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# Relations between the colorimetric values and densities of sapwood

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**Abstract** Color measurements were made for sapwood specimens of 26 hardwood species. The densities of the specimens ranged from 258.5 to 945.6 kg/m$^3$. The colorimetric values and densities were compared among the species. The tristimulus values of $X$, $Y$, and $Z$ were poorly correlated with the densities. The chromaticity coordinate $x$ had a good linear correlation with the densities of the wood specimens, especially in the transverse planes. The transverse plane of wood fibers is thought to emphasize the relative values in the long wavelength region of the visible ray.

**Key words** Density · Colorimetry · Sapwood · Hardwood

## Introduction

Most of the broad-leaved forests in Shimane Prefecture, Japan, are secondary forests of deciduous trees grown after having used the wood produced from the forests as resources of fuel and charcoal.[1] During the last 50 years consumption of fuel derived from wood has diminished, and secondary forests have been grown without using the wood produced from them. The diameters of the trees are not large, but in the near future we will be able to use the wood produced from the forest if we control the forests adequately. Thinning the forests to control their density is important for enhancing the ability of the forest to fix carbon dioxide.[2] For commercial reasons the thinned hardwood logs should be used even though the diameter of the thinned logs is small.

Various tree species are found in the secondary forest, and the wood cut from the trees shows widely different visual features among species. The color of wood is one of the important characteristics, as are the mechanical properties, when using such wood in our daily lives. The color of wood has not often been discussed in relation to the other physical characteristics. By knowing the relations between the color and other physical characteristics of wood, we can understand some of the mechanisms of wood color. These relations might be applied to determine an appropriate use for unused wood species. In this report the colorimetric features of sapwood are discussed using their colorimetric values and comparing them with their densities.

## Materials and methods

Altogether 25 species of broad-leaved trees were cut down in the secondary forest in Sambe Experimental Forest, Shimane University, Japan. The forest is in the Japan Sea climate region, which has an annual average temperature of 11°C and an annual average rainfall of 2300 mm.[3] The soil in the forest consists of brown forest soil.[4] The diameters of the hardwood logs obtained approximately ranged from 150 to 300 mm. We also obtained logs of *Liliodendron tulipifera* L. from the campus of Shimane University, Matsue City, which had fallen owing to a typhoon. In total, then, we obtained 26 species of broad-leaved logs for the color measurements.

Wood specimens for color measurement were elaborated from the logs. Their dimensions were 30 mm in the tangential direction, 40 mm in the radial direction, and 50 mm in the longitudinal direction, as shown in Fig. 1. They were dried in a drying chamber at 60°C overnight and then put in a constant-temperature room at 20°C and 65% relative humidity (RH). We prepared 10 specimens for each species. The surfaces of the specimens were sanded by a portable sanding machine with 150-mesh abrasive paper.

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The color the specimens was measured with a colorimeter (Minolta CR-200b) to obtain the colorimetric values of $Y$, $x$, and $y$ on the R-T planes (transverse planes), L-R planes (radial planes), and L-T planes (tangential planes). The colorimetric values $X$, $Y$, $Z$ are called the tristimulus values, and the values $x$, $y$, $z$ are called the chromaticity coordinates. The optical system of the colorimeter was diffuse illumination and 0 viewing angle. The diameter of the measurement area of the sensor head was 10 mm. The mean value of the 10 measurements were calculated for each plane. The colorimetric values of $z$, $X$, and $Z$ were obtained from the formulas below.[5]

$$z = 1 - x - y \tag{1}$$

$$X = \frac{x}{y} Y \tag{2}$$

$$Z = \frac{1 - x - y}{y} Y \tag{3}$$

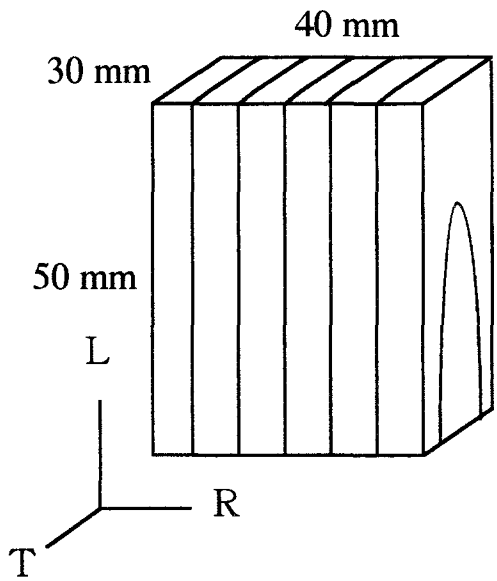


**Fig. 1.** Wood specimen for color measurement

## Results and discussion

The densities and colorimetric values of the wood species are shown in Table 1. The densities of the specimens ranged from 258.5 kg/m$^3$ for kiri wood to 945.6 kg/m$^3$ for yamaboushi wood.

A typical example of the colorimetric relations among the wood principal planes is shown in Fig. 2 for kumanomizuki sapwood. The values of $Y$ for the radial and tangential planes were higher than those for the transverse planes, and the values of $x$ for the radial and tangential planes were lower than those for the transverse planes. No greater difference in the values between the radial and transverse planes were found in most species. These results are similar to those of luminance in the case of yellow

**Table 1.** Densities and colorimetric values of sapwood of the hardwood specimens

| Japanese name | Scientific name | Density (kg/m$^3$) | R-T plane | | | L-R plane | | | L-T plane | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Y$ | $x$ | $y$ | $Y$ | $x$ | $y$ | $Y$ | $x$ | $y$ |
| Koshiabura | *Acanthopanax sciadophylloides* Fr. et Sav. | 466.7 | 44.3 | 0.334 | 0.350 | 57.9 | 0.338 | 0.353 | 56.9 | 0.337 | 0.353 |
| Itayakaede | *Acer mono* Maxim. | 687.8 | 50.7 | 0.361 | 0.361 | 60.3 | 0.354 | 0.359 | 55.9 | 0.353 | 0.358 |
| Urihadakaede | *Acer rufinerve* Sieb. et Zucc. | 643.9 | 36.8 | 0.359 | 0.356 | 41.8 | 0.365 | 0.364 | 35.6 | 0.375 | 0.368 |
| Nemunoki | *Albizzia julibrissin* Durazz. | 566.2 | 41.2 | 0.358 | 0.362 | 61.3 | 0.353 | 0.361 | 63.4 | 0.355 | 0.364 |
| Mizume | *Betula grossa* Sieb. et Zucc. | 736.8 | 39.9 | 0.366 | 0.363 | 49.2 | 0.380 | 0.377 | 46.8 | 0.382 | 0.378 |
| Akashide | *Carpinus laxiflora* (Sieb. et Zucc.) Blume | 687.2 | 33.2 | 0.370 | 0.367 | 41.3 | 0.374 | 0.372 | 39.0 | 0.373 | 0.370 |
| Inushide | *Carpinus tschonoskii* Maxim. | 687.8 | 33.0 | 0.352 | 0.362 | 43.9 | 0.355 | 0.365 | 42.2 | 0.354 | 0.364 |
| Ryoubu | *Clethra barbinervis* Sieb. et Zucc. | 768.9 | 48.3 | 0.369 | 0.366 | 64.6 | 0.355 | 0.358 | 60.4 | 0.360 | 0.365 |
| Kumanomizuki | *Cornus brachypoda* C. A Mey. | 766.3 | 36.2 | 0.373 | 0.356 | 56.8 | 0.358 | 0.355 | 54.7 | 0.359 | 0.357 |
| Yamaboushi | *Cornus kousa* Buerger ex Miq. | 945.6 | 42.5 | 0.372 | 0.363 | 55.8 | 0.360 | 0.360 | 59.7 | 0.357 | 0.360 |
| Karasuzansyou | *Fagara ailanthoides* Engl. | 551.3 | 39.6 | 0.354 | 0.361 | 57.2 | 0.356 | 0.366 | 56.3 | 0.353 | 0.364 |
| Buna | *Fagus crenata* Blume | 795.8 | 33.2 | 0.368 | 0.363 | 41.4 | 0.376 | 0.371 | 40.8 | 0.377 | 0.371 |
| Marubaaodamo | *Fraxinus sieboldiana* Blume | 712.8 | 49.0 | 0.365 | 0.367 | 61.6 | 0.358 | 0.365 | 58.2 | 0.358 | 0.365 |
| Iigiri | *Idesia polycarpa* Maxim. | 381.2 | 49.9 | 0.345 | 0.356 | 62.5 | 0.347 | 0.358 | 60.9 | 0.345 | 0.357 |
| Harigiri | *Kalopanax pictus* (Thunb.) Nakai | 554.1 | 49.1 | 0.346 | 0.355 | 66.0 | 0.338 | 0.352 | 62.7 | 0.341 | 0.355 |
| Yurinoki | *Liriodendron tulipifera* L. | 524.2 | 37.2 | 0.341 | 0.353 | 45.3 | 0.347 | 0.357 | 45.8 | 0.346 | 0.357 |
| Hoonoki | *Magnolia obovata* Thunb. | 435.0 | 44.4 | 0.332 | 0.347 | 53.4 | 0.343 | 0.354 | 51.0 | 0.340 | 0.353 |
| Akamegashiwa | *Mallotus japonicus* (Thunb.) Muell. Arg. | 489.8 | 54.0 | 0.352 | 0.362 | 64.2 | 0.347 | 0.359 | 62.7 | 0.348 | 0.358 |
| Yamaguwa | *Morus bombycis* Koidz. | 678.2 | 36.5 | 0.368 | 0.373 | 65.6 | 0.353 | 0.367 | 62.7 | 0.357 | 0.368 |
| Kiri | *Paulownia tomentosa* Steud. | 258.5 | 50.5 | 0.341 | 0.350 | 59.4 | 0.344 | 0.352 | 56.1 | 0.344 | 0.352 |
| Kihada | *Phellodendron amurense* Rupr. | 473.7 | 47.6 | 0.347 | 0.362 | 61.5 | 0.347 | 0.363 | 58.0 | 0.349 | 0.364 |
| Nogurumi | *Platycarya strobilacea* Sieb. et Zucc. | 518.6 | 43.6 | 0.360 | 0.365 | 62.6 | 0.351 | 0.362 | 62.5 | 0.354 | 0.366 |
| Yamazakura | *Prunus jamasakura* Sieb. ex Koidz. | 675.1 | 27.2 | 0.380 | 0.379 | 37.5 | 0.384 | 0.383 | 35.2 | 0.383 | 0.383 |
| Konara | *Quercus serrata* Thunb. | 754.8 | 36.4 | 0.375 | 0.372 | 57.2 | 0.365 | 0.370 | 55.8 | 0.364 | 0.369 |
| Abemaki | *Quercus variabilis* Blume | 786.8 | 28.7 | 0.371 | 0.368 | 42.4 | 0.370 | 0.370 | 41.9 | 0.370 | 0.370 |
| Egonoki | *Styrax japonica* Sieb. et Zucc. | 674.1 | 40.4 | 0.372 | 0.366 | 44.6 | 0.385 | 0.376 | 32.5 | 0.403 | 0.380 |

Colorimetric values were measured under the condition of standard illuminant of $D_{65}$ and the 2 degrees standard observer

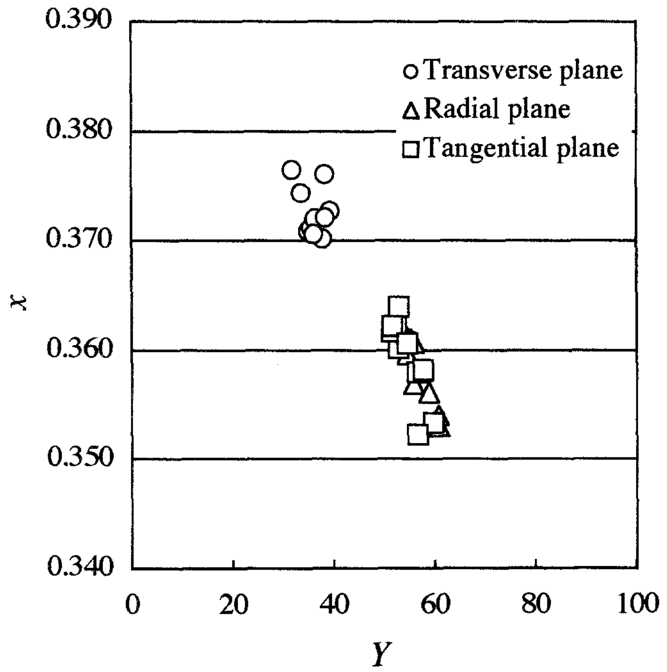


**Fig. 2.** Colorimetric relation between $Y$ and $x$ among the principal planes for kumanomizuki sapwood

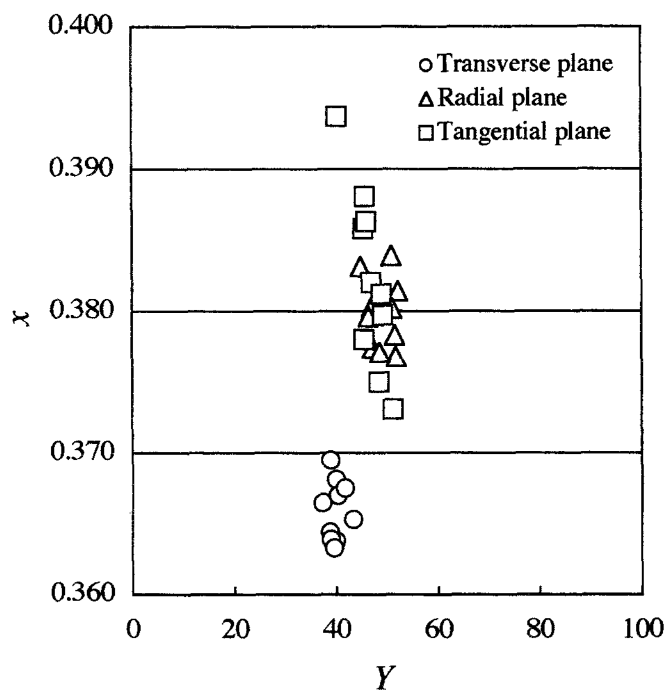


**Fig. 3.** Colorimetric relation between $Y$ and $x$ among the principal planes for mizume sapwood

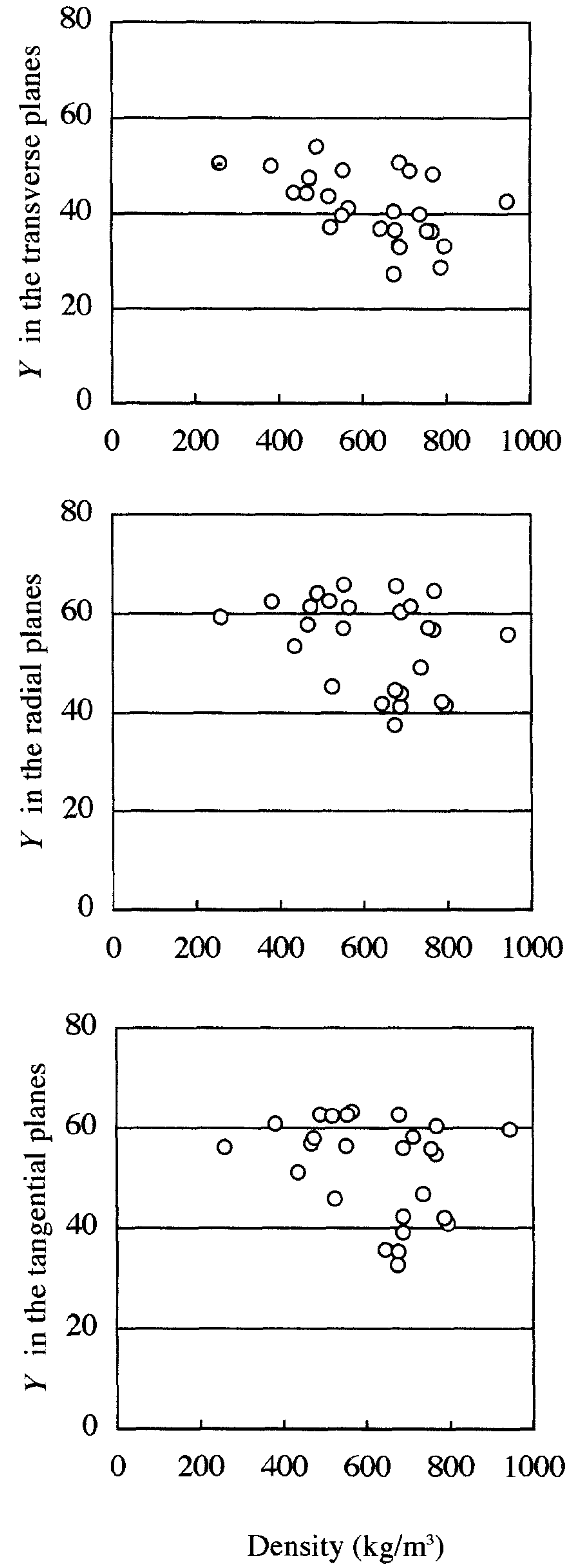


**Fig. 4.** Relations between the values of $Y$ for sapwood and the densities

poplar reported by Sullivan.[6] For the values of $x$, the trend is not as simple. Another example of the colorimetric relations of mizume wood is shown in Fig. 3. The $x$ values for the transverse planes are smaller than those in the radial and tangential planes. They are thought to be affected by some properties of the wood, such as the density, composition of the chemical substances, and anatomical features. In the case of sapwood the color may be less affected by chemical substances than that of heartwood.

The relations between the $Y$ values of sapwood and the density are shown in Fig. 4. A correlation was found only in

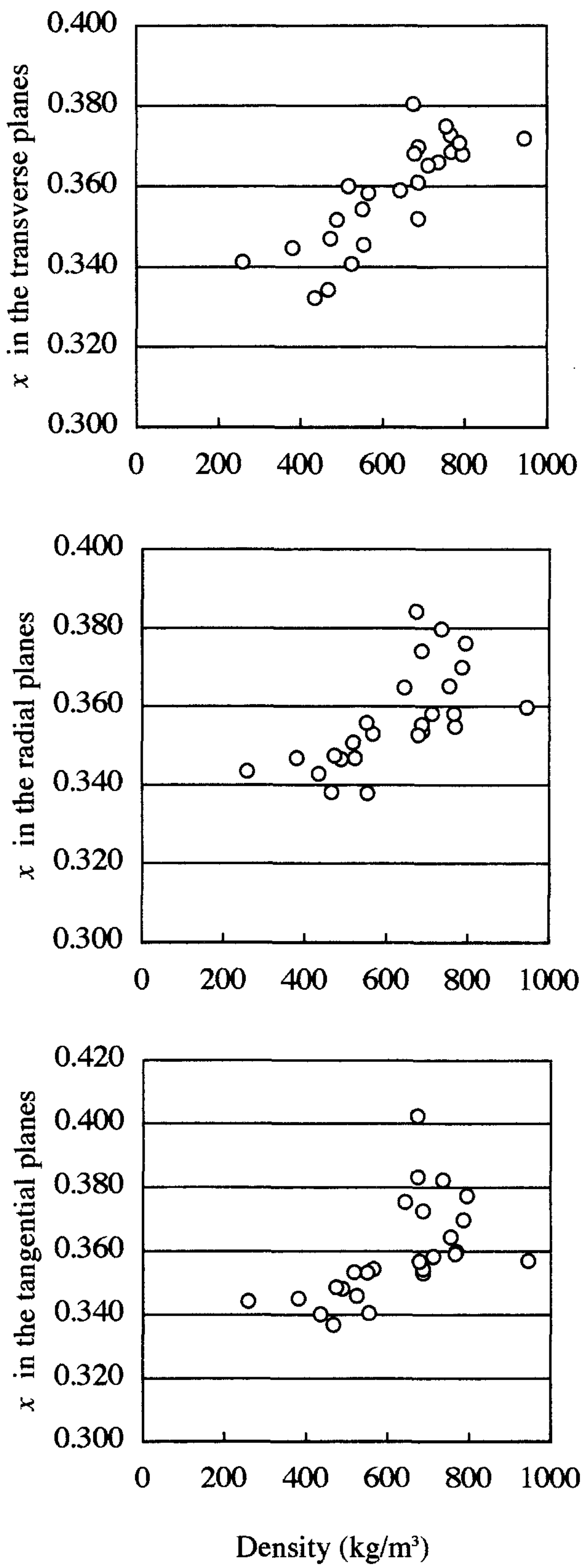


**Fig. 5.** Relations between the values of $x$ of sapwood and the densities

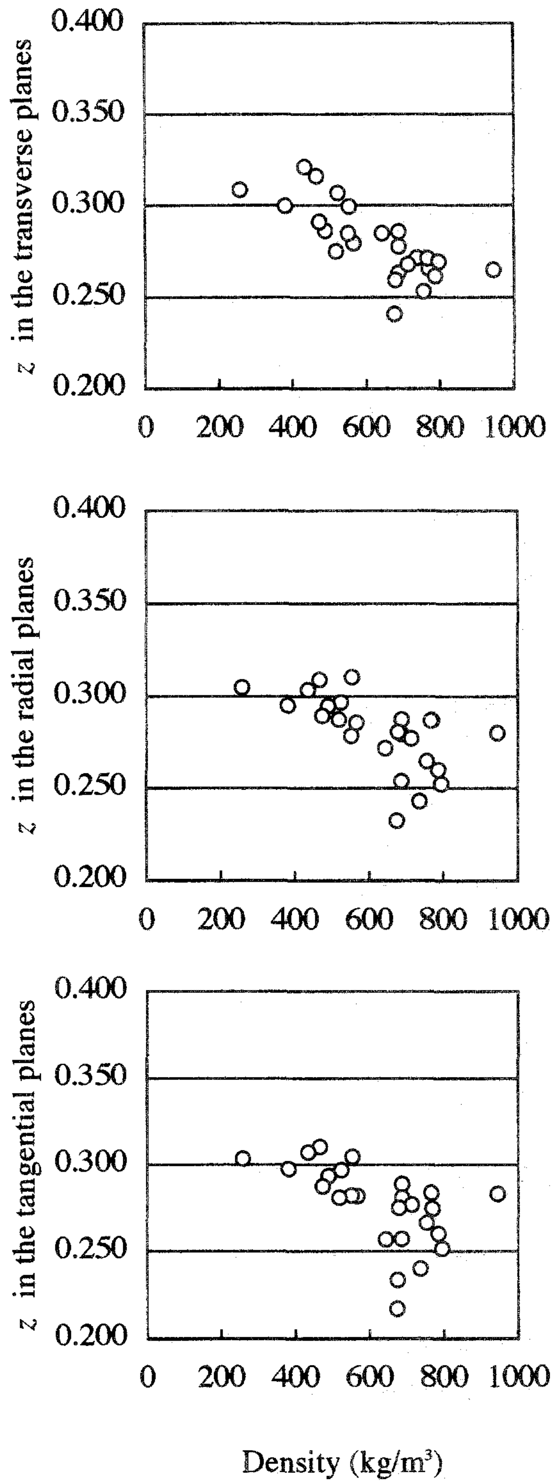


**Fig. 6.** Relations between the values of $z$ of sapwood and the densities

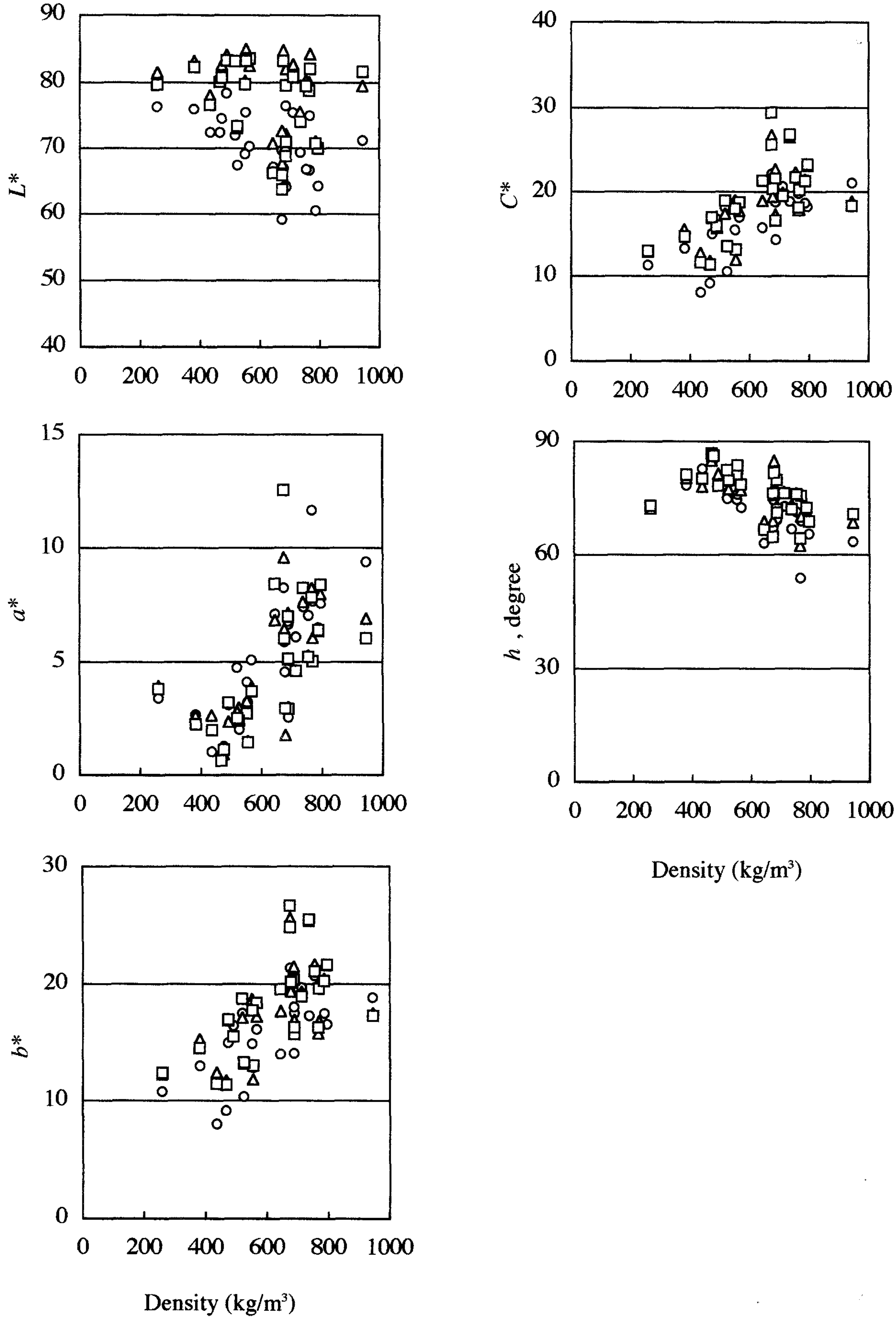


**Fig. 7.** Relations between the CIE 1976 ($L^*a^*b^*$) colorimetric values of sapwood and the densities. *Circles*, values in transverse planes; *triangles*, those in radial planes; *squares*, those in tangential planes

the relation between $Y$ in the transverse plane and the density. Because the correlation is negative, the more the transverse plane of the fiber substance appears, the less is the luminance; that is, the transverse planes of the cell fiber substance may decrease the luminance. It is thought that the lumen holes may not decrease the luminance of the transverse planes of wood. Therefore, that the luminance in the transverse planes being lower than in the radial and tangential section cannot attributed to the existence of lumen holes in the transverse sections. Rather, it may be attributed to the anisotropy of the luminance of the cell wall substance and the anatomical features of each plane.

The relations between the $x$ values of sapwood and the density are shown in Fig. 5. Positive correlations were found for the relations between the $x$ in all planes and the densities. The correlation coefficient had the highest value (0.813) in the transverse plane. The $x$ value indicates the proportion of the spectrum of longer wavelengths of the visible ray.[7] In contrast, the relations between the $z$ values and density were significantly negative, as shown in Fig. 6. The cell wall substance is thought to have a nature that emphasizes the longer wavelength region than the short wavelength region.

The approximately uniform color space in rectangular coordinates with $L^*$, $a^*$, and $b^*$ is employed to obtain the color differences of the objects. The values of the CIELAB color system ($L^*$, $a^*$, and $b^*$) are calculated with the tristimulus values by the following equations.[5]

$$L^* = 116\left(\frac{Y}{Y_0}\right)^{1/3} - 16 \tag{4}$$

$$a^* = 500\left\{\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right\} \tag{5}$$

$$b^* = 200\left\{\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right\} \tag{6}$$

In the case of the standard illuminant of $D_{65}$ and the 2 degrees standard observer, $X_0 = 95.045$, $Y_0 = 100$, and $Z_0 = 108.892$. The values of $C^*$ (chroma) and $h$ (hue) were calculated using the following equations.

$$C^* = \sqrt{a^{*2} + b^{*2}} \tag{7}$$

$$h = \tan^{-1}(b^*/a^*) \tag{8}$$

Figure 7 shows the relationships between the CIE 1976 ($L^*a^*b^*$) colorimetric values of sapwood and the density. The relation of $L^*$ (lightness) and density is similar to that of $Y$ and density; and this result is understood by the simple relation in Eq. (4). Positive relations can be observed for the values of $a^*$, $b^*$ and $C^*$ versus the density of wood. These results are understandable from the results of the relations for the values of $x$ and $z$ versus the density. In the transverse plane a negative correlation between $h$ and the density can be observed, but in the other planes the correlations are not significant. A positive relation between the chroma of sapwood and the density can be observed in all the principal planes, whereas negative correlations between lightness and density and between hue and density are found only in the transverse plane. All the trends of the relations between the CIE 1976 ($L^*a^*b^*$) colorimetric values of sapwood and the densities can be derived from the results for the tristimulus values. The CIE 1976 ($L^*a^*b^*$) colorimetric values describe the color difference suitably; that is, they are linear with the human perception but not linear with the physical intensity of the visible ray. It is adequate to employ the $XYZ$ values when discussing the relations between the colorimetric values and density.

## Conclusions

The relations between colorimetric values and densities are discussed for the sapwood specimens made from 26 Japanese hardwood species. The correlation between the $Y$ value and the densities was found only in the transverse sections. The transverse section of the cell fiber substance may decrease the luminance. Good positive correlations were found for the relations between the $x$ values in the transverse plane and density. The cell wall substance is thought to be of a nature that emphasizes the longer wavelength region rather than the shorter wavelength region of the visible ray.

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