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CHROMATIC INDIVIDUALITY OF FIR (*Abies alba* Mill.) COMPRESSION WOOD

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Abstract: *The encountered difficulties in fir's normal structure wood delimitation from compression wood, due to numerous intermediary forms, have been motivated the research of better efficiency indicators for defect investigation. The colorimetric investigations in CIELab chromatic space, presented in current paper, had as object the felled fir wood from Braşov surrounding areas. The discriminatory aptitude of colour components is statistically proved, especially for yellow colour and reflectance. There are also analysed the quantitative relations between the chromatic indexes values from characterized structure type perspective.*

Key words: *compression wood, wood colour, colour space, colour-structure relation.*

1. Introduction

Compression wood is frequently considered as being a structural particularity specific to gymnosperm, produced by the modification of the axial growth direction of stem and branches, in whose transversal section occupies the portion periodically or continuous stressed [4], [11]. In the portion which is stressed by traction, the resinous wood usually keeps its regular structure, whereas to the broadleaved species it forms a particular structure type: tension wood [6], [10]. The compression wood is differentiated by the normal structure especially by: abnormal thickening of the late wood, tracheids section rounding, intercellular spaces extending, architecture modification of secondary cellular wall, increasing of lignin and decreasing of cellulose contents [1], [7], [8], [12]. The mutations which occur in wood structure, affect the properties and, by this, the utilization value, considerably restricting its potential utilization spectrum [2].

The conformation of the growth rings, as well as late wood burring in their interior, generates a particular chromatic aspect, which facilitates both the identification and measuring of this defect. For example, the color of spruce late wood varies in compression wood insertions from orange to black-brown by comparison with the normal structure yellowish one [9].

2. Research Materials and Methods

2.1. Investigations materials

The investigations, of which results are presented in this paper, follow the delimitation of compression wood in normal structure, as well as physical characterization by considering color of

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the compression wood. The used material was sampled from timber harvesting sites where operations were realized in 2003-2007 period, in Noua and Troiner basins, managed by Kronstadt Public Forest Administration. From there were sampled and transported a number of 46 growth samples. The primary sample package was completed with samples (61 growth samples) prevailed from two sample trees.

2.2. Research Methodology

2.2.1. Samples preparing for colorimetric examination

After conditioning period (necessary for equilibrium humidity attaining in laboratory conditions), the harvested samples were introduced in physical investigations circuit. The chromatic determinations accuracy, as well as objective necessities related to colorimetric instruments manipulation imposed the preparation of one of the transversal surface of each sample (growth samples) by abrasion. For this purpose, a belt abrasion machine was used; in order to obtain of a satisfying rugosity, for necessary precision of chromatic determinations, were successively used abrasive strips with increasing granularity (up to 120x).

The growth samples were cut in quarters, following the directions of the ovality concurrent directions in medullar area. The chromatic measurements were realized on the radial section of the quarters.

2.2.2. Colour study

The surface nature imposed the usage of a portable colorimeter. Such an instrument, into a constructive variant produced by Konica-Minolta served to this paper research purpose (Figure 1). It is composed from a measuring head and a data processor. The measurement head can be used independently. The color analysis is

Fig. 1. *The colour measurement on radial side of wood using CR-400 colorimeter*

realized by an 8 mm surface scanning by a radiation beam produced by a xenon lamp and electronic interpretation of the reflected radiation [12]. The instrument was configured for the following options: three consecutive scanning of the same surface, in order to obtain an average value and color space $L^*a^*b^*$.

The chromatic space $L^*a^*b^*$ is frequently used in color study in Western Europe and USA (especially to broadleaved species) and is composed from the following coordinates:

- L^*: brightness (which value varies between 0% for black and 100% for white);
- a^*: the value of red/green colour (with negative values for green and positive values for red);
- b^*: the value of yellow/blue colour (with negative values for blue and positive values for yellow);

This coordinates permit the determination of the following derived measures:

- h: colour tonality (determined by calculus: arctg (b^* / a^*);
- ΔE^*: the difference between two measurements (Equation 1):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}, \qquad (1)$$

where ΔL^*, Δa^* and Δb^* represent the absolute brightness differences, red/green colours and yellow/blue colours.

The mathematical analysis of the experimental data was realized with STATISTICA 8.0 software.

3. Results and Discussion

3.1. The experimental distribution indicators of the chromatic components

The descriptive statistics of the variables which form the colour space CIELab indicate a tide grouping of the observed values on the position average - variation coefficients present values in 2.8...22.1% interval; the chromatic tonality is the parameter presenting the greater valoric homogenity. All the distributions are unimodal. The measure classes with maximum frequencies are: 82...84% for brightness index, 3...4 for red grade, 18...20 for yellow grade and 78...80 for tonality. The experimental distribution shape parameters indicate a strong asymmetry for variables L^*, a^* and h frequency curve (the rapport between the asymmetry index and determination standard error is situated over 2), as well as an excess of h parameter, by comparison with normal distribution curve. The Shapiro-Wilk test indicates the significant abberation from normality of all the analyzed chromatic elements (the results are covered on transgression probabilities smaller than 5%) - Table 1. A certain similitude with normal distribution can be found only in yellow colour distribution (b^*), where the asymmetry and excess are not significant.

Descriptive statistics of the chromatic components distributions Table 1

Chromatic parameter	$\bar{x}$	max	min	$s_{\%}$	A	s_A	E	s_E	W	p [%]
L^*	81.03	87.38	73.37	3.42	–0.52	0.15	–0.22	0.29	0.97	0.004
a^*	4.09	6.82	2.09	22.11	0.69	0.15	0.47	0.29	0.97	0.001
b^*	19.06	23.51	13.30	7.68	0.02	0.15	0.29	0.29	0.99	4.8
h	77.96	83.01	70.22	2.80	–0.74	0.15	0.95	0.29	0.97	0.001

3.2. The chromatic components stratification by considering the wood structure type

Nonparametric test Mann-Whitney (a nonparametric alternative on t test, more sensitive in acceptance or rejecting of null hypothesis) confirms the differentiation of compression wood by normal structure wood by considering the colour components (L^*, a^*, b^*, h) - Table 2; there can be remarked high significance level of produced variations by the structure type in quantitative expression of colour traits.

The observed values stratification for chromatic components by considering the wood structure type leads to statistical distributions normalization for L^*, a^* and h variables: brightness, red colour measure and tonality are distributed by respecting the normal distribution only in compression wood. The yellow colour frequency curves remain, after stratification, outside the normal distribution.

Presence of compression wood in stem structure can be highlighted by colour traits, fact which is statistically proved and graphically presented in Figure 2. There can be remarked, the modulus localization at superior classes in compression wood by comparison with normal structure wood.

The colour variations induced by the compression wood presence produce a narrow ecart (Table 3). The effectuated measurements on radial sections of the samples, by using CR-400 colourimeter, shown that the brightness grade (L^*) of normal wood varies nonsignificantly ($s_{\%}$ =

2.8%) into an interval with amplitude of only 12.49 chromatic units. Quantitative nonsignificant variations ($s_{\%}$ = 2.6%) presents, also, the yellow colour as well as chromatic tonality.

In conditions of these narrow dispersions, the arithmetic means present a high representativity grade and can be used for comparisons with other colectivities or species.

Table 2

Compression wood influence signification on color components, by applying Mann-Whitney test

Chromatic parameter	Sum of ranks in normal structure wood	Sum of ranks in compression wood	*U*	*Z*	*p* [%]
*L**	31362	7419	4016	6.58***	< 0.001
*a**	22790.5	15990.5	3484.5	–7.45***	< 0.001
*b**	22818	15963	3512	–7.40***	< 0.001
h	3147	7634	4231	6.22***	< 0.001

Table 3

The Shapiro-Wilk test for the stratified distributions statistical indicators of experimental distributions for chromatic parameters by comparing the compression wood with normal structure wood

Chromatic parameter	Arithmetic mean		Variation amplitude		$s_{\%}$	A_s♦
	measure	confidence interval	min	max		
L^*: brightness	81.76♦♦ 79.27♦♦♦	81.44…82.09 78.61…79.92	74.89 73.37	87.38 85.95	2.82 3.77	–0.18 –0.03
a^*: red chrome measure	3.82 4.74	3.72…3.92 4.52…4.96	2.09 2.51	6.28 6.82	18.51 20.94	+0.10 +0.18
b^*: yellow chrome measure	18.64 20.07	18.48…18.81 19.70…20.43	17.85 13.30	20.88 23.51	6.11 8.27	–0.20 –0.01
h: chromatic tonality	78.45 76.79	78.17…78.73 76.32…77.26	70.22 72.17	83.01 81.63	2.56 2.78	–0.09 +0.11

♦ Bowley coefficient; ♦♦ in normal structure wood; ♦♦♦ in compression wood

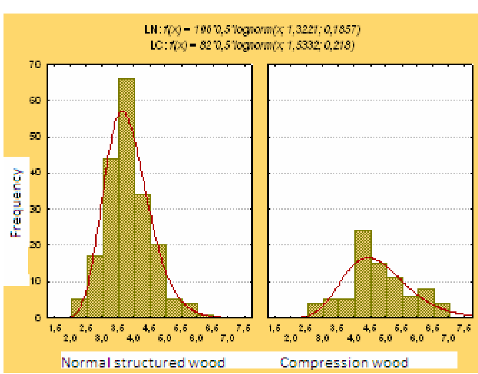

Fig. 2. *Normal logarithmic adjusted distribution of red colour in normal structure and compression wood*

Despite the fact that the colour variations between species as well as in the case of the same species are very pronounced, there were not available for comparison but a small number of colourmetric studies. From these studies (Table 4), most of them were realized mainly for broadleaved species presenting veneer destination.

There was remarked a certain similitude between white fir (*Abies alba*) and Vancouver fir (*Abies grandis*), especially regarding the brightness grade and the yellow colour value - Table 4.

The sampled and examined material presents a more pronounced red grade by comparison with Vancouver fir which presents the a^* parameter slowly turned to green. These differences could be the effect of macrostructural differences: the first one presents growth rings narrower than the second one, having a higher percent of late wood reflected in red. Beech wood presents a brightness weeker than fir wood, but with very closed values for red and yellow colours. The comparisons with the broadleaved species with hartwood make no sense. From the presented data there can be underlined the yellow colour domination to fir and beech wood, even to walnut; in cashew case the rapport between the red and yellow colours is closed to unity.

Table 4

Average values for chromatic parameters in case of some economic interest species [3], [5]

Chromatic parameter	***Juglans regia***	***Juglans nigra***	***J. nigra* 23 X *J. regia***	***Fagus silvatica***	**Acajou**	***Abies grandis***
L^*	87•/56••	86/46	86/57	71	42	80
C^*	18/19	18/19	18/18	-	-	-
h	74/6	75/65	74/65	-	-	-
a^*	3	-	-	4.3	4.3	–0.4
b^*	15	-	-	20.8	20.8	19

• in sapwood on radial side; •• in heartwood on radial side

By comparing the average values and chromatic parameters variation amplitude regarding the compression wood and the normal structure wood there can be concluded the following:

- Normal wood presents a greater reflectance than the compression wood (both, in average values, as well as in maximum values): the relative difference in case of means is of 3.1%, and in case of maximum values is of 1.7%.
- Despite the fact that the differences between the compression wood and normal structure wood regarding the red colour value are statistically confirmed, the contribution of this colour to defect definition becomes real only in combination with yellow colour, of which global influence is superior as value (the relative difference of compression and normal structure wood means regarding yellow colour is of 7.6%, and maximum values difference is of 12.6%).
- The smallest measured value for yellow colour of normal structure wood is with 19.2% greater then the biggest measured value in case of the compression wood, representing the same measure in which the red colour measured to compression wood is greater than that measured to normal structure wood, a supplementary argument in favour of proportional participation of two colours in wood colour edification.
- The variation coefficients of chromatic parameters are greater by 1-2% in compression wood, but remain, surprisingly, at a modest level.

3.3. Structural type differentiated relations between the chromatic components

The values of nonparametric correlation coefficients confirms the direct proportionality between the red colour value and yellow colour value, relation of which intesity increases form normal structure wood to compression wood (Table 5). Nonparametric Spearman correlations atest other links between colour components. For example, at the tonality value in normal structure wood majoritary contributes the red colour ($r_{a^*h} = -0.929^{***}, r_{b^*h} = -0.101^{ns}$), whereas in the compression wood the yellow colour participate as well ($r_{a^*h} = -0.911^{***}$, $r_{b^*h} = -0.446^{***}$). Both, normal structure wood, as well as compression wood present a brightness which is inverse proportional with the red and yellow colours values, the link being more intense in the defect space ($r_{L^*h} = -0.860^{***}$, $r_{L^*b} = -0.516^{***}$ respectively $r_{L^*a} = -0.886^{***}$, $r_{L^*b} = -0.649^{***}$); in both cases the brightness is directly proportional with tonality value ($r_{L^*h} = +0.740^{***}$ in normal structure wood, $r_{L^*h} = +0.796^{***}$ in compression wood). In our opinion, the brightness variation (L^*) by yellow and red colours values (b^*, a^*) - Figure 3, has a biochemical explanation.

Table 5

Spearman correlation coefficients of color components a^* and b^* ranks differentiated by structure type

Structure type	***R***	**Significance test**			**Significance level**
		t	***f***	***p* [%]**	
Ensemble	0.584	11.95	276	< 0.001	***
Normal structure wood	0.412	6.31	194	< 0.001	***
Compression wood	0.712	9.08	80	< 0.001	***

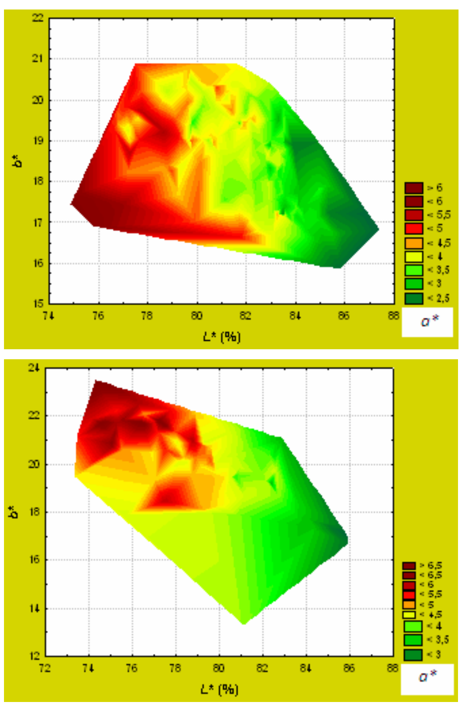

Fig. 3. *Relations in $L^*a^*b^*$ colour space under wood structure influence* (*up - normal structure wood, down - compression wood*)

Brightness or luminance measures, in chromatic values, the relative difference in comparison with the reflected energy by a black body; great brightness values indicate a small distance from white base colour. On the other hand, white colour is a cellulose property. In *Abies* species wood, the extractible substances present a nonsignificat proportion, and the wood colour displacement to darker colours cannot be, in the absence of some abnormal colorations, but the effect of lignin excedent, which characterises some structure defects, mainly the compression wood (the extracts lignin colour varies form yellow to dark-brown) [1].

In Figure 4, are graphically presented the synchronous variation amplitudes of a^* and b^* colour components, by comparing the normal structure wood with compression wood, as well as their absolute frequencies. The relation between the values of the two colours can be explained by the following regression equation:

$$b^* = 14.623 + 1.148\, a^*. \tag{2}$$

The regression linearity is confirmed by *F* test. By comparison, for normal structure wood there was adopted the polynomial regression:

$$b^* = 7.813 + 16.314\,a^* - 11.472\,(a^*)^2 + 3.836\,(a^*)^3 - 0.581\,(a^*)^4 + 0.032\,(a^*)^5.$$

The corrected values by considering the polynomial distribution indicate a maximum frequency of yellow colour value (19-19.5) at values of red colour of approximately 4.5. If the red colour proportion is greater than 4.5, the tallow content decreases to 17.5. In conclusion, if in the compression wood the yellow colour value increases by the red colour value in all the variation domain of the two chromatic components, in the normal structure wood this direct proportionality is manifested only in the correlation field delimited by red colour 4.5. After this limit, the yellow content is reduced in favor of red colour.

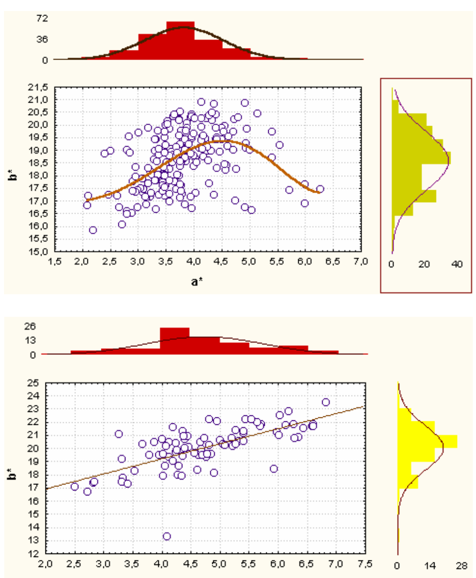

Fig. 4. *Experimental distributions and variation field for* a^* *and* b^* *colour components in normal structure* (*up*) *and compression wood* (*down*)

4. Conclusions

Diversity of secondary xylem involved in mechanical equilibrium of the trees becomes macroscopically perceptible through colour. The investigations begun from the premise that colour represents a mark of compression wood identity. This was colorimetric followed on a number of 105 samples harvested form felled fir trees, from stands oriented to irregular shelterwood system. Relation colour-structure expressed through compression wood, presents to the compression wood the following characteristics:

- colour space variables present a remarkable dimensional homogeneity; greater amplitude presents the value of yellow colour;
- colour components tight variation domain does not restrict the individualisation of compression wood forms in comparison with normal structure wood;
- chromatic space compartimentation by considering the wood structure type determines its components distribution normalisation excepting yellow colour;
- yellow colour contribution to colour constitution is, in case of fir wood, quantitatively superior by comparison with red colour, regardless the structure type;
- mathematical correspondence between the two colours (underlined by compression wood: $R = +0.712^{***}$) indicates their synergic participation in fir wood chromatic individuality;
- red colour intensifying which characterises the compression wood, is invariabiley followed by yellow colour participation in colour matrix;
- wood radial section reflectance has a negative correlation with yellow and red colours;
- weaker brightness of compression wood surface could be the effect of chemical composition participation of wood in colour-structure relation.

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