1983a, b). At age 15 years, white oak trees averaged 6% taller and 24% larger in DBH than English oak trees. However, of the sampled trees, English oaks were 13% taller than white oak but 5% smaller in DBH.

In both white oak and English oak, heartwood specific gravity was greater than sapwood specific gravity. In white oak, heartwood specific gravity averaged 0.57 (range: 0.5–0.6) and the mean specific gravity for sapwood was 0.54 (range: 0.43–0.58). Similarly, in English oak, the average specific gravity for heartwood was 0.55 (range: 0.48–0.61) and for sapwood it was 0.51 (range: 0.45–0.58). This was an expected trend, because it is commonly generalized that in oaks specific gravity declines from the pith toward the bark (Paul, 1963). This decline in specific gravity is associated with narrowing ring-width from the pith toward the bark.

Correlations between specific gravity and height as well as diameter were significantly negative for sapwood and heartwood of English oak and between diameter and specific gravity of white oak; the correlations tended to be greater for English oak than for white oak, perhaps due to the substantially smaller white oak sample (table I). Because faster growth in ring-porous tree species is associated with greater wood specific gravity (Panshin and de Zeeuw, 1980), our negative correlations were unexpected. The effect of growth rate on specific gravity has been shown to vary with age and is usually more significant with increasing age (Zhang and Zhong, 1991), so it may be hypothesized that the negative correlations are a manifestation of juvenility of our trees. Alternatively, extractives in the heartwood may be obscuring the true pattern of specific gravity variation.

The heritabilities for heartwood and sapwood specific gravity (table II) reflect high genetic control over wood density in both oak species, although heritabilities are slightly higher for English oak than for white oak. High heritabilities indicate great potential for genetic gains through selection in systematic tree improvement programs. For both oak species, heritabilities for sapwood specific gravity are greater than those for heartwood specific gravity.

Although heartwood color of *Q robur* was slightly darker than that of *Q alba* (30.0 *vs* 31.7%), the color differences were too small to be visually detected. Color variation within both species substantially exceeded variation between species (the range in luminance values was 24.5–37.1 for *Q alba* and 20–40.2 for *Q robur*). As with black walnut (Rink and Phelps, 1989), there was no indication of genetic control over heartwood color, as reflected in a lack of statistical significance for family effects in analysis of variance of luminance data.

Table II. Narrow-sense heritability of sapwood and heartwood specific gravity of white oak and English oak.

Species	*Sapwood specific gravity*	*Heartwood specific gravity*
English oak	0.78	0.69
White oak	0.70	0.63

It is recommended that future studies of oak specific gravity and other wood properties deal with extracted wood samples.

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