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Colorimetry of wood specimens from French Guiana

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Abstract The color of 97 species of wood specimens from French Guiana was measured on their radial and tangential surfaces with a colorimeter. We obtained the tristimulus values of X, Y, and Z of the 10° standard observer under the illuminant of D_{65}, and the values of the CIELAB color system, L^*, a^*, b^*, C^*, and h. When the lightness index (L^*) was <54, b^*, C^*, and h showed positive correlations against L^*. When L^* was >54, a^* and C^* showed negative correlations against L^*. These results imply that wood color should be discussed by separating wood specimens into the high- and low-lightness groups. A good positive correlation was found between the L^* and h throughout the whole range of L^*. It is thought that the value of h can be an important index, as can L^*, for comparing of wood color because h shows a simple relation with L^*.

Key words Color of wood · CIELAB color system · Colorimeter · Tropical wood

Introduction

The color of wood differs widely among species. Color is an important factor when finding uses for wood, and the quality of wood is sometimes evaluated by its color. It is difficult to describe the appearance of wood using physical values because the wood surface is never expressed with a simple color, and it shows various figures including the grain. Furthermore, even in the heartwood portion of a single wood specimen, the color may be different from place to place.

Colorimetry is a good method for obtaining objective information on the color of wood. The CIELAB color system has been employed to evaluate the color of wood, for example to determine wood decay,[1] to measure the color of knots in wood,[2] and to detect color changes of pine wood after thermal treatment.[3] There are few reports on which color measurement was made on the wide variation of wood species using the CIELAB color system, and relations among the values of the color system. It is fundamental to understand the trend in relations of the values of the color system for communicating information about wood color precisely. Because the color of wood is an important factor in determining its usage, a database with appropriate color information would be useful for outlining the uses for unused wood resources. It should be based on the colors of a wide variety of wood species.

We measured the color of 97 species of wood from French Guiana on their radial and tangential surfaces using a colorimeter. The values of the CIELAB color system (L^*, a^*, b^*, C^*, and h) were obtained, and the relations among the values were studied to obtain information about the trend of wood color among the wide variety of wood species.

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Materials and methods

Specimens of 97 wood species from French Guiana were obtained between May 1953 and October 1982. The samples had been covered with paper and stored in a dark place. The colors on the surfaces were well stabilized throughout the long period of storage. We did not do any surface processing such as planing or sanding because the stability of the surface of the specimens would have been lost. The dimensions of the specimens were approximately

20 mm in the radial (R) direction, 20 mm in the tangential (T) direction, and 330 mm in the longitudinal (L) direction. The color was measured on the radial and tangential surfaces with a colorimeter (Datacolor Microflash 200 d) under ambient temperature and humidity from May to June 1996 at LMGC, Université Montpellier II. The diameter of the sensor head was 6 mm. The illuminant D_{65} and the 10° standard observer were employed as the conditions of measurement. The measurement was repeated five times on each surface, and the data were averaged. We obtained the colorimetric tristimulus values of X, Y, and Z and the values of the CIELAB color system (L^*, a^*, and b^*), which are calculated with the tristimulus values by the following equations.

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

$$a^* = 500\left\{\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right\} \quad (2)$$

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

In the case of the standard illuminant D_{65} and the 10° standard observer, $X_0 = 95.018$, $Y_0 = 100$, and $Z_0 = 108.845$. The values of C^* (chroma) and h (hue) were calculated by the following equations.[4]

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (4)$$

$$h = \tan^{-1}(b^*/a^*) \quad (5)$$

When a specimen showed a color difference between the heartwood and the sapwood, the measurement was made on the heartwood portion.

Results and discussion

Colorimetry in the CIELAB color system

Table 1 shows the colorimetry results for the wood specimens. The lightness index (L^*), whose possible range is from 0 to 100 in the CIELAB color system, ranged approximately from 36 to 79. The values of a^* and b^* can be in the range of less than −100 to more than 100 in the color system.[4] The values of a^* and b^* in Table 1 ranged approximately from 4 to 19 and from 11 to 33, respectively. All the values of a^* and b^* obtained in the measurement were positive. Note that the values of a^* and b^* were distributed in a narrow region compared to the possible ranges. Some specimens had a color difference between the radial surfaces and the tangential surfaces, which can be attributed to the difference of appearance owing to the anatomical features such as cell arrangement, existence of wide ray, interlocked grains, and so on. The trend of the color difference between the two surfaces could not be detected in relation to such anatomical features. So long as we used the colorimeter with a diameter of 6 mm, we had to average the measurement values. It is difficult to discuss the color difference between the two sections in relation to the anatomical features. We therefore discuss the results of the colorimetry of wood specimens with the 194 sets of data for the two surfaces of the 97 specimens.

Relations among the values of CIE XYZ color system

The values of X, Y, and Z are plotted in the coordinates of X and Y and Y and Z in Fig. 1. Note that the values of X, Y, and Z were variable according to the measurement condition, that is, by the standard illuminant and the standard observer. We found good positive linearity between X and

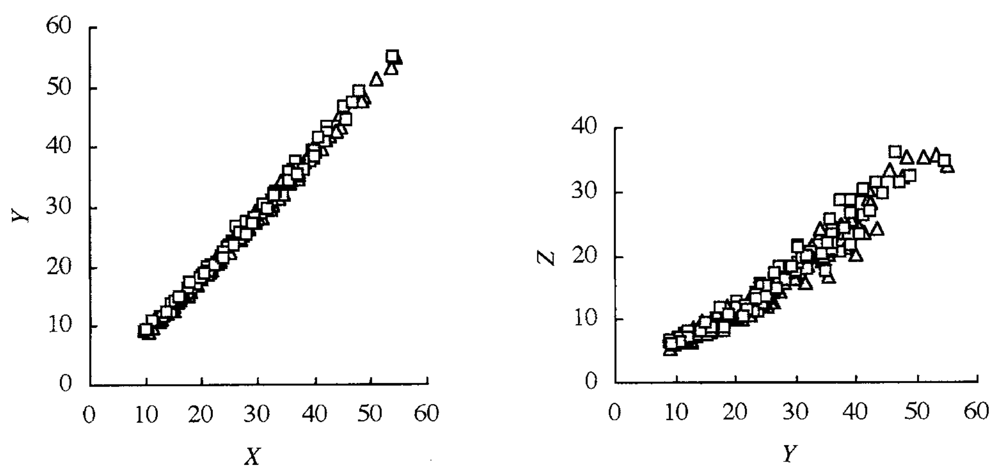

Fig. 1. Relations between X, Y, and Z of wood specimens from French Guiana. *Triangles*, radial surfaces; *squares*, tangential surfaces

Table 1. Color of the wood specimens from French Guiana in the CIELAB color system

Scientific name	Radial surface					Tangential surface				
	L	a*	b*	C*	h(deg.)	L*	a*	b*	C*	h(deg.)
Andira coriace Pulle	44.36	15.37	19.53	24.86	51.80	41.65	14.97	17.81	23.27	49.95
Andira sp.	47.20	13.99	19.71	24.17	54.63	40.51	12.89	15.16	19.90	49.63
Antonia ovata Pohl.	66.47	5.43	21.19	21.87	75.62	71.87	3.71	19.78	20.12	79.39
Aspidosperma Album R. Ben.	62.88	13.79	30.97	33.90	66.00	55.57	15.26	25.33	29.57	58.94
Bagassa guianensis Aubl.	40.85	12.61	18.64	22.51	55.93	46.88	13.92	24.20	27.87	60.09
Balizia pedicellaris Barneby et Grimes	61.86	15.02	27.14	31.02	61.04	63.33	14.27	27.19	30.71	62.31
Bombacopsis nervosa Robyns	52.42	16.01	24.63	29.38	56.99	46.14	17.07	24.94	30.23	55.61
Brosimum utile Pitt.	67.68	8.29	22.09	23.59	69.42	66.59	7.97	21.24	22.69	69.44
Caraipa densifolia Mart.	54.54	11.02	22.34	24.91	63.74	56.43	10.12	20.56	22.92	63.79
Carapa guianensis Aubl.	43.10	15.14	19.80	24.93	52.59	44.04	15.09	20.02	25.07	53.00
Carapa procera DC.	48.33	15.30	22.09	26.87	55.30	48.28	14.05	20.55	24.89	55.65
Caryocar glabrum Pers.	79.10	5.02	28.45	28.89	79.98	78.98	5.08	27.41	27.87	79.50
Chrysophyllum prieurii A. DC.	42.35	15.81	23.48	28.31	56.04	49.76	16.06	29.33	33.44	61.29
Chrysophyllum sanguinolentum Baehni	62.23	10.74	23.96	26.26	65.87	60.84	11.42	24.27	26.83	64.80
Couma guyanensis Aubl.	66.23	10.09	23.92	25.96	67.12	66.50	9.49	22.69	24.59	67.31
Couratari guyanensis Aubl.	69.83	6.99	25.63	26.57	74.76	70.53	6.81	24.57	25.49	74.50
Couratari multiflora Eyma	65.62	9.83	28.81	30.44	71.16	65.63	10.36	27.71	29.59	69.50
Dicorynia guianensis Amsh.	39.93	12.04	16.88	20.73	54.50	39.01	12.66	17.18	21.34	53.60
Dimorphandra polyantha R. Ben.	46.74	14.18	22.43	26.54	57.70	48.48	12.62	21.05	24.54	59.06
Diplotropis purpurea Amsh.	39.33	9.99	14.45	17.56	55.33	36.17	8.10	12.64	15.01	57.36
Dipteryx odorata Willd.	58.47	14.19	30.42	33.57	65.00	52.59	15.71	28.16	32.24	60.84
Drypetes variabilis Vitt.	65.30	10.35	27.77	29.64	69.56	58.79	12.16	27.07	29.67	65.81
Enterolobium oldemannii Barneby et Grimes	57.92	12.76	29.17	31.84	66.37	56.09	13.43	30.51	33.34	66.25
Enterolobium schomburgkii Benth.	59.43	13.25	27.76	30.76	64.49	57.53	12.86	27.50	30.36	64.94
Eperua falcata Aubl.	37.31	16.15	15.72	22.54	44.23	42.64	15.66	18.58	24.30	49.87
Eperua grandiflora Benth.	39.13	16.81	16.67	23.67	44.77	40.49	15.32	15.52	21.81	45.37
Eperua rubiginosa Miq.	42.12	19.36	21.21	28.72	47.61	41.56	19.38	20.62	28.30	46.77
Eperua sp.	50.47	11.89	21.43	24.51	60.97	52.29	11.79	20.14	23.34	59.65
Eriotheca crassa Robyns	52.83	16.01	26.67	31.10	59.03	49.16	15.62	25.97	30.30	58.97
Erisma uncinatum Warm.	57.21	13.02	22.68	26.15	60.14	55.58	13.02	22.07	25.63	59.46
Eschweilera coriacea Mart.	54.58	11.55	23.55	26.23	63.89	50.18	12.70	23.61	26.81	61.73
Glycydendron amazonicum Ducke	60.46	10.95	21.61	24.22	63.14	59.33	9.21	19.53	21.60	64.76
Goupia glabra Aubl.	50.80	16.56	23.42	28.68	54.75	45.35	17.60	21.39	27.70	50.54
Guarea gomma Pulle	46.76	16.69	24.49	29.64	55.73	47.17	17.43	24.41	29.99	54.47
Humiria balsamifera St Hill.	41.56	14.28	15.45	21.04	47.25	38.58	12.56	14.05	18.85	48.20
Hura crepitans L.	70.35	8.49	28.92	30.14	73.64	71.17	6.66	24.83	25.71	74.99
Hymenaea courbari L.	49.42	15.31	23.22	27.82	56.60	48.45	15.48	23.48	28.13	56.60
Jacaranda copaia D. Don	70.38	4.55	18.52	19.07	76.20	73.87	3.68	16.63	17.04	77.52
Laetia procera Eichl.	69.37	10.28	33.00	34.57	72.70	65.91	11.66	32.50	34.53	70.26
Lecythis idatimon Aubl.	39.38	11.54	14.15	18.26	50.80	36.00	9.55	10.92	14.51	48.85
Licania majusculata Sagot	54.33	9.97	22.39	24.51	65.99	56.72	14.36	28.44	31.86	63.20
Licania ovalifolia Kleinh.	46.60	12.51	20.60	24.10	58.74	50.55	13.62	24.57	28.10	61.00
Licaria canella Kosterm.	47.74	9.71	22.99	24.95	67.11	43.87	9.99	21.14	23.38	64.70
Licaria cayennensis Kosterm.	35.97	15.08	15.78	21.83	46.30	36.74	13.94	16.43	21.55	49.69
Licaria chrysophylla Kosterm.	49.91	10.21	21.00	23.35	64.08	44.54	11.14	20.40	23.24	61.37
Manilkara bidentata A. Chev.	44.80	14.12	15.50	20.97	47.68	41.58	14.16	15.20	20.77	47.03
Micropholis guianensis Pierre	64.98	11.95	26.11	28.72	65.41	61.84	12.54	25.35	28.29	63.68
Micropholis melinoniana Pierre	67.93	8.90	24.80	26.35	70.27	62.00	9.87	22.73	24.79	66.52
Moronobea coccinea Aubl.	66.17	11.69	34.22	36.16	71.14	69.06	9.40	30.42	31.84	72.82
Ocotea benthamiana Mez	46.08	16.88	23.52	28.94	54.34	44.96	15.77	21.19	26.41	53.35
Ocotea glomerata Benth.	53.27	11.47	25.71	28.15	65.96	51.69	10.26	23.92	26.03	66.77
Ocotea oblonga Mez	68.98	7.33	22.60	23.76	72.03	69.02	7.16	21.73	22.88	71.76
Ocotea petalanthera Mez	65.16	9.39	26.48	28.10	70.47	63.73	8.55	22.61	24.17	69.29
Ocotea rubra Mez	50.29	16.33	24.04	29.07	55.81	50.89	15.39	23.62	28.19	56.90
Ocotea schomburgkiana Benth.	65.62	9.46	25.56	27.25	69.70	60.21	10.10	25.55	27.47	68.43
Ocotea splendens Mez	57.36	13.52	30.04	32.94	65.78	55.26	12.55	29.15	31.73	66.70
Ormosia sp.	60.02	14.96	25.74	29.77	59.84	56.58	15.76	21.62	26.75	53.91
Parinari campestris Aubl.	75.08	7.23	19.54	20.83	69.70	72.61	9.64	23.28	25.20	67.52
Parkia nitida Miq.	76.81	6.56	22.62	23.55	73.82	74.52	4.95	24.10	24.61	78.39
Parkia pendula Benth.	71.83	9.64	30.11	31.61	72.24	70.01	10.01	28.79	30.48	70.83
Parkia sp.	74.62	8.92	22.85	24.53	68.68	68.65	10.66	26.40	28.47	68.02
Platonia insignis Mart.	53.01	14.24	28.39	31.76	63.36	49.59	13.37	26.93	30.06	63.59
Platymiscium sp.	39.93	14.51	16.91	22.28	49.38	41.42	15.20	18.87	24.23	51.14
Pradosia cochlearia Penn.	54.89	10.60	22.52	24.89	64.78	47.26	13.18	22.99	26.50	60.17
Protium sagotianum March	64.86	7.73	19.55	21.02	68.43	62.06	8.36	18.19	20.01	65.32
Pseudopiptadenia psilostachya (DC) Lewis et Lima	60.11	11.91	22.30	25.28	61.91	55.64	14.92	23.49	27.83	57.58
Pseudopiptadenia suaveolens (Miq) Brenan	45.87	14.54	19.72	24.50	53.59	52.16	15.24	22.43	27.12	55.81

Table 1. *Cont.*

Scientific name	Radial surface					Tangential surface				
	L	a^*	b^*	C^*	h(deg.)	L^*	a^*	b^*	C^*	h(deg.)
Qualea rosea Aubl.	56.82	15.41	28.22	32.15	61.37	57.39	14.78	26.24	30.12	60.61
Qualea sp.	51.58	15.16	25.78	29.91	59.54	53.74	13.05	23.99	27.31	61.45
Ruizterania albiflora Marc. Berti	50.29	12.78	18.28	22.31	55.04	45.55	12.22	17.88	21.66	55.65
Sacoglottis guianensis Benth.	42.85	9.05	15.05	17.56	58.97	48.77	8.76	16.69	18.85	62.30
Schefflera decaphylla (Seem.) Harms	73.22	4.44	19.28	19.78	77.03	70.55	4.52	18.48	19.03	76.24
Schefflera morototoni (Aubl.) Magui. Steyerm. Frodin	70.84	4.91	21.00	21.57	76.84	67.59	3.81	15.95	16.40	76.55
Sclerolobium melinonii Harms	61.77	11.09	23.84	26.30	65.06	62.62	10.75	22.57	25.00	64.52
Simaba multiflora A. Juss.	61.05	6.32	24.93	25.72	75.77	58.62	4.27	20.84	21.27	78.41
Simarouba amara Aubl.	66.42	7.24	26.74	27.70	74.84	75.44	4.51	24.38	24.79	79.52
Sterculia pruriens K. Schum.	57.45	11.13	23.32	25.84	64.49	57.77	10.86	23.63	26.00	65.32
Stryphnodendron polystachyum Kleinh.	51.33	15.84	23.63	28.45	56.17	55.64	15.57	24.75	29.24	57.82
Symphonia globulifera L. F.	68.18	10.96	29.12	31.11	69.38	67.67	11.65	29.85	32.04	68.68
Tabebuia sp.	39.93	7.83	17.01	18.72	65.28	39.28	7.16	17.88	19.26	68.18
Tachigali paniculata Aubl.	66.16	8.24	23.32	24.74	70.55	63.51	8.85	24.14	25.71	69.87
Terminalia amazonia Exell	66.19	6.88	27.61	28.45	76.01	66.61	6.80	26.91	27.76	75.82
Terminalia guianensis Eichl.	57.35	10.42	26.93	28.88	68.85	54.30	12.41	27.10	29.80	65.40
Tetragastris altissima Swart.	61.49	14.98	27.13	30.99	61.09	57.38	16.48	26.79	31.45	58.41
Tetragastris panamensis O. Ktze.	51.16	14.56	24.57	28.56	59.35	50.60	13.61	22.12	25.97	58.40
Tetragastris sp.	54.47	17.36	28.63	33.49	58.77	53.27	17.10	27.59	32.46	58.21
Thyrsodium spruceanum Benth.	70.89	8.24	19.32	21.00	66.89	68.91	8.78	18.59	20.56	64.71
Trattinickia rhoifolia Willd.	65.09	5.91	18.43	19.36	72.21	66.42	5.70	18.59	19.44	72.97
Virola michelii Heck.	66.40	10.41	26.69	28.64	68.69	65.27	10.81	26.37	28.50	67.71
Virola sp.	68.98	9.37	23.33	25.14	68.12	63.25	10.49	23.43	25.67	65.89
Virola surinamensis Warb.	63.82	8.17	20.89	22.43	68.64	62.02	8.74	18.45	20.41	64.66
Vochysia cayennensis Warm.	71.30	10.26	22.85	25.05	65.82	68.27	11.62	24.33	26.96	64.47
Vochysia guianensis Aubl.	65.42	14.37	25.25	29.05	60.36	58.99	14.91	26.57	30.47	60.70
Vochysia neyratii D. Norm.	63.34	14.37	25.80	29.53	60.88	66.63	13.22	25.40	28.64	62.50
Vochysia speciosa Warm.	78.02	8.35	24.37	25.76	71.09	66.07	12.08	24.54	27.35	63.78
Vochysia tomentosa DC.	63.58	14.33	24.12	28.06	59.28	61.26	14.13	23.17	27.14	58.63
Vouacapoua americana Aubl.	40.58	9.62	14.98	17.80	57.28	36.69	9.79	13.87	16.98	54.77

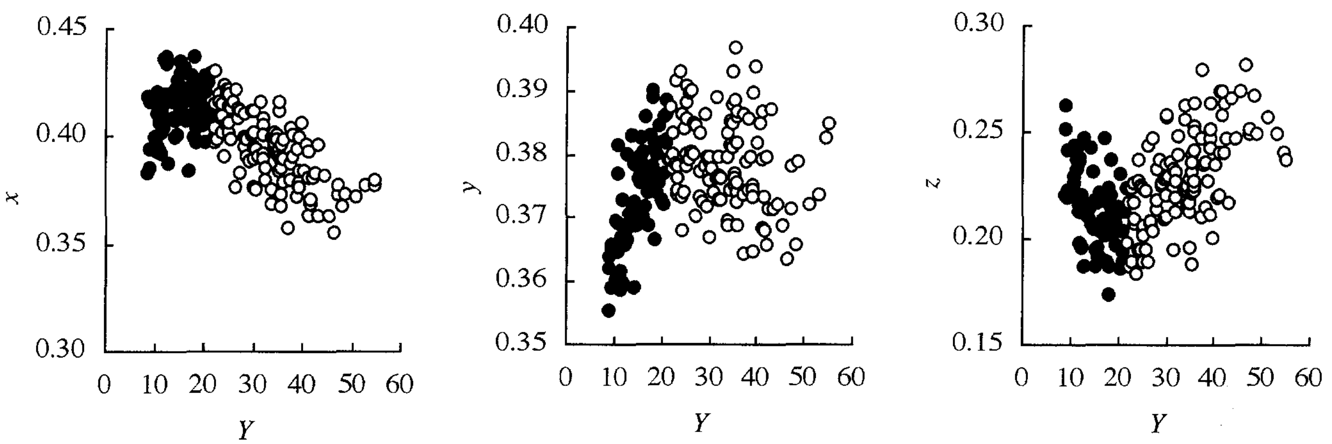

Fig. 2. Relationship of x, y and z against Y of wood specimens from French Guiana. *Solid circles*, $Y < 22$; *open circles*, $Y > 22$

Y. This relation is related to the fact that a^* distributes in a narrow region. We also found a positive correlation between Y and Z, but Z is somewhat dispersed in the higher region of Y, and the slope of Z against Y looks smaller in the lower region of Y than in the higher region of Y. The boundary between the two regions seems to exist in the range of Y from 20 to 25. From this result we can expect that there are different trends concerning wood color between the regions of the high and low values of Y. The value of Y is called luminance, and the lightness $(L)^*$ is derived from the Y. For the sake of convenience, we divided the specimens by the luminance into two cases: $Y < 22$ and $Y > 22$. We have 79 sets of data when $Y < 22$ and 115 sets when $Y > 22$. From Eq. (1), the L^* is approximately 54 when $Y = 22$.

In the XYZ color system, chromaticity coordinates with x, y, and z are often used in the discussion of color itself without luminance.[4]

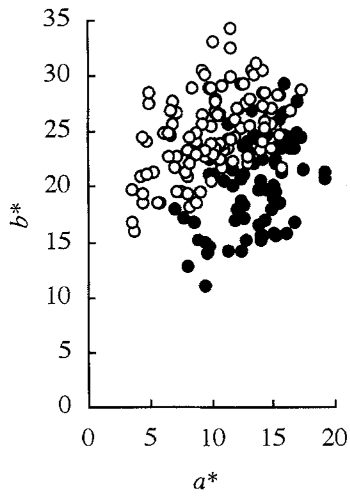

Fig. 3. Relation between a^* and b^* of wood specimens from French Guiana. *solid circles*, $L^* < 54$; *open circles*, $L^* > 54$

The values of x, y, and z are plotted against Y in Fig. 2. A negative correlation is found between Y and x with a correlation coefficient (r) of -0.670 through the whole range of Y. When $Y < 22$, however, we find a weak positive correlation ($r = 0.321$) between the two; when $Y > 22$, a negative correlation ($r = -0.687$) is found. The y shows a positive correlation ($r = 0.718$) against Y only in the case of $Y < 22$. The z shows a positive correlation ($r = 0.447$) against the whole range of Y, but where $Y < 22$ there is a negative correlation ($r = -0.555$) between Y and z. When $Y > 22$, a positive correlation ($r = 0.558$) is found between Y and z. The Z is measured on the basis of the color-matching function, which has a peak in the short-wavelength region of visible light.[4] Thus the portion in the short-wavelength region decreases with increasing luminance among the specimens with lower luminance and increases with increasing luminance among the specimens with higher luminance.

$$x = \frac{X}{X+Y+Z} \quad (6)$$

$$y = \frac{Y}{X+Y+Z} \quad (7)$$

$$z = \frac{Z}{X+Y+Z} \quad (8)$$

Relations among the values of CIELAB color system

Figure 3 shows a relation between a^* and b^*. No significant correlation is found between the two at a significance level of 5%. Among the specimens whose L^* is >54, a correlation ($r = 0.492$) is found, and a correlation ($r = 0.454$) is also found among the specimens with the L^* value <54. Roughly speaking, the lighter specimens show greater values of b^* and smaller values of a^*.

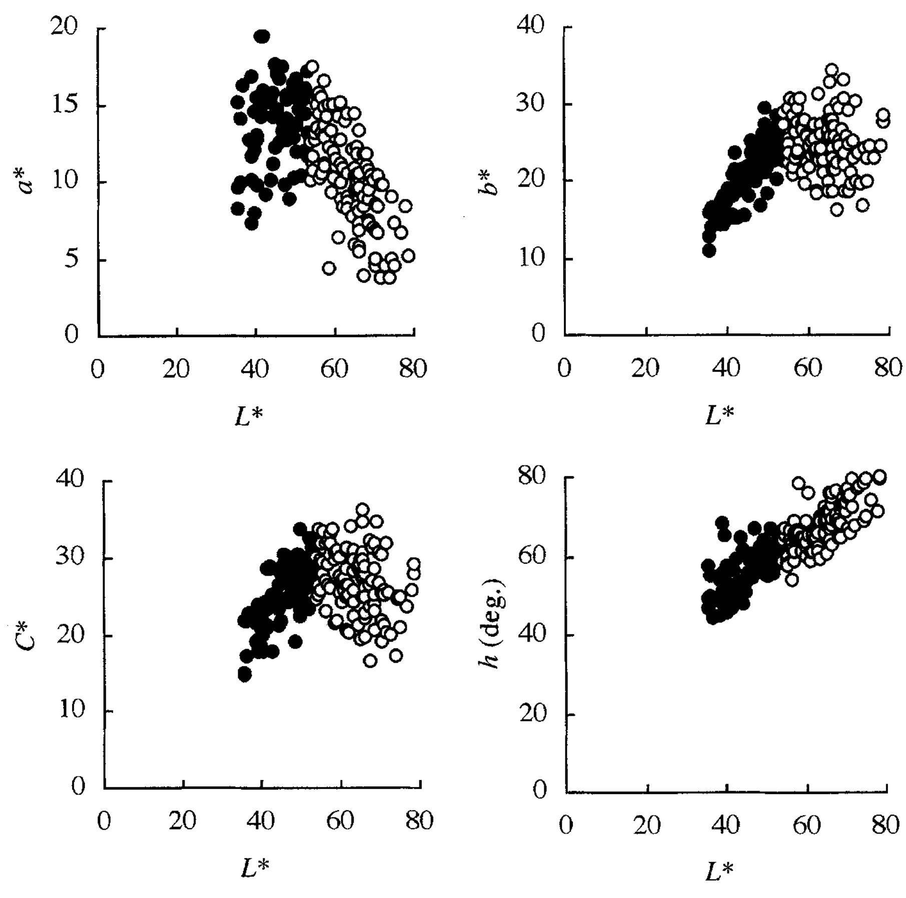

Fig. 4. Relation of a^*, b^*, C^*, and h against L^* of the wood specimens from French Guiana. *solid circles*, $L^* < 54$; *open circles*, $L^* > 54$

Figure 4 shows the relations of a^*, b^*, C^*, and h against L^*. The a^* shows a negative correlation ($r = 0.677$) against L^* when $L^* > 54$, but when $L^* < 54$, the correlation is not significant at a significance level of 1%. The b^* shows a good correlation ($r = 0.832$) against L^* when $L^* < 54$, but the correlation when $L^* > 54$ is not significant. The C^* shows a positive correlation ($r = 0.737$) against L^* when $L^* < 54$ and a negative correlation ($r = -0.307$) against L^* when $L^* > 54$. The trend of C^* against the L^* is reflected by the positive correlation of b^* against the L^* when $L^* < 54$ and by the negative correlation of a^* against L^* when $L^* > 54$. The h shows an excellent positive correlation ($r = 0.852$) against the whole range of L^*. The correlation coefficients are 0.584 and 0.704 when $L^* < 54$ and $L^* > 54$, respectively. In the case of the specimens measured in this research, the lighter one tends to approach the b^* axis. The values of a^*, b^*, and C^* do not show simple relations against L^*. Wood color should be discussed after separating wood specimens into high and low-lightness groups. The h can be an important index, as can L^*, for comparing of wood color because it shows a simple relation against L^*.

We have ascertained that some wood species show different colorimetric values from the values in this report. Even in such cases, though, the results obtained from this kind of study are useful as fundamental information for evaluating the special cases.

Conclusions

We conclude the following as a result of the colorimetry of the wood specimens from French Guiana in the CIELAB color system. When the specimens were divided into two categories ($L^* < 54$ and $L^* > 54$) b^*, C^*, and h show positive correlations against L^* when $L^* < 54$, and a^* and C^* showed negative correlations against L^* when $L^* > 54$. The color of wood showed different trends for the specimens with higher and lower lightness. We should therefore discuss wood color by categorying wood specimens into high- and low-lightness groups. An excellent positive correlation was found between h and L^* throughout the range of L^*, which means that the lighter specimens tend to approach the b^* axis. It is thought that the value of h can be an important index, as can L^*, for comparing wood color because h shows a simple relation with L^*.

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