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Original article

The influences of age, extractive content and soil water on wood color in oak: the possible genetic determination of wood color

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Summary — Natural wood color was investigated in approximately 200 French oaks (*Quercus petraea* and *Q robur*). Color was measured with a spectrocolorimeter and represented using the color volume CIELab. The most important factor influencing color is age. Oak wood from younger trees has a lighter and more yellowish color than that from older trees. The amount of available water is the major soil factor influencing wood color. Much of the variation in the color of oak wood remains unexplained and it is possible that some of this is under genetic control. Genetic studies on oak wood color are difficult, because the colored heartwood only begins to develop between 10 and 20 years of age, and genetic trials for oak of this age are scarce.

***Quercus petraea* / *Quercus robur* / CIELab color / age / soil**

Résumé — L'influence de l'âge, de la teneur en extraits et du sol sur la couleur du bois de chêne: réflexion sur l'influence de la génétique sur la couleur du bois de chêne. *La couleur naturelle d'environ 200 chênes français (*Quercus petraea *and* Quercus robur*) a été étudiée. La couleur a été mesurée à l'aide d'un spectrocolorimètre et représentée dans le volume de couleur CIELab. L'âge est le facteur qui influence le plus la couleur du bois de chêne. Des jeunes chênes ont une couleur plus jaune et plus claire que les âgés. La quantité en eau disponible est le paramètre de sol le plus important. Une partie non négligeable de la variabilité de la couleur du bois de chêne ne peut pas être expliquée. La connaissance de la détermination génétique de la couleur pourrait fournir les informations manquantes. Des études génétiques sur la couleur du bois de chêne sont difficiles, sachant que le bois de cœur commence à se développer à l'âge de 10 à 20 ans seulement.*

Quercus petraea / Quercus robur / *couleur CIELab / âge / sol*

INTRODUCTION

The color of wood is an important quality criterion and is often the decisive one for consumers. In furniture or other interior equipment, wood is competing with other materials such as steel, stone, glass, several plastics and decorative papers. Wood is often favored because of its aesthetic properties, particularly color.

A survey of wood-using professionals by Mazet and Janin (1990) showed that lightness is the most important color criterion, followed by its hue and saturation.

Since 1985, the wood color of several species has been systematically and objectively investigated by INRA's wood quality laboratory in Nancy, using a spectrocolorimeter. Techniques for measuring color and some environmental, individual tree and chemical factors influencing it in oak (*Quercus petraea* and *Quercus robur*) are reported here.

MATERIALS AND METHODS

Wood

In 1987, INRA's forest phytoecology laboratory collected 1600 increment cores from the Forêt d'Amance, near Nancy. Three species (*Q robur, Q petraea* and *Fagus sylvatica*) from 99 plots were sampled at 2.8 m above the ground.

Work reported her is based upon the study of 480 oak cores selected from the original sample of 1600. So far, 3 scientific investigations on these increment cores have been reported by Flot (1988), Nieminen (1988) and Klumpers (1990). Janin and Mazet (1987) clearly described the use of increment cores for investigating wood color.

Air-dried increment cores were glued into a wooden holder and then radially bisected to expose a radial or approximately radial surface for the measurement of color (fig 1).

For chemical investigations, wood from 20 oak trees (65–150 yr old) was sampled in a sawmill at approximately 3 m height. Five radial sections per tree were analyzed for their extract contents.

Colorimetry

Wood color was measured with a ColorQUEST spectrocolorimeter from HUNTERLAB simulating the CIE standard illuminant A (corresponding to incandescent light) and an observation angle of 10°. The color is represented by the values L^*; a^*, b^*, C^* and h^* (fig 2).

Extractions

Wood meal (250 mg) from 100 oak wood samples (see above) was extracted 3 times with 10

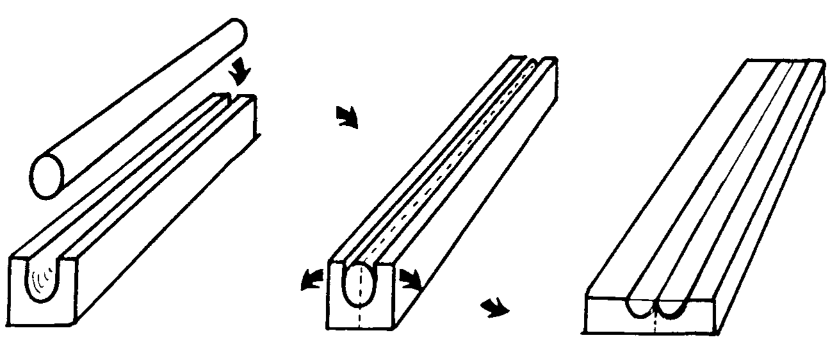

Fig 1. Preparation of increment cores for measuring color. Left, the increment cores are inserted and glued into specially designed wooden holders. Center, the wooden holders and the increment cores are sawn into 2. Right, after cutting their radial surfaces are exposed.

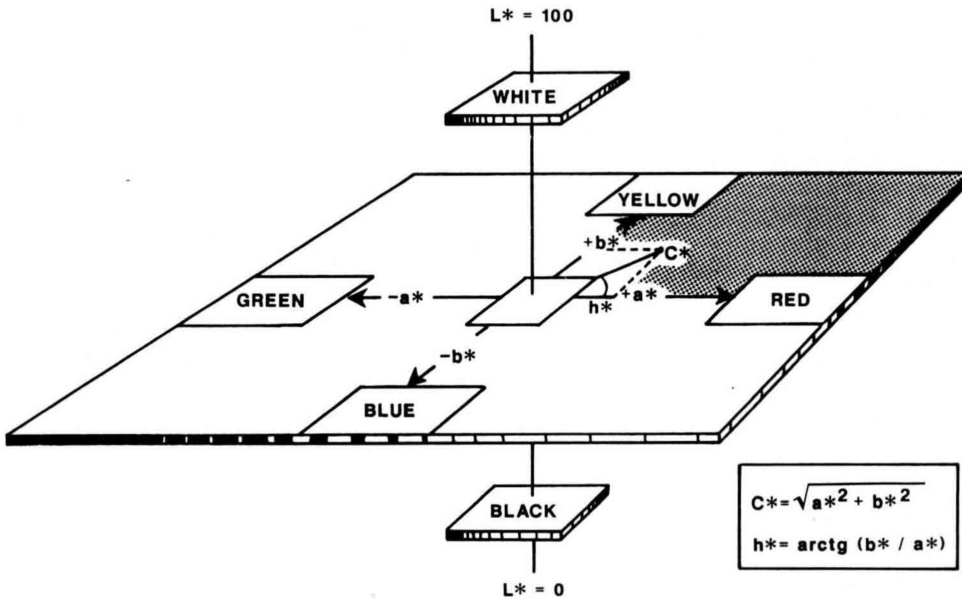

Fig 2. The color volume CIELab. The L^* value indicates the lightness of an object and varies from 0 (perfectly black) to 100% (perfectly white). a^* and b^* characterize the chromaticity; a^* places the color of an object on, the green–red axis, and b^* on the blue–yellow axis. The parameters C^* (which describes the color saturation) and h^* (the hue of a color) are calculated from a^* and b^*. The shaded surface indicates where the color of oak wood is located in the CIELab volume.

ml of an acetone:water (7:3) solution; twice for one hour's duration and the last time for 15 h. Total phenol content was estimated using the Folin–Ciocalteu method (Singleton and Rossi 1965) and expressed in mg of gallic acid equivalents (GAE) per gram of dry wood.

RESULTS

Soil water content and wood color

Examination of core samples revealed that the amount of available soil water influenced the color of *Q robur* but not *Q petraea*. In pedunculate oaks, a darker, more reddish wood was produced in trees where soil water was abundant in spring. The correlation coefficients between 2 soil parameters and the color parameter L^* are presented in table I.

Soil pH was not significantly correlated with wood color. This was not surprising however, because all sampled trees were located in one forest where soils were relatively uniform.

There was no evidence that tree vigor, as indicated by parameters such as crown length and diameter, was related to wood color in samples from the Forêt d'Amance.

Age and wood color

We should distinguish tree age (biological age) from wood age (as indicated by the

Table I. Pearson's correlation coefficients (r) and coefficients of determination (r^2) for associations between lightness L* and 2 soil parameters. RU2 x (tree utilizable water reserve) = thickness of layer x texture coefficient (1-% gravel/100). Two examples for the texture coefficient are presented: coarse sand has a texture coefficient of 0.38 and light clay one of 0.90. Palo: depth of impervious layer. *df*: degree of freedom.

Soil parameter	r^2	r	df	*Level of significance (%)*
RU2	0.34	–0.58	27	0.1
Palo	0.29	–0.54	27	1

number of annual rings away from the cambium). Both ages greatly influence wood color.

Lightness *L** and hue *h** diminish with increasing wood age (see figs 3 and 4). This means that the color of the wood becomes darker and more reddish towards the pith.

All color parameters were significantly related to tree age (see table II; figs 3 and 4). The relationships are particularly strong for hue *h** and the green–red axis *a**. It was found that the reflection in the red wavelengths (600–700 nm) increased with

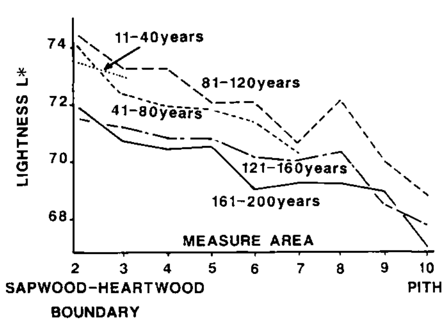

Fig 3. Lightness *L** in the heartwood of pedunculate oak as a function of wood age and of tree age. The figure indicates the changes that occur from the outer to the inner heartwood. Every measured area corresponds to 9 x 3.5 mm of radial core surface.

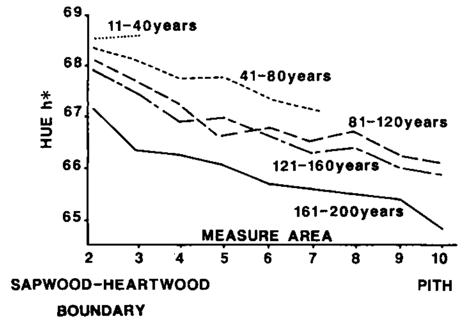

Fig 4. Hue *h** in the heartwood of pedunculate oak as a function of wood age and of tree age. The figure indicates the changes that occur from the outer to the inner heartwood. Every measured area corresponds to 9 x 3.5 mm of radial core surface.

biological age. This indicates that, as trees get older, the heartwood color gradually changes from bright yellow–brown to increasingly reddish–brown in color (fig 4).

Species and wood color

Table III indicates that, on the average, very little difference exists in wood color for

Table II. Pearson's correlation coefficients *(r)* and coefficients of determination (r^2) for associations between tree age (for both *Quercus petraea* and *Quercus robur*) and color parameters. Minimum age, 11 yr; maximum age, 240 yr.

Dependent variable	r^2	r	*Level of significance (%)*
*L**	0.23	–0.45	0.1
*a**	0.42	+0.65	0.1
*b**	0.05	+0.22	1
*C**	0.11	+0.33	0.1
*h**	0.59	–0.74	0.1

Number of observations: 185. Degree of freedom: 183.

Table III. Comparison of colour parameters of wood from *Q petraea* and *Q robur*. MS: mean square; *Fs*: *F*-ratio = MS inter/MS intra; *P*: probability.

Color parameter	*Mean* Q petraea	*Mean* Q robur	*MS inter* df *1*	*MS intra* df *38*	Fs	P
*L**	72.2	71	12.22	4.33	2.82	ns
*a**	10	9.8	0.33	0.24	1.37	ns
*b**	22.8	23	0.45	0.83	0.55	ns
*C**	24.9	25	0 .15	0.99	0.16	ns
*h**	66.3	66.9	3.58	0.44	8.15	0.01

the 2 oak species. Differences between the species' mean values of *a**, *b** and *C** were very small and were not significant. On the average, there was some suggestion that the wood of sessile oak is slightly lighter than that of pedunculate oak. This difference was barely perceptible to the human eye and was not significant. However, the differences in hue (*h**) were significant with the wood of sessile oak tending to be more reddish in color than that of pedunculate oak.

Extractive content and wood color

Figure 5 indicates that the extractive content of sapwood is considerably lower than that of heartwood, a result that numerous other authors reported before (*eg*, Hillis, 1987; Weißmann *et al*, 1989; Peng *et al*, 1991). This result supports the hypothesis that wood color is related to extractives because the heartwood is much darker and redder than the sapwood.

Extractive content decreases from the outer to the inner heartwood (fig 5), but heartwood becomes darker and more reddish towards the pith (see above), so that intra-tree color variation in the heartwood cannot be explained by extractive content.

There is a significant correlation between the color of the outer heartwood and its extractive content, whereas the color of the inner heartwood cannot be correlated with extractive content (table IV).

Table IV. Pearson's correlation coefficients for associations between extract content and color parameters of the heartwood.

Area	L*	a*	b*	C*	h*
2	ns	−0.48	0.75	0.63	0.7
3	ns	ns	ns	ns	ns
4	ns	ns	ns	ns	ns
5	ns	ns	ns	ns	ns
Total heartwood	ns	−0.41	ns	ns	0.48

Four areas were analyzed relative to their extractive content. Area 2 corresponds to the outer heartwood, areas 3, 4 and 5 follow in radial direction, with 5 in the pith region. Area 1, which is not represented here, corresponds to the sapwood. Total heartwood means that all 4 areas were used to establish the correlation. All communicated correlation coefficients are significant at a probability of 0.01. The degree of freedom for the total heartwood correlation is 79 and for the others it is 19.

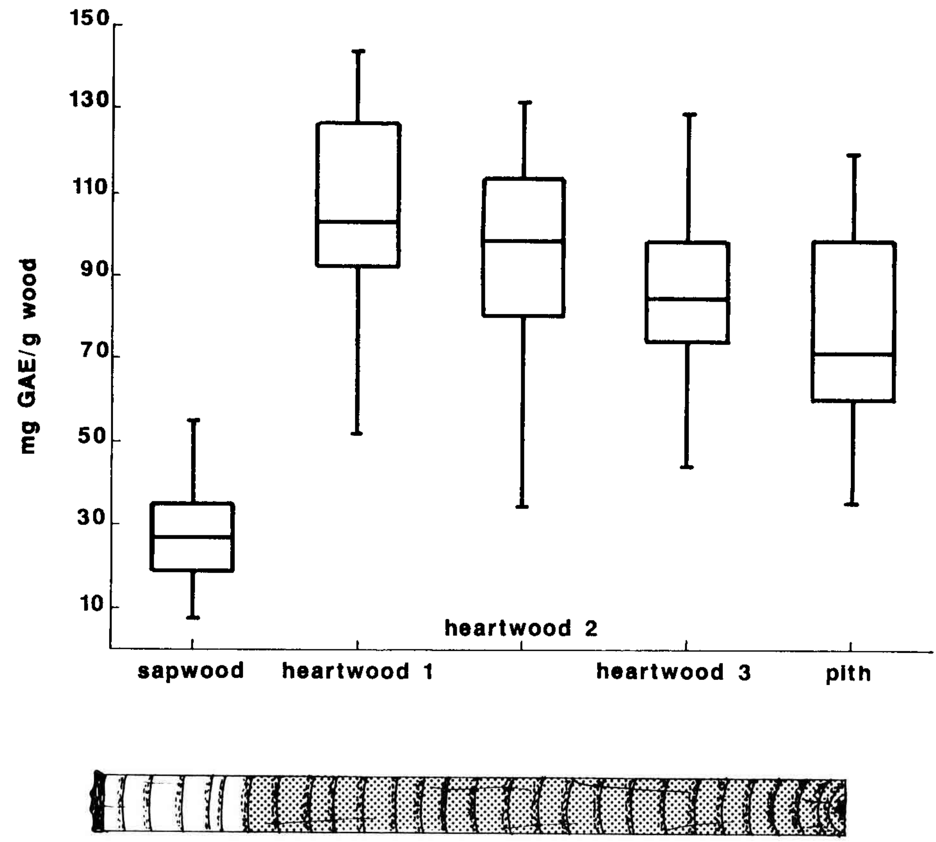

Fig 5. Extractive contents of sapwood and heartwood of 20 oaks (both *Quercus petraea* and *Quercus robur*, 65–150 years old). The box and whisker plots convey the following information: lower quartile: bottom line of the box; median: middle line of the box; upper quartile: top line of the box; lower whisker: minimum value; upper whisker: maximum value. GAE: gallic acid equivalents.

DISCUSSION

The most important factors influencing the color of oak wood were found to be both tree age and wood age, with wood becoming redder and darker with increasing tree age. Nevertheless, much of the variation in wood color remains unexplained.

It is also possible that some color variation, particularly in the outer heartwood, is mainly a function of extractive quantity or quality. It is not known whether extractives are genetically controlled, caused by various environmental influences, or purely due to some process of chemical transformation.

There was a small but statistically significant suggestion that the wood of sessile oak is slightly redder than that of pedunculate oak. However, Scalbert *et al* (1986) found no differences in the quantity and quality of extractives of the 2 species.

Rink (1987) found no evidence for genetic control over any heartwood color parameter in a progeny trial for black walnut (*Juglans nigra* L). Average color differences between oaks growing in different regions were suspected to be due to different soil properties rather than genetic control (Janin *et al*, 1990).

At present there are no indications that wood color is under genetic control. Unfortunately, a thorough study of the genetic control of oak wood color will only be possible when recently established genetic trials are of sufficient age for the observation of colored heartwood, which begins to develop only after 10–20 years.

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