

WOOD SPECIFIC GRAVITY VARIABILITY IN *CEIBA PENTANDRA*

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ABSTRACT

We examined the wood specific gravity variability in *Ceiba pentandra* trees from four Costa Rican life-zones and a moist tropical forest in Sierra Leone, West Africa. Trees from the African site averaged higher wood specific gravity than those occurring at two high-rainfall sites in Costa Rica. However, the high degree of variability within sites reduced our capacity to detect environmental and/or genetic differences among the sites. Higher intensity field samples, and/or provenance testing under specific environmental conditions, are recommended to help clarify the sources of this variation.

Keywords: *Ceiba pentandra*, kapok, wood specific gravity.

INTRODUCTION

Ceiba pentandra, the kapok or silk-cotton tree, ranks among the largest trees in tropical America and Africa. This early successional species typically colonizes alluvial, well-drained sites (Purseglove 1968; Hartshorn and Poveda 1983), and reaches heights of 60 m and diameters >2.4 m above its wide spreading "plank" root buttresses (Little and Wadsworth 1964; Baker 1983; Chudnoff 1984). In recent years, the wood of this species has increased in commercial importance because of its suitability for light construction and plywood core stock, large size which facilitates processing, and local abundance following deforestation activities (Gentry and Vasquez 1988). The diffuse-porous wood of *Ceiba* is light brown in color, soft, straight-grained, weak, and exceedingly light weight. Wood specific gravity (SG) for this species is reported to range from 0.089 to 0.300 (Wangaard et al.

1954; Little and Wadsworth 1964; Kukachka 1970; Chudnoff 1984), increasing linearly from the pith to the bark (Wiemann and Williamson 1989a, b).

Tree species often demonstrate a high degree of variability in their SG, both within stands and between provenances (Howe 1974; Wright 1976; Zobel and Talbert 1984; Zobel and van Buijtenen 1989; Omolodun et al. 1991). We hypothesized that the wood specific gravity in *Ceiba* would differ among life-zones in response to environmental and genetic influences. To examine this condition, we evaluated the wood SG variability within individual trees of *C. pentandra*, among individuals growing in a single life-zone, and between races from four Costa Rican life-zones and a moist tropical forest in west Africa.

METHODS

In 1990 we sampled trees in four tropical life-zones (Holdridge 1968): a wet, a dry, two

TABLE 1. General characteristics of the five study sites.

Site	Mean elev (m)	Annual precip (mm)	Mean temp (°C)	Canopy ht (m)
Costa Rica, S. America				
La Selva (LS) (tropical wet forest)	<150	4,000	24	45-55
Palo Verde (PV) (tropical dry forest)	<200	1,250	24	20-30
Hojancha (H) (tropical moist forest)	350	2,000	22	40-50
Las Cruces (LC) (tropical premontane rain forest)	675	5,000	20	30-40
Sierra Leone, Africa				
Tiwai Island (TI) (tropical moist forest)	<50	2,600	24	30-50

moist, and one premontane rain forest (Table 1). We selected six to seven healthy dominant trees at each location, collecting wood samples at breast height from each specimen except where buttresses required the samples to be taken farther up the trunk (just above the swelling, at a distance of 1 m or less above breast height). Pith to bark wood samples were extracted with a 45-cm long, 12-mm inside-diameter increment borer, limiting the maximum diameter of individual trees to 90 cm. At four of the five sites, we cored three to seven trees twice, with extractions 90–120 degrees to one another. The pith to bark samples were then divided into 1-cm segments, starting from the pith, with each segment containing a green volume of 1.13 cm³. The wood was later oven-dried at 105 C to a constant weight, and the SG of individual segments calculated as dry weight over green volume (Panshin and deZeeuw 1980). In addition to collecting the wood samples, we measured tree height and live crown ratio.

We plotted SG as a function of distance from the pith using a linear regression model. Sapwood segments from the outermost portions of the cores (1–2 cm) were discarded as these tended to show a much lower SG than adjacent heartwood segments. Specific gravity variability was then compared within and across life-zones, using an analysis of variance (ANO-

VA) based on the Y-intercept, slope, and coefficient of determination (r^2) values from the regression analyses. Where two cores were taken from a single tree, we randomly selected one core for use in the ANOVA tests. Tukey's Studentized Range (HSD) Test was used to identify significant differences ($P \leq 0.05$) between life-zones. We also utilized paired t -tests to assess differences in the intercept, slope, and r^2 -values between cores extracted from the same tree. All assumptions of the statistical models were satisfied. We used the Statistical Analysis Systems (SAS, Cary, North Carolina) to perform each analysis.

RESULTS AND DISCUSSION

All *Ceiba* stems demonstrated increases in SG with distance from the pith (Table 2), supporting earlier work by Wiemann and Williamson (1989a, b); however, trees on Tiwai Island exhibited a higher overall wood SG (higher mean intercept) compared to trees at La Selva and Las Cruces (Table 3, $P = 0.0450$). The higher SG at Tiwai (slopes and r^2 -values were similar at all five sites) may reflect the influence of environmental factors upon tree development and wood production (Larson 1962; Howe 1974; Wiemann and Williamson 1989b; Zobel and van Buijtenen 1989).

The wood SG of *Ceiba* appears to be neg-

TABLE 2. Summary of the specific gravity characteristics and regression analyses, by life-zone and tree, for wood cores from *Ceiba pentandra* in Costa Rica and Sierra Leone.

Site	Tree	Diam ¹	Segm ²	r ²	Int	Slope	Old ³	New ⁴	New/old
LS	1	38	16	0.762	0.0637	0.0105	0.118	0.254	2.146
LS	2	52	23	0.806	0.1338	0.0097	0.113	0.326	2.879
LS	3	63	24	0.723	0.1991	0.0064	0.204	0.350	1.717
LS	4	47	21	0.519	0.2152	0.0076	0.195	0.347	1.920
LS	5	76	30	0.907	0.0436	0.0129	0.105	0.448	4.253
LS	6	27	11	0.725	0.1006	0.0154	0.138	0.261	1.896
PV	1s ⁵	65	25	0.626	0.2336	0.0048	0.310	0.377	1.219
PV	11	65	31	0.796	0.1762	0.0060	0.208	0.340	1.636
PV	2	27	12	0.779	0.1187	0.0116	0.122	0.231	1.886
PV	3s	64	26	0.813	0.1843	0.0086	0.178	0.365	2.049
PV	31	64	28	0.715	0.2207	0.0066	0.199	0.392	1.971
PV	4s	36	17	0.139	0.1836	0.0032	0.195	0.251	1.283
PV	41	36	20	0.116	0.1824	0.0025	0.178	0.243	1.366
PV	5	69	34	0.773	0.1592	0.0075	0.107	0.411	3.826
PV	6	69	31 ⁶	0.558	0.2322	0.0028	0.229	0.304	1.328
H	1	88	38	0.884	0.1118	0.0060	0.124	0.282	2.280
H	2s	58	27	0.836	0.1011	0.0085	0.153	0.340	2.224
H	21	58	31	0.778	0.1441	0.0056	0.159	0.320	2.019
H	3	57	30	0.788	0.1904	0.0068	0.156	0.409	2.620
H	4	39	17	0.885	0.1653	0.0141	0.186	0.378	2.029
H	5s	73	31	0.890	0.1658	0.0067	0.206	0.374	1.814
H	51	73	35	0.834	0.1969	0.0052	0.215	0.370	1.719
H	6s	73	29	0.740	0.1638	0.0061	0.158	0.328	2.078
H	61	73	39	0.836	0.1474	0.0046	0.154	0.295	1.918
LC	1s	51	21	0.777	0.1381	0.0071	0.171	0.289	1.692
LC	11	51	25	0.402	0.1830	0.0029	0.202	0.263	1.300
LC	2	65	37 ⁶	0.934	0.0290	0.0090	0.047	0.388	8.255
LC	3	39	15	0.531	0.1213	0.0067	0.168	0.275	1.634
LC	4s	54	22	0.675	0.1339	0.0064	0.170	0.317	1.867
LC	41	54	28	0.406	0.1354	0.0026	0.169	0.221	1.307
LC	5s	55	29	0.685	0.0704	0.0059	0.122	0.270	2.210
LC	51	55	34	0.644	0.0927	0.0035	0.108	0.261	2.409
LC	6	85	40 ⁶	0.315	0.2730	0.0029	0.279	0.413	1.480
TI	1s	46	14	0.621	0.2281	0.0109	0.223	0.364	1.636
TI	11	46	23	0.687	0.1551	0.0084	0.158	0.358	2.271
TI	2s	50	27	0.412	0.2421	0.0058	0.205	0.376	1.831
TI	21	50	29	0.394	0.2072	0.0038	0.219	0.351	1.599
TI	3s	52	18	0.720	0.2350	0.0106	0.226	0.384	1.697
TI	31	52	28	0.673	0.2208	0.0068	0.195	0.393	2.015
TI	4s	42	18	0.626	0.2002	0.0071	0.202	0.299	1.481
TI	41	42	25	0.212	0.1446	0.0042	0.222	0.292	1.318
TI	5s	54	22	0.565	0.2197	0.0078	0.170	0.356	2.092
TI	51	54	24	0.676	0.2149	0.0073	0.176	0.360	2.044
TI	6s	86	34	0.425	0.2614	0.0030	0.275	0.382	1.391
TI	61	86	42	0.598	0.2279	0.0032	0.259	0.401	1.547
TI	7s	75	24	0.792	0.2367	0.0087	0.226	0.403	1.785
TI	71	75	38	0.895	0.1761	0.0063	0.187	0.382	2.045

¹ Diameter at breast height (1.4 m) measured in centimeters, or directly above the buttress-swell if this structure exceeded 1.4 m in height.² Number of 1 cm segments from the pith to the outer edge of the heartwood.³ SG of the three segments located nearest to the pith were averaged to generate a measure of the SG of the wood produced when a tree was young.⁴ SG of the outermost three segments of heartwood averaged to give a measure of SG for the most recently formed wood.⁵ Two cores from one tree, extracted 90–120 degrees from one another, at the same elevation above the ground.⁶ Tree contained rot near pith; thus SG for “old” segments were developed using the slope and intercept values from the regression analysis.

atively related to the precipitation at a site. High rates of annual rainfall and the absence of a pronounced dry season (i.e., La Selva and Las Cruces in Costa Rica) yield wood with a lower overall SG. Wiemann and Williamson (1989b) also compared SG versus distance from pith for dry forest and wet forest trees of *Ceiba* and found that the dry forest tree had greater SG wood at every radial position, but the slopes of the plots did not differ. Whitmore (1973) observed a similar trend in balsa, another member of the Bombacaceae family. Other tropical hardwood species demonstrate similar, opposite, or no response patterns to this environmental factor (Howe 1974; Chudnoff 1976; Barajas Morales 1987; Zobel and van Buijtenen 1989).

An additional factor that may have contributed to *Ceiba*'s high wood SG on Tiwai was the density of the forest. Tiwai was the only site where all trees were components of a closed canopy secondary forest. At the four Costa Rican sites, the *Ceiba* stems represented residual trees following deforestation or invasions along fence rows. The canopy structure on Tiwai could have restricted the crown development of these stems (the live crown ratio of these trees averaged 65–80% of ratios observed in the Costa Rican sites), possibly leading to a reduction in stem growth (Oliver and Larson 1990) and/or a more rapid shift from juvenile to mature wood (Larson 1962). These conditions may in part explain the high wood SG observed on Tiwai. Other factors may also have influenced the wood SG of this species (tree age, soil fertility, etc.), suggesting opportunities for future research.

The general similarity in *Ceiba* wood SG among the sites (intercept, slope, and r^2) lead us to consider that either sampling errors, or high variability within the populations, may have masked differences in wood production due to environmental and/or genetic factors. Errors may have occurred in several ways. The pith in *Ceiba* stems seldom lies in the center of the tree. Hence, the "run" (x-axis) portion of the slope calculation varies according to the length of the extracted radius, with longer radii

TABLE 3. Comparison of the mean *Ceiba pentandra* wood specific gravity properties from four Costa Rican life zones and a moist tropical forest site in Sierra Leone.

Site	Intercept	Slope	r^2	(New/old)/diam
LS	0.1260b	0.0104a	0.740a	0.0510a
PV	0.1741ab	0.0073a	0.743a	0.0401a
H	0.1522ab	0.0075a	0.843a	0.0353a
LC	0.1313b	0.0059a	0.646a	0.0342a
TI	0.2160a	0.0073a	0.644a	0.0334a
P-value	0.0450	0.1488	0.0771	0.1970

Numbers within columns that are followed by the same letter are not significantly different at $P \leq 0.05$.

yielding flatter slopes (paired t -test, $P = 0.0001$, $n = 16$). To test the change in SG from the pith-to-bark in these two core length groups, we examined the ratio of "new" wood (outermost three segments of heartwood averaged to give a measure of SG for the recently formed wood) to the "old" wood (SG of the three segments located nearest to the pith were averaged to generate a measure of wood SG when the tree was young). This technique is reviewed in Wiemann and Williamson (1988). The paired t -test used to evaluate the new/old ratio between long and short cores indicated that the SG change between the pith and bark in a tree (the "rise") was similar across varying distances (radii) from the pith to the bark (same elevation above the ground).¹ Thus, while the increase in *Ceiba* wood SG from the pith to the bark was the same in a tree across all radius lengths at breast height, the slope of that change was dependent upon the radius direction (core length).

Knowing that the change in SG from the pith to the bark is the same across all portions of a stem (at a fixed height above the ground), we "standardized" the SG slopes from each tree by dividing the new/old ratio by the diameter of the tree. Average stem radius is perhaps a more logical choice than diameter; how-

¹ It appears that the cambium deposits fewer cells in the narrow pith-to-bark portions of a given stem cross section, rather than a lateral compaction of an equal number of cells, when compared to those deposited across a wider radius.

ever, it requires an unnecessary additional calculation and diameter is a more common measurement in forestry. We then subjected these new slopes (new/old ratios per diameter) to an ANOVA to test for differences in slope between the various study sites. This second test of the slopes again failed to indicate any significant SG differences among the sites (Table 3, $P = 0.1970$). Thus, *Ceiba* stems of similar diameters appear to exhibit similar pith-to-bark changes in SG regardless of their site of origin.

The small samples sizes used in our study, however, may have reduced the sensitivity of our analyses to identify differences in the wood SG among the study sites. We examined the variability within the statistical models using estimated mean square values, and found that tree-to-tree variation accounted for 76–90% of the variability within these analyses. This high 'within' site variability suggests that the parent tree exerted a greater influence on *Ceiba* wood SG than the overall environmental factors associated with the site. This condition reflects either high microsite and/or genetic variability. Yet the relatively low P -values in the SG ANOVAs (≤ 0.1970 , Table 3), imply that site conditions also influence the wood properties of this species (especially the overall density, as the west African site demonstrated a trend toward higher initial SG, while maintaining similar rates of increase [slope] to those observed in the four Costa Rican sites). Larger sample sizes may have helped to clarify the role of 'site' on *Ceiba* wood SG.

The high tree-to-tree variability within site and the potential for site conditions to influence this wood property suggest that where SG of *Ceiba* wood is a resource concern (i.e., planting stock for fiber production), or a tool to evaluate ecological processes (adaptability to certain climatic, edaphic, or biotic conditions), then both parent tree selection and site conditions should be considered before meaningful inferences can be established.

CONCLUSIONS

Specific gravity within *Ceiba pentandra* ex-

hibits a strong, positive increase from the pith-to-bark, with individual stems demonstrating a high degree of wood SG variation within a site. The wood SG of *Ceiba* also responds to differences in the environmental conditions characterizing different sites, although to a lesser extent than the within site tree-to-tree variation. Whether these phenotypic differences are strictly environmental or reflect genetic adaptations remains unanswered. A greater number of field samples and/or provenance testing under specific environmental conditions would help to identify the sources of this variation.

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