COMPARISON OF WOOD PROPERTIES OF PLANTED BIG-LEAF MAHOGANY (*SWIETENIA MACROPHYLLA*) IN MARTINIQUE ISLAND WITH NATURALLY GROWN MAHOGANY FROM BRAZIL, MEXICO AND PERU

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LANGBOUR P, GÉRARD J, RODA JM, AHMAD FAUZI P & GUIBAL D. 2011. Comparison of wood properties of planted big-leaf mahogany (*Swietenia macrophylla*) in Martinique Island with naturally grown mahogany from Brazil, Mexico and Peru. Big-leaf mahogany (*Swietenia macrophylla*) has been harvested and traded since the 16th century. It is highly valued and is used to craft luxury furniture and items. Its natural populations are found in South and Central America. It has been planted throughout the tropical world and sustainable plantations have existed for many decades in a limited number of areas such as the Caribbean. Wood properties of 24 mahogany plantation trees (< 40 and > 40 years old) from Martinique Island were compared with randomly collected data from CIRAD reference collection: 24 trees from natural forest in Brazil, Mexico and Peru. Density of plantation trees was found to be significantly lower compared with natural forest trees. The tangential shrinkage of young trees (< 40 years old) was significantly higher than that of old trees (> 40 years old). Both values were significantly higher than that of natural forest trees. The radial shrinkages of young and old trees were significantly higher than that of natural forest trees. Although the density of natural forest wood was higher than that of plantation trees, the difference in modulus of elasticity (MOE) was insignificant. The static bending strengths (MOR) of young and old trees were significantly lower than that of natural forest trees. The crushing strength in compression parallel to grain of plantation trees was significantly lower than that of natural forest. Mahogany from Martinique Island seems to be a promising tree species for use in joinery and cabinet work.

Keywords: Physical properties, mechanical properties, Caribbean, natural forest, plantation

LANGBOUR P, GÉRARD J, RODA JM, AHMAD FAUZI P & GUIBAL D. 2011. Perbandingan antara ciri-ciri kayu mahogani berdaun besar (*Swietenia macrophylla*) yang ditanam di Pulau Martinique dengan kayu hutan semula jadi dari Brazil, Mexico dan Peru. Mahogani berdaun besar (*Swietenia macrophylla*) ditebang dan didagangkan sejak abad ke-16. Mahogani bernilai tinggi ini digunakan untuk membuat perabot mewah dan barangan. Populasi aslinya dijumpai di Amerika Tengah dan Amerika Selatan. Mahogani ditanam di seluruh negara tropika. Penanaman secara mampan wujud sejak beberapa dekad yang lalu di beberapa kawasan terhad seperti Karibea. Ciri-ciri kayu 24 batang pokok mahogani yang ditanam di Pulau Martinique (< 40 tahun dan > 40 tahun) dibandingkan dengan data rawak yang diperoleh daripada koleksi CIRAD iaitu daripada 24 pokok dari hutan semula jadi di Brazil, Mexico dan Peru. Pokok yang ditanam mempunyai ketumpatan kayu yang lebih rendah daripada pokok di hutan semula jadi. Pengecutan tangen bagi pokok muda (< 40 tahun) lebih tinggi daripada pokok tua (> 40 tahun) dan kedua-duanya lebih tinggi daripada pokok hutan semula jadi. Pengecutan jejari bagi pokok muda dan pokok tua lebih tinggi daripada pokok hutan semula jadi. Walaupun ketumpatan kayu pokok hutan semula jadi lebih tinggi daripada pokok yang ditanam, modulus kekenyalan kedua-duanya tidak berbeza dengan signifikan. Kekuatan lentur statik (MOR) pokok muda dan pokok tua lebih rendah daripada pokok di hutan semula jadi. Kekuatan mampatan selari ira bagi pokok yang ditanam lebih rendah daripada pokok hutan semula jadi. Mahogani dari Pulau Martinique merupakan spesies pokok yang berpotensi digunakan untuk kerja tanggam dan pembuatan kabinet.

INTRODUCTION

Big-leaf mahogany (*Swietenia macrophylla*, Meliaceae) is probably the most precious wood species from tropical America. It is greatly valued in the international market. The aesthetics of the wood, its physical characteristics and ease in woodworking have paved the way for use mainly

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for noble and luxury items (office interiors, cabinets, stylish furniture, naval construction and music instrument). Mahogany has been used in Spain and England since the 16th century. It is still harvested in Central and South America. Bolivia, Brazil and Peru have witnessed intensive harvests only from the beginning of the 20th century (Miller 1999). This species attracts attention from forest services and customs since it is CITES listed. More precisely, it is listed in Annex II of the Washington Convention which governs the harvest and trade of protected and endangered species (ITTO 2004). This means that the species is vulnerable (International Traffic Network 2002, CITES 2009, IUCN 2009).

Due to its endangered status and importance in the global market, big-leaf mahogany is the focus of conservation, harvest and regeneration (Grogan & Schulze 2008). Beyond that, exemplary progress has been made in sustainable valorisation. For many decades, some countries and/or some private bodies have invested in plantations in order to ensure a sustained production of high value timber (Mead & Odoom 2001, Lugo et al. 2003). Such cases exist in Asia (Indonesia, Philippines, Sri Lanka, Fiji), where the species finds good growing conditions (Hammond 2002) as well as, to a lesser extent, in some countries of Central America (Costa Rica) and South America (Brazil, Peru, Bolivia). At the same time, South America still harvests big-leaf mahogany from its natural forests. Many studies have been conducted in Central and South America on the silviculture, regeneration and harvesting regimes of the species (Verissimo et al. 1995). From a social point of view, there is a growing number of rural communities who exercise their rights and they actively contribute to the sustainable management of big-leaf mahogany (Lugo 2005). Of the 108 000 m^3 of exports of mahogany sawn timber by Central and South America in 2002, Peru accounted for 47% and Brazil, 38%. The main consumer countries are the United States, Canada and United Kingdom (ITTO 2004). These three countries imported around 90 000 m^3 of mahogany sawn timber in 2002.

Regarding the wood properties of a specific species, one usually compares differences between materials sourced from plantations and those from natural forests. Such differences may lead to different end-uses and market segments. These physical and mechanical differences may be linked to the soil, growth conditions, age and genetics.

This paper presents some physical and mechanical characteristics of planted big-leaf mahogany and compares them with wood properties of big-leaf mahogany from the natural forest in Brazil, Mexico and Peru, obtained from the CIRAD database. A total of 24 trees in the database were randomly selected. Our comparison is open to criticism because several parameters of the data set were unknown, e.g. the provenance of plantation material and growing conditions of natural forest material. However, given the limited publications on wood characteristics of planted *S. macrophylla*, our work remains a useful first approach.

The case of Martinique Island is specific, for it represents old plantations with long and known history since the early 1920s, thus allowing a sound comparison with natural forest trees. The trees selected for the study came from Martinique Island, which is located in the Caribbean (14° 30' N, 61° 00' W). Big-leaf mahogany was first planted in 1905, over 3 ha (Huguet & Marie 1951). It was planted on a wider scale from 1924 and now covers 1500 ha with a log production of 3000 to 4500 m^3 per year. In this particular case, the local forest department (Office National des Forêts) has succeeded in matching sustainable forest conservation with sustainable production of good quality timber. However, only approximately 35% of this quality resource is valorised, mainly because of restrictive economic local conditions (harvesting conditions, manpower cost and geographical position of Martinique Island). On the island, we can find three sawmills each converting approximately 1500 m^3 of logs per year and one mobile mill which converts between 500 and 800 m^3 of logs per year. At the same time, some logs are milled with chainsaw and specific equipment frames in order to produce even-sized planks at stump. This sawing practice, which induces low material recovery rate (between 20 and 30%), nevertheless, allows the sawn timber to be manually extracted from the forest with an extremely reduced logging impact. Furthermore, cable skidding is occasionally used on steep slopes.

With seeds collected in the plantation, the seedlings are grown in nurseries. They are later planted at a density of 800 stems ha^{-1}. In between the rows, a band of 3 m of natural vegetation is untouched, which allows natural species to grow and enrich the vegetation. For the next three or four years, the rows are regularly weeded. When the dominant height reaches 7 m, thinning-to-waste is done. Later, one more thinning is conducted when the stems reach merchantable girths. The stocking then varies from 150 to 200 stems ha^{-1}. Finally, when the trees are about 60 years old and when their diameter breast height (dbh) reaches 50 to 65 cm, the final felling takes place and is arranged by coupes of approximately 1 ha each. A new cycle then begins on each of these patches.

MATERIALS AND METHODS

Field sampling of forest plantations

Different plantation plots were selected within Martinique Island in order to reduce the variation induced by the different growing conditions. The genetic variability of the mahogany populations in Martinique Island is not known but is presumably narrow.

The main geographical information and growing conditions of the sampled plantations are summarised in Table 1 and the location of the stands is shown in Figure 1. Table 1 also gives the number of trees specifically felled in each plantation plot: 24 trees in total. Since young trees (12) less than 40 years old as well as older trees (12) more than 40 years old were included in the study, the plantation periods were also given.

The 24 sample trees were obtained during thinning operations. Their dbh ranged from 16 to 38 cm and the trees were grouped essentially into two age groups.

On the felling sites, one diametric plank (1 m long and 10 cm thick) was cut with chainsaw and sawmilling equipment at the dbh level of each tree. The position of the diametric plank and localisation of specimen squares used for the assessments are shown in Figure 2. Martinique Island is located in the tropics and after felling, logs are subject to attack by insects and fungi. Before transporting, the diametric planks were sprayed with preservative. To avoid checks and splits, the ends were coated with a layer of paraffin. These pieces were subsequently shipped to the International Center in Agricultural Research for Development (CIRAD) in Montpellier, France for testing.

Data set from natural forest

CIRAD has a comprehensive and extensive database comprising quantitative wood species collected from natural tropical forests of the world. The database was developed more than 90 years ago.

For comparison with the 24 trees felled in the plantations of Martinique Island, data from 24 trees in the database were randomly selected. A total of 19 of them came from the Brazilian and Peruvian Amazon basin and 5 from Mexico. The provenance is known for some of the trees but we have no information on growth conditions and tree age, as it is commonly the case for trees from the natural forest. We also did not have information of provenance relationships between these natural trees and the Martinique plantation set.

Tests were carried out on this native material between 1965 and 1980. The tests were carried out according to procedures described by Sallenave (1971).

Sample preparation

All samples used for mechanical and physical tests were taken from heartwood and clear wood. The sapwood, being clearly distinct, was

Table 1 Growing conditions of the plantation plots included in the study

Plot	Elevation (m)	Orientation	Slope	Plantation period	No. of stems sampled
Saint-Joseph (SJ)	300–350	East	Limited	1941–46	3
Sainte-Marie (SM)	310	North-east	Limited	1951–60	3
Montravail (MT)	250	North-west	Limited	1953	6
B12	200–300	South-east	Limited	1985–87	6
D10	300–350	South-west	Medium	1961–70	6

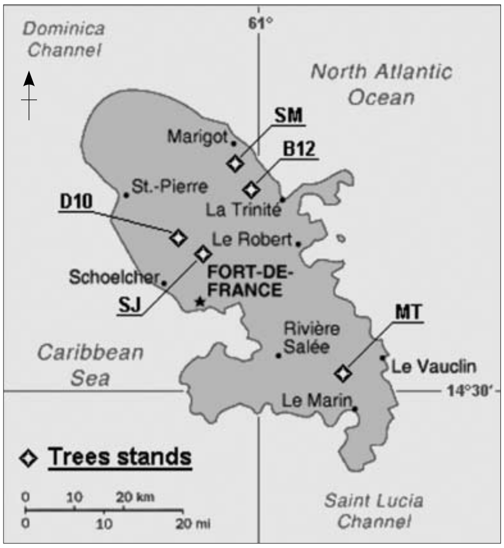

Figure 1 Martinique Island with the location of plantation plots involved in the study (SM = Sainte Marie, SJ = Saint Joseph, MT = Montravail)

removed. Pieces of wood of 30 mm radial (R) by 30 mm tangential (T) by 500 mm length (L) were sawn from the planks and air dried so that their moisture content stabilised around 20% (Figure 2). These pieces of wood were ultimately cut into test samples of 20 (R) × 20 (T) × 450 mm (L).

Before testing, they were kept in a regulated conditioned room with standard conditions (20 ± 2 °C and relative humidity 65 ± 5%) until the moisture content of the wood samples reached approximately 12%.

Mechanical and physical properties

The longitudinal modulus of elasticity (MOE) was measured using free vibration and Fast Fourier transform analysis (FFT) developed by CIRAD (Bordonne 1989). This system is based on mechanical principles that state relationship between the natural vibration frequencies and the elastic properties of a material. Comparison tests revealed that the results obtained by the vibratory method are closely correlated with those obtained by conventional methods (three and four point bending tests) (Bordonne 1989, Brancheriau et al. 2002). Dimensions of specimens were 20 (R) × 20 (T) × 380 mm (L) (Figure 3). After dimension and weight measurements, the wood sample was placed on two elastic bands under a microphone that registered the noise accompanying the bending vibrations resulting from a small tap on one extremity using an iron stick.

This is a non-destructive test and the specimens were reused in order to measure the static bending strength through deformation tests. Four-point bending tests were conducted with a Universal testing machine and the (crushing) bending strength, also called modulus of rupture (MOR), was obtained according to the ISO 3133 (ISO 1975a).

The compression parallel to the grain tests (to determine the crushing strength) were performed on 20 (R) × 20 (T) × 60 mm (L) (Figure 3) samples between two parallel steel plates on the same Universal testing machine. The protocol followed ISO 3132 (ISO 1975b).

In order to calculate the density of wood at 12% moisture content, the dimensions and weight measured on bending samples before MOE test were utilised. Dimensions in R, T and L directions were measured with digital callipers accurate to 0.01 mm. Weight was measured with a scale accurate to 0.01g.

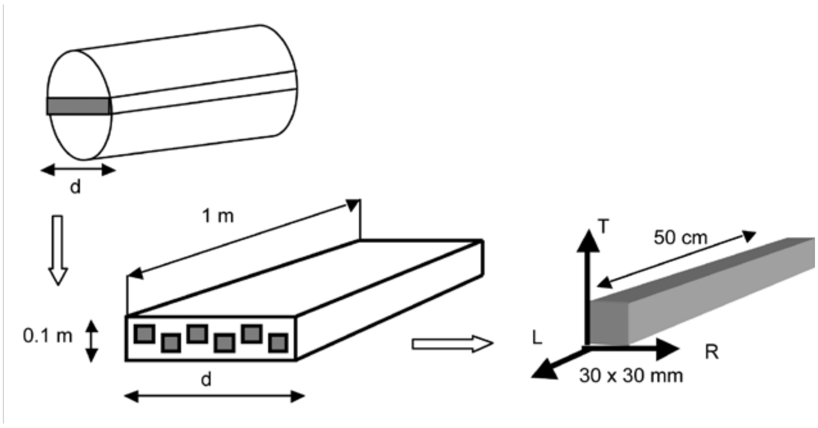

Figure 2 Localisation and size of diametrical planks and squares used

The test specimens were conditioned in a regulated chamber at 20 °C and 65% relative humidity until they reached 12% relative moisture content. The real moisture content in samples was controlled after determination of mechanical properties. A total of 100 test samples were weighed with initial conditions (20 °C and 65% RH) and then oven dried at 103 ± 2 °C for 24 hours. The actual moistures were between 10.5 and 12.3%, with an average of 11.3%. This range satisfied the requirements of the standard.

Total tangential and radial shrinkages were calculated as the ratio of the dimensional variation in each direction between saturated and oven-dry states on the dimension in saturated state. As indicated in Figure 3, samples of 20 (R) × 20 (T) × 10 mm (L) were taken from near the samples used to determine MOE and MOR. Samples were rewetted until saturation by vacuum impregnation in demineralised water. The radial and tangential dimensions were measured with a displacement transducer (with a precision of 1 µm). By marking the specimen for positioning of the transducer, it was possible to have precision on successive measurements at different moisture contents.

RESULTS AND DISCUSSION

Density

In plantation trees (< 40 and > 40 years old), density was found to be significantly different from natural forest trees (Table 2). The density in young trees (< 40 years old) was 472 kg m^{-3}, 16.3% lower than plantation trees > 40 years old, i.e. 549 kg m^{-3}. Likewise, in plantation trees > 40 years old, density was 11.5% lower than trees from natural forest, i.e. 612 kg m^{-3} (Table 2).

These values were consistent with those of the Honduras plantation, where densities ranged from 420 to 660 kg m^{-3}, averaging about 540 kg m^{-3} (Normand & Sallenave 1955). In Puerto Rican plantation, the density was 470 kg m^{-3} (Francis 2003). In Asian plantations (Hawaii, Fiji, Philippines), values ranged from 510 to 570 kg m^{-3} (Keating & Bolza 1982). In particular, the Fijian young trees (30-year-old plantation) were denser than young trees from Martinique Island. In addition, the density values from natural forest were in agreement with those of the literature (Berni et al. 1979, Chudnoff 1984, Mainieri & Chimelo 1989).

The radial increases (or decreases) of wood specific gravity are due to differences in the anatomical structure such as proportion of vessels, fibres and cell wall thickness (Panshin & de Zeeuw 1980). Radial trends have been reported to relate to the presence of juvenile and mature woods (Zobel & Sprague 1998). In a 10-year-old mahogany stand in the Philippines, Sedenio (1991) studied the influence of growth rate of 20 trees on specific gravity, fibre length and cell wall thickness of the wood, and demonstrated a systematic juvenile pattern along the radial direction.

In our study, we did not undertake comparative analyses of anatomical parameters such as proportion of fibres and vessels due to the lack of suitable samples from the natural forest.

Total tangential and radial shrinkage

In plantation trees (< 40 and > 40 years old), tangential and radial shrinkages were significantly different from those of natural forest trees (Table 2). The tangential and radial shrinkages of young trees (< 40 years old) were 83 and 44% respectively higher than those of natural forest trees. Likewise, the tangential and radial shrinkages of trees > 40 years old were 54 and 40% respectively higher than natural forest trees (Table 2). There was no significant difference in radial and tangential shrinkages between young (< 40 years old) and old trees (> 40 years old). The shrinkage values were similar to those from

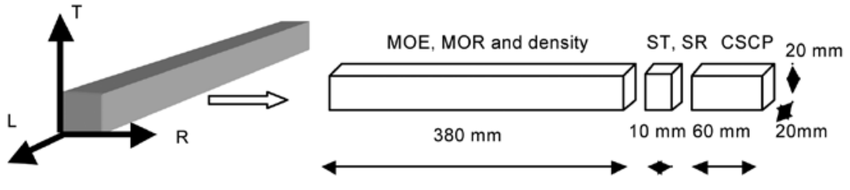

Figure 3 Size of samples used for mechanical and physical properties. ST = tangential shrinkage, SR = radial shrinkage, CSCP = crushing strength in compression parallel to the grain.

Table 2 Mechanical and physical characteristics of trees from natural forest and plantation

Characteristic	Natural forest	Plantation < 40 years old (B12, D10)	Plantation > 40 years old (SJ, SM, MT)
Density (kg m^{-3})	612 (58)	472 (46)	549 (70)
Modulus of elasticity (MPa)	10 960 (1330)	10 850 (1200)	11 100 (1280)
Static bending strength (MPa)	88.3 (11.2)	70.7 (11.6)	75.1 (16.1)
Crushing strength (MPa)	55.1 (7.3)	40.6 (4.7)	45.1 (6.8)
Total tangential shrinkage (%)	3.5 (0.6)	6.4 (1.3)	5.4 (0.7)
Total radial shrinkage (%)	2.5 (0.4)	3.6 (0.7)	3.5 (0.6)

Values are averages with standard deviations in parentheses.

the Philippine plantations (Keating & Bolza 1982) However, the young plantation wood (< 40 years ago) had higher shrinkage compared with the plantations in Fiji and Hawaii. Shrinkage values from plantation trees in this study were higher than the values reported by Longwood (1962).

The anisotropy is the ratio of tangential to radial shrinkage (T/R). T/R is often used to evaluate the risk of a species to distort. Woods with larger ratios will crack and warp more than those with smaller ratios. Trees from natural forest had T/R ratio of 1.4. Similar ratios were reported by Kukachka (1959), Longwood (1962), Keating and Bolza (1982) and IPT (1989). Plantation trees of < 40 and > 40 years old had T/R ratio of 1.8 and 1.5 respectively. The T/R ratio indicated that plantation wood (> 40 years old) was stable and it would allow very small radial cracks. On the contrary, young plantation wood (< 40 years) was more sensitive to climatic variation and was more at risk of splitting or cracking.

Mechanical characteristics

Modulus of elasticity (MOE)

Longitudinal MOE from the naturally grown timber ranged from 9490 to 13 020 MPa, with an average of 10 960 MPa (Table 2). These results were consistent with previous works (Kukachka 1959, Longwood 1962, IPT 1989). In plantation trees (< 40 and > 40 years old), MOE values were not significantly different from natural forest trees (Table 2). Even though the density of natural forest wood was higher than that of plantation trees, the difference in MOE was insignificant. This is surprising as generally MOE within the species tends to be linearly or curvilinearly related to density (Kollmann & Côté 1984, Kretschmann 2010).

Static bending strength (MOR)

The MOR values of plantation trees (< 40 and > 40 years old) were significantly different from that of natural forest trees (Table 2). The MOR values of < 40- and > 40-year-old trees were 24.8 and 17.6% respectively lower than trees from the natural forest. There was no significant difference between young (< 40 years old) and old trees (> 40 years old). Contrary to MOE, the difference in MOR between native material and plantation trees was probably related to differences in densities.

Crushing strength in compression parallel to grain

The crushing strengths in plantation trees (< 40 and > 40 years old) were 35.7 and 22.2% respectively lower than trees from the natural forest (Table 2). In plantation trees (< 40 and > 40 years old), crushing strength was found to be significantly different from natural forest trees. The difference in crushing strength between native material and plantation trees is probably related to differences in densities.

TECHNICAL AND MARKETING PERSPECTIVES

Our comparison of wood characteristics of natural growth material and immature thinned plantation trees is complicated because several parameters are unknown such as the provenance of plantation material and the growing conditions in natural forest. Since published data on wood characteristics of plantation grown mahogany are lacking, our results provide a useful first approximation of likely effects compared with a wide sample of naturally sourced material.

Mahogany, when grown in plantations in Martinique, can be considered as light hardwood, with average densities at 12% moisture content ranging from 472 (< 40 years old) to 549 kg m^{-3} (> 40 years old). Its average density is lower than that of wood sourced from natural forest in Central and South America. Such a gap partially explains the differences observed in mechanical and physical characteristics. The static bending (MOR) and crushing strength in compression parallel to the grain were lower for plantation wood. However, MOE did not differ significantly between the different origins of samples. The shrinkage values (radial and tangential) of plantation trees were higher than those of wood from the natural forest. The results showed that utilisation should concentrate on trees at least 40 years old.

Although the overall characteristics of plantation wood are relatively lower in performance than those from natural forest, they are sufficient for enduses specific to mahogany. The values compared favourably with plantation material elsewhere. Commercial thinnings planned by the forest manager can be valued as quality timber, except in cases of prohibitive defects along the stem. Big-leaf mahogany is widely used and valued in Martinique Island. This wood is easy to work with, including when using modern woodworking machines. Due to its ability to be coloured and lacquered, particularly reddish and brownish colours, this wood is in demand in the local and North American market.

GLOBAL PERSPECTIVE

Beyond the regional market, these results demonstrate the effective marketability of the planted big-leaf mahogany. The success of its economic development in countries such as Indonesia and Philippines demonstrates its potential as an alternative to natural forest timber. Being perfectly adequate for joinery, furniture and cabinet making, the big-leaf mahogany represents a good species for the development of sustainable sources of light hardwoods.

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