Color Change and Consumer Preferences towards Color of Heat-Treated Korean White Pine and Royal Paulownia Woods

By Wahyu Hidayat; Yue Qi; Jae Hyuk Jang; Byung Ho Park; Irwan Sukri Banuwa; Fauzi Febrianto; Nam Hun Kim

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Original Article

Color Change and Consumer Preferences towards Color of Heat-Treated Korean White Pine and Royal Paulownia Woods[1]

Wahyu Hidayat[2,3] · Yue Qi[2,4] · Jae Hyuk Jang[2,5] · Byung Ho Park[6] · Irwan Sukri Banuwa[3] · Fauzi Febrianto[7] · Nam Hun Kim[2,†]

ABSTRACT

Heat treatment of wood is an attractive alternative environmentally-friendly treatment to add value of less valuable woods by improving color, dimensional stability, and natural durability. To improve the color properties of Korean white pine (*Pinus koraiensis*) and royal paulownia (*Pauwlonia tomentosa*), we treated the woods at 160℃, 180℃, 200℃, and 220℃ for 2 hours. Color change after heat treatment was evaluated using the *CIE-Lab* color system and survey was conducted to determine the consumer preferences towards color of heat-treated wood. Lightness (L^*) decreased with increasing temperature and the higher degree of change was obtained in royal paulownia. The red/green chromaticity (a^*) in both wood decreased after heat treatment at 160℃, and constantly increased after heat treatment at 180℃ to 220℃. Yellow/blue chromaticity (b^*) in Korean white pine tended to increase after heat treatment at 160℃, then decreased gradually afterwards. In royal paulownia, b^* values linearly increased with increasing temperature. Overall color change (ΔE^*) increased with increasing temperature with higher degree obtained in royal paulownia. Samples with the clamps in both wood species showed lower degree of the change in L^*, a^*, b and ΔE^*. The results of the consumer preferences test showed that the darker colors of heat-treated woods were more preferred by consumers compared to the lighter colors of untreated woods. Consequently, heat treatment could enhance the color properties of Korean white pine and royal paulownia woods for value added products.

Keywords : clamping, color change, *CIE-Lab* color system, consumer preference, heat treatment

1. INTRODUCTION

Color is one of the most important aesthetic aspects of wooden products. Wood color can be naturally or artificially modified. Natural modification or color degradation of wood can be occurred due to the aging of wood, which is defined as the irreversible change of physical,

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chemical, and mechanical properties of wood during extended storage or usage which may occur due to climate, environment conditions, and wood-destroying organisms such as insects, fungi, bacteria, and marine borers (Sandoval-Torres *et al.*, 2010; Kránitz *et al.*, 2016). Artificial modifications of wood color have been widely applied, but mostly toxic chemical staining was used.

The aging of wood can be accelerated by artificial aging methods that simulate the conditions of outdoor weathering or indoor photo-degradation processes (Pandey and Vuorinen, 2008; Park *et al.*, 2016). An environmentally-benign technology that has been used as an accelerated wood aging method to modify wood color is heat treatment of wood (Mitsui *et al.*, 2001; Ganne-Chédeville *et al.*, 2012). Heat treatment induces color changes in wood, especially darkening (Bekhta and Niemz, 2003). In comparison to wood staining, the color change by heat treatment takes place not only on the surface but in the whole wood including the inner parts with no toxic chemical used during the process (Esteves and Pereira, 2009; Kranitz *et al.*, 2016).

The light color of Korean white pine (*Pinus koraiensis*) and royal paulownia (*Pauwlonia tomentosa*) can be altered by heat treatment into a darker color similar to highly-valuable woods such as ebony and teak, which is an aesthetical advantage for some applications (Mitsui *et al.*, 2001; Bekhta and Niemz, 2003). In addition, heat treatment can grade up the wood properties, particularly the dimensional stability (Chang *et al.*, 2012; Hwang *et al.*, 2015; Kim, 2016) and decay resistance (Kamdem and Pizzi, 2002; Hakkou *et al.*, 2006).

Heat treatment can cause both desirable and undesirable color change defending on the process conditions such as treatment temperature, duration, and furnace atmosphere conditions (Sundqvist, 2002; Bekhta and Niemz, 2003; Lee *et al.*, 2015; Won *et al.*, 2015; Kim, 2016). In addition, our previous studies with high density wood as okan (*Cylicodiscus gabunensis*) showed that the application of mechanical restraint also affected the intensity of color change after heat treatment and contributed positive effects in preventing drying defects and minimizing strength reduction (Hidayat *et al.*, 2015; Hidayat *et al.*, 2016). In this study, we applied the mechanical restraint during heat treatment of low density woods as Korean white pine and royal paulownia. Heat treatment was performed under different temperatures to obtain good color appearance and to avoid undesirable color change. To determine optimum temperature resulted on the desirable color change of the wood, we also studied the consumer preferences towards color of the heat-treated woods. The results could provide valuable information to increase added value of such wood species.

2. MATERIALS and METHODS

2.1. Materials

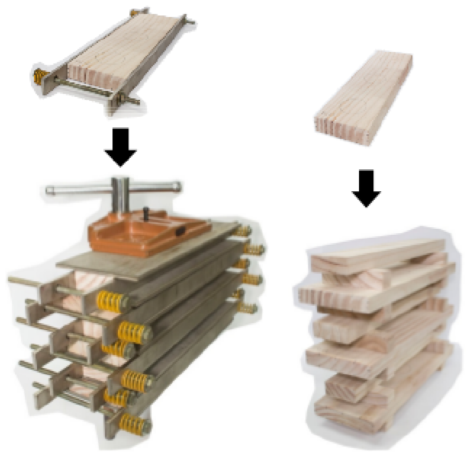
Boards from Korean white pine (*Pinus koraiensis*) and royal paulownia (*Paulownia to-*

mentosa) were prepared for heat treatment. Both woods have light color. Korean white pine has light brown color in its heartwood and pale yellow to nearly white sapwood, while royal paulownia has pale white sapwood which is not clearly demarcated from its heartwood. The air-dried densities were 0.43 g/cm^3 and 0.27 g/cm^3 for Korean white pine and royal paulownia, respectively. The equilibrium moisture content of Korean white pine and royal paulownia were about 8.69% and 7.68%, respectively. Board samples were prepared with the dimensions of 300 mm (length) × 90 mm (width) × 20 mm (thickness). Before and after heat treatment, the surfaces of the boards were sanded prior to color measurement.

2.2. Methods

2.2.1. Heat treatment

During heat treatment, the boards were stacked with the clamps (Fig. 1a), using similar method described in previous paper (Hidayat *et al*., 2016). The boards were also stacked without the clamps for comparison (Fig. 1b). Heat treatment was initiated at room temperature and then rose to the target peak temperatures of 160℃, 180℃, 200℃, and 220℃ with a heating rate of 2℃/min. The target temperatures were maintained for 2 hours and in the final stage of the heat treatment process, the oven chamber was allowed to cool naturally until they reached 30℃. Then, the boards were taken out and stabilized at room temperature and relative humidity of 65% for 2 weeks until further testing.



(a) (b)

Fig. 1. Stacking of samples during heat treatment: (a) with the clamps, (b) without the clamps.

2.2.2. Color evaluation

The colorimetric evaluation was performed using the *CIE-Lab* system (Esteves *et al*., 2008). The *CIE-Lab* system is characterized by three color parameters as L^*, a^*, b^*. The L^* axis represents lightness with the maximum value of 100 (white) and minimum value of 0 (black). The a^* axis represents red/green chromaticity with the positive values are in the red direction ($+a^*$) and negative values are in the green direction ($-a^*$). The b^* axis represents yellow/blue chromaticity with the positive values are in the yellow direction ($+b^*$) and negative values are in the blue direction ($-b^*$).

For each sample, three measurement points were marked on the board surface. The measurements were taken both before and after heat treatment with a chromameter (CR-400, Konica Minolta Inc., Tokyo, Japan). The chromameter used illuminant C light source and an observed angle of 2°. Prior to the measurement, the chromameter was calibrated with a white plate (Y = 93.6, x = 0.3134, y = 0.3194). The differences in lightness (ΔL^*), red/green chromaticity (Δa^*), and yellow/blue chromaticity (Δb^*) and the overall color change (ΔE^*) were calculated using the following equations,

$$\Delta L^* = L_a^* - L_b^* \quad (1)$$

$$\Delta a^* = a_a^* - a_b^* \quad (2)$$

$$\Delta b^* = b_a^* - b_b^* \quad (3)$$

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \quad (4)$$

where, L_b^*, a_b^*, and b_b^* are lightness, red/green chromaticity, and yellow/blue chromaticity before heat treatment; L_a^*, a_a^*, and b_a^* are lightness, red/green chromaticity, and yellow/blue chromaticity after heat treatment; ΔL^*, Δa^*, Δb^*, and ΔE^* represent the changes in lightness, red/green chromaticity, yellow/blue chromaticity, and the overall color, respectively.

The values of color changes (ΔE^*) were then used to define the levels of perceived difference in color (Cui *et al.*, 2004; Valverde and Moya, 2014). ΔE^* between 0 to 0.5 is defined as negligible, between 0.5 to 1.5 is slightly perceivable, between 1.5 to 3.0 is noticeable, between 3.0 to 6.0 is appreciable, between 6.0 to 12.0 is very appreciable, and more than 12.0 is totally changed.

2.2.3. Color preferences survey

Public survey was conducted to determine preferences of consumers associated with wood color for flooring application. Accidental sampling method was used by choosing the respondents who were readily available and wished to participate for the survey. Survey was performed in Kangwon National University, Republic of Korea. Two poster sets were prepared, one set using Korean white pine wood and another set using royal paulownia wood. Untreated sample and samples after heat treatment with the clamps at 160℃, 180℃, 200℃, and 220℃ from each wood species were attached on the posters.

Respondents were asked to choose his/her preferred color from each poster set by putting a color sticker (according to the sex and age of the respondent). The total of 182 respondents participated in the survey, consists of 100 male and 82 female respondents. The respondent classification and the associated sticker according to their age range and sex are as follow:

- Age between 20-30-year-old, consisted of 52 male respondents and 28 female respondents.
- Age between 31-40-year-old, consisted of 38 male respondents and 22 female respondents.
- Age above 40-year-old, consisted of 10 male respondents and 32 female respondents.

3. RESULTS and DISCUSSION

3.1. Color changes

The appearances of Korean white pine and royal paulownia boards before and after heat treatment are shown in Fig. 2 and the results of color measurements, *i.e.* the changes of lightness (L^*), red/green chromaticity (a^*), and yel-

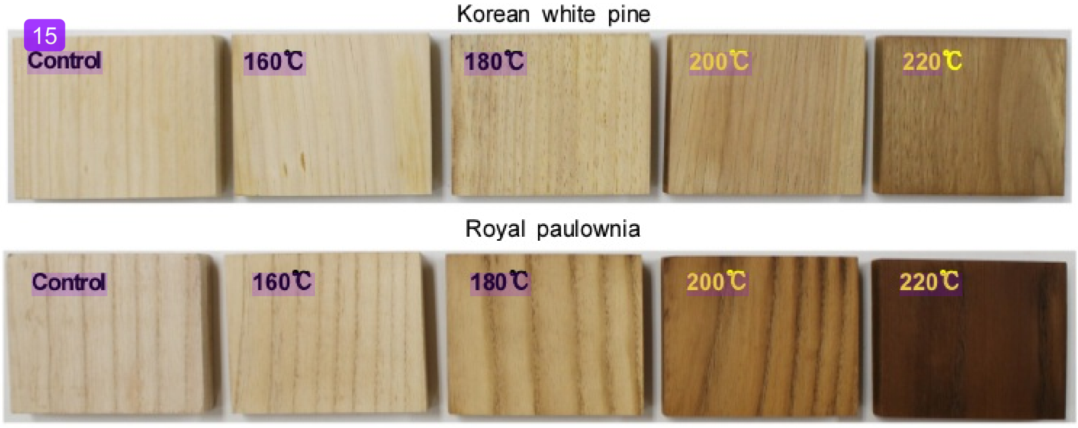


Fig. 2. Colors of Korean white pine and royal paulownia woods before and after heat treatment with the clamps at different temperatures.

low/blue chromaticity (b^*) values after heat treatment at 160℃, 180℃, 200℃, and 220℃ for 2 hours are presented in Fig. 3 to Fig. 5.

The results showed that the untreated boards of Korean white pine showed similar L^* values to royal paulownia, but the a^* and b^* values of Korean white pine were higher. In both Korean white pine and royal paulownia boards, with and without the clamps, L^* values decreased slightly after heat treatment at 160℃ and 180℃, and decreased remarkably after heat treatment at 200℃ and 220℃ (Fig. 3). Samples with the clamps showed lower L^* decreases than without the clamps. The a^* values in both woods decreased after heat treatment at 160℃, and constantly increased after heat treatment at 180℃ to 220℃ (Fig. 4). The results of L^* values were similar to the results obtained in okan wood, showing a decrease of L^* values with increased temperatures, but okan wood showed no significant changes in a^* values after heat treatment (Hidayat *et al.*, 2015).

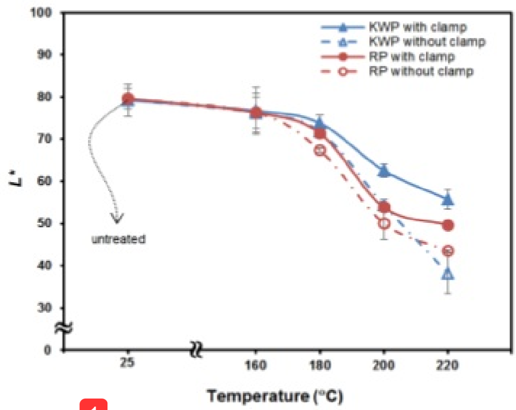


Fig. 3. Effect of temperature and clamping method on the change of L^* value (KWP = Korean white pine; RP = Royal paulownia).

The b^* values after heat treatment showed different responses between in Korean white pine and royal paulownia (Fig. 5). In Korean white pine, b^* values tend to increase after heat treatment at 160℃, then decreased gradually afterwards. In royal paulownia, b^* values linearly increased with increasing temperature.

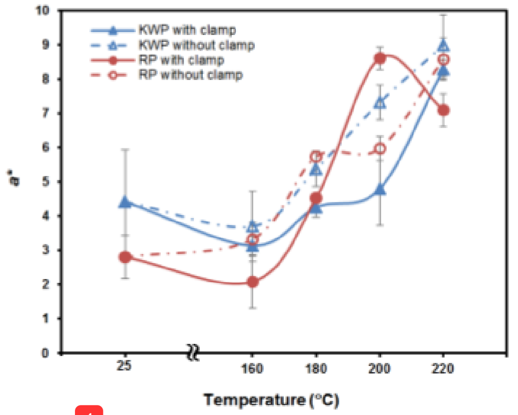


Fig. 4. Effect of temperature and clamping method on the change of *a** value (KWP = Korean white pine; RP = royal paulownia).

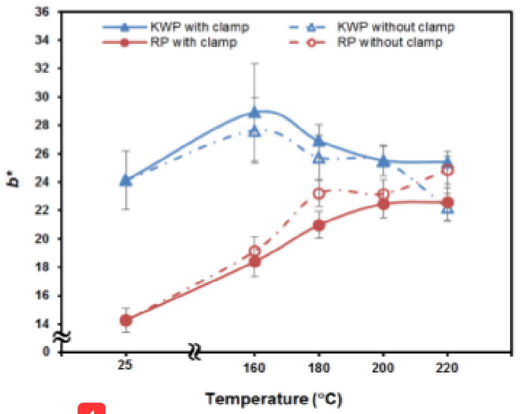


Fig. 5. Effect of temperature and clamping method on the change of *b** value (KWP = Korean white pine; RP = royal paulownia).

Samples with the clamps in Korean white pine had higher b^* values than without the clamps, while samples with the clamps in royal paulownia had lower b^* values than without the clamps.

The overall color change (ΔE^*) increased with an increase in temperature (Fig. 6). The most visually obvious change after heat treatment was the reduction in lightness (L^*) or the darkening of the woods (Fig. 2). Cui *et al.* (2004) also reported that the lightness change (ΔL^*) was the most important parameter affecting the color change. Salca *et al.* (2016) added that the reduction in L^* values was related to the degradation of hemicelluloses during heat treatment.

The results revealed that Korean white pine had lower ΔE^* than royal paulownia, with the exception of Korean white pine sample without the clamps heat-treated at 220℃ (Fig. 6). The results were in a good agreement with Sandoval-Torres *et al.* (2010), who stated that hardwoods generally discolor at lower temperature than softwoods. The ΔE^* in both woods were similar after heat treatment at 160℃. In Korean white pine, the ΔE^* increased very slightly with increasing temperature to 180℃, then drastically increased after heat treatment at 200℃ and 220℃. Overall results revealed that colors of both Korean white pine and royal paulownia woods were totally changed (ΔE^*=> 12.0) after heat treatment at 200℃, with the detail levels of perceived differences in color are presented in Table 1. This results are in a good agreement with the findings of Bekhta and Niemz (2003), who observed that the color of wood changed drastically after heat treatment at 200℃. Hidayat *et al.* (2015) reported that temperatures ranging from 180℃ to 200℃ are significantly critical to the change in color of heat-treated okan wood.

Fig. 6 clearly shows that the samples with

Table 1. The levels of perceived difference in color after heat treatment

Species	Temp. (℃)	ΔE^* Level	
		With the clamps	Without the clamps
Korean white pine	160	Appreciable	Appreciable
	180	Very appreciable	Very appreciable
	200	Totally changed	Totally changed
	220	Totally changed	Totally changed
Royal paulownia	160	Appreciable	Very appreciable
	180	Very appreciable	Totally changed
	200	Totally changed	Totally changed
	220	Totally changed	Totally changed

* According to the classification of the level color change by Cui *et al*. (2004) and Valverde and Moya (2014): (1) negligible: ΔE^* between 0 to 0.5; (2) slightly perceivable: ΔE^* between 0.5 to 1.5; (3) noticeable: ΔE^* between 1.5 to 3.0; (4) appreciable: ΔE^* between 3.0 to 6.0; (5) very appreciable: ΔE^* between 6.0 to 12.0; and (6) totally changed: ΔE^* more than 12.0.

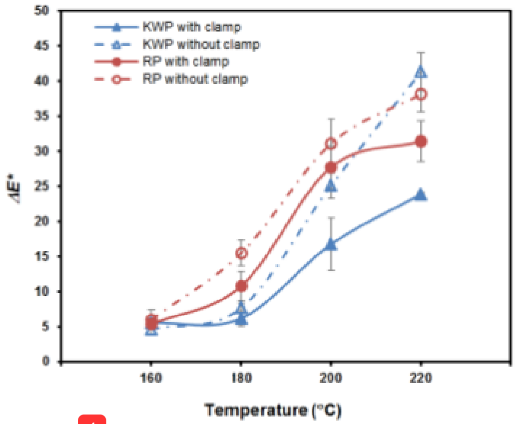


Fig. 6. Effect of temperature and clamping method on the change of ΔE^* value (KWP = Korean white pine; RP = royal paulownia).

the clamps exhibited a lower magnitude of ΔE^* than the samples without the clamps. Hidayat *et al*. (2016) stated that clamping during heat treatment protected the wood sample surfaces (radial and tangential surfaces) from direct contact with the heated air, and allowed only the cross section surfaces to be exposed. This may have resulted in a lower oxidation of wood components than for the samples without the clamps.

3.2. Consumer preferences towards colors of heat-treated woods

Information about consumer preferences towards wood products is one of the important considerations to several decision makers in the forest sector (Hoibo and Nyrud, 2010). The study that reveals consumer preferences could provide useful information for marketing and manufacturing of wood products, and also provide information of relevance to designers and decision makers involved in building design and construction processes. Color is an attribute of visual perception, which is one of the important factors that influence customers when choosing wood products (Sandoval-Torres, 2010).

In this study, the overall results of color preferences test revealed that respondents expressed a stronger preference for the darker color of

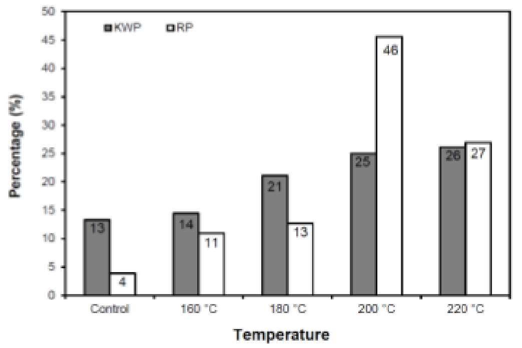


Fig. 7. Consumer preferences towards color of Korean white pine and royal paulownia woods.

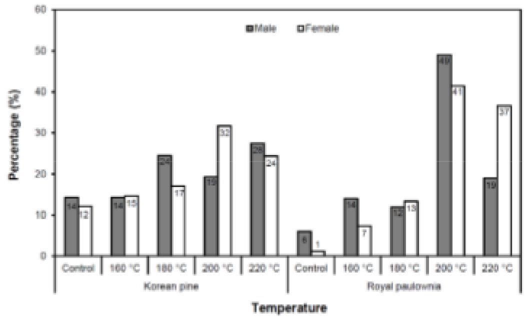


Fig. 8. Consumer preferences by sex towards color of Korean white pine and royal paulownia woods.

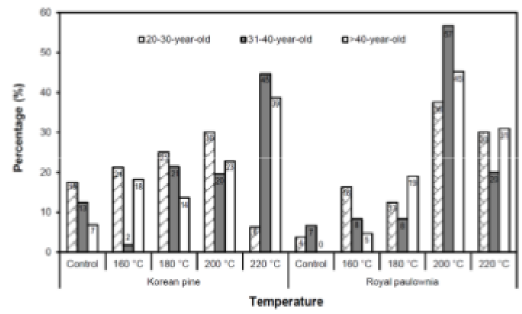


Fig. 9. Consumer preferences by age towards color of Korean white pine and royal paulownia woods.

heat-treated woods than the original color Korean white pine and royal paulownia woods (Fig. 7). In Korean white pine, the colors of heat-treated wood at 200℃ and 220℃ were the most preferred color according to the choice of 25% and 26% of the total respondents. In royal paulownia, the most preferred color was the color of heat-treated wood at 200℃ according to the preference of 46% of the total respondents. The overall results were in a good agreement with previous report by Cao *et al*. (2012), they stated that dark brown colors are currently in demand and widely appreciated by customers in the flooring, furniture, and decoration markets.

The results of consumer preferences test according to sex and age also showed similar trends with the overall results, showing respondents more appreciated heat-treated woods having darker colors to be used for flooring and furniture applications, particularly woods treated at 200℃ and 200℃ (Fig. 8 and Fig. 9).

In Korean white pine, most male respondents preferred darkest color or wood treated at 220℃ (28%), while most female respondents preferred the color of wood treated at 200℃ (32%). According to age, respondents at younger age range (20-30-year-old) mostly preferred Korean white pine wood treated at 200℃ and the respondents at older age range (30-40 and >40-year-old) preferred more darker wood treated 220℃. In royal paulownia, the results were more consistent, showing woods treated at 200℃ as the most appreciated color according to sex and age ranges. The results of in-depth interview with representative respondents revealed that they preferred darker colors of heat-treated royal paulownia. However, the color of wood treated at 220℃ almost wore off the natural texture of the wood.

4. CONCLUSION

Heat treatment affected the color parameters of Korean white pine and royal paulownia woods. Lightness (L^*) decreased with increasing temperatures and remarkable decreased obtained after heat treatment at 200℃ and 220℃. Korean white pine showed lower L^* decreases than royal paulownia. The red/green chromaticity (a^*) in both woods decreased after heat treatment at 160℃, and constantly increased after heat treatment at 180℃ to 220℃. Yellow/blue chromaticity (b^*) in Korean white pine tended to increase after heat treatment at 160℃, then decreased gradually afterwards. In royal paulownia, b^* values linearly increased with increasing temperature. Overall color change (ΔE^*) increased with increasing temperature with higher degree obtained in royal paulownia. Clamping lowered the degree of the changes in L^*, a^*, b and ΔE^* in both woods. The results of color preferences test revealed that consumers preferred the darker colors of heat-treated woods than the original color Korean white pine and royal paulownia woods, particularly at 200℃.

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Aims and Scope

The *Journal of The Korean Wood Science and Technology* (*JKWST*) launched in 1973 as an official publication of The Korean Society of Wood Science and Technology has been served as a core of knowledges on wood science and technology. The Journal acts as a medium for the exchange of research in the area of science and technology related to wood, and publishes results on the biology, chemistry, physics and technology of wood and wood-based products. Research results about applied sciences of wood-based materials are also welcome. The Journal is published bimonthly, and printing six issues per year. Supplemental or special issues are published occasionally.

The abbreviated and official title of the journal is '*J. Korean Wood Sci. Technol.*'. All submitted manuscripts written in Korean or English are peer-reviewed by more than two reviewers. The title, abstract, acknowledgement, references, and captions of figures and tables should be provided in English for all submitted manuscripts. All articles are indexed in SCOPUS and Korea Citation Index (KCI).

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