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Original article

Studies on European beech (*Fagus sylvatica* L.). Part 1: Variations of wood colour parameters

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Abstract – Colour parameters of European beech were measured using CIELab system. 103 logs from 87 trees in 9 sites were cut into boards to study the radial variations of wood colour parameters. Both site and tree effects on colour were observed. Patterns of red heartwood occurrence were defined. When excepting red heartwood there was still a highly significant effect of site and tree. Axial and radial variations were small, except very near the pith or in red heartwood, suggesting possible early selection at periphery under colour criteria. Red heartwood is darker, redder and more yellow than normal peripheral wood.

***Fagus sylvatica* L. / CIELab colour system / solid wood / red heartwood**

Résumé – Études sur le Hêtre (*Fagus sylvatica* L.). 1. Variations des paramètres de couleur du bois. Les paramètres de couleur du hêtre européen ont été mesurés à l'aide du système CIELab. Cent trois grumes obtenues à partir de 87 arbres abattus dans 9 sites ont été débitées en quartiers afin de déterminer les variations radiales des paramètres de couleur. Des effets site et arbre sur la couleur ont été observés. Des types avec ou sans cœur rouge ont été définis. En exceptant le cœur rouge on conserve un effet hautement significatif du site et de l'arbre. Les variations radiales et axiales étaient faibles, excepté très près de la moelle ou dans le cœur rouge, suggérant la possibilité d'une sélection précoce sur des critères de couleur en périphérie. Le cœur rouge est plus foncé, plus rouge et plus jaune que le bois normal périphérique.

***Fagus sylvatica* L. / système de couleur CIELab / bois matériau / cœur rouge**

1. INTRODUCTION

The colour of wood differs widely among species and also within a tree. It is an important factor for end user to consider and the price of wood is often dependent on its colour parameters [2, 3, 8]. European beech (*Fagus sylvatica* L.) is a popular and major tree species distributed in the whole Europe. Its timber with beautiful grain and proper texture is widely used in sawing, veneer, decoration and furniture. In western Europe beech is appreciated for its light pinkish colour: darker wood is less valuable in general. Moreover, industrial operations using heat treatment such as steaming or hot drying are known to change beech colour by inducing a more or less pronounced reddening and darkening. Although process parameters are of the outmost importance in these phenomena, it should be interesting to know how beech wood colour is dependent on intra or inter trees, intra or between sites variations. In the present paper, the variations of colour parameters from pith to bark were studied in different trees from 9 sites under different growth conditions and management practices.

2. MATERIALS AND METHODS

2.1. Materials

Eighty-three trees of European beech were taken from 9 European sites from 5 different countries (Austria, Denmark, France, Germany and Switzerland, designated by A, D, F, G and S respectively), with 9–10 trees selected per site. One log of 50 cm long at the height of 4 m (bottom) was cut for each tree. In addition, another log was cut at the height of 9 m (top) in only 9 selected trees to compare the wood properties between top and bottom of the stem. The age of the selected trees ranges from 70 to 200, the diameter at breast height (DBH) from 51 to 85 cm and the tree height from 30 m to 43 m (Tab. I). Data for top

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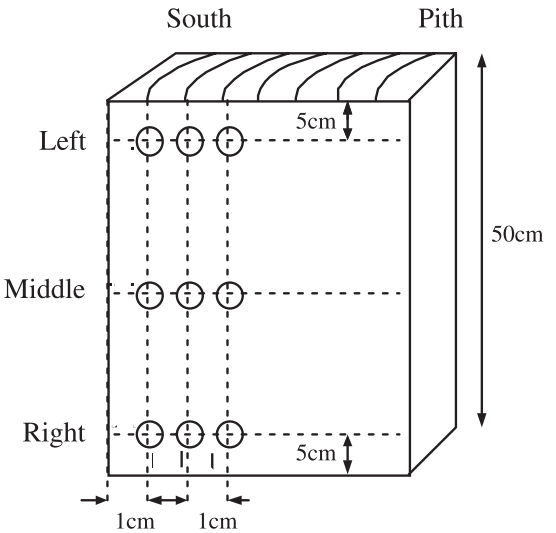

Figure 1. Schematic localisation of colour measurement points for boards.

logs are given in Table II. The "red heartwood" proportion defined as the ratio of red heart zone diameter to log diameter, is also indicated for each log.

Stands A1, D1, F1, G1 and S1 (left column in the table) belonged to a first campaign where more data were measured. These 5 stands were chosen for their similar growing condition: rather low altitude (about 500 m above see level), typical high forest with rather narrow spacing. Based on the results from the first campaign, the procedure was somewhat simplified for stands A2, S2, G2 and G3 from the second campaign (right column), as will be explained later. These stands were selected to represent specific situations encountered in the various countries: mountain forest for A2 and S2, with a pronounced slope, high forest with large spacing for G2 and G3. The stand G3 contained two age classes (220–230 years and 140–160 years) and allowed very large spacing between trees, thus holding some similarities with typical French middle forests ("taillis sous futaie"). The harvesting occurred between November 1998 to February 1999 for the first campaign, between October 1999 and January 2000 for the second.

Each log was sawn into two radial boards through pith from north to south direction, labelled N and S, respectively. These boards were dried under shelter in open air during several weeks until they reach a moisture content of 12 to 14%, than planed. Colour measurement was performed immediately after planning in order to avoid any aging of the surface [10].

The colour parameters of boards were measured every 1 cm from pith to bark (Fig. 1).

2.2. Colour measurement

The measurements of colour parameters were performed in the wood physics laboratory of CIRAD with a spectrocolorimeter (Datacolor Microflash 200d) under ambient temperature and humidity from July to September 1999 (1st campaign) and in October 2000 (2nd campaign). The diameter of sensor head was 6 mm (SAV, "small area view"), the illuminant A and 10° standard observer were used as the conditions of measurement [3]. We obtained the values of the CIELab colour system (L*, a* and b*) directly, in which L* means brightness, a* means red colour, b* means yellow colour. A larger L*, a* or b* means a lighter, redder and more yellow colour, respectively [4, 9]. Occasionally, the following colour parameters derived from L*, a*, b* will be documented:

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$H^* = \text{atan}(b^*/a^*)$$

In each pair of board the width of the red heart zone was measured; the ratio between this width and total diameter was used as an indicator of red heartwood occurrence in the log.

3. RESULTS AND DISCUSSION

3.1. General results

In general, 17 to 33 points were measured along a radius according to the tree diameter. The lightness index (L*) ranged from 58.2 to 90.3, redness index (a*) from 6.2 to 18.7, yellowness index (b*) from 15.4 to 30.3, C* from 16.9 to 33.4 and H* from 50.4° to 72.5°. In Figure 2 beech colour is compared to that of various hardwood species [7]: it is characterised by a high lightness L*. The mean and standard deviation obtained in the present set of data has been indicated by segments, as well as results of red hardwood beech that will be discussed later. Mean values obtained on Oriental beech (*Fagus orientalis)* [6] are also shown for comparison.

There is a highly significant correlation between L* and a* (L*= –2.37a* + 103.8 with $R^2 = 0.82$) and a lower correlation between L* and b* (L* = –1.88b* + 118.0 with $R^2 = 0.49$) or a* and b* (b* = 0.80a* + 12.4 with $R^2 = 0.67$), number of couples = 4548. The lighter the wood, the less red and less yellow it is. However, the scatter is considerable especially in the relation between L* and b*.

A major defect in beech wood products is the presence of red heartwood, so it had to be characterised. This was done by observing, for each board, the variation patterns of colour parameters from pith to bark. Figure 3 shows typical patterns observed on pairs of opposite boards. Usually, there is a similar variation pattern of colour parameters from pith to bark in the north and in the south directions for the same log: either no or very few radial variations like in (a) or a pronounced change in the central portion of the stem like in (b), indicating the presence of red heart. The irregular case illustrated by (c) can be partly attributed to the eccentricity of the stem that prevented the symmetric cutting of the two boards. The two boards of (a) and the southern board of (c) are examples of "non-red heart" (NRH); whereas the two boards of (b) and the northern board of (c) will be classified as "red heart" (RH) boards.

3.2. Accounting for the Red Heartwood

To compare the colour of NRH and RH, we selected 5 successive positions near the pith, usually points 5 to 9 except in the case of red heart where we adjusted to the position of the darkest zone. The examples of selected zones are indicated by rectangles in Figure 3. It was also necessary to compare these NRH or RH to the wood close to the periphery. For each board, we selected the last 5 points (before the very last) nearest to the bark, as outer wood. These positions will be labelled as "peripheral wood" (PW). In Tables I and II the logs containing red heart were indicated by a non-zero value of redheart diameter D_{RH}. The lowest values correspond to the case of boards containing

Table I. Tree main data.

Stand designation	Tree nb	Log age	H (m)	BH (m)	DBH (cm)	Board type	RH %
A1	1	139	31.5	23	57	R	75.5
	2	130	31.5	24	55	R	57.8
(Austria)	9	–	30.5	20	57	R	67.3
high forest	10	131	33.5	23	52	R	50.0
	16	123	35	23.5	57	R	41.3
	18	112	30	23	51	N	15.9
	23	–	33	21	54	R	35.7
	27	150	32	19	56	R	36.4
	29	151	34	20	57	R	62.2
	30	–	35	18	63	R	36.5
Mean A1	–	134	32.6	21.5	56	–	47.9
S1	1	126	30.8	16.9	63	R	49.0
	11	55	36.9	9.8	55	N	7.1
(Switzerland)	14	75	23.7	12.7	55	RN	27.7
high forest	20	73	30.9	19.2	59	N	6.4
	25	–	36.3	22.2	61	RN	27.7
	26	100	36.3	18.2	58	N	0.0
	28	97	33.7	20.6	51	N	0.0
	33	115	35.9	18.2	64	N	0.0
	37	118	38	22	52	N	23.3
	39	–	37.4	20.8	52	RN	27.9
Mean S1	–	95	34	18.1	56.9	–	16.9
G1	3	125	34.3	19.8	53	R	30.6
	4	123	40.8	23.5	58	N	14.6
(Germany)	6	123	35.9	22.1	60	R	50.0
high forest, narrow spacing	7	125	40	19.6	54	R	53.2
	9	121	39.1	14.9	60	N	0.0
	11	120	33.8	16.2	55	R	35.3
	13	111	31.1	14	51	N	23.8
	15	116	35	19.9	51	RN	27.5
	19	121	36.1	21.4	53	R	35.4
	20	117	33.6	19	57	R	34.0
Mean G1	–	120	36	19	55.5	–	30.4
D1	3	101	42	27	64	R	28.6
	7	98	33	19.2	57	N	0.0
	8	101	31.5	18	63	N	9.4
(Denmark)	10	88	36	18.6	48	RN	11.1
high forest	11	93	37.2	19.2	66	R	35.8
	12	106	37.5	22.5	58	R	25.0
	32	107	32.1	18	61	N	17.6
	35	102	39.3	23.4	67	R	34.6
	42	106	33	19.5	63	R	52
	45	99	33.9	19.5	59	N	23.4
Mean D1	–	99	35.8	20.6	60.5	–	20.6
F1	2	–	35	20	52	N	17.6
	5	96	34	22	51	N	0.0
(France)	6	96	37	24	56	N	17.4
high forest	12	104	35	20	59	N	0.0
	20	95	38	25	54	N	0.0
	21	–	40	20	57	N	10.0
	22	105	36	26	62	N	0.0
	28	100	35	24	64	N	0.0
	33	–	39	24	57	R	33.3
	43	97	32	20	54	R	34.0
Mean F1	–	99	36.1	22.5	56.6	–	11.2
A2	51	123	31	17	53	R*	26.7
	52	126	31	16	51	R	45.3
(Austria)	82	131	35	22	50	RN	21.8
mountain forest, with slope	86	124	33	19	47	R	47.6
	89	121	34	22	47	R	37.2
	90	123	33	17	53	RN	17.4
	94	105	33	21	49	N	12.8
	95	–	32	17	50	R	30.8
	96	118	31	14	49	R	33.3
	99	121	31	18	48	R	39.0
Mean A2	–	121	32	18.3	49.7	–	31.2
S2	56	159	39	22	49	N	0.0
	57	–	41	25	54	N	17.8
(Switzerland)	63	158	37	25	60	N	0.0
mountain forest, with slope	64	158	37	19	68	R	29.5
	65	156	37	26	54	N*	28.6
	74	158	38	14	63	RN	23.2
	78	153	42	26	56	RN	22.0
	80	153	42	24	63	RN	18.5
	85	158	40	22	59	N	14.7
	86	–	39	16	59	RN	21.2
Mean S2	–	157	39	21.9	58.5	–	17.6
G2	57	117	38	32	60	RN	25.2
	59	111	36	19	62	N	0.0
(Germany)	64	116	36	22	61	RN	23.0
high forest, large spacing	70	121	37	24	69	R	39.6
	73	120	42	24	71	R*	12.7
	79	119	42	22	83	Not cut	
	89	–	37	20	55	R	40.4
	94	111	43	21	69	N	0.0
	97	–	38	23	55	R	53.0
Mean G2	–	116	39	23	65	–	24.2
G3	107	174	39	25	73	R	39.2
	113	166	34	21	73	R	56.8
(Germany)	120	186	37	24	85	R	49.3
middle forest large spacing	122	177	41	25	75	R	30.2
	125	171	37	23	84	RN	22.1
	131	141	30	18	64	R	38.5
	133	–	33	19	67	RN	17.6
	150	142	31	14	77	R	26.7
Mean G3	–	165	35	21.1	74.8	–	35.1
Mean All	–	122	36	20.6	58.8	–	26

Log age: number of year rings measured on the bottom log used for the study; the total age of the tree is about 20 years more than the bottom age; DBH: Diameter at breast height, H: Tree height; BH: "Base" height or distance from soil to living crown; Board Type: Board considered as having Red Heartwood (R) or not (N) and (RN) have the two kinds of boards (three boards have been excluded); "% RH" Percentage of red heartwood (red heart width / board width); "–": missing age data and "*": one of the board is excluded. Log 79 was too large to be sawn.

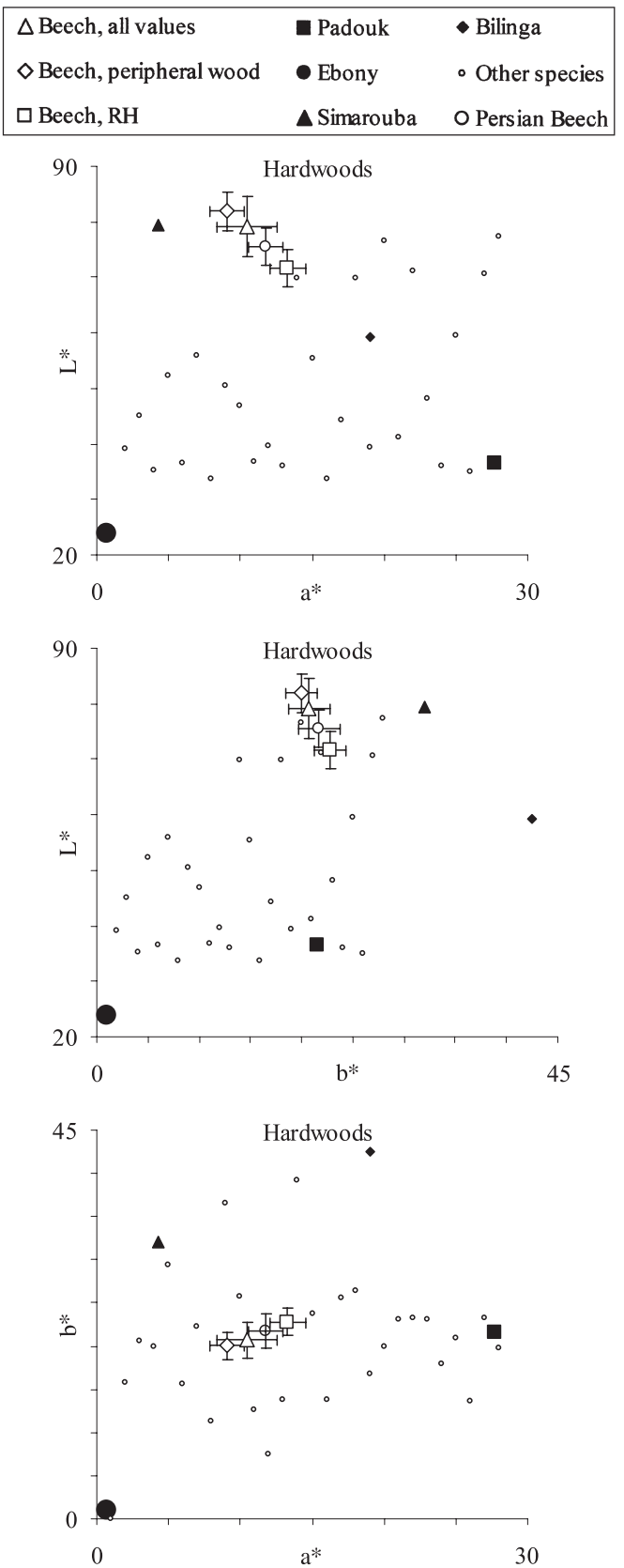

Figure 2. Beech colour compared to that of other hardwoods.

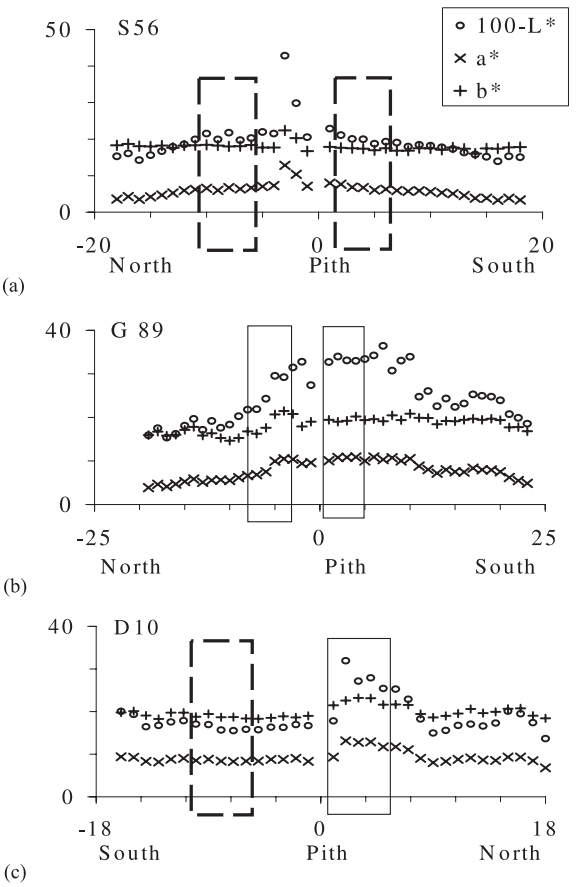

Figure 3. Examples of variation patterns from pith to bark of colour parameters: (**a**) type NN (a Swiss tree); (**b**) type RR (a German tree); (**c**) type RN (a Danish tree).

too few red heart positions to be classified as RH boards. In addition a "type of board" column indicates with "R–R" a log with two RH boards, with "N–N" a log with two NRH boards and with "R–N" a log where both boards are of different type.

Figure 4 shows the relation between the colour of PW and corresponding RH or NRH, depending on the case; each point is obtained by averaging the 5 selected positions. RH is systematically darker (9.6 ± 3.6), redder (3.9 ± 1.3) and more yellow (2.7 ± 1.7) than PW, while no obvious difference is observed between NRH and PW, except for a few boards exhibiting very low level of PW redness. The relation between colour parameters is shown in Figure 5, separating the means of PW, RH and NRH for all boards. The considerable scatter in the relationship between L* and b* and between a* and b*, are tendencies that would have been observed when considering the whole range of values. RH forms a clearly distinct group, while NRH and PW are difficult to distinguish, except for NRH being slightly redder than PW. Red heartwood appears more or less in the continuity of normal wood in each case. Variance analysis indicated that the colour difference between RH and PW is significant at the 0.1% level for all colour parameters. Between NRH and PW the difference of a* is significant at the 0.1% level, that of L* at the 5% level; that of b* is not significant even at the 5% level.

Table II. Data for the 34 top logs (see legend in Tab. I).

Stand designation	Tree nb	Log age	Board Type	% RHW	Stand designation	Tree nb	Log age	Board Type	% RHW
A1	16	107	R	35.4	A2	86	102	R	46.3
	18	100	N	0.0		90	–	RN	20.7
S1	37	97	N	0.0	S2	56	145	N	0.0
	39	117	R	27.6		80	141	R	27.8
G1	3	114	R	30.4	G2	73	109	R	27.5
	13	99	N	0.0		79	119	R	43.1
D1	3	83	R	35.7	G3	107	166	R	36.1
	45	82	N	0.0		113	168	R	56.6
F1	21	–	N	9.0					

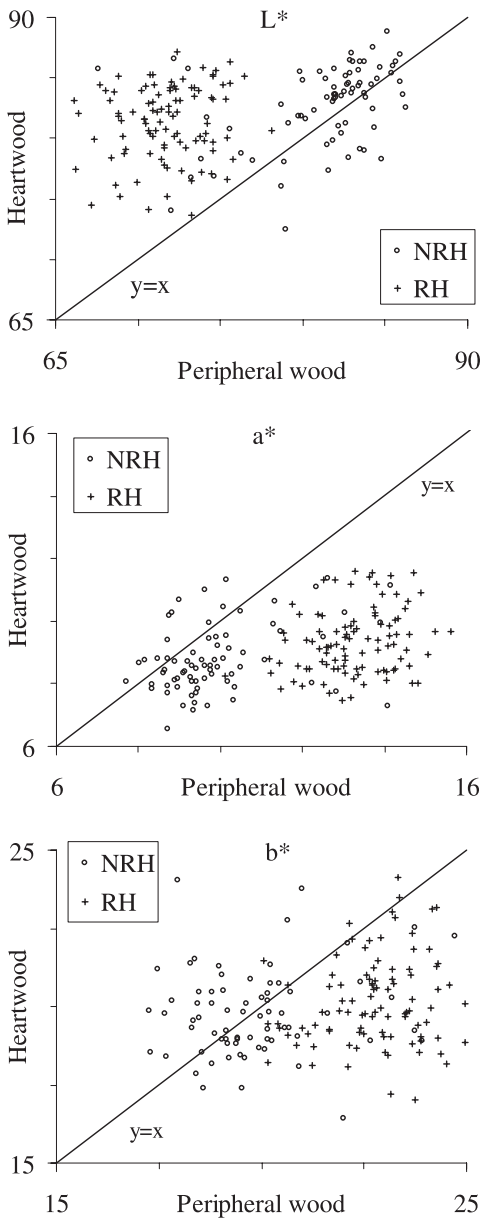

Figure 4. Relationships between peripheral wood and heartwood for L*, a* and b*, in mean per boards (74 points for NRH and 97 points for RH).

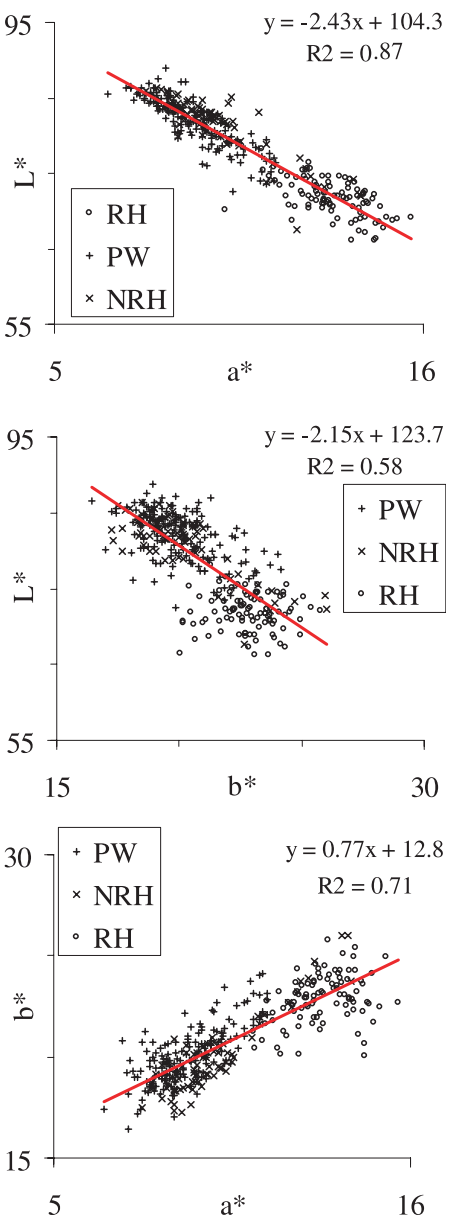

Figure 5. Relationship between L*/a*, L*/b* and a*/b*, separating peripheral wood (PW), red heartwood (RH) and non red heartwood (NRH) points (mean for 342 boards).

Table III. Mean and standard deviation per stand for peripheral wood values (10 points per tree).

		A1	D1	F1	G1	S1	A2	G2	S2	G3	All
L*	Mean	79.03	80.49	83.15	84.24	83.36	78.87	80.89	85.34	81.92	81.95
	Sd	3.33	2.68	2.39	1.36	2.42	2.85	3.89	1.73	3.23	3.48
a*	Mean	9.60	9.44	8.76	8.30	8.55	10.36	9.61	8.00	9.42	9.10
	Sd	0.93	1.02	0.71	0.60	1.02	0.88	1.27	0.69	1.29	1.19
b*	Mean	19.82	20.15	19.52	18.91	19.84	21.06	20.33	19.59	21.27	20.02
	Sd	1.32	1.46	1.05	0.92	1.51	1.62	2.05	0.86	1.46	1.55
C	Mean	22.03	22.26	21.39	20.66	21.61	23.48	22.5	21.16	23.28	22
	Sd	1.54	1.73	1.19	1.04	1.72	1.78	2.31	0.93	1.73	1.81
H	Mean	64.2	64.95	65.85	66.32	66.73	63.79	64.73	67.79	66.17	65.62
	Sd	1.23	1.14	1.16	0.96	1.59	1.30	1.76	1.62	2.21	1.91
Nb values		100	100	100	100	100	100	80	100	80	860

Table IV. Mean and standard deviation per stand for all radii values measured on bottom logs.

		A1	D1	F1	G1	S1	A2	G2	S2	G3	All
L*	Mean	75.70	79.50	81.20	80.38	81.68	76.43	77.21	81.95	77.00	79.05
	Sd	5.32	4.35	4.32	5.41	4.66	4.34	5.30	4.67	5.87	5.45
a*	Mean	11.10	10.15	9.59	9.72	9.23	11.68	11.32	9.83	11.49	10.44
	Sd	2.00	1.75	1.50	1.89	1.56	1.88	2.07	2.01	2.25	2.09
b*	Mean	21.03	20.74	19.91	19.86	19.80	21.99	21.72	20.13	21.50	20.72
	Sd	2.03	2.05	1.86	1.88	1.65	1.90	2.37	1.33	1.92	2.06
C	Mean	23.80	23.11	22.11	22.14	21.87	24.92	24.52	22.45	24.43	23.23
	Sd	2.66	2.58	2.25	2.46	2.06	2.45	2.93	1.95	2.52	2.67
H	Mean	62.38	64.09	64.38	64.13	65.12	62.18	62.65	64.20	62.09	63.48
	Sd	2.51	1.87	2.04	2.59	2.43	2.43	2.64	3.55	3.66	2.92
Nb values		429	439	423	444	416	400	369	458	461	3839

Table V. Analysis of variance for the 3 colour parameters L*. a*, b*.

	Source of variation	df	SS	MS	F	*P*-value
L*	Among stands	8	412	51.5	11.83	8E-11
	Within stands	77	335.2	4.354		
	Total	85	747.3			
a*	Among stands	8	45.37	5.671	11.39	2E-10
	Within stands	77	38.32	0.498		
	Total	85	83.69			
b*	Among stands	8	41.68	5.21	4.423	2E-04
	Within stands	77	90.71	1.178		
	Total	85	132.4			
Critical value for F (0.1% level)					3.723	

At this point, a comment can be made concerning the denomination of red heartwood. In the case of a board with red heart, this higher level of redness in the heart, a tendency already observed in normal situation, is exacerbated. However, the systematic observation of radial profiles suggested that the transition between the so-called "red heartwood" zone and the "normal" zone is often sharper with respect to lightness than to redness. Therefore, the qualification of "dark" can be as appropriate as that of "red".

3.3. Variations among trees and stands

There exist significant differences among the 9 stands and among trees in each stand. The grouping of trees or stand is not always the same depending on the chosen colour parameter.

Tables III and IV give, for each of the 9 stands, the values of mean and standard deviation of the five colour parameters L*, a*, b*, C* and H*. Table III presents the values obtained for the only 10 peripheral positions labelled PW (10 per log); as a comparison Table IV gives the mean of all radial positions in the bottom logs. Mean values of L* are higher while those of a* and b* are lower, when peripheral values are compared to all measured values. Additionnaly standard deviations are all increased (more than 60% for L* and about 75% for a*) when comparing peripheral and all values. This strong variation is due to the occurrence of red heartwood that produces a darker and redder wood.

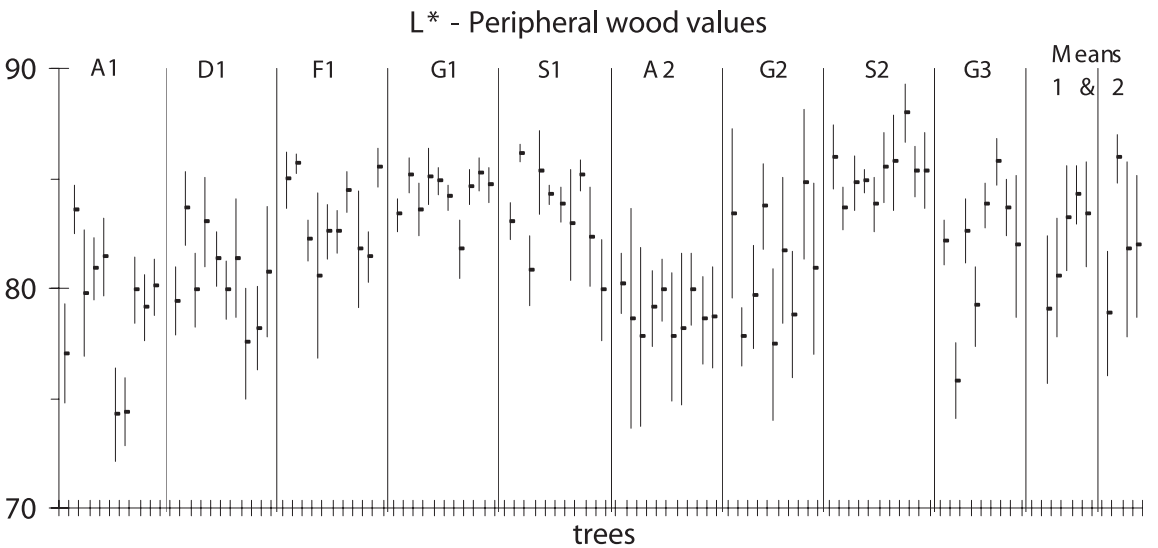

Figure 6. Mean colour for brightness for peripheral wood values per tree.

Figure 6 illustrates these variations of colour for L* only on the peripheral positions. Each vertical bar corresponds to the bottom log of one of the 87 trees tested, with the black mark giving the mean and the half-length of the bar the standard deviation. The trees are grouped by stands, separated by vertical dotted lines. The means and standard deviations of the 9 stands are grouped on the extreme right of the graph.

These graph and tables evidence a highly significant stand effect (at the 0.1% level). For instance the wood from stands D1, F1, G1 and S1 appears lighter, less red and less yellow than that from stands A1, A2, S2. There is also a clear tree effect within some stands, made apparent in the figure (e.g., stands A1, S1). Table V presents the ANOVA.

3.4. Differences of the colour parameters among positions in the stem

The colour parameters of boards coming from the north (N) and the south (S) directions of the same log were not significantly different even at the 5% level. We also compared logs situated in the height of 4 m (bottom) and 9 m (top) in the stem. When only the peripheral wood values were considered, the difference between colour parameters was not significant even at the 5% level; Figure 7 shows the absence of log-by-log colour differences.

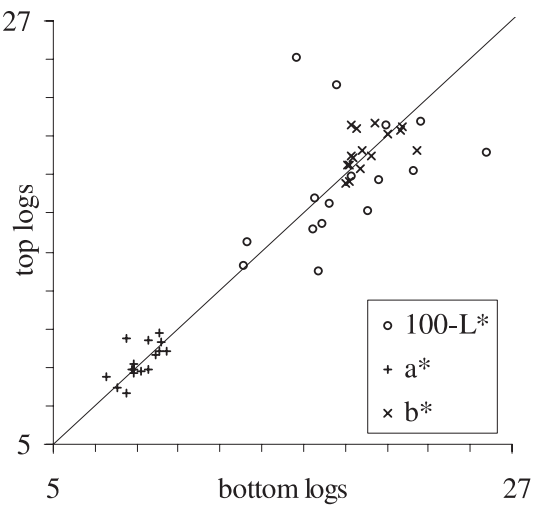

Figure 7. Comparison between bottom and top logs (16 trees).

4. CONCLUSION

Different variance analyses have put in evidence both a stand and a tree effect on colour variations for beech wood. At the first level this is true for the occurrence of red heartwood inside of the logs. Although the number of stands is small, it seems that stand effect is a very important parameter for red heartwood development. But stand effect in our case is a complex mixture of soil, climate, age and silviculture management. When putting aside the red heartwood there is still both a highly significant effect of stand and tree on peripheral wood colour. Besides, the differences remain very low inside one tree from bottom to top, north to south, and from outside to inside (except very near the pith or in case of red heartwood). Thus it is possible to sort or select on colour components rather easily at early stage from periphery, or from increment cores [5]. This can be used either by foresters or by industry depending on the objective.

Red heartwood is strongly darker, redder and more yellow than peripheral wood. Including or not the red heartwood there exists very strong relationships between colour components of beech wood, mainly for the couples L*/a* and a*/b*.

In order to use also beech red heartwood it seems necessary to sort it away and to use it separately because the colour differences are very high and remain high after heating.

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