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RAPID COMMUNICATION

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Red color enhancement of sugi (*Cryptomeria japonica* D. Don) heartwood by light irradiation

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Introduction

Wood holds a special place in our culture because of its impressive range of attractive qualities: its aesthetic appearance, low density, low thermal expansion, and desirable mechanical strength. Among these properties, color is one of the most distinctive and is of considerable aesthetic importance in woods used for decorative purposes. Color also affects human feelings in various ways, such as red as a passionate color. The normal heartwood of sugi (*Cryptomeria japonica* D. Don) is red to rose-pink. Because of their red heartwood, sugi and hinoki wood have the highest value as building materials in Japanese-style houses and are widely used as ceiling board, wall paneling, and posts.[1] It has been well known that the color of some heartwood of sugi changes from reddish brown to black a few hours after being felled. Many reports have discussed the phenomenon of heartwood blackening in sugi,[2–6] and this problem is under investigation by many researchers.

In addition to the blackening phenomenon of sugi heartwood, a few studies are addressing the behavior of normal red heartwood of sugi after irradiation by light or exposure to various environmental factors. All wood changes color with light irradiation, but the rate and course of these changes vary with the wood species. According to Minemura and Umehara's study, sugi wood changes its color from dark to faded and back to dark after exposure to carbon arc light for 100 h. Moreover, the ΔE^* was 4.8, and the declining rate of whiteness was 9.0.[7]

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We were interested in the color changes of sugi wood planted in Taiwan after exposure to environmental conditions. Therefore a study with different combinations of environmental factors, such as moisture, oxygen, light, and even light with different wavelengths, was designed to elucidate this subject. In contrast to the previous results of our study on the effects of light wavelengths on the discoloration of taiwania (*Taiwania cryptomerioides* Hayata) heartwood,[8] an abnormal and fascinating result was obtained when sugi red heartwood was irradiated with light of different wavelengths. We report the results of that study herein.

Materials and methods

The 30-year-old sugi (*Cryptomeria japonica* D. Don) used in this study was collected from the Experimental Forest of National Taiwan University. Blocks of sugi red heartwood with dimensions of $2.5 \times 2.5 \times 1.0\,cm^3$ were prepared from a freshly cut log. All specimens were air-dried in a dark room at constant temperature (20°C) and moisture (relative humidity 65%). For demonstrating the effects of light wavelengths on the discoloration of sugi heartwood, we selected five filters with different light transmissions to cover the surface of the wood. Figure 1 shows the transmission curves of the various light filters. According to Fig. 1, the no. 1 filter allows light wavelengths only above 600 nm to pass, no. 2 filter allows light wavelengths above 450 nm to pass, and so on. Sugi specimens covered with different filters were then exposed to sunlight at the ambient conditions.

Color measurements were conducted using a color and color difference meter (Dr Lange Co. LMG082). The tristimulus values X, Y, and Z for all specimens were obtained directly from the colorimeter. The recommended CIE (Commission International del'E elarirange) L^* (lightness), a^* (along the X-axis red to green), and b^* (along the Y axis yellow to blue) color parameters were then computed to calculate the color difference (ΔE^*) based on the following formula: $\Delta L^* = L_t^* - L_o^*$; $\Delta a^* = a_t^* - a_o^*$;

$\Delta b^* = b_t^* - b_o^*$; $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$; where subscripts o and t are the values obtained before and after exposure, respectively.

Results and discussion

To discriminate the effects of light of different wavelengths on the discoloration of sugi red heartwood, five filters were used to cut off different transmission ranges of light. Blocks of sugi red heartwood (a^* 15.9–17.6) (Table 1) covered with different filters were exposed to sunlight. To achieve homogeneity of the light intensity absorbed by the specimens during irradiation, all specimens were irradiated under sunlight from 10:00 a.m. to 2:00 p.m. every day. Table 1 shows the color parameters of sugi specimens irradiated for 48 h with light of different wavelengths. It is obvious that the order of the discoloration of sugi is "above 600 nm" ($\Delta E^* = 9.5$) > "above 280 nm" ($\Delta E^* = 8.3$) > "above 340 nm" ($\Delta E^* = 5.8$) > "above 400 nm" ($\Delta E^* = 3.2$) > "above 450 nm" ($\Delta E^* = 2.8$). In regard to the energy absorbed by the wood specimens, the tendency of color change is reasonable except for the specimen exposed to light with wavelengths above 600 nm. When we focused on the color parameters, including L^*, a^*, and b^*, it was found that all specimens had the same tendency to change color except the one exposed to light of wavelengths above 600 nm. That is, the L^* value changed slightly, the a^* value decreased, and the b^* value increased after 48 h of irradiation. In fact, the discoloration of specimens irradiated with light wavelengths above 450 nm and above 400 nm was slight. Moreover, the discoloration tendency of specimens irradiated with light wavelengths above 600 nm was beyond that anticipated. Although it received the lowest energy, the discoloration was unexpectedly noticeable. Figure 2 shows the changes in Δa^* and Δb^* of sugi specimens irradiated with light of different wavelengths for 48 h. In contrast to others, sugi specimens changed their color to red after irradiation

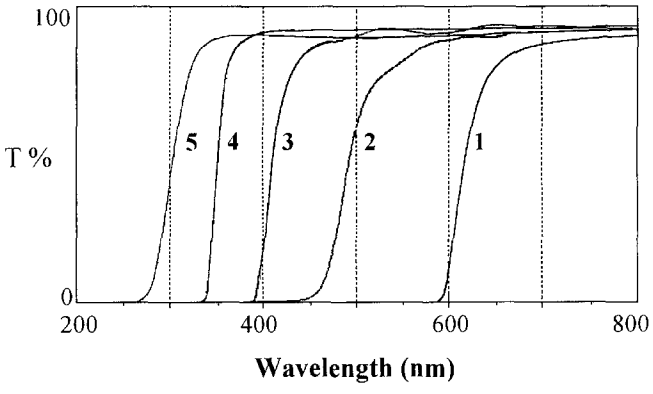

Fig. 1. Transmission curves for various light filters

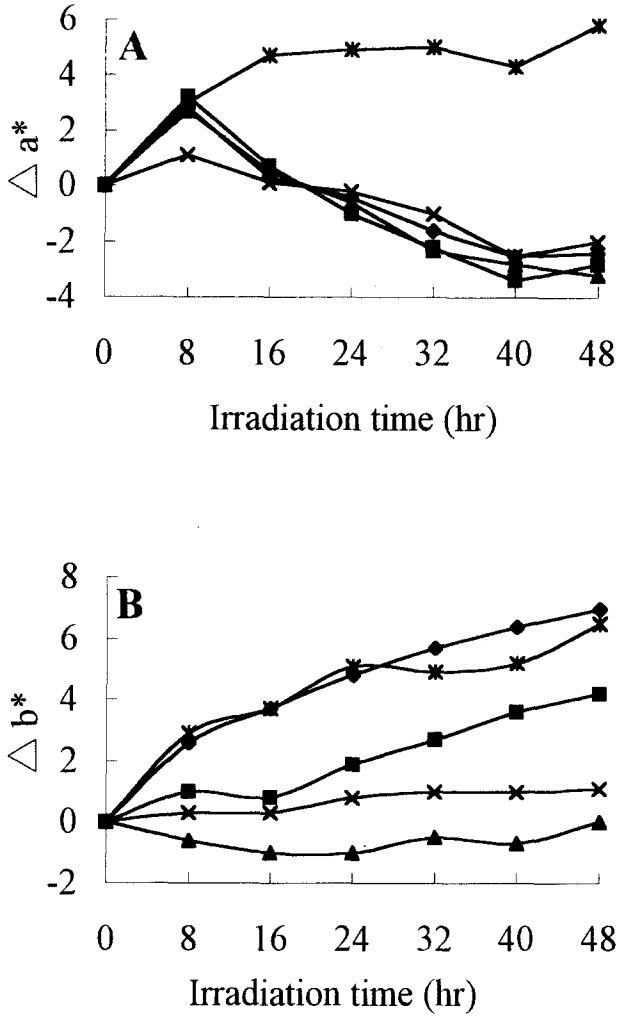

Fig. 2. Changes in Δa^* (**A**) and Δb^* (**B**) of sugi red heartwood irradiated with light of different wavelengths for 48 h. *, wavelengths above 600 nm; ×, wavelengths above 450 nm; *triangles*, wavelengths above 400 nm; *squares*, wavelengths above 340 nm; *diamonds*, wavelengths above 280 nm

Table 1. Color variation of sugi red heartwood irradiated with light of different wavelengths for 48 h

Sample time	Above 600 nm			Above 450 nm			Above 400 nm			Above 340 nm			Above 280 nm		
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Before irradiation	67.6	17.0	19.4	68.8	16.1	20.0	67.7	15.9	19.8	67.0	17.6	20.0	61.8	17.0	20.1
Irradiation for 48 h	63.9	22.8	26.0	67.2	14.1	21.6	67.2	12.7	19.8	64.1	14.8	24.4	63.0	14.6	27.1
ΔE^*		9.5			2.8			3.2			5.8			8.3	

with light of wavelengths above 600 nm. In addition to Δa^*, the Δb^* of sugi specimens irradiated with light of wavelengths above 600 nm exhibited a significant increase. Thus the appearance of sugi wood specimens was redder than nonirradiated wood after exposure to light of wavelengths above 600 nm.

In a previous study[8,9] we proved that the color change in taiwania from yellowish red to bluish green was caused by the combined effects of light and oxygen. Moreover, the color darkened and eventually turned to black in the presence of moisture. Overall, the pronounced discoloration on the surface of taiwania heartwood was mainly induced by light with wavelengths in the range 350–450 nm. In addition, one of the color substances, taiwanin A, was isolated from taiwania heartwood. It was proven that deep orange crystalline taiwanin A changed to the white and pale yellow compounds taiwanin C and taiwanin E after light irradiation.[9] In contrast to the effects of light wavelengths on the color of taiwania heartwood, the discoloration of taiwania heartwood was negligible after irradiation with light wavelengths in the range above 600 nm.

The results of the coloration of sugi red heartwood irradiated with light using the same wavelengths are amazing. Wood with a red color is often more popular and valuable. Thus, from a utilization point of view, it is possible to produce the highly economically valued sugi wood by light irradiation with wavelengths above 600 nm. Further study of the photodiscoloration of sugi will be reported in the near future.

References

1. Hon DNS, Minemura N (1991) Color and discoloration. In: Hon DNS, Shiraish N (eds) Wood and cellulosic chemistry. Marcell Dekker, New York, pp 395–454
2. Abe Z, Oda K, Matsumura J (1994) The color change of sugi (*Cryptomeria japonica* D. Don) heartwood from reddish brown to black. I. The color changes and its causes (in Japanese). Mokuzai Gakkaishi 40:998–1005
3. Abe Z, Oda K, Matsumura J (1994) The color change of sugi (*Cryptomeria japonica* D. Don) heartwood from reddish brown to black. II. Identification of potassium hydrogen carbonate as one of the causative materials (in Japanese). Mokuzai Gakkaishi 40:1119–1125
4. Takahashi K (1996) Relationships between the blacking phenomenon and norlignans of sugi (*Cryptomeria japonica* D. Don) heartwood. I. A case of partially black heartwood (in Japanese). Mokuzai Gakkaishi 42:998–1005
5. Takahashi K (1998) Relationships between the blacking phenomenon and norlignans of sugi (*Cryptomeria japonica* D. Don) heartwood. II. On blacking heartwood containing two mail norlignans, sugiresinal and hydroxysugiresinol (in Japanese). Mokuzai Gakkaishi 44:125–133
6. Kubo T, Ataka S (1998) Blackening of sugi (*Cryptomeria japonica* D. Don) heartwood in relation to metal content and moisture content. J Wood Sci 44:137–141
7. Minemura N, Umehara K (1979) Color improvement of wood. I. (in Japanese). Rep Hokkaido For Prod Res Inst 68L92
8. Wang SY, Chang ST, Su YC (1994) The effect of environmental factors on the discoloration of *Taiwania cryptomerioides* heartwood (in Chinese). For Prod Ind 13:351–361
9. Change ST, Wang SY, Su YC, Huang SL, Kuo YH (1999) Chemical constituents and mechanisms of discoloration of Taiwania (*Taiwania cryptomerioides* Hayata) heartwood. I. The structure reconfirmation and conversion mechanism of Taiwanin A. Holzforschung 53:142–146