THERMAL MODIFICATION OF COLOR IN RED ALDER VENEER. PART II. EFFECTS OF SEASON, LOG STORAGE TIME, AND LOCATION OF WOOD IN STEMS

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ABSTRACT

The value of red alder lumber is diminished by discoloration caused by the enzyme-mediated polymerization of the diarylheptanoid xyloside, Oregonin that results in the formation of red-colored chromophores in freshly felled wood. This discoloration can be reduced by pre-steaming wood prior to kiln drying of lumber or veneer slicing, but in practice, there is still variation in the color of heat-treated wood, particularly in veneer sliced from heat-treated cants processed at different times of the year. There is seasonal variation in the concentration of Oregonin that is involved in the discoloration of red alder wood and it is hypothesized here that heat-treated red alder wood will be redder and darker when the wood is obtained from logs harvested during spring when the concentration of Oregonin is known to be higher than in other seasons. The aim of this research was to test this hypothesis, and also examine the effects of log storage time and location of wood in stems on the color of heat-treated red alder wood. The color of red alder wood subjected to an isothermal heat treatment at 70°C was strongly influenced by the season in which parent trees were harvested and the length of time that logs were stored prior to heat treatment of wood. In particular, wood harvested in spring and stored for 2 wk prior to heat treatment was significantly darker than similarly treated wood obtained from logs harvested in other seasons, and redder than wood harvested in summer and winter. If the storage time of logs harvested in spring and summer was extended to 4 wk, however, the heat-treated wood became lighter and less red. Heat-treated wood from the inner part of the logs was redder and darker than heat-treated wood from the outer part of the logs except occasionally, when the outer sapwood was obtained from logs harvested in spring or summer. Careful control of log storage time, heating temperature, and duration of heat treatment could be used to minimize seasonal variation in the color of veneer sliced from heated red alder cants.

Keywords: Red alder, veneer, color, heat-treatment, season, storage time, diarylheptanoid xyloside, Oregonin, sapwood.

INTRODUCTION

Red alder (*Alnus rubra* Bong. Betulaceae) derives its name from the behavior of its wood, which becomes red-orange in color as a response to wounding (Bailey 1910). This discoloration results from the formation of red-colored phenolic compounds caused by a chemical reaction between the diarylheptanoid xyloside, 1,7-bis-(3,4-dihydroxyphenyl)heptan-3-one-5-xylopyranoside (Oregonin) and catechol oxidase (Kurth and Becker 1953; Karchesy et al. 1974; Karchesy 1975; Terazawa et al. 1984b). These red-colored compounds or chromophores also discolor red alder lumber and reduce its value (Bailey 1910; Kurth and Becker 1953). To overcome this problem, modified kiln-drying schedules have been developed for red alder lumber,

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which involve pre-steaming freshly sawn wood at 80–100°C for up to 30 h prior to kiln-drying (Kozlik 1967, 1987). Similar, although more prolonged (up to 14 d), thermal treatments are applied to veneer cants (Kaufmann 2003). Following such heat treatments, the color of kiln-dried red alder lumber and veneer sliced from heat-treated cants is more uniform (Kozlik 1967, 1987). Nevertheless, in practice there is still variation in the overall color of the heat-treated wood (Kurth and Becker 1953). In particular, manufacturers of red alder veneer have noted significant variation in the color of veneer sliced from heat-treated cants processed at different times of the year (Kaufmann 2003).

The color of kiln-dried wood is influenced by phenolic extractives present in wood before drying (Luostarinen and Möttönen 2004; Luostarinen 2006). These extractives are oxidized and polymerized by heat to form complexes that discolor the wood (Haluk et al. 1991; Burtin et al. 2000; Luostarinen 2006). In Part I of this study, we concluded that the final color of heat-treated red alder wood was influenced by the presence of red-orange chromophores in the wood before heat treatment (Thompson et al. 2005). Therefore, seasonal variation in color of red alder veneer sliced from heat-treated cants, mentioned above, could occur as a result of factors that influence the development of red-orange chromophores in the parent wood. Bailey (1910) noted that the sapwood of alder (*A. incana* (L.) Moench) stained "very easily and rapidly during the spring," and a seasonal pattern to the variation in concentration of Oregonin has been observed in the leaves of red alder and in the xylem of Japanese alder (*A. japonica* (Thunb.) Steudel). In both cases, the concentration of Oregonin was at a maximum in the spring and decreased through to autumn, disappearing completely from the wood of *A. japonica* during winter (González-Hernández et al. 2000; Terazawa et al. 1984a). The tannin content of bark in red alder also reaches a maximum in spring and declines to a low level in winter (Clark and Offord 1926). Accordingly, it is hypothesized here that heat-treated red alder wood will be redder and darker when the wood is obtained from logs harvested during spring than when it is derived from logs harvested at other times of the year.

The aim of this research was to test this hypothesis and also to examine the effect of log storage time on the color of heat-treated red alder wood, since recent studies have shown that storage time of white birch (*Betula pendula* Roth, Betulaceae) logs before they were sawn and kiln-dried influenced the final color of the kiln-dried boards (Luostarinen et al. 2002; Luostarinen and Möttönen 2004). Red alder is one of the most economically important hardwood species in North America (AHEC 2003), and a better understanding of the extent and causes of variability in color of heat-treated red alder wood would help manufacturers of red alder veneer modify their processing techniques to produce more uniformly colored veneer.

MATERIALS AND METHODS

Experimental design and statistical analysis

A factorial experiment was designed to examine the effects of four fixed factors: (a) season (trees felled in spring, summer, autumn, or winter); (b) log storage time (logs stored for 0, 1, 2, or 4 wk prior to heat treatment of wood); and (c/d) wood type in terms of (c) location along the bole and (d) distance from the pith (3 rings from pith v. 5 rings from the bark) on the color of red alder wood following heat treatment at 70°C under isothermal conditions. Trees harvested from two separate sites provided replication at the higher level. Eight trees (four from each site) were harvested in each season and allocated to the different storage times (Fig. 1). Four disks cut from each tree along the bole, and replicate color measurements on wood close to the pith and the bark, were used to estimate the effects of wood type on the color of heat-treated red alder wood (Fig. 1). The resulting split-split plot design accounted for random variation at 4 levels: variation between sites, trees, and samples (disks and inner and outer wood specimens). Analysis of variance for data with a multi-level structure, in preference to mixed modeling, was used to

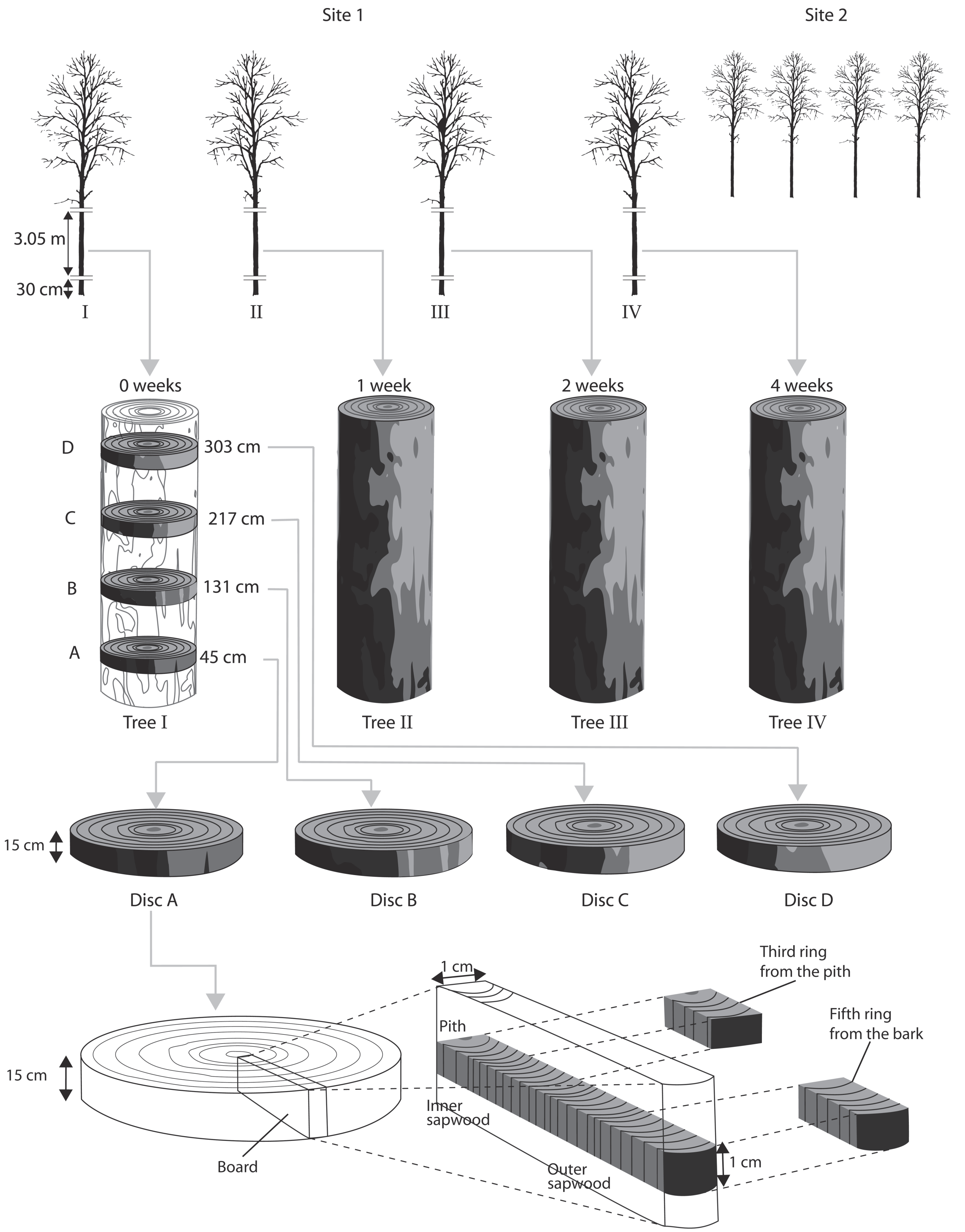

FIG. 1. Sampling of red alder trees, and preparation of wood samples before heat treatment (sampling was repeated in each season).

examine the effect of fixed and random factors on the response variables, a*—redness and L*—lightness of heat-treated wood (Allan and Rowlands 2001). Statistical computation was performed using Genstat 5 (Genstat 2000). Before the final analysis, diagnostic checks were performed to determine whether data conformed to the underlying assumptions of analysis of variance, i.e., normality with constant variance. Significant results ($p < 0.05$) are presented graphically and least significant difference (lsd) bars ($p < 0.05$) or 95% confidence intervals can be used to compare differences between individual means. In addition, we present a table that summarizes the variability of data between sites, trees, and samples (random effects), and the statistical significance of the fixed factors and their interactions on the color of heat-treated red alder wood.

Sample preparation

Two stands of red alder trees, each consisting of 16 trees, were selected based on site conditions (non-riparian) and similarities in height (18–25 m), diameter (25–32 cm at breast height), and ages (26–31 years) of the trees growing in the stands. The two stands were located ~2 km apart in two different areas of UBC's Malcolm Knapp Research Forest, 6.5 km north of Haney, British Columbia (Lat. 49.216 N, Long. 122.515 W). Four trees were felled 0.3 m above ground level at each site in autumn (November), winter (February), spring (May), and summer (August) (Fig. 1). The mean air temperatures at these times were 5.2, 7.1, 13.3, and 19.7°C, respectively. A log 3.05 m in length was cut from the base of each felled tree and randomly assigned a number corresponding to its storage time (0, 1, 2, or 4 wk) prior to processing (Fig. 1). The logs in each group marked '0' were immediately sampled in the field. The remaining logs were transported to the Centre for Advanced Wood Processing at the University of British Columbia where they were placed on 150- × 150-mm lumber spacers to ensure that they were not resting directly on the ground. Each log was stored outside without any cover or protection in accord with the way in which red alder logs are stored in commercial veneer mills.

After storage of logs, four 150-mm-thick discs were cut from each log using a chainsaw at positions that equated to heights within the tree (from ground level) of (A) 0.45, (B) 1.31, (C) 2.17, and (D) 3.03 m (Fig. 1). A 10-mm-wide quarter-sawn board was cut from each disc from pith-to-bark using a band-saw (Fig. 1). The location of the board within each disc was randomized. A 10- × 10-mm strip was then cut from the middle of each board (Fig. 1). Each strip was wrapped in an 80- × 230-mm sheet of aluminum foil and labeled with the appropriate disc and sample group numbers.

Thermal treatments and color measurement

Wood strips wrapped in aluminum foil were individually placed in separate 25- × 200-mm test-tubes, which were submerged in pre-heated glycerol baths maintained at 70°C, as described previously (Thompson et al. 2005). These strips were heated for 48 h and then removed from the aluminum foil. They were then cross-cut within the earlywood at positions located 3 rings from the pith, and 5 rings from the bark, thus allowing color measurements to be made on inner and outer sapwood specimens (Fig. 1). The exposed longitudinal surfaces were allowed to dry for 24 h at room temperature before the color of individual heat-treated wood samples was measured using a Minolta CM-2600d spectrophotometer, as described previously (Thompson et al. 2005). Color is expressed using the CIELab color coordinates a* (+60 [red] to −60 [green]) and L* (100 [white] to 0 [black]). The a* and L* parameters of several slices of veneer with color characteristics sought by manufacturers of red alder veneer were also quantified. These measurements provide maximum and minimum acceptable limits for a* and L* values, and are displayed as dashed lines on graphs displaying the color of red alder wood samples following heat treatment.

RESULTS

The season in which trees were felled and log storage time interacted in a complex way to influence the final color of heat-treated red alder wood (Table 1). Figures 2 and 3 show the effects of season and storage time on the red color (a*) and lightness (L*) of heat-treated wood, respectively. The most prominent finding was that heat-treated wood obtained from logs harvested in spring and stored for 2 wk was significantly darker than all other samples (Fig. 3). This difference occurred because heat-treated wood obtained from logs harvested in spring became increasingly redder and darker with increasing storage time up to 2 wk (Figs. 2 and 3). Similar, although less pronounced, trends were observed for heat-treated wood obtained from logs harvested in summer. Further storage of logs for 4 wk, however, was associated with decreases in the redness of heat-treated wood obtained from logs harvested in spring, summer, and autumn (Fig. 2), and increases in the lightness of samples obtained from logs harvested in spring

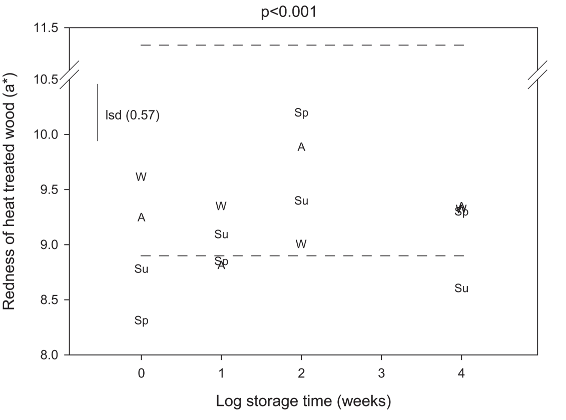

FIG. 2. Effects of season and log storage time on the redness (a*) of heat-treated red alder wood; Sp = Spring; Su = Summer; A = Autumn; W = Winter. The dashed lines represent maximum and minimum limits for redness.

TABLE 1. *Variability of data between sites, trees, and samples and the statistical significance of the fixed factors and their interactions on the color of heat-treated red alder wood.*

Source of variation	D.F.†	Variances (mean squares) Redness (a*)	Variances (mean squares) Lightness (L*)
Site level	1	0.5495	64.604
Site × tree level			
Storage [4 storage times]	3	5.4561*	25.519[a]
Residual	3	0.4290	2.903
Site × tree × position level			
Height [4 heights along bole]	3	0.8097**	1.916[b]
Storage × height	9	0.1851	6.057**
Residual	12	0.1347	1.108
Site × tree × position × wood type level			
Wood type [inner and outer sapwood]	1	11.039***	1368.986***
Storage × wood type	3	0.6542	5.444
Height × wood type	3	0.2108	1.834
Storage × height × wood type	9	0.6577	3.074
Residual	16	0.5904	4.133
Site × tree × position × wood type × sample level			
Season [4 seasons]	3	1.8033[c]	35.878***
Season × storage	9	3.6036***	23.956***
Season × height	9	0.2192	2.690
Season × wood type	3	0.8836	9.075
Season × storage × height	27	0.4235	4.560
Season × storage × wood type	9	1.4034[d]	7.200[e]
Season × height × wood type	9	0.1577	2.079
Season × storage × height × wood type	27	0.5064	2.751
Residual	96	0.7354	5.639
Total	255		

† = Degrees of freedom; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; a = p = 0.054; b = p = 0.214; c = p = 0.068; d = p = 0.06; e = p = 0.260

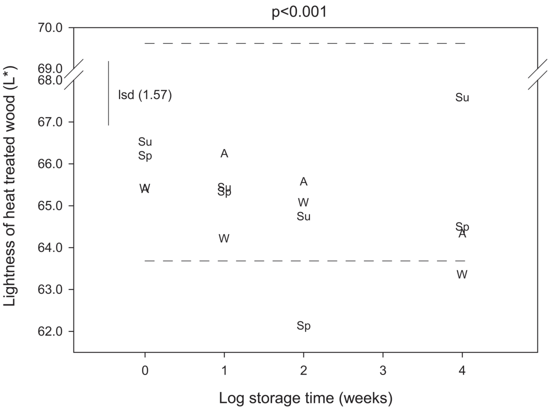

FIG. 3. Effects of season and log storage time on the lightness (L*) of heat-treated red alder wood; Sp = Spring; Su = Summer; A = Autumn; W = Winter. The dashed lines represent maximum and minimum limits for lightness.

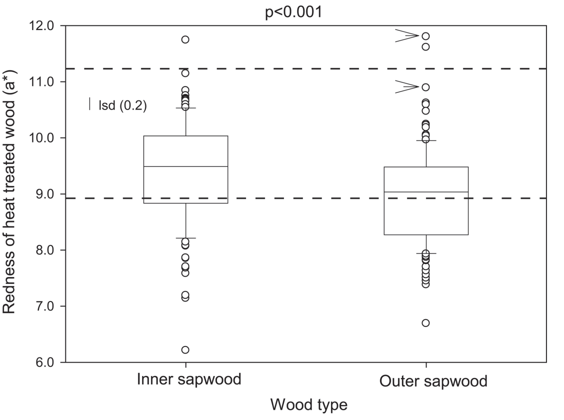

FIG. 4. Differences in the redness (a*) of heat-treated red alder wood from the inner (3 rings from pith) and outer sapwood (5 rings from bark). The dashed lines represent maximum and minimum limits for redness.

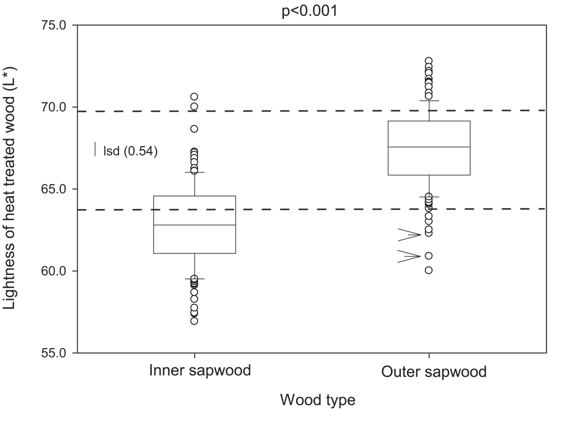

FIG. 5. Differences in the lightness (L*) of heat-treated red alder from the inner (3 rings from pith) and outer sapwood (5 rings from bark). The dashed lines represent maximum and minimum limits for lightness.

and summer (Fig. 3). The opposite trend in lightness was observed for heat-treated wood obtained from logs harvested in autumn and winter, but these differences in the lightness of the samples were not statistically significant ($p > 0.05$). The red color of heat-treated wood obtained from logs harvested in winter also displayed the opposite trend to that observed for samples obtained from logs harvested at other times of the year, decreasing with increasing storage time up to 2 wk and then increasing.

There was a very large effect ($p < 0.001$) of wood type (inner v. outer sapwood) on the color of heat-treated wood (Table 1). Figures 4 and 5 are box plots showing the complete range of redness and lightness values for heat-treated wood from the inner and outer sapwood, as well as the means and associated confidence intervals (lsd). Heat-treated wood from close to the pith was significantly ($p < 0.001$) redder and darker than heat-treated wood obtained from close to the bark, but there was considerable variation in the color of the two wood types across all observations (128 observations each for each wood type). In particular there are a series of observations that indicate that the redness of heat-treated wood from close to the bark approached and, in one case, exceeded the reddest heat-treated inner sapwood samples. Close examination of the data revealed that the latter observations represented heat-treated wood samples obtained from logs harvested in spring and stored for 2 wk (points arrowed in Fig. 4). This effect is reflected in the season × storage × wood type interaction for the redness parameter a*, which approaches statistical significance ($p = 0.06$; Table 1). Similarly, some of the darkest heat-treated samples from the outer sapwood were obtained from logs harvested in spring and stored for 2 wk (points arrowed in Fig. 5), although this is not reflected in a strong season × storage × wood interaction for the lightness parameter L* ($p = 0.26$; Table 1).

TABLE 2. *Effect of season and log storage time on the redness (a*) of heat-treated wood from the inner (3 rings from pith) and outer sapwood (5 rings from bark).*

	Winter		Spring		Summer		Autumn	
Time (wk)	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer
0	9.95	9.28	8.26	8.36	9.38	8.18	9.31	9.19
1	9.59	9.10	9.04	8.66	8.63	9.56	9.16	8.47
2	9.25	8.75	10.32	10.08	9.93	8.87	10.27	9.50
4	9.52	9.12	9.29	9.31	8.63	8.58	9.90	8.79
Average	0.958	0.906	9.23	9.10	9.14	8.79	9.66	8.99

lsd ($p < 0.05$) = 0.82

Table 2 shows the redness of heat-treated outer and inner sapwood samples obtained from logs harvested in the four different seasons and stored for various periods of time. It is apparent from this table that differences in the redness of heat-treated inner and outer sapwood samples were, on average, less pronounced in wood from logs harvested in spring and summer. In three cases, heat-treated wood samples from the outer part of the logs were redder than wood from the inner sapwood (Table 2). Differences in the lightness of heat-treated inner and outer sapwood samples were also less pronounced in wood from logs harvested in spring and summer, although there were no instances where the mean lightness of outer sapwood samples for any season × storage combination was less than that of inner sapwood samples.

Heat-treated wood samples obtained from the base of the stems were redder than those obtained farther up the stem, but differences in the redness of samples obtained at different heights were small (Fig. 6), although statistically significant (Table 1). The effect of stem position on the lightness of samples depended on storage time (Table 1). Thus, the lightness of heated samples obtained from positions A and C (0.45 and 2.17 m above ground level) was negatively correlated with storage time of logs (Fig. 7). Samples obtained from positions B and D (1.31 and 3.03 m above ground level) showed a similar trend up to 2 wk storage, but thereafter the samples became lighter.

DISCUSSION

Our results provide partial support for the hypothesis that red alder wood obtained from logs harvested in spring will be redder and darker following heat treatment than similarly treated wood obtained from logs harvested in other seasons. However, such seasonal variation in the

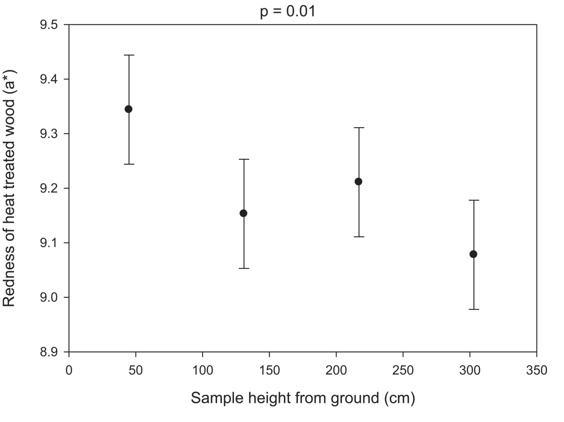

FIG. 6. Effect of bole position on the redness (a*) of heat-treated red alder wood. The error bars represent 95% confidence intervals.

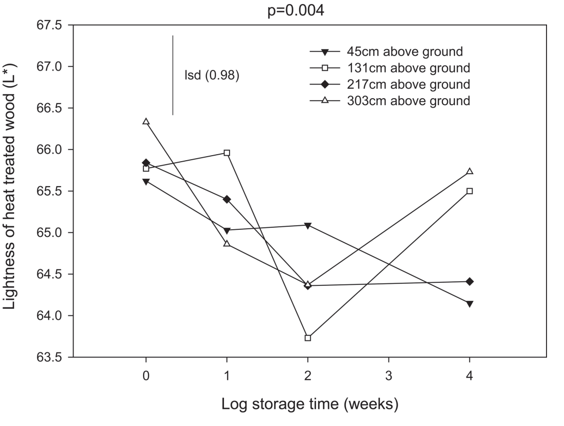

FIG. 7. Effects of bole position and storage time on the lightness (L*) of heat-treated red alder wood.

color of heat-treated red alder wood was only pronounced when wood subjected to heat treatment was derived from logs stored for 2 wk. The color of heat-treated red alder wood depends in part on the presence of red-orange chromophores in the wood before heat treatment, as mentioned above (Thompson et al. 2005). These chromophores are rapidly formed at the surface of freshly sawn red alder logs as a response of parenchyma cells to wounding (Bailey 1910; Kurth and Becker 1953; Karchesy 1975). This response involves the production of catechol oxidase that causes the polymerization of diarylheptanoid xylosides to form red-orange complexes (Terazawa et al. 1984b). Injury and death of parenchyma cells would occur rapidly at the surface of freshly felled logs, but below the surface, parenchyma cells would remain alive for longer (Zycha 1948). Hence, the formation of red-orange chromophores in wood deeper within logs may be delayed until drying stresses trigger the death of parenchyma cells and the release of enzymes and phenolic compounds that form red-orange complexes. This lag between felling of trees and death of parenchyma cells and formation of red orange chromophores may explain why the redness and lightness of heat-treated wood increased and decreased, respectively, with log storage time up to 2 wk (Figs. 2–3). The pronounced redness and reduced lightness of heat-treated wood derived from logs harvested in spring and stored for 2 wk compared to heat-treated wood obtained from logs harvested in the other seasons and stored for various periods of time, may be explained by the higher concentrations of phenolic xylosides in alder in spring compared to other seasons (González-Hernández et al. 2000; Terazawa et al. 1984a) and the relatively high temperatures in spring (Bailey 1910). A previous study of the effect of log storage on the color of kiln-dried birch by Luostarinen and Möttönen (2004) found that there was a good relationship between the concentration of phenolic compounds in wood and darkening during kiln-drying. They also found that prolonged storage of birch logs reduced the concentrations of phenolic compounds in the wood and its tendency to discolor during drying (Luostarinen et al. 2002; Luostarinen and Möttönen 2004). Similarly, we observed that increasing the time that red alder logs were stored from 2 to 4 wk prior to heat treatment of wood generally decreased the redness of the heat-treated wood (Fig. 2). Previously, we found that heating freshly felled red alder wood at 30°C for up to 36 h, which is insufficient to thermally degrade wood's structural components, caused the wood to become redder, but thereafter on further heating there was a decrease in the redness of the wood (Thompson et al. 2005). These observations suggested that red-orange complexes formed in red alder may decrease in concentration over time at temperatures close to ambient. This effect may explain the reversion in color of heat-treated samples obtained from logs stored for 4 wk and, in particular, why decreases in redness and increases in lightness of heat-treated wood were most pronounced in samples obtained from logs stored for 4 wk in summer, when average ambient temperatures were at their highest (20.9°C).

Wood samples cut from near the center of the alder logs (3 rings from the pith) were significantly redder and darker following heat treatment than similarly treated samples obtained from the periphery of the logs (5 rings from the bark). These findings accord with those of Luostarinen et al. (2002), who found that the redness of kiln-dried white birch increased towards the pith. Red alder is classified as a tree species that does not form heartwood in the conventional sense (Bosshard 1966); however, Kurth and Becker (1953) found that its 'heartwood' had a higher tannin content than its sapwood. Tannins in wood can be transformed during kiln-drying into darker-colored compounds that discolor wood (Haluk et al. 1991; Kreber and Byrne 1994). Hence, the higher tannin content of inner sapwood in red alder may explain why it was redder and darker than the outer sapwood following heat treatment (Figs. 4–5). In some cases, however, we observed that heat-treated outer sapwood from logs harvested in spring and summer was redder (although not darker) than heat-treated sapwood from the inner part of the logs (Fig. 4 and Table 2). This may have been due to the greater tendency of the outer sapwood to form red-colored chromophores before heat treatment, possibly because of increased levels of phenolic xylosides in the wood or higher drying stresses and temperatures at the periphery of the logs (Bailey 1910). Further research is necessary to confirm these suggestions and more generally to establish a relationship between the extractive content of red alder wood and its color after heat treatment.

Manufacturers of red alder veneer sliced from heated cants have remarked on seasonal variation in the color of their veneer and our findings help explain why such variability occurs. Direct comparison of our findings with observations of the seasonal variation in color of heat-treated veneer from commercial red alder veneer manufacturers, however, is complicated by differences in the heat treatments used commercially and the isothermal heating method employed here. In this study, inner and outer sapwood were subjected to the same temperature, whereas during heat treatment of veneer cants, the outer sapwood probably experiences higher temperatures than the inner sapwood due to the presence of a centripetal (bark-to-pith) thermal gradient in the cant. Previously, we noted a positive correlation between temperature and darkening of heat-treated red alder (Thompson et al. 2005) and, hence, the existence of a temperature gradient from the outside to the inside of a commercial veneer cant would tend to offset the tendency of the inner sapwood to become darker than the outer sapwood following heat treatment. The same temperature gradient, however, would accentuate color differences between outer and inner sapwood in spring when the outer sapwood probably contains a higher concentration of Oregonin and its response to heat treatment more closely resembles that of the inner sapwood. This may help explain comments by manufacturers of sliced red alder veneer that they have difficulty in obtaining veneer from heated cants with acceptable color in the spring when the 'sap is running' (Kaufmann 2003). To overcome this problem, our findings suggest that red alder logs harvested in spring should be processed immediately after harvesting, since there was a positive correlation between the darkness of heat-treated wood and storage time (up to 2 wk). Alternatively, storage could be extended because heat-treated wood cut from logs harvested in spring and stored for 4 wk was lighter than similarly modified wood from logs harvested in spring and stored for 2 wk. In support of this suggestion, studies with white birch have noted that extending log storage time reduced the tendency of boards cut from the logs to discolor during kiln-drying (Luostarinen et al. 2002; Luostarinen and Möttönen 2004).

Heat-treated wood samples obtained from lower in the stem tended to be redder than those higher up in the stem following thermal modification, but the differences were small, although statistically significant. Similarly, differences in lightness of heat-treated wood as a result of the interaction of bole position of samples and season were less than 3 units, which according to Phelps et al. (1994), is the threshold below which color differences quantified using CIELab parameters, a* and L*, are discernible. Therefore, differences in color of heat-treated red alder wood due to sampling position along the tree stem, in contrast to those existing radially from pith to bark, are unlikely to translate into large color variation along the length of veneer sheets. In accord with this suggestion, Luostarinen et al. (2002) concluded that the effect of longitudinal position of wood in white birch stems had a much smaller effect on discoloration during kiln-drying than did radial location in stems.

In our previous paper, we found that the color of heat-treated red alder wood depended on heating time and temperature and we suggested that novel heating technologies were needed to evenly heat veneer cants in order to obtain more uniformly colored veneer from such cants (Thompson et al. 2005). The results of this study suggest that, even if veneer cants could be more evenly heated by reducing their size or, for example, by employing microwave heating technology (Zielonka and Gierlik 1999), seasonal variation in veneer color might still persist as a result of the season × storage interactions noted here. Previously, we found that increasing heating time and temperature could alter the color of thermally modified red alder wood (Thompson et al. 2005), and careful adjustment of these parameters and the length of time logs are stored prior to heat treatment could be used to reduce seasonal variation in color of veneer sliced from heated cants. Further research involving thermal modification of large veneer cants would be needed to develop log storage and heating schedules to minimize seasonal variation in the color of sliced red alder veneer.

CONCLUSIONS

1. Red alder wood obtained from logs harvested in spring and stored for 2 wk was redder and darker following heat treatment than similarly treated wood obtained from logs harvested in other seasons and stored for various periods of time.
2. Heat-treated sapwood from close to the pith was redder and darker than heat-treated sapwood from close to the bark, but the difference was smaller in wood from logs harvested in spring and, to a lesser extent, summer.
3. Variation in the color of heat-treated wood obtained from different positions along the length of red alder stems was small, in contrast to differences in the color of heat-treated wood from the inner and outer parts of the stem.
4. The effects of season, log storage time, and location of wood in the stems on the color of heat-treated red alder wood explain why it is very difficult in practice to obtain uniformly colored veneer from heated red alder cants. Careful control of heating temperature and time and the development of differential heating schedules and storage times for logs harvested in different seasons could be used to minimize seasonal variation in the color of veneer sliced from heated red alder cants.

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