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ENGINEERING PROPERTIES OF TWO UNDERUTILISED CÔTE D' IVOIRE SPECIES: ADJOUABA AND ANIOUKETI

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STOKER, D.L., WINANDY, J.E. & ACHI, E.K. 1996. Engineering properties of two underutilised Côte d' Ivoire species: adjouaba and aniouketi. Two hardwoods indigenous to Côte d' Ivoire, Africa, adjouaba *(Daclyodes klaineana)* and aniouketi *(Puchypodanthium staudtii)* were evaluated for mechanical and physical properties using the American Society for Testing and Materials Standards. Both hardwoods exhibited high levels of bending strength, crushing strength and tangential shrinkage as well as medium levels of stiffness. However, aniouketi and adjouaba exhibited medium and high levels of radial shrinkage respectively. Both adjouba and aniouketi appear comparable to hickory *(Carya* spp.). Both woods seem appropriate for use in furniture, cabinet work, flooring, millwork, and plywood. Test results from this study were compared with published values obtained from AFNOR (French) standard tests. Differences reported between one data set and a published data set were probably due to inadequate sample size, geographic sampling pattern, and procedural differences inherent in each test method.

Key words: Adjouaba - *Dacryodes klaineana* - aniouketi - *Pachypodanthium staudtii* - Côte d' Ivoire - mechanical properties - physical properties

STOKER, D.L., WINANDY, J.E. & ACHI, E.K. 1996. Ciri-ciri kejuruteraan bagi dua species Côte d' Ivoire kurang guna: adjouaba dan aniouketi. Dua kayu keras asli kepada Côte d' Ivoire, Afrika, adjouaba *(Dacryodes klaineana)* dan aniouketi *(Pachypodanthium staudtii)* telah dinilai ciri-ciri fizikal dan mekanikalnya dengan menggunakan Piawaian Persatuan Amerika untuk Ujian dan Bahan. Kedua-dua kayu keras menunjukkan tahap kekuatan lentur, kekuatan hancur serta pengecutan tangen yang tinggi dan tahap kekukuhan yang sederhana. Akan tetapi, aniouketi dan adjouaba masing-masing menunjukkan tahap pengecutan radial yang sederhana dan tinggi. Kedua-dua adjouaba dan aniouketi adalah setanding dengan hickori *(Carya* spp.) Kedua-dua kayu sesuai digunakan untuk perabot, kerja kabinet, pelantaian, kerja-kerja memproses dan papan lapis. Keputusan ujian ini dibandingkan dengan nilai-nilai yang telah diterbitkan daripada ujian piawai AFNOR (Perancis). Perbezaan di antara satu set data dengan set data yang lain mungkin disebabkan saiz sampel yang tidak mencukupi, polapenyampelan geografik dan perbezaan prosedur yang wujud dalam setiap kaedah ujian.

Introduction

For more than a century, many well-known species of wood have been managed, harvested, and exported from Côte d' Ivoire (Aubrèville 1959). The economy of Côte d' Ivoire relies heavily on the revenue obtained from the forest products industry, and the export of tropical woods has been an important source of revenue since 1960. In 1989, 2.5 x 10^6 m^3 (1.06 x 10^9 board feet) of timber were exported and from 1980 - 1992 more than 1.148 x 10^6 m^3 (4.8 x 10^8 board feet) of timber were exported annually (IDEFOR, per. comm.).

In 1978, approximately 45 000 jobs existed in various areas of Côte d' Ivoire, such as logging, sawing, milling, trade, and secondary manufacture. Today, far fewer jobs are available in the forest products industry. This is partially because the industry currently depends on a limited number of tree species. These limited species have been over-exploited and now lack quality and quantity required in today's competitive market (Durand & Achi 1983).

As in many parts of the world, secondary tree species are underutilised in Côte d' Ivoire, partly because little information exists on the mechanical and physical properties of these species. This information is needed before these underutilised species can compete in the market. Additional information will enable knowledgeable use of these underutilised species, thereby lessening the demand on the existing overutilised species.

To identify potential underutilised species for the export market, a survey was conducted on 40 x 10^{12} m^2 (9.9 x 10^6 acres) of forest in Côte d' Ivoire (SODEFOR 1974 - 1978). This survey revealed the existence of 29 secondary tree species having a diameter greater than 600 mm (23.6 in) and a total standing volume of nearly 100 x 10^6 m^3 (4.2 x 10^{10} board feet) (Miellot 1979, Durand & Achi 1983). However, little technical data are available for these species.

In an effort to develop a systematic methodology to address this problem, two viable wood species were selected. The two-fold objectives of this project were to develop material property information and establish an overall programme for underutilised species. Through a cooperative study with the Wood Techology Division of the Centre Technique Forestier Tropical in Abidjan, Côte d' Ivoire and the USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA, and sponsored under a Cochran Fellowship through the USDA International Cooperative Development Office, preliminary samples of adjouaba [*Dacryodes klaineana* (Pierre) Lam, family Burseraceae] and aniouketi [*Pachypodanthium staudtii* (Engl. & Diels), family Annonaceae] were evaluated.

Materials and methods

Material procurement

To achieve a representative range of specific gravity, four diverse locations within Côte d' Ivoire were sampled (Figure 1) The locations were selected based on results of all initial forest sampling of adjouaba and aniouketi (SODEFOR 1974 - 1978)

One bolt (defined as a short section of a tree trunk) of each species was harvested at the four locations (Table 1). Mature trees were selected, having the average shape and height characteristics determined during the preliminary sampling.

Table 1. Log (bolt) data

Region	Diameter (cm) *Adjouaba*	Diameter (cm) *Aniouketi*	Annual rainfall (cm (in)	Forest type
I	75 (29.5)	57 (22.4)	>1000 (394)	Deciduous
II	66 (26.0)	61 (24.0)	>1600 (630)	Rain
III	53 (20.9)	53 (20.9)	>1600 (630)	Rain
IV	65 (25.6)	60 (23.6)	>1600 (630)	Rain

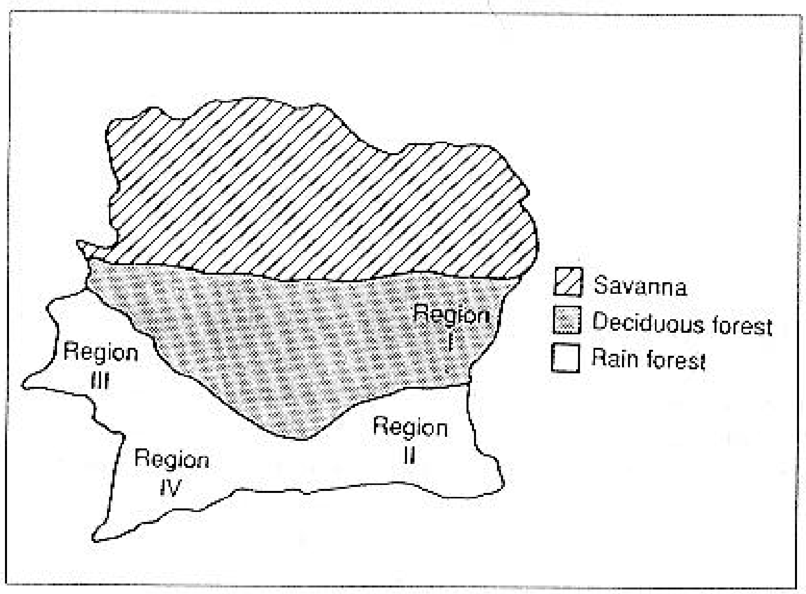

Figure 1. Côte d'Ivoire, West Africa, sampling location

Sample size

Because the specimens were shipped to the United States for testing before the two-fold objectives of this project were finalised, only one bolt from each region was sampled. Hence, the properties must be recognised as not statistically characterising each location and may present a better national perspective than a regional perspective.

A total of 64 specimens was tested. The following summarises the sampling matrix:

2 species
4 regions/species
1 bolt/region

4 sticks/bolt
2 end-matched specimens/stick

Six mechanical and five physical property tests were performed, with 16 specimens/tests/species. Some properties were measured from the undamaged portions of mechanically-tested specimens.

Specimen preparation

Each bolt was cut 1.5 m above ground and measured 1.75 to 1.8 m long. If the bottom of the tree was buttressed, the log was cut at the next available height. All bolts were processed 48 h after harvest.

Each bolt was reduced to a pith-centered flitch with a thickness of 63 mm (2.48-in). If defect free, both sides of the flitch were cut to yield four 63-mm (2.48-in) square sticks. Each stick was labeled to indicate the location with respect to the pith and side (Figure 2). All sticks cut from the flitch were heartwood, with the outer strips near the heartwood/sapwood boundary. In general, the sapwood width was 89 to 115 mm (0.35 to 0.40 in).

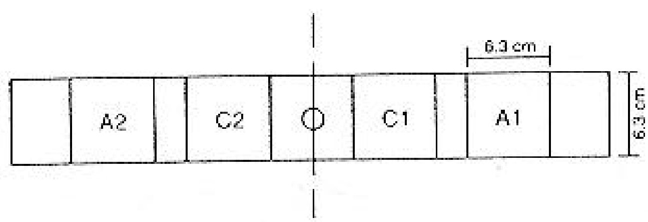

Figure 2. Specimen cutting scheme showing end view of a pith-centred flitch

Each stick was then cut into half to yield two end-matched specimens with a length of 810 mm (31.9 in), clear of defects (Figure 3). The specimens closest to ground level were used for static-bending test and physical property assessment. The specimens farthest from ground level were used for other mechanical property tests, such as compression parallel- and perpendicular-to-grain, shear parallel-to-grain, cleavage, and hardness.

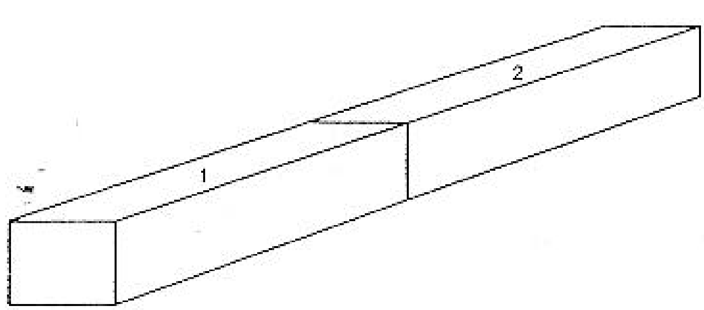

Figure 3. Specimen cut from stick obtained from flitches: the half located nearest the ground level was used for static bending test and physical property assessment; the other half was used to obtain all other mechanical properties.

All specimens were shipped to the Forest Products Laboratory (FPL) in Madison, Wisconsin. Moisture content ranged from 15 to 19% upon arrival at the FPL. Specimens were conditioned in an environment of 2.3 °C, 65% relative humidity to reach an equilibrium state of 12% moisture content. Specimens were then cut into dimensions of 45.7 mm^2 (1.80 in^2); those exhibiting deep splits or warp were eliminated.

The ASTM D143 (Anonymous 1993) standard was used as a guideline for all mechanical property tests in this study. However, because some selection and processing decisions were made prior to the involvement and agreement on project objectives, the specimens differed from those required by the ASTM D143 standard. The ASTM standard recommends that at least five trees representative of the species be selected but only four trees were sampled. Also, two bolts from each log are required; but only one was used. The direction with reference to the north, south, east, and west should be noted on the log so that specimes are cut from each direction; these references were not noted. In the study reported here, the order, selection, and mode of tests as stated in the standard were followed, but specimen dimensions were different than those required by as ASTM D143.

Test methodology

Six mechanical and five physical properties were evaluated. Both mechanical and physical properties were tested using ASTM D143 as a guideline with the following differences: sample replication was smaller, cutting pattern was different, and specimen size was not the standard 2 x 2 in (50.8 x 50.8 mm).

Mechanical properties

Moisture content and specific gravity were measured on each specimen that was subjected to a mechanical property test.

Static bending

For each species, sixteen 45.7 x 45.7 mm (1.8 x 1.8 in) specimens were tested (4 specimens/region). Bending specimens had a 709-mm (28-in) span and were loaded at the centre point. The resulting span-to-depth ratio was 15.5:l. Specimens were positioned so that the tensile stress was maximum on the tangential face furthest from the pith. A constant deflection rate 2.5 mm min^{-1} (0.1 in min^{-1}) was used.

Moisture content

The moisture content was obtained from a 52-mm (2.04in) long block cut from an undamaged area near the static-bending-failure point. The blocks were oven-dried at 103 °C for 72 h and the weight recorded. These blocks were retained for later use in the shrinkage/swelling tests.

Compression parallel-to-grain

The specimen dimensions were 45.7 x 45.7 x 182 mm (1.8 x 1.8 x 7.2 in). The rate of loading was 0.6 mm min^{-1} (0.024 in min^{-1}) and the deflection gauge length was 152 mm (6 in).

Compression perpendicular-to-grain

The specimen dimensions were 45.7 x 45.7 x 152 mm (1.8 x 1.8 x 6 in) long. The rate of loading was applied at 0.3 mm min^{-1}(0.012 in min^{-1}) until a 2.5-mm 0.1-in) deformation was induced. The standard definition of deformation is load-head displacement, stress failure is reported at 1 mm (0.04 in) of deformation.

Hardness

Specimens were 45.7 x 45.7 x 152.4 mm (1.8 x 1.8 x 6 in). The load was applied until a 11.3-mm(0.444in) diameter steel ball held in a metallic ring was embedded in the specimen to half its diameter. Six penetrations were performed: one on each end; two on a radial face; and two on a tangential face, approximately 37.5 mm(1.5 in) from each end. The rate of loading was 6.35 mm min^{-1} (0.25 in min^{-1}).

Shear parallel-to-grain

A 45.7 x 45.7 mm (1.8 x 1.8 in) square cross-section was used with a 17.1-mm (0.67-m) notch cut on the tangential face (Figure 4). Just prior to testing, each specimen was weighed and measured. The rate of loading was 0.6 mm min^{-1} (0.024 in min^{-1})

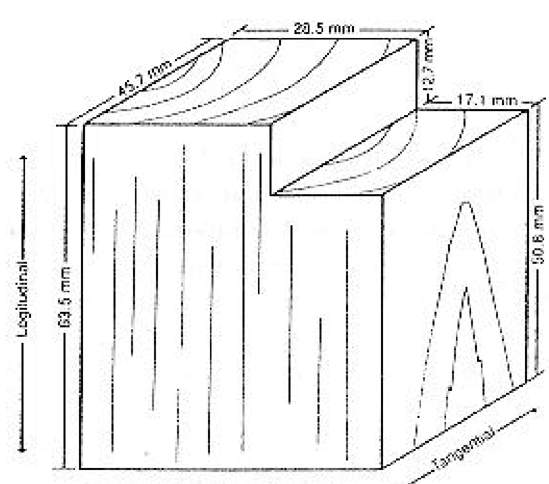

Figure 4. Shear block dimensions

Cleavage

The specimen dimensions were 45.7 mm (1.8 in) square with a cleavage length of 52.7 mm (2.07 in) (Figure 5). Specimens marked Al or Cl were loaded parallel to the tangential axis, and those marked A2 or C2 were loaded parallel to the radial axis. The rate of loading was 2.5 mm min^{-1} (0.1 in min^{-1})

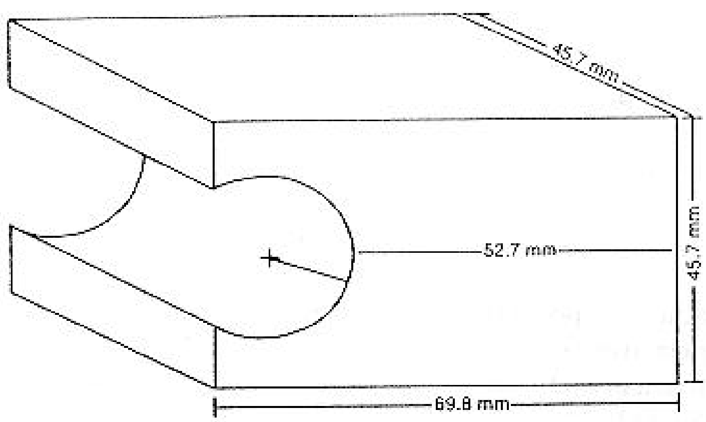

Figure 5. Cleavage specimen dimensions. Half the specimens were tested so that crack propagated in the radial plane; the remaining half were tested so that crack propagated in the tangential plane. Radius of notch was 12.5 mm.

Physical properties

The physical property tests were performed on the undamaged portions of specimens that had been used in the static bending tests. The undamaged specimens were cut as near as possible to the failure point and then cut to non-standard dimensions of 45.7 x 45.7 x 38.1 mm (1.8 x 1.8 x 1.5 in). At the time of cutting, the moisture content was approximately-l 4%. The blocks were weighed and measured at three conditions :

Test condition - equilibrated to 23 °C(74 °F), 65% relative humidity
Oven-dried
Saturated - soaked in water for 24 days
Five physical properties were determined:
Specific gravity, at the three listed conditions
Moisture content, at time of test
Linear swelling, from oven-dried to saturated conditions
Volumetric shrinkage/swelling, from oven-dried to saturated conditions
Fibre saturation point

Specific gravity

The specific gravity was determined using oven-dry weight and volumes obtained at three conditions :

Over-dry
As tested
Saturated

Linear shrinkage/swelling

The linear shrinkage/swelling in both the radial and tangential directions was determined by comparing the oven-dry, as tested, and saturated dimensions. The volumetric shrinkage/swelling was obtained by comparing the oven-dry, as tested, and saturated volumes.

Fibre saturation point

The fibre saturation point (FSP) was determined for each direction by extrapolating a line drawn from each oven-dried dimension (0%) through the test dimension ratio, then to a point of intersection with a constant saturated dimension ratio (Figure 6). The FSP was defined as the average of the means for all directions: volumetric, tangential, and radial

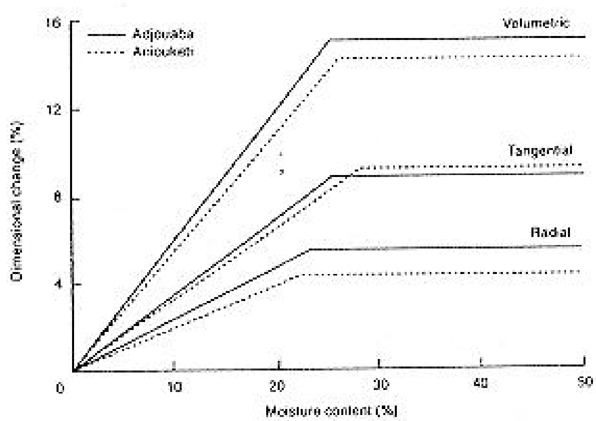

Figure 6. Dimension changes used to calculate the fibre saturation point for (-) adjouaba and (- - -) aniouketi

Results

The physical and mechanical properties of the two species studied are shown in Table 2. The tested mean, standard deviation and approximated standard deviation are reported. The fewer the samples used in a study, the less likely can the tested mean and standard deviation be representative of the true species mean and standard deviation. The approximated standard deviation was calculated using an estimated coefficient of variation for each property determined from tests of more than 50 softwoods and hardwoods (Anonymous 1987). In each case, the approximated standard deviation was greater than the tested ones and it provided a better means for comparison with other test results and species.

Table 2. Results obtained using ASTM standard test methods. Shown are the combined means and standard deviations of four independent tests from four geographic regions.

Property		Aniouketi			Adjouaba		
		Mean	Tested standard deviation	Approximate standard deviation	Mean	Tested standard deviation	Approximate standard deviation
Mechanical n=16	MOE (GPa)	17.8	3.17	3.39	16.3	1.17	3.59
	MOR (MPa)	128	12.5	20.5	141	14.1	22.6
	WML (J m^{-3})	77.4	13.5	26.3	87.1	16.0	29.6
	SHEAR (MPa)	13.8	1.03	1.93	17.9	2.14	2.51
	CMCS (MPa)	79	11.9	14.2	71.8	5.1	12.9
	COME (GPa)	17.9	3.31	–	17.0	1.65	–
Physical n=16	FSP (%)	25	1		26	3	
	SGD	0.69	0.07		0.80	0.04	
	SGG	0.60	0.06		0.69	0.03	
	SGT	0.66	0.11		0.73	0.03	
	SHRD (%)	4.37	0.99		5.39	0.55	
	SHTN (%)	9.11	0.82		9.03	0.91	
	SHV (%)	14.29	1.60		15.22	1.68	
	HSIDE (kN)	7.56	0.98	1.51	9.25	1.47	1.85

MOE = modulus of elasticity,
MOR = modulus of rupture,
WML = work to maximum load,
CLVR = cleavage in radial plane,
CLVT = clevage in tangential plane,
CMCS = maximum crushing strength (compression parallel to the grain),
CMOE = modulus of elasticity from compression parallel to the grain test,
FSP = fibre saturation point,
SGD = specific gravity (dry basis),
SGG = specific gravity (saturated basis)),
SGT = specific gravity (at time of test),
SHRD = radial shrinkage,
SHTN = tangential shrinkage,
SHV = volumetric shrinkage,
HSIDE = side hardness.

The results of the two species obtained using American standards were compared with those using AFNOR (French) standards (Sallenave 1955). Before a direct comparison could be made, adjustments were needed to account for the differences in specified load configuration, moisture content, rate of load, specimen size, load control, and data analysis between the two standard methods.

A comparison of adjusted properties from Sallenave (1955) and the FPL data sets for the two species showed that most properties were significantly different, because the means from the published data did not fall within a 95% confidence interval of the data obtained at the FPL (Tables 3 & 4). For instance, the radial and tangential shrinkage values for the French data were lower than those of FPL for aniouketi, but greater for adjouaba. The difference in specific gravity was not significant for aniouketi, but significant for adjouaba. The French modulus of rupture (MOR) value for aniouketi was within the confidence interval of FPL, but for adjouaba it was 31% greater than that of FPL. Also, the French modulus of elasticity (MOE) value for aniouketi is 26% less than that of FPL but only 10% less for adjouaba.

Table 3. FPL test results with corresponding 95 % confidence intervals

Species	Property[a]	Mean	Confidence interval Low	Confidence interval High
Aniouketi	Shrinkage, radial (%)	4.4	3.8	4.9
	Shrinkage, tangential (%)	9.1	8.7	9.5
	Shrinkage, volumetric (%)	14.3	13.4	15.1
	Specific gravity[b] (%)	0.66	0.60	0.72
	Modulus of rupture (MPa)	128	117	139
	Modulus of elasticity (GPa)	17.8	15.7	19.9
	Maximum crushing strength (MPa)	79.0	71.4	86.6
	Shear (MPa)	13.8	12.8	14.8
Adjouaba	Shrinkage, radial (%)	5.4	5.1	5.7
	Shrinkage, tangential (%)	9.0	8.5	9.5
	Shrinkage, volumetric (%)	15.2	14.3	16.1
	Specific gravity[b] (%)	0.73	0.71	0.75
	Modulus of rupture (MPa)	141	129	153
	Modulus of elasticity (GPa)	16.3	14.4	18.2
	Maximum crushing strength (MPa)	71.8	64.9	78.8
	Shear (MPa)	17.9	16.6	19.2

[a]Mechanical properties at 12% moisture content.
[b]ASTM D 143 at time of test (12% moisture content).

Table 4. AFNOR values compared to confidence intervals of FPL data

Species	Sample Size	Property	Mean	Relation to confidence intervals of FPL data
Aniouketi	18	Shrinkage, radial (%)	3.4	lower
		Shrinkage, tangential (%)	8.2	lower
		Shrinkage, volumetric (%)	14.0	within
		Specific gravity (%)	0.64	within
		Modulus of rupture (MPa)	134	within
		Modulus of elasticity (GPa)	11.6	lower
		Maximum crushing strength (MPa)	66.5	lower
		Shear (MPa)	7.73	lower
Adjouaba	16	Shrinkage, radial (%)	6.4	higher
		Shrinkage, tangential (%)	10.3	higher
		Shrinkage, volumetric (%)	18.6	higher
		Specific gravity (%)	0.83	higher
		Modulus of rupture (MPa)	201	higher
		Modulus of elasticity (GPa)	12.9	lower
		Maximum crushing strength (MPa)	77.7	within
		Shear (MPa)	–	–

[a]Mechanical properties at 12% moisture content; AFNOR specific gravity values converted to ASTM D143 basis of oven-dry mass and volume at 12% moisture content.

Conclusion

Rased on the general comparison with U.S hardwoods (Anonymous 1987) and tropical species (Chudnoff 1984), aniouketi and adjouaba exhibited high levels of bending strength, crushing strength, and tangential shrinkage and medium levels of stiffness. However, aniouketi exhibited a medium level of radial shrinkage, and ajouaba a high level. Both hardwoods appear comparable to hickory (*Carya* spp.) (Farmer 1972, Anonymous 1987). Both woods seem appropriate for use in furniture, cabinet work, flooring, millwork, and plywood.

In this study, both sets of data were too small to precisely represent the population of each species. For instance, adjouaba exhibited a wide range of specific gravity between data sets. Due to the direct relationship between specific gravity and engineering properties, a greater variability is expected in the properties than that demonstrated by relying on either data set. To effectively use any species, data must be obtained using a representive sampling plan.

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