WITHIN-TREE VARIABILITY OF WOOD COLOR IN PAPER BIRCH IN QUÉBEC

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Abstract. Color variations in paper birch wood were examined in boards sawn from sawlogs from 168 trees harvested from two different stands. Approximately 2250 boards were sawn from the logs. The within-tree variability was considered by looking at the effect of log quality and log height class on board color. Results show that neither the log quality nor the log height class had a significant effect on the proportion of discolored wood on the surface of the board. However, these log parameters had an effect on the wood colorimetric variables. Log position in the tree was found to significantly influence sapwood yellowness as well as discolored wood luminosity and redness. Log quality on the other hand significantly influenced only one colorimetric factor, sapwood redness.

Keywords: *Betula papyrifera* Marsh., sapwood, discolored wood, log quality, log position, colorimetry, color scanner.

INTRODUCTION

The lack of availability of quality high-value hardwoods traditionally used by the Québec sawmilling industry has recently spurred new interest in alternative, underutilized species

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such as paper birch (*Betula papyrifera* Marsh.). Paper birch is the highest volume hardwood in Québec and it has wood characteristics that make it an attractive raw material for many uses. Its sapwood presents uniform anatomical features forming a homogeneous and pale wood that is appreciated for applications in which visual quality is important. However, the frequent occurrence of a red heart in paper birch trees results in the production of boards in which there is often a simultaneous presence of sapwood and discolored wood of a darker reddish brown shade. This contrast in coloration reduces the value of the boards and creates a challenge for the manufacturers who want to produce homogeneously colored wood products.

The reddish brown discolored wood frequently found in paper birch trees is most often described in the literature as traumatic heartwood (Campbell and Davidson 1941; Shigo 1967, 1986; Siegle 1967; Shigo and Larson 1969; Shigo and Hillis 1973; Basham 1991; Allen 1996; Hallaksela and Niemistö 1998; Boulet 2005). According to most of these authors, a succession of events involving abiotic and biotic factors is responsible for this discoloration and a triggering event stressing the tree is needed for them to take place. Most of the time, broken branches and, to a lesser extent, stem wounds seem to be the responsible agents. According to Shigo and collaborators, the sequence of events is as follows. First the injured area exposes wood cells to the external conditions and constitutes a way of entrance in the tree for air and microorganisms. An initial discoloration appears in reaction to these injured cells and a chemical barrier is formed to create a protective zone to prevent infection. A second stage of the process may happen when bacteria and nondecay fungi invade this wounded area that can induce more discolorations. This part of the discoloration process can be explained by oxidation reactions catalyzed by the enzymes produced by the fungi (Campbell and Davidson 1941; Siegle 1967). Finally, the process could go to a third stage if decay fungi invade the area and degrade the wood (Shigo and Hillis 1973).

Although often cited as the main defect in paper birch (Campbell and Davidson 1941; Basham 1991; Brière 1992), red heartwood is not necessarily considered undesirable by the industry in that boards completely covered by red heartwood are sold at higher prices (Hardwood Market Report 2009). The presence of red heartwood becomes problematic when it intermingles with sapwood on the board in an inconsistent pattern or manner. Thus, the real problem is not the color per se, but the lack of color consistency within a board that makes it more challenging to match components and to apply finishes in mass production.

In this hardwood products manufacturing context, colorimetry appears as a useful quality control tool to help control (or monitor) inconsistent color variations and sort wood color objectively and rapidly. The CIE L*a*b* color space is the most common system used to describe colors objectively (Hunter Lab 2008). In this three-dimensional colorimetric space, the L* coordinate quantifies the luminosity of the color and the a* and b* coordinates are chromatic values that define the position of the object on the red–green axis (a*) and the yellow–blue axis (b*). In industrial applications, these colorimetric parameters help to quickly and objectively detect slight color changes in wood and therefore allow better sorting of the material during manufacturing.

A previous part of this study confirmed that tree age, dimension, and vigor had a certain effect on paper birch wood color in general and on the proportion of traumatic heartwood in boards (Drouin et al 2009). Tree age and tree diameter were found to be the most important variables affecting paper birch colorimetric parameters, whereas tree vigor and tree diameter were two significant variables controlling the fraction of discolored wood in boards. To summarize, larger diameter trees and less vigorous trees had more discoloration within their boards. The effect of tree age and tree diameter was variable among the colorimetric parameters (L*a*b*) for the sapwood and discolored wood zones. Whereas this information about intertree variations helped to understand how wood coloration is linked to the status of the trees and how it is induced in the tree, this second part of the study aims to improve our knowledge about the dispersion of wood coloration within the tree. The present study examines the relationships between log characteristics and wood colorimetric parameters.

Prior research provided information about the dispersion of red heart in birch stems. A study on the distribution and sources of initiation of red heart in paper birch found that the discoloration column increases in diameter from the breast height (1.3 m) to a maximum diameter at 3 – 4 m (Belleville et al 2008). In more than 77% of the stem portions analyzed in Belleville et al (2008), the discoloration was initiated from an external defect confirming the traumatic nature of red heart. The vertical distribution of red heartwood in paper birch was also studied by Giroud et al (2008). It was found that for 18 paper birch stems, red heartwood had a spindle shape for 14 trees and a conical shape for 4 trees.

The stem discoloration in planted silver birch (*Betula pendula* Roth.) was investigated in another study (Hallaksela and Niemistö 1998). The results showed that discoloration was present in most of the birch, either in a central column around the pith or in independent areas outside the pith. The highest frequency of discoloration in the pith was at a relative tree height of 2.5%, which corresponds to an average of 0.46 m height. This discoloration spread to a height of 6 m in one-half of the mature stems. The cross-sectional area of the pith discolorations had a diameter of less than 40 mm in most cases (in 81% of the stems), whereas it was about 9 – 11 mm for the discolorations located outside the pith. The most typical distributions of the discolored areas in the stem had a spindle shape, with or without branch discolorations connected to it, with a maximum cross-sectional area when approaching 1 m height. Discoloration outside the pith was found in 25% of the sampled discs. When the trees were separated in three age classes, the discoloration areas outside the pith were more frequently found in butt logs for the 18- to 29-yr-old birch, in the second log (between 4.5 – 8.5 m) for the 30-yr-old birch, and in the top sections of the mature birch. More than one-half of those discolorations were found in the branches, which supports the theory that broken branches would be a way of entrance of microorganisms responsible for the color changes in wood.

The color of Scots pine wood was studied and it was demonstrated that the sampling height within the tree had a significant influence on color of both heartwood and sapwood (Grekin 2007). When the log position in the tree increased in height, the wood had higher luminosity values. Differing results were found in a study on the variation of the color parameters of European beech (*Fagus sylvatica*) (Shengquan et al 2005). The color of bottom (4 m) and top (9 m) logs were compared and no significant differences were found for the peripheral sapwood.

Log quality, which is partly assessed by the presence of defects on the log surface and cross-cuts, is another factor to analyze in relation to paper birch wood color given that log quality determines the value of the wood traded from public land in Québec. Therefore, developing more knowledge about the distribution of wood color among the boards produced from different log quality classes becomes relevant.

In Québec, log quality is determined according to a log grading system used by the Québec Ministry of Natural Resources (MRNFQ 2007) in which logs are classified as Class A, B, C, D, or E. In this classification, the log dimensions (length and diameter) and log defects (knots, curves, holes, decay, splits, etc) are the main criteria to identify the proportion of usable wood that determines log quality. Class A is the highest quality class. It regroups logs that are large and having allowable defects to be used for veneer. Class B is a sawlog grade that requires logs of the same dimensions as Class A, but more defects are accepted and minimum size cuttings are defined. Class C is also a sawlog grade, regrouping logs that have smaller minimal dimensions than Class B logs, smaller minimal size cuttings, and more defects. Finally, all logs that do not meet the minimal requirements of A, B, and C classes are in Class D for pulp production or can be retained as nonconventional logs (short logs) in Class E. This provincial log grading system is based on an older classification system developed by Petro and Calvert (1976). This system is based on three main classes for the sawing of quality logs (F1, F2, and F3), a short log class (F4), and does not have veneer or pulp-quality logs. To assess log quality, the Petro system is also based on log diameter and length, and the number of clear cuttings and their length, but also takes into consideration the log position in the tree.

Discolored wood has an impact on the result of the log classification only when it is at a stage of decay. When evaluating the cross-cut sections, discoloration downgrades the logs only if the decay is at an intermediate stage (physical and chemical alteration of the fibers) or an advanced stage (softening and collapse of the wood structures). It must moreover cover an important part of the log cross-sectional area to be considered, meaning that both internal and external zones of the cross-sectional area must be affected. Discoloration or decay that is limited to the central core or to only one zone does not affect the classification. When the two cross-cut sections of the logs are affected by an advanced or intermediate stage of decay on two quality zones, no clear cutting can be calculated and the log is allocated to the pulp grade. On the other hand, if only one cross-cut section is affected by decay, the clear cutting is considered to be on one-sixth of the total log length.

This article aims to assess the variation of coloration of paper birch wood as a raw material for the wood appearance products industry. After looking at the between-tree color variability in a previous study (Drouin et al 2009), between-log variation is now considered to get more information about within-tree color variability. The objectives of this study are to evaluate the effect of log quality and log height class on the percentage of discolored wood per board and on the colorimetric variables of paper birch sapwood and discolored wood.

Accordingly, the following hypotheses were set for this study. First, concerning log height class, it is expected that boards sawn from lower logs will have more discoloration than the upper logs given that previous studies found that the discolored column was a spindle shape in birch trees (Hallaksela and Niemistö 1998; Belleville et al 2008; Giroud et al 2008). Second, according to the theory of the traumatic nature of red heartwood, lower quality logs, which are believed to have more external defects, are expected to produce more discoloration in the boards.

MATERIALS AND METHODS

To evaluate the influence of the log-related factors on the color of paper birch, the same material and methods used in the previous paper (Drouin et al 2009) were utilized.

The 168 trees under study were collected in two different stands located in the north of the Laurentian region in Québec. These two stands were located less than 1 km from each other on the same ecological site type (*MJ22*: Bétulaie jaune à sapin sur dépôt de texture moyenne mésique [yellow birch-fir forest on loamy or midtexture and well-drained soil]) (Gosselin 2002). In both stands, paper birch stems were left as standing trees after partial cuttings to harvest softwoods approximately 40 – 50 yr ago. Tree selection was conducted using the MSCR classification (Boulet 2005). This classification established by the Québec Ministry of Natural Resources and Wildlife determines tree vigor based on external tree defects. Trees classified as M (*mourir*) standing for *dying stock* and S (*survie*) standing for *surviving stock* correspond to the less vigorous trees. Trees classified as C (*conserver*), standing for *growing stock*, and R (*réserve*), standing for *premium growing stock*, are assigned to the most vigorous trees. These MSCR classes correspond to priorities for harvesting, M being the highest priority.

From the first stand, harvested in March 2005, 100 paper birch stems were selected. The trees were felled but then left in the forest unprocessed until June 2005 when they were cut into logs following optimized bucking based on Petro and Calvert's (1976) rules for log quality. A total of 130 saw logs and short logs (F2, F3, F4) were obtained, and 131 logs were pulpwood (P). The sawing-quality logs, short logs, and veneer logs originated from 68 trees and only those logs were retained for the study. More than 1400 boards were sawn at a hardwood sawmill in June 2005.

The same procedure was repeated in the fall of 2007 for the second stand in which 68 paper birch trees were selected in August 2007 and harvested at the beginning of October 2007. After the optimized bucking that occurred in mid-October, 84 saw logs and short logs (F2, F3, F4) and one veneer log were obtained (from 55 different trees); the other 101 logs produced were pulpwood (P). The saw-quality logs were sawn at the beginning of November 2007 with more than 800 boards produced. Age of the trees ranged 46 – 154 yr and were 24 – 66 cm dia. Vigor classifications were M (32%), S (26%), C (22%), and R (20%).

The 215 logs obtained after bucking had an average length of 2.78 m, ranging 1.92 – 5.20 m. The average small-end log diameter was 0.26 m, whereas it was 0.30 m for the large end. Almost one-half of the logs were butt logs (49.3%); the remainder were second (32.1%), third (14.9%), fourth (3.3%), and fifth (0.5%) logs.

When log quality was assessed by the Petro classification system, the highest proportion of the logs (69.8%) was in the lowest sawlog category (F3), whereas 17.7% were in the second quality sawlog category (F2) and 12.1% were short logs (F4). No log reached the highest sawlog quality (F1).

Log quality also was determined using the provincial classification system (MRNFQ 2007). One-half of the logs (48.8%) were classified in the lowest sawlog category (C), whereas 21.9% were in the intermediate category (B). Only 0.5% was in the veneer quality category (A). Some logs in the lowest sawlog grade (F3) in the Petro classification were classified as pulp logs in the MRNFQ system. For this study, they were included with short logs (E) and this category (D – E) represented 28.8% of the logs (Fig 1).

A total of 2284 boards from these 215 logs were the research material for this study. Board dimensions were variable, 1.2 – 3.6 m long and 76 – 330 mm wide. All boards from both stands were dried in a conventional kiln in the month after sawing. A mild schedule with a maximum dry-bulb of 60°C was used to limit color change and checks (Normand 2004). Boards were surfaced with a molder (Weinig Unimat *23 EL*) to get a fresh and clean surface to study wood color.

The colorimetric information for each board was collected using the BoréalScan (Caron 2005), an industrial scanner developed for the wood furniture industry by CRIQ (Québec's industrial research center). The complete methodology used to obtain this information is described in Drouin et al (2009). The percentage of discoloration per board and the colorimetric values of the sapwood and discolored wood zones were obtained through a segmentation of every image using software developed for the scanner, CRIQTraitement.

The mean color of each board, and each sapwood/discolored region, was determined by the CIE L*a*b* color system (Hunter Lab 1996). The colorimetric values (L*a*b*) and the proportion of sapwood/discolored wood were analyzed

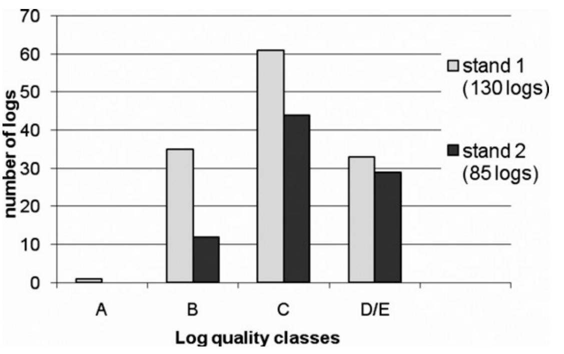

Figure 1. Log quality distribution according to the Provincial classification (MRNFQ 2007).

statistically using SAS software version 9.1 for Windows (SAS Institute 2003). Multiple regression was used to test and simultaneously model the effects of log quality and position in the tree on these dependent variables. A mixed model procedure was used to take into consideration the random effects associated with the hierarchical nature of the data set, ie board, log, tree, and stand associations. The significance threshold used in this study was $\alpha = 0.05$.

RESULTS AND DISCUSSION

Proportion of Discolored Wood

The effect of the log position and log quality on the proportion of discoloration in paper birch boards was considered. It was found through the statistical analysis that neither the log quality nor the log position in the tree induced significant differences on the proportion of red heart (discolored wood) in the boards analyzed. It can be noted that both log grading systems (Petro and Calvert 1976; MRNFQ 2007) have been evaluated in separate statistical mixed models and the conclusions were the same for both (Table 1).

It was hypothesized that log quality would affect the proportion of discoloration in the boards, but this was not confirmed by the statistical results. Therefore, the choice of logs based on quality classes should not influence the presence of discoloration in paper birch boards. In other words, this study was not able to establish a clear link showing that boards coming from lower quality logs have a higher fraction of red heart. This outcome suggests first that the proportion of discoloration in the logs was not the main factor degrading them, or second that the defects that degraded the logs were not related to large proportions of discoloration. Moreover, it is noteworthy to remember that there were few high-quality logs (veneer logs or F1 sawlogs) in this study. It would be interesting to study more logs to determine if their boards have less discoloration.

Log quality directly affects forest royalties paid to the provincial government by the industries operating on Crown land. Royalties are calculated considering the pricing zone and the log quality and adjusted each quarter to the market prices (MRNFQ 2008). Table 2 shows the average prices for the 187 provincial pricing zones for paper birch standing volumes in the fall of 2008. It can be observed that the wood prices vary greatly among log qualities, especially for the A class that is approximately 16 times greater than the highest sawing quality class (B). Between the two principal sawing quality Classes B and C, there was a difference of Can\$3.5/m^3. Therefore, because a change in log quality does not relate to significant changes in the proportion of discolored wood in boards, companies buying lower quality sawing logs do not necessarily have to expect higher proportions of discoloration in their raw material.

To get a deeper understanding about the wood quality evolution, the link between tree vigor and log quality was studied (Fig 2). It can be seen in Fig 2, where the proportion of logs of each quality is given for every tree vigor classes (MSCR classification), that there is no clear trend showing that the less vigorous trees produced logs of lower quality. On the contrary, the highest proportion of the higher quality sawlog (B) was found in the least vigorous tree category (M). These same trees also produced the

Table 1. *Effects of the independent variables on the colorimetric parameters (Pr > F).*

Variable	L* Sapwood	a* Sapwood	b* Sapwood	L* Discolored wood	a* Discolored wood	b* Discolored wood	Percent of discolored wood
Log position	0.5817	0.6885	<0.0001*	0.0016*	0.0021*	0.3522	0.1531
Log quality MRNF	0.5855	0.3317	0.1207	0.1344	0.0006*	0.2908	0.3583
Log quality Petro et Calvert	0.3317	0.8562	0.1232	0.1177	0.0004*	0.3428	0.3283

* Significant effect of the independent variable on the dependant variable ($p < 0.05$).

Table 2. *Market value of standing paper birch timber in Québec for the Fall 2008 quarter.*

Paper birch quality classes	Mean	Maximum	Minimum
	($/m^3 Canada)		
A	28.6	75.5	21.9
B	4.5	19.8	3.2
C	0.5	5.4	0.2
D, E	0.2	0.2	0.2

Source: MRNFQ, 2008.

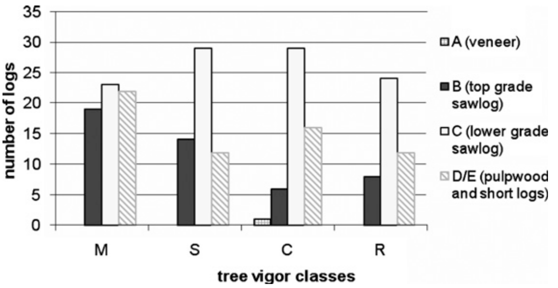

Figure 2. Relation between log quality and tree vigor (M = dying stock, S = surviving stock, C = growing stock, and R = premium growing stock).

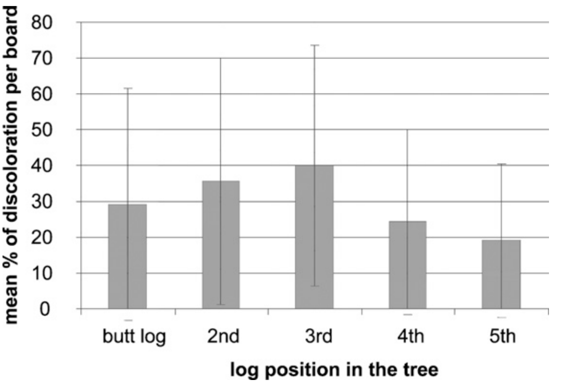

Figure 3. Average percentage of discoloration per board in relation to log position in the tree.

highest proportion of the lowest quality logs (D – E) and the lowest proportion of medium-quality logs (C). These results are in accordance with the results presented in the previous paragraph, ie just as high-quality logs did not guarantee to obtain less discoloration in boards, a better quality tree, determined by the MSCR classification, does not assure high-quality logs after bucking. Once again, if more high-quality logs were studied and if the pulp logs were kept in the process, we might have obtained different results.

The relationship between the proportion of discolored wood in paper birch boards and the log position in the tree was assessed as well in the model and as noted previously, no significant effect was found. It was hypothesized that a relationship would exist between these variables because previous studies observing the distribution of the red heart in birch stems have found that this discoloration column does not have a perfect cylindrical shape from the bottom to the top of the stem (Hallaksela and Niemisto 1998; Belleville et al 2008; Giroud et al 2008). Consequently, according to earlier findings, the expectation was that there would have been more red heart in the butt logs where spindle-shaped discoloration was at its maximum diameter. This hypothesis was not supported by the results of the present study. However, when the proportion of discoloration per board is plotted against log height class, a trend can be observed in which more discoloration is found in the second and third logs (Fig 3), positions that are closer to the tree crown where the discoloration processes are believed to start. The standard deviations associated with these values are large with coefficients of variation of 84 – 113%, making it difficult to draw statistical conclusions.

Colorimetric Observations

The effects of the log position and log quality (MRNFQ 2007) on the board colorimetric parameters were evaluated. The results are summarized in Table 1. It can be seen that the color of the discolored wood areas was slightly more influenced by the log variables than the color of sapwood. Also, log position influenced more colorimetric variables than log quality in both systems (Petro and Calvert 1976; MRNFQ 2007).

The log position in the tree had a significant effect on sapwood yellowness (b*). Significant differences were found among log positions 1 – 2, 1 – 3, 1 – 4, 1 – 5, 2 – 3, 2 – 5, and 3 – 5.

The relation shows that when going higher in the tree, paper birch gets yellower (Fig 4). The luminosity (L*) and redness (a*) of sapwood was not influenced by the log height class. Similar results were obtained for beech wood (Shengquan et al 2005) in which no effect of the position in the tree on the colorimetric parameters was found. Conversely, for Scots pines, the luminosity of the wood increased when going higher in the tree (Grekin 2007).

The effect of the log position on the color parameters of the discolored wood zones was significant for the luminosity and redness parameters. Significant differences were found between the first and second log positions and the first and third positions for the luminosity and redness (Fig 4). According to the statistical results, the bottom log tends to have a higher luminosity and lower redness than the second and third logs. Among discolored wood zones, yellowness was not significantly affected by the log height class in the tree.

The differences in log quality showed a significant difference in only one of the six colorimetric parameters, redness (a*), of the discolored wood for both grading systems (Petro and Calvert 1976; MRNFQ 2007). In the provincial system (MRNFQ 2007), the results show significant differences between the redness of the A and D log classes, the B and C classes as well as between the B and D class logs. In both cases, the B class logs produced wood that was redder than the C and D classes (Fig 5). These data do not permit us to conclude that there is an important effect of log quality on the color of paper birch boards.

However, the relatively small variations detected in sapwood yellowness, in discolored wood luminosity, and in redness in tree height and between log classes can still be distinguished by the human eye when boards are put side by side, which emphasizes the difficulty of matching wood components in secondary manufacturing processes.

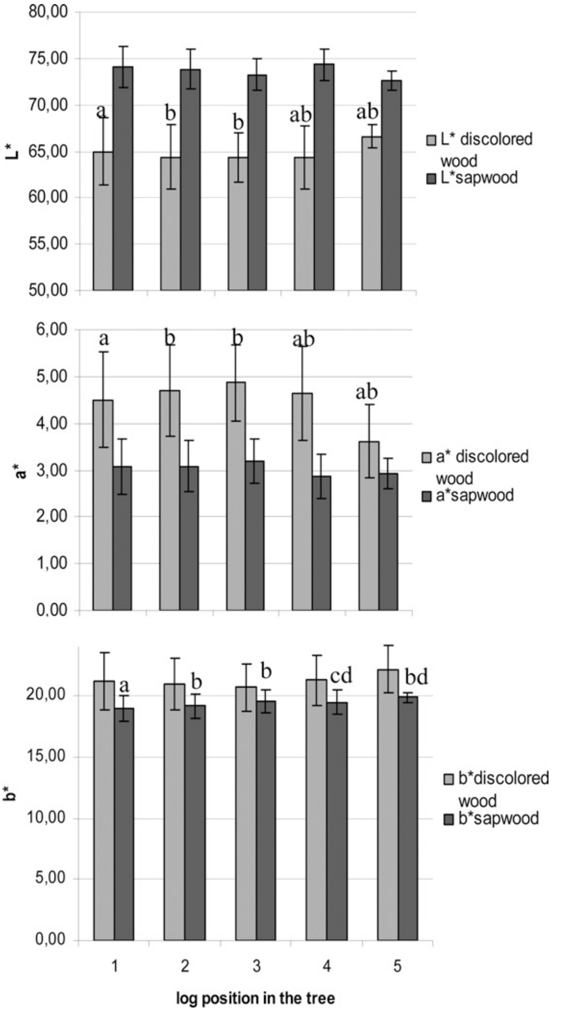

Figure 4. L*, a*, and b* color parameter in relation to log height class (average and standard deviation).

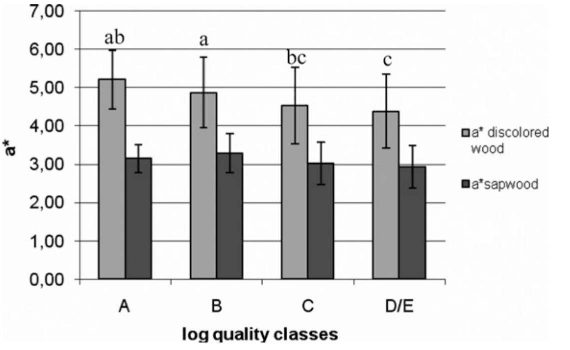

Figure 5. Wood redness (a*) in relation to log quality classes (average and standard deviation).

Random Variation

The hierarchical nature of the data set was taken into consideration in the model through the use of random effects. Through this procedure, the association among boards, logs, trees, and stands is considered in the distribution of the variance in the model. The between-stand, tree, log, and board variations were measured through the covariate parameters in which the between-board variation corresponded to the residual term (Tables 3 and 4). Based on the total random variation of the model, the most significant source of variation encountered was more often between the residual term and the tree effect. These results confirm, first, that taking into account the random variables helped to specify the model and that the fixed effects considered had a significant contribution in the model. Second, the high percentages obtained for the residual term demonstrate that most of the measured variations come from the random variability between boards. The fact that the between-tree parameter was always significant indicates that there is an effect of the tree on wood colorimetric variables. In other words, boards coming from a same tree share some similarities in their colorimetric information. The log effect was found to be significant only for the b* sapwood parameter, whereas the stand effect did not play a significant role in explaining these color variations. This last result might be explained in that only two stands were evaluated. Consequently, there was too much uncertainty for this variable to be significant in the model. Sampling more stands would permit better determination of the site influence on wood color.

Table 3. *Covariance parameter estimates for the percentage of discolored wood per board.*

	Percentage of discolored wood		
Covariance parameters	Estimate	Percent	Pr > Z
Stand	0.04450	22.05	0.2435
Tree	0.03655	—	<0.0001*
Log	0	0	—
Residual (between board)	0.1208	59.84	<0.0001*

* Significant effect of the independent variable on the dependant variable ($p < 0.05$).

CONCLUSIONS

A previous study demonstrated how color of paper birch wood varies between the stems, where tree age, diameter, and vigor were studied. In this present study, the variation at the log level was analyzed to discover how the log properties are linked to the differences in wood color. The log position in the tree and the log quality were assessed as possible variables influencing paper birch board coloration and red heart distribution within these boards.

The results obtained lead to the conclusion that the log parameters evaluated had only a minor

Table 4. *Covariance parameter estimates for sapwood and discolored wood colorimetric values.*

	L*			a*			b*		
	Sapwood			Sapwood			Sapwood		
Covariance parameters	Estimate	Percent	Pr > Z	Estimate	Percent	Pr > Z	Estimate	Percent	Pr > Z
Stand	2.3825	42.35	0.2424	0.08307	22.52	0.2469	0.3450	29.13	0.2435
Tree	1.5310	27.22	<0.0001*	0.1526	41.37	<0.0001*	0.2627	22.18	<0.0001*
Log	0.0926	1.65	0.0131*	0.001486	0.40	0.2580	0.06807	5.75	<0.0001*
Residual	1.6187	28.78	<0.0001*	0.1317	35.70	<0.0001*	0.5084	42.93	<0.0001*
	L*			a*			b*		
	Discolored wood			Discolored wood			Discolored wood		
	Estimate	Percent	Pr > Z	Estimate	Percent	Pr > Z	Estimate	Percent	Pr > Z
Stand	4.2485	28.14	0.2434	0.4974	42.29	0.2407	0.1078	2.12	0.2712
Tree	3.4766	23.03	<0.0001*	0.06607	5.62	<0.0001*	0.6980	13.73	<0.0001*
Log	0.1540	1.02	0.1444	0.01465	1.25	0.0799	0	0	
Residual	7.2169	47.80	<0.0001*	0.5980	50.85	<0.0001*	4.768	84.15	<0.0001*

* Significant effect of the independent variable on the dependant variable ($p < 0.05$).

impact on the colorimetric characteristics of paper birch wood. It can be seen that neither the log position nor the log quality significantly influenced the fraction of discoloration in boards. Therefore, these results did not support the research hypotheses. When considering the L*a*b* values of the sapwood and discolored wood zones, some of these values were significantly influenced by log position and quality. Log position in the tree was found to significantly influence sapwood yellowness (b*) as well as discolored wood luminosity (L*) and redness (a*). Log quality on the other hand significantly influenced only the sapwood redness (a*). Because these variations were different between sapwood and heartwood regions, it is difficult to draw clear conclusions of the effect of log position and quality on paper birch wood color.

In practice, according to these results, buying logs of different quality is unlikely to substantially influence the proportion of red heart in boards. In other words, sawing lower quality logs did not produce boards with more discoloration. On the other hand, it has to be remembered that only the sawing quality material was retained following the log grading and only the usable boards were retained following the board grading step. This was done with the objective of evaluating the presence of discolored wood and the variability of the colorimetric parameters of paper birch of industrial quality in the context of birch utilization for appearance products. It can be hypothesized that if all the material was kept during all the steps, there could have been more discoloration in the boards produced. Moreover, it would have been interesting to process more of the high-quality "A logs" to determine if these logs, generally devoid of severe defects, would produce boards with higher sapwood proportions.

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