BIOLOGICAL, PHYSICAL AND MECHANICAL WOOD PROPERTIES OF PARAÍSO (*MELIA AZEDARACH*) FROM A ROADSIDE PLANTING AT HUAXTLA, JALISCO, MEXICO

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VENSON, I., SILVA GUZMÁN, J. A., FUENTES TALAVERA, F. J. & RICHTER, H. G. 2008. Biological, physical and mechanical wood properties of paraíso (*Melia azedarach*) from a roadside planting at Huaxtla, Jalisco, Mexico. The present study was undertaken with the objective of evaluating the wood quality of 11-year-old paraíso (*Melia azedarach*) trees from a roadside planting near Huaxtla, Jalisco, Mexico. The biological, physical and mechanical properties studied include density, dimensional stability, strength (bending, compression, tension, shear, impact) and natural durability. The medium density (0.56–0.68–0.76 g/cm^3 at 12% moisture content) wood is similar in strength to true mahogany (*Swietenia macrophylla*) and is of moderate dimensional stability. Its attractive appearance (colour, figure) resembles that of cedro (*Cedrela* spp.) and suren (*Toona* spp.). Heartwood resistance against white rot and brown rot fungi is on average moderate, but quite variable. Based on the property profile established by the present study paraíso wood from trees planted in Mexico appears suitable for the manufacture of decorative veneers sliced and peeled, furniture parts, plywood, glue board, laminates, panelling, window and door framing, general carpentry, and light construction under cover.

Keywords: Paraíso, dimensional stability, strength properties, natural durability, uses

VENSON, I., SILVA GUZMÁN, J. A., FUENTES TALAVERA, F. J. & RICHTER, H. G. 2008. Ciri biologi, fizik dan mekanik kayu paraíso (*Melia azedarach*) yang ditanam di sisi jalan Huaxtla, Jalisco, Mexico. Kajian ini dijalankan bertujuan untuk menilai kualiti kayu pokok paraíso (*Melia azedarach*) berusia 11 tahun yang ditanam di sisi jalan berhampiran Huaxtla, Jalisco, Mexico. Ciri biologi, fizik dan mekanik yang dikaji termasuklah ketumpatan, kestabilan dimensi, kekuatan (lenturan, mampatan, tegangan, ricih, hentaman) serta ketahanan semula jadi. Kayu berketumpatan sederhana (0.56–0.68–0.76 g/cm^3 pada tahap lembapan 12%) ini mempunyai kestabilan yang serupa dengan mahogani (*Swietenia macrophylla*) dan kestabilan dimensinya pula adalah sederhana. Sementara itu warna dan belaknya yang menarik menyerupai kayu cedro (*Cedrela* spp.) dan suren (*Toona* spp.). Ketahanan teras kayu menentang kulat reput putih dan reput perang secara puratanya adalah sederhana tetapi agak berbeza-beza. Berdasarkan profil ciri yang diperoleh daripada kajian ini, kayu paraíso daripada pokok yang ditanam di Mexico nampaknya sesuai untuk pembuatan venir hiasan yang dihiris atau dikupas, bahagian perabot, papan lapis, papan perekat, kayu laminat, kayu panel, kerangka tingkap serta pintu, pertukangan kayu dan pembinaan ringan di tempat yang bertutup.

INTRODUCTION

The paraíso tree (*Melia azedarach*) belongs to the mahogany family (Meliaceae) which produces many well-known timber trees such as true mahogany (*Swietenia macrophylla*) and cedro (*Cedrela odorata*) in South America and African mahogany (*Khaya* spp.), utile (*Entandrophragma utile*) and sapele (*Entandrophragma cylindricum*) in tropical Africa. Paraíso is native to the sub-Himalayan region of India and, including several varieties, is also found in Indochina, China, Indomalesia and Australasia. The tree, often referred to as chinaberry or Persian lilac, has been cultivated outside its area of natural distribution since the 16th century, chiefly for ornamental purposes. It is now naturalized in most subtropical and tropical regions of the world (World Agroforestry Centre 2006). Its bark, leaves and roots possess important medicinal

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properties used in treating virus infections, as insect repellent, and as an antiseptic and diuretic (Keating & Bolza 1982). The tree is also frequently employed as auxiliary plant with important service functions in cropping systems such as coffee (*Coffea arabica*), wheat (*Triticum* spp.), sugarcane (*Saccharum officinarum*) and abaca (*Musa textilis*) to sustain and/or increase the yield of these crops (Faridah Hanum & van der Maesen 1997).

In the past decades, paraíso has seen a remarkable shift from a purely ornamental, medicinal or auxiliary plant to an important tree for wood production plantations established in many regions of the world, notably in China, Indochina and South-East Asia (Indonesia), West Africa (Nigeria), Australasia (Australia, Fiji), and southern South America (Argentina, Brazil, Paraguay) (Wagenführ 1993). Experimental industrial plantations on a smaller scale also exist in Central America, the Caribbean and in México (Guanajuato, Jalisco, Michoacán, Oaxaca, Querétaro, San Luis Potosí, Veracruz, and Yucatán) (CONAFOR 2006).

Paraíso is a deciduous to semi-deciduous, medium-size tree that grows to a height of approximately 20–25 m and a diameter at breast height (dbh) of 40–70 cm, with a straight and cylindrical bole free of branches for 4–10 m (Dahms 1990). It is highly adaptable and tolerates a wide range of climatic and soil conditions. Plantation-grown trees show excellent growth in height (up to 21 m) and diameter (up to 50 cm) at age 15 to 20 years (Frühwald *et al.* 1989, Matzek 1996, Do Van Ban 1997, Pramana 1998), with considerable variation depending on variety, locality, site conditions and silvicultural treatment.

The sapwood of paraíso is narrow, yellowish white and distinct from the uniformly pale brown, pink or reddish-brown heartwood. Its wood is ring-porous to semi ring-porous with distinct growth rings producing an attractive figure on plain and quarter sawn surfaces (Keating & Bolza 1982, Anonymous 1994). The mostly straight-grained, medium density timber is similar in external appearance to that of coloured ash (*Fraxinus* spp.) or red elm (*Ulmus* spp.) and to the botanically-related commercial timbers cedro (*Cedrela* spp.) and suren (*Toona* spp.) (Betancourt 1987, Anonymous 1994). The wood is reported to season rapidly but tends to warp and split considerably under severe drying conditions. It is easy to work with all hand and machine tools and is suitable for peeling and slicing. It glues well, has a high natural gloss, dresses to a smooth finish and takes a good polish (Keating & Bolza 1982, Chudnoff 1984, Martawijaya *et al.* 1992, Wagenführ 1993).

Information on wood structure as well as physical and mechanical properties of plantation-grown paraíso is available from such diverse provenances as India (Pearson & Brown 1932), Vietnam (Wagenführ 1993, Do Van Ban 1997), China (Chen 1962), Australia (Bolza and Kloot 1963), Malaysia (Pun 1969), Argentina (Coronel 1989), Paraguay (Frühwald *et al.* 1989), Indonesia (Pramana 1998) and México (Rechy & van Roth 2004), among others.

The objective of the present study was to present comprehensive information on biological, physical and mechanical properties as well as possible uses of paraíso wood planted in México. Data on wood properties of plantation-grown paraíso from other regions of the world are presented which enable direct comparison and evaluation of the wood quality produced by the Mexican trees.

MATERIALS AND METHODS

Ten average size trees, around 11 years old (ring count), with a dbh of about 20 to 25 cm were collected from a roadside planting at Huaxtla near Guadalajara, Jalisco, Mexico. No information on seed source or genotype could be provided by the owner. The selection of trees was strictly along commercial lines as mandated by the owner, namely, minimum values for dbh (20 cm) and bole clear of branches (4.5 m), sound and straight. Disks were taken at six height levels of the clear bole, namely, 0.70 (A), 1.30 (B), 2.10 (C), 2.90 (D), 3.60 (E) and 4.30 m (F). Initial moisture contents as well as basic, oven-dry and green densities were determined with specimens from the six disks of each tree, divided into two zones (inner and outer) about half way along the radius from inside out. Normal density (at equilibrium moisture content in standard climate of 20 °C and 65% relative humidity (RH)) was determined using specimens prepared for strength tests, all values mathematically adjusted to 12% MC. Density was determined with test specimens after conditioning in normal climate.

Since actual moisture content is rarely exactly 12% (it usually varies between 11 and 13% after reaching equilibrium), all values were adjusted to 12% as required by the relevant standards.

Specimens for the determination of natural durability, swelling and shrinkage were extracted from disk B taken at dbh. Due to the variation in diameter between trees and at different height levels, the number of specimens available for the various tests differed between trees and disks. However, emphasis was placed on having a representative number of specimens that would provide reliable information about the variability of the evaluated wood properties. The remaining short logs were sawn into boards of dimensions commensurate with requirements of the various standards employed. After pre-dimensioning, all specimens destined for strength tests were air-dried and subsequently conditioned to equilibrium moisture content in standard climate (20 °C, 65% RH). The following properties were determined according to the standards given in parentheses.

Natural durability (ASTM D 2017-81, 1998)—laboratory tests were conducted with heartwood specimens using the white rot fungi *Trametes versicolor* (syn. *Coriolus versicolor*) and *Phanerochaete chrysosporium*, and the brown rot fungi *Neolentinus suffrutescens* (syn. *Lentinus lepideus*) and *Postia placenta* (syn. *Poria monticola*). Thirty decay chambers consisting of glass jars half-filled with either potato dextrose agar (PDA) for *P. chrysosporium* or malt extract agar (MEA) for all other test fungi were prepared. The jars were loosely capped, sterilized for 20 minutes at 100 °C and allowed to cool. After cooling, jars were inoculated with a 1 cm^2-agar plug cut from the actively growing edge of the respective test fungus. The jars were kept at 28 °C until the mycelium nearly covered the substrate surface. Then one wood specimen was placed on each surface. The jars were then incubated at 27°C for 16 weeks. After exposure and carefully removing the adhering mycelium, specimens were conditioned at 60 °C until constant weight and weighed to the nearest 0.001 g. Natural durability was determined based on the mass loss caused by each of the fungi employed.

Physical and mechanical properties were determined in accordance with German DIN and DIN EN standards as follows: moisture content (DIN 13183-1, 2002); density (DIN 52182, 1976); shrinkage and swelling (DIN 52184, 1979); bending strength—modulus of rupture (MOR) and modulus of elasticity (MOE) (DIN 52186, 1978); compression strength parallel and perpendicular to the grain—MOR and MOE (DIN 52185, 1976); tensile strength—MOR and MOE (DIN 52188, 1979); shear strength (DIN 52187, 1979); impact bending strength (DIN 52189, 1981); and side hardness BRINELL (DIN EN 1534, 2000). Equivalent values for JANKA side hardness presented in Table 6 are estimates based on mathematical conversion using the equation (Schwab 1990):

$$H_{JANKA} = (H_{BRINELL} - 7.3)/3.1$$

Statistical data analyses were conducted with the software package Statgraphics 5.0, making use of simple (ANOVA) and multivariate (MANOVA) analyses of variance as well as *t*-test options offered by the package. Results given in the diverse tables are values representing the entire population of specimens obtained from the 10 trees investigated.

RESULTS AND DISCUSSION

Growth increments are well demarcated owing to the pronounced ring porosity of the wood. Width of annual increments varied from 3 (outermost rings) to 25 mm (innermost rings), with an overall mean of 10.7 mm, indicating considerable growth potential. Corresponding mean values of 9.5 mm are reported for 17–19-year-old trees from plantations in Vietnam (Do Van Ban 1997), 9 mm for 18-year-old trees from plantations in Paraguay (Frühwald *et al.* 1989), and 8 mm for 19-year-old trees from plantations in Indonesia (Pramana 1998).

Moisture content and density

Initial moisture content and basic density according to height level of clear bole are shown in Table 1. Moisture content was highest at the lower part of the stem (level B, 60%) and lowest towards the top of the commercial bole (level E, 51%). Basic density varied little from 0.54 g/cm^3 for levels C to F to 0.56 g/cm^3 at the stem base (levels A to B). Both initial moisture content (55 to 60%) and basic density (0.55 to 57 g/cm^3) along the stem radius tend to increase from inside out (Table 2). Frühwald *et al.* (1989), in their study of fast-grown plantation paraíso trees from Paraguay, observed an initial moisture content of similar magnitude (50 to 55% on average), with the lowest values near the pith and the highest at the stem periphery.

The radial increase of density from inside out is accompanied by a decrease in growth ring width, a trend also reported by Frühwald *et al.* (1989). This observation contradicts the general rule for ring-porous hardwoods that a decrease in ring width causes an over-proportional reduction of the higher density latewood and, therefore, a decrease in overall density. A reasonable explanation for this counter trend may be the young age of the examined Huaxtla trees. The trees had a high proportion of lower density juvenile wood caused by generally thin-walled latewood fibres often described for plantation-grown hardwoods and softwoods (Zobel & Sprague 1998) and wide earlywood bands in the first three to four growth increments representing the inner zone of the material studied. Similar density trends were observed for other ring-porous woods such as teak (*Tectona grandis*), both from old growth (Myanmar) as well as plantations in Ghana (Sonntag 2003) and Brazil (Polato *et al.* 2003). However, no explanation or specific reference to juvenile wood formation was offered. A radial increase of density from pith to bark accompanied by a decrease in ring width has also been reported by Dünisch *et al.* (2007) for black locust (*Robinia pseudoacacia*) from planted forests in central Hungary and the state of Brandenburg, Germany. The authors equate this phenomenon with the presence of juvenile wood characterized by a high proportion (37%) of thin-walled axial parenchyma in the first five formed rings, decreasing to 22% in adult wood.

Average values for basic, oven-dry, normal and green densities are presented in Table 3. These values were compared with corresponding data from literature (Table 4). Based on normal density, the wood of paraíso from Huaxtla and, for that matter, from other Latin-American provenances, slightly exceeds the range of the medium density class (0.45–0.65 g/cm^3, Farmer 1988) with modest within-tree variation. It is superior to the mean density reported for wood of *M. azedarach* from plantations in Asia and Australasia, independent of tree age (Table 4).

Table 1 Variation of moisture content and basic density with tree height

Height level of clear bole	Number of specimens	Moisture content (%)				Basic density (g/cm^3)			
		Min	Mean*	Max	SD	Min	Mean*	Max	SD
A (0.70 m)	50	33.2	58.9a, b	83.6	10.0	0.482	0.560a	0.650	0.038
B (1.30 m)	63	38.7	60.5a	82.8	7.2	0.439	0.559a	0.658	0.042
C (2.10 m)	52	38.9	56.3b	71.3	7.2	0.468	0.547a, b	0.594	0.031
D (2.90 m)	38	40.7	58.3a, b	77.5	7.7	0.438	0.538b	0.577	0.026
E (3.60 m)	24	35.5	51.2c	70.6	8.9	0.493	0.541b	0.588	0.026
F (4.30 m)	24	35.9	52.2c	66.3	8.3	0.441	0.545a	0.591	0.033

Average values obtained from 10 paraíso trees; SD = standard deviation
*Values assigned the same letter do not show statistically significant differences at 95% confidence level.

Table 2 Variation of initial moisture content and basic density with inner and outer zones of the tree

Zone	Number of specimens	Moisture content (%)				Basic density (g/cm^3)			
		Min	Mean*	Max	SD	Min	Mean*	Max	SD
Inner	171	33.7	55.3	66.3	7.2	0.468	0.546	0.573	0.031
Outer	65	38.4	59.8	73.1	8.5	0.509	0.569	0.656	0.032

Average values obtained from 10 paraíso trees; SD = standard deviation
* Means show statistically significant differences at 95% confidence level.

Table 3 Wood density values of paraíso planted at Huaxtla, México

	Density			
	Basic (g/cm^3)	Oven-dry (g/cm^3)	Normal* (g/cm^3)	Green (kg/m^3)
Mean	0.55	0.61	0.68	870
Min / Max	0.49/ 0.66	0.48 / 0.73	0.56 / 0.76	666 / 1095
CV [%]	6.5	6.7	5.3	8.6
N	262	257	807	259

*Conditioned to approximately 12% moisture content in standard climate (20 °C and 65% relative humidity)
Averages obtained from 10 trees; CV = coefficient of variance; N = number of specimens

Table 4 Density of paraíso planted at Huaxtla, México compared with corresponding data from other provenances

	Mean density				Source and provenance (tree age)
	Basic [g/cm^3]	Oven-dry [g/cm^3]	Normal [g/cm^3]	Green [kg/m^3]	
Melia azedarach	**0.55**	**0.61**	**0.68**	**870**	This study, Huaxtla, México (11)
do.	**0.47**	**0.53**	**0.56**	**640**	Chen (1962), China (ny)
do.	*0.35*	*0.40*	**0.45**	**600–650**	Wagenführ (1993), Vietnam (ny)
do. (2 locations)	*0.43/0.44*	**0.47/0.50**	**0.51/0.53**	-	Do Van Ban (1997), Vietnam (17–19)
do.	**0.47**	*0.53*	**0.60**	**810**	Pun (1969), Malaysia (ny)
do.	*0.47*	**0.53**	*0.56*	-	Pramana (1998), Indonesia (19)
do. (2 locations)	*0.34/0.46*	*0.36/0.53*	**0.42/0.59**	-	Botero (1956), Brazil (ny)
do.	*0.56*	*0.62*	**0.68**	-	Rechy and van Roth (2004), México (ny)
M. azedarach var. *australasica*	-	*0.39*	**0.45**	-	Bolza and Kloot (1963), Australia (ny)
M. azedarach var. *gigantea*	*0.49*	*0.57*	**0.63**	-	Frühwald *et al.* (1989), Paraguay (18)
M. azedarach var. *gigantea*	*0.59*	**0.69**	**0.72**	-	Coronel (1989), Argentina (ny)

Averages obtained from 10 trees; ny = no data on tree age
Numbers in bold represent values for which the moisture content of the wood to which the weight relates is clearly stated in the respective source; numbers in italics represent estimates based on mathematical conversion equations provided by Niemz (1993) and ISO 3131 (1975).

Shrinkage and swelling

Shrinkage and swelling data are presented in Table 5. From this data one can infer relevant information about movement in service and dimensional stability as well as calculate the dimensional changes that are likely to occur with changes in wood moisture content within a range of approximately 5 to 25%. From results for swelling, shrinkage, differential swelling and various ratios between tangential and radial movement (anisotropy) we classify paraíso wood (Huaxtla, México) as intermediate with movement in service expected to be medium to large according to Farmer (1988). Essentially, the same holds true for values reported by other sources, notwithstanding the considerable variation evident from data given in Table 5.

Modulus of elasticity and strength properties

Results obtained from the static and dynamic strength as well as hardness tests are summarized in Table 6. In agreement with its density the wood of paraíso (Huaxtla, Mexico) is of low to medium strength. Its property profile is, in general terms, very similar to that of paraíso from other locations in Latin America (Argentina, Paraguay) and Indonesia, yet superior to that from Vietnam (Table 7). Hardness is presented in BRINELL [N/mm^2] and JANKA [kN] values in order to meet the respective preferences prevalent in Europe and countries of Anglo-American background. Our comparison of paraíso (México) with *S. macrophylla* (true mahogany) and *C. odorata* (cedro) showed that paraíso may eventually substitute the two

Table 5 Shrinkage and swelling parameters of paraíso planted at Huaxtla, México compared with corresponding data from other provenances

Parameter	*M. azedarach* (Huaxtla)		*M. azedarach* (other provenances)	
	Radial	Tangential	Radial	Tangential
Maximum swelling $\alpha_{máx}$ (%)	4.3	8.6	4.9[7]; 6.0[1]	8.9[1]; 10.8[7]
Maximum shrinkage $\beta_{máx}$ (%)	4.1	7.9	2.3[4]; 3.3–3.8[5]; 4.5[7]; 5.0[3]; 5.7[4];	5.7[4]; 7.0[5]; 7.5[2]; 8.5[3]; 8.6[4, 5]; 9.8[7]
Normal shrinkage (from green to 12% MC) β_N (%)	1.5	3.8	3.3[6]	4.4[6]
Differential swelling q (%/%)	0.17	0.33	0.17[7]	0.31[7]
Differential shrinkage s (%/%)	-	-	0.15[2]	0.25[2]
Ratio $q_{tang} \div q_{rad}$ A_q	2.0		1.5[1]; 2.2[7]	
Ratio $\beta_{Ntang} \div \beta_{Nrad}$ $A_{\beta}N$	2.5		1.3[6]	
Ratio $\beta_{max\text{-}tang} \div \beta_{max\text{-}rad}$ $A_{\beta max}$	1.9		1.5[4]; 1.7[2, 3]; 2.1–2.3[5]; 2.2[7]; 2.5[4]	

Averages obtained from 10 trees
[1]Frühwald *et al.* 1989 (Paraguay); [2]Pramana 1998 (Indonesia); [3]Wagenführ 1993 (Vietnam); [4]Botero 1956 (Brazil); [5]Do Van Ban 1997 (Vietnam); [6]Chen 1962 (China); [7]Coronel 1989 (Argentina)

Table 6 Elastic and strength properties of paraíso planted at Huaxtla, Mexico

Property	Mean (N/mm²)	Maximum (N/mm²)	Minimum (N/mm²)	CV (%)	ρ_{test} (g/cm³)
Bending					
MOR	112	137	70	12.4	0.67
MOE	10260	12900	8160	10.4	
Compression parallel					
MOR	51	58	42	7.2	0.67
MOE	9840	13180	7710	10.8	
Compression perpendicular					
MOR_{radial}	8.7	13.5	6.0	22.7	0.69
MOE_{radial}	1410	1990	630	18.6	
$MOR_{tangential}$	6.5	9.0	4.8	15.7	0.69
$MOE_{tangential}$	796	1196	576	18.6	
Tension parallel					
MOR	128	167	84	13.3	nd
MOE	9920	13000	7180	11.6	
Shear					
Radial	14.9	16.9	12.7	6.5	0.68
Tangential	15.2	19.8	10.2	13.1	
Impact bending (kJ/m²)					
Tangential	88	169.0	41.0	29.3	0.68
Hardness BRINELL (N/mm²) / JANKA (kN)					
End grain	53.7 / 15.0	66.8 / 19.2	37.0 / 9.6	12.5	0.68
Side (radial)	31.6 / 7.8	51.3 / 14.2	15.0 / 2.5	21.9	
Side (tangential)	35.4 / 9.1	55.0 / 15.4	17.0 / 3.1	19.9	

Averages obtained from 10 trees; nd = not determined; CV = coefficient of variance; MOR = modulus of rupture; MOE = modulus of elasticity; ρ_{test} = density at test (wood conditioned in standard climate of 20 °C and 65% relative humidity to approximately 12% moisture content

traditional New World timbers (Table 8). In addition, the table contains data for the Asian *Toona* spp., a close relative of *Cedrela*, and for two important trade timbers, namely, *Cedrelinga cataeniformis* and *Virola* spp. from South America currently imported in large quantities by Mexico as replacements for the native *Swietenia* and *Cedrela* which have both become very scarce and expensive. The comparison showed that paraíso can hold its place well with regard to density and related strength properties. For exterior use under exposure, it is inferior to *Swietenia*, *Cedrela*

Table 7 Wood properties of paraíso planted at Huaxtla, México compared with data from other locations (rounded values, representing original sources only)

		M. azedarach	*M. azedarach*	*M. azedarach*	*M. azedarach* var. *gigantea*	*M. azedarach* var. *gigantea*
Location		México, Huaxtla[1]	Indonesia, Java[2]	Vietnam, Dong-ngac; Tay-tien[3]	Paraguay[4]	Argentina, Parque Chaqueño[5]
Source						
Normal density (g/cm^3)		0.68	0.56	0.51 / 0.53	0.63	0.72
Max. shrinkage (%)	tangential	8.6	7.5	7.3 / 8.6	8.9	9.8
	radial	4.3	4.5	3.2 / 3.8	6.0	4.5
Bending (N/mm^2)	MOR	112	101	65 / 66	93	111
	MOE	10260	9930	9250 / 9275	9800	9665
Compression || (N/mm^2)	MOR	51	49	43 / 46	46	46
Tension (N/mm^2)	MOR	128	145	87 / 90	n.d.	n.d.
Shear (N/mm^2)	R_{max}	15	nd	6.5 / 7.6	15.6	10
Impact (kJ/m^2)	R_{max}	88	95	56 / 60	115	81
Side hardness						
BRINELL (N/mm^2)		33.5	39	n.d.	n.d.	47*
JANKA (kN)		8.5	10.2	n.d.	n.d.	n.d.

Averages obtained from 10 trees; n.d. = not determined; *value out of range, originating from a doubtful method of determination
[1]This study; [2]Pramana 1998; [3]Do Van Ban 1997; [4]Frühwald *et al.* 1989; [5]Coronel 1989

Table 8 Average values for normal density, shrinkage (green to oven dry) and selected mechanical properties, comparing wood of paraíso planted at Huaxtla, México with traditional and new trade timbers for which it may substitute

	Unit	Paraiso (*M. azedarach*, Huaxtla)[1]	True mahogany (*Swietenia macrophylla*)[2]	Cedro (*Cedrela odorata*)[3]	Suren (*Toona ciliata*)[4]	Banak (*Virola* spp.)[5]	Tornillo (*Cedrelinga catenaeformis*)[6]
Density (± 12% MC)	(g/cm^3)	0.68	0.60	0.50	0.51	0.52	0.51
Shrinkage	radial (%)	4.1	3.7	3.1	3.4	5.6	4.1
(green to oven dry)	tangential (%)	7.9	6.3	7.0	7.3	10.3	8.3
Compression MOR	(N/mm^2)	51	54	36	34	37	38
Bending MOR	(N/mm^2)	112	85	67	61	65	70
Bending MOE	(N/mm^2)	10 260	10 790	6700	8000	12 400	10 900
Shear	(N/mm^2)	15	9.1	5.5–9.1	9.5	8.0	9.5
JANKA side hardness	(kN)	8.5	4.2	3.2	3.7	3.0	3.5
Natural durability*	class	3–5	2	2	2–3	5	3–4

*Adapted to DIN EN 350-2 (1994)
[1]This study; [2]Anonymous (s.a), CIRAD-Forêt 2003; [3]Anonymous (s.a), CIRAD-Forêt 2003; [4]Anonymous 1963, 1969, Lemmens *et al.* 1995; [5]Anonymous (s.a), CIRAD-Forêt 2003; [6]Anonymous (s.a), CIRAD-Forêt 2003

and *Toona* but yet it compares favourably in this respect with *C. cataeniformis* and *Virola* spp.

Natural durability

The heartwood of planted paraíso (Huaxtla, Mexico) proved highly resistant to the white rot fungus *P. chrysosporium* (mass loss 7.3%, class I) and the brown rot fungi *N. suffrutescens* and *P. placenta* (mass loss around 0.3%, class I) (Table 9). The more aggressive white rot fungus *T. versicolor* caused a mass loss of 37% classifying the wood as moderately resistant (class III). These results are at odds with the very low natural durability reported by Bobadilla *et al.* (2005) who classified paraíso from plantations in Argentina as not durable when exposed to *Ganoderma applanatum* (white rot) with a mass loss of 26% (class IV) and as perishable when exposed to *Laetiporus sulfureous* (brown rot) and *Pycnoporus sanguineus* (white rot) with mass loss values of 50 and 33% (class V) respectively. However, the authors used different fungi and their evaluation was based on a five-class system comparable with that stipulated by DIN EN 350-2 (1994). A transfer of the mass loss values obtained in the present study to this 5-class system (Table 9) would change the natural

Table 9 Mass loss and natural durability classification* of paraíso planted at Huaxtla, Mexico

	Mass loss (%)	Classification ASTM D 2017-81	Classification DIN EN 350-2
		White rot	
Trametes versicolor	37.1	Moderately resistant (III)	Perishable(V)
Phanerochaete chrysosporium	7.30	Highly resistant (I)	Resistant (II)
		Brown rot	
Neolentinus suffrutescens	0.32	Highly resistant (I)	Highly resistant (I)
Postia placenta	0.26	Highly resistant (I)	Highly resistant (I)

Average values obtained from 10 trees
*ASTM D 2017-81, 4 classes; DIN EN 350-2, 5 classes

durability classification for *T. versicolor* from moderately resistant (ASTM D 2017-81) to perishable (DIN 3050-2), that for *P. chrysosporium* from highly resistant to resistant whereas the classification for the other two test fungi remains unchanged (highly resistant). On the other hand, *M. azedarach* heartwood grown in India was classified as resistant (weight loss range 11–24%; class II) after a 16-week exposure to the white rot fungus *Pycnoporus sanguineus* and the brown rot fungus *Oligoporus placenta* (Suresh & Harsh 2005). This indicated a natural resistance similar to that of the Mexican material. In essence, the natural durability of paraíso appears highly variable and its classification will depend as much on the test fungi and classification system used for evaluation as on origin and tree age of the material investigated.

Uses

The wood of paraíso is generally considered a promising utility timber for interior use on account of its medium weight and strength, ease of drying, processing and gluing, moderate movement in service, and an appearance described by most reports as very attractive (Pearson & Brown 1932, Keating & Bolza 1982, Chudnoff 1984, Martawijaya *et al.* 1992). It has been recommended as a substitute for *S. macrophylla* for furniture, shop and office fittings and other interior uses (Keating & Bolza 1982, Martawijaya *et al.* 1992). Equally, it has been likened to wood of cedro and suren because of similar technical properties and appearance (Pearson & Brown 1932, CONAFOR 2006, Dahms 1990). High quality logs have been successfully converted into veneer, both sliced for decorative purposes and peeled for plywood faces and core stock. Several authors have reported that paraíso is a suitable raw material for pulp and paper (Singh *et al.* 1977, Sanjuán *et al.* 1994) as well as particle board (Singh *et al.* 2001) production. Paraíso is also considered suitable for manufacturing specialty items such as sporting goods (Pearson & Brown 1932, Amjad 1980) and compressed wood for shuttle blocks (Shukla & Bhatnagar 1988).

The Mexican as well as other Latin American market is in constant need to compensate for dwindling supplies of true mahogany and cedro which were and still are among the most highly valued commercial timbers. Due to continuous overexploitation both timbers are now subject to protective legislation on a national (Central and South America) and international (CITES) level. The availability of a substitute timber similar in appearance and/or technical aspects and originating from plantations under sustainable management could help reduce the pressure on these two traditional timbers for interior applications. In Mexico, for instance, the large furniture industry has come to rely almost entirely on imports from South and North America such as red oak (*Quercus* spp.), banak (*Virola* spp.), tornillo (*C. catenaeformis*), sandé (*Brosimum utile*), quaruba (*Vochysia* spp.), louro vermelho (*Ocotea rubra*), requía (*Guarea* spp.) and other look-alikes to substitute for true mahogany and cedro. Where similarity in technical properties and resemblance in appearance (surface structure, colour) are required, paraíso sliced and peeled decorative veneers as well as solid wood furniture parts, laminates and glue board produced from small dimension stock could become viable options for the furniture industry. The timber may also serve for light exterior construction under cover and for flooring under normal conditions of traffic where a decorative wood is required.

CONCLUSIONS

Eleven-year-old paraíso trees of Mexican (Huaxtla, Jalisco) origin show considerable growth potential and produce an attractive, good quality timber. It is a suitable substitute for the overexploited and CITES-protected precious timbers of the true mahogany, *S. macrophylla* and cedro (*Cedrela* spp.) in many of their traditional uses. Paraíso wood also compares favourably with current large-scale imports from South America such as tornillo and banak.

Its overall property profile (density, dimensional stability, strength properties and natural durability) makes paraíso a promising general utility timber that can be recommended for a variety of structural and non-structural uses provided that direct exposure to weathering is avoided and its limited load-bearing capacity not exceeded.

The establishment of large-scale plantations of paraíso trees on suitable sites in Mexico is highly recommended provided that care is taken in selecting appropriate genotypes and clones.

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