ARTÍCULO DE INVESTIGACIÓN

Strength properties and natural durability of Avocado (*Persea americana* Mill.) branch wood

Propiedades de resistencia y durabilidad natural de la madera de ramas de aguacate (*Persea americana* Mill.)

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ABSTRACT

This paper reports on mechanical properties and natural durability of avocado branch wood (*Persea americana* Mill.) with the objectives of providing a reliable property profile and to promote the rational use of this abundant yet largely neglected natural resource. The mechanical properties (static bending, compression, shear, impact bending) and hardness were determined in accordance with European standards (CEN). Natural durability was assessed according to the European standard EN 350-1 (agar block test) using the white rot fungi *Trametes versicolor* and *Phanerochaete chrysosporium*, and the brown rot fungus *Postia placenta*. Avocado trees yield a low to medium density (0,44-0,54-0,64 g/cm^3 at 12% mc) branch wood with below average strength under static bending, compression and tension parallel to the grain and average values for longitudinal shear, impact bending and hardness. The wood is rated non-resistant (class 5 according to EN 350-1) and thus is not suitable for exterior applications unless treated. Considering its property profile and the small dimensions available, avocado wood is recommended for general carpentry, furniture, interior paneling, glue-boards for closets and cabinets, and glue-lams for indoor framework.

KEY WORDS:
Persea americana, *Trametes versicolor, Phanerochaete chrysosporium*, *Postia placenta*, branch wood, density, strength properties, natural durability, uses.

RESUMEN

Este artículo presenta información sobre las propiedades mecánicas y la durabilidad natural de madera de las ramas de aguacate (*Persea americana* Mill.) con los objetivos de proporcionar un perfil de propiedades confiable y promover el uso racional de este recurso natural abundante pero en gran parte abandonado. Las propiedades mecánicas (flexión estática, compresión, cortante, resistencia al impacto) y dureza se determinan de conformidad con las normas europeas (CEN). La durabilidad natural se evaluó de acuerdo con la norma europea EN 350-1 (prueba de bloque de agar) utilizando los hongos de pudrición blanca *Trametes versicolor* y de hongo de pudrición parda *Phanerochaete chrysosporium*. Árboles de aguacate producen una madera de rama de baja a mediana densidad (0,44-0,54-0,64 g/cm^3 en 12% mc) con valores medios a bajos de flexión estática, compresión y tensión paralela a la fibra y valores medios de resistencia al cortante longitudinal, impacto y dureza. La madera se considera como no resistente (clase 5 según EN 350-1) y por lo tanto no es apta para aplicaciones en el exterior a menos que esté tratada. Teniendo en cuenta su perfil de propiedades y las pequeñas dimensiones disponibles, la madera de aguacate se recomienda para carpintería

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general, muebles, decoración interior, placas encoladas para armarios y archivadores y madera laminada para usos interiores.

KEY WORDS:
Persea americana, *Trametes versicolor, Phanerochaete chrysosporium*, *Postia placenta*, branch wood, density, strength properties, natural durability, uses.

INTRODUCTION

In Mexico, approximately 101 882 ha are planted with avocado trees for fruit production. About 89% pertain to the commercially most important variety "Hass", the remaining 11% to other varieties, including the wild or "criollo" form (SIACON, 2006). Thanks to this large and growing plantation area, Mexico has become the major avocado producer worldwide with slightly over one million metric tons of fruit in 2003 (FAO, 2006) of which about 75% are consumed in the country and 25% (slightly over US$ 400 million) exported, mainly to the United States of America (Del Castillo, 2008).

The largest area, 86 538 ha or 84% of the total area of avocado orchards planted in Mexico and responsible for 25% of worldwide fruit production (Del Castillo, 2008), is located in the state of Michoacan, mainly of the Hass variety (95%), with a great diversity as regards age, productivity and phytosanitary conditions. These plantations are frequently subject to thinning, coppicing, felling and replanting operations, which yield a considerable volume of wood that is largely moved to the plantation boundaries and burned or left to rot.

There are no statistical data that would allow a reliable calculation of the wood volume per hectare/year available from such coppicing and clearing operations in avocado plantations. However, taking an avocado orchard in Jujucato, Michoacán, as a fairly typical example for size (4 ha) and number of trees (125/ha) as well as tree age (from 14 to 30 years) and sound coppicing practices, the potentially available volume of wood can be estimated by extrapolation as follows: Assuming that coppicing of a tree yields 12 (Silva, 2009, personal communication) small logs of 1m in length and 20 to 25 cm in diameter (0,38 to 0,59 m^3 per tree) and 10% of the trees/ha are subject to coppicing each year, the yield is 4,75 to 7,36 m^3/ha/year. Further assuming that about 50% (slightly over 50 000 ha) of the productive avocado plantations in Mexico are subjected to such cleaning operations, the total wood volume expected per year could amount to between 237 500 to 368 000 m^3.

The rational utilization of this byproduct of avocado fruit production could be greatly enhanced by providing reliable scientific information about the timber's biological and technological properties as well as appropriate end uses.

Avocado wood is easy to work in all machining operations and finishes smoothly (Martínez y Martínez, 1996). Fuzzy grain may occur due to the presence of tension wood often present in branch wood. Based on its tangential and radial shrinkage values the wood is rated moderately stable and movement in service is expected to be low with little risk of deformation of manufactured goods within the relative humidity range (35% to 85% RH) to which wood is usually exposed in service (Fuentes *et al.*, 2002). Avocado wood is also considered a suitable raw material for pulping and papermaking. Paper produced from this material has physical and mechanical properties similar to that made with eucalypt (*Eucalyptus grandis*) fibers (Vargas *et al.*, 2006).

As regards strength properties of avocado wood, there is very little information available from literature. Echenique y Plumptre (1990) and also the Prospect (1997) database report on strength properties in a very general way without giving numerical values for means and variation. The same authors classify *Persea americana* heartwood as not durable or class IV according to EN 350-2 (CEN, 1994).

The objective of this study is to provide the potential users of this raw material with reliable numerical data on its elastic and strength properties in order to facilitate decisions as to where and in what form avocado wood from coppicing operations can be put to appropriate use. Further, the question whether this material consists entirely of sapwood (generally rated perishable = class V) or contains appreciable portions of heartwood (class IV) was analyzed by means of macro and microscopic observation (presence vs. absence of tyloses) and a bioassay to evaluate its resistance against decay producing white and brown rot fungi.

MATERIAL AND METHODS

Logs, approximately 100 cm in length and 20 to 25 cm in diameter, were cut from a main branch of each of 10 trees coppiced during a clearing operation at an avocado orchard in Jujucato, Michoacán. Branch wood constitutes the only raw material commonly available from this operation whereas the coppiced stump is usually left in place for resprouting from stem buds. The trees were between 14 and 17 years old and had reached a total height of about 12 m. A two-inch thick disk was cut from each log for observations of wood structure and natural durability bioassays. The remainder was sawn into 50 mm thick radial boards, which were stacked and air-dried to equilibrium moisture content of approximately 10 %. From the dry boards test specimens were prepared in the dimensions required by the standards (table 1) employed for static bending, compression parallel to the grain, tension parallel to the grain, longitudinal shear, impact bending and hard-

Table 1 Standards employed for determining physical and mechanical wood properties (DIN, 1979).

DIN 52 182 Density
DIN 52 185 Compression parallel to the grain
DIN 52 186 Static bending
DIN 52 187 Shear parallel to the grain
DIN 52 188 Tension parallel to the grain
DIN 52 189 Impact bending
DIN C 3011 Hardness BRINELL (mathematical conversion to JANKA hardness according to the equation

$hardness_{JANKA}$ = ($hardness_{BRINELL}$-7.3) / 3.1 (Schwab, 1990) ness. Since the test specimens could not be conditioned in standard climate (20 °C, 65 % RH) prior to testing, the test results for MOR and MOE in bending, compression and tension as well as density were adjusted to 12 % mc in accordance with ASTM D-2915-94 (1998) and ISO 3131 (1975) standards, respectively.

The natural decay resistance of *P. americana* to decay fungi was evaluated with disks cut from five of the ten harvested logs according to the procedures described in the European standard EN 350-1 (CEN 1994). Specimen size was reduced to 2,5 x 2,5 x 1,0 cm^3 to accommodate more specimens per disk than would have been possible with the larger dimensions (2,5 x 1,5 x 5,0 cm^3) suggested in the standard. All specimens were oven-dried at 102 ºC to determine the initial dry weight (W1). The dry specimens were subsequently reconditioned the moisture saturated condition and steam-sterilized (15 min/121 ºC). The test fungi used were *Postia placenta (*Fries) M. Larsen & Lombard (brown rot); *Phanerochaete chrysosporium* Burdsall and *Trametes versicolor* (L. Fries) Pilát (white rot). The fungi were grown on malt extract agar (MEA, 3,6 %) before inoculation. Ten replicates per fungus were conducted. Glass jars (225 ml) with 40 ml of malt extract agar (MEA, 3,6 %) were sterilized (30 min/121 ºC) and the fungal inoculum deposited on the MEA surface. The glass jars were incubated (27 ºC/70 % RH) until the mycelium completely covered the agar surface. The test specimens were then placed in the jars on two small capillary tubes (diameter 1,5 mm) to separate the agar from the wood surface. Ten non-inoculated specimens served as controls in both test series. Specimens of the non-durable wood of Mexican aile (*Alnus acuminata*) were used as reference to verify the respective white and brown rot fungi's capacity of degrading wood.

The jars with the test specimens were incubated in a decay chamber at 27 ºC and 70 % RH for 12 to 16 weeks. At the end of that period the specimens were taken out of the jars, cleaned carefully, weighed and subsequently oven-dried to determine the final dry weight (W2). Weight loss (WL) was calculated as follows:

Statistical data analyses were conducted with the software package Statgraphics 5.0, making use of the simple (ANOVA) analysis of variance offered by the package.

RESULTS AND DISCUSSION

Density

The histogram presented in figure 1 depicts the density frequency distribution of all test specimens (N = 144). Normal density (adjusted to 12 % mc) shows a normal distribution (USDA Forest Service, 1999) within a range from 0,45 to 0,63 g/cm^3, an overall mean of 0,54 g/cm^3 and a coefficient of variation of 6,6 %.

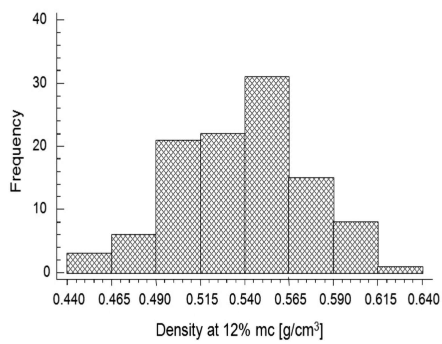

Figure 1 Density distribution of *Persea americana* branch wood

Table 2. Selected elastic and strength properties and density adjusted to 12% mc of *Persea americana* branch wood featuring the number of specimens per test (N); mean, minimum and maximum values; coefficient of variation (CV).

	Mean	Min	Max	CV [%]
Static bending (N = 33)				
MOR [N/mm²]	73	60	92	11
MOE [N/mm²]	5937	4328	8235	17
Density at 12% mc [g/cm³]	0,54	0,47	0,60	6
Compression parallel to the grain (N = 25)				
MOR [N/mm²]	35	23	47	15
MOE [N/mm²]	5548	3367	7611	20
Density at 12% mc [g/cm³]	0,45	0,44	0,51	8
Tension parallel to the grain (N = 23)				
MOR [N/mm²]	63	33	83	15
MOE [N/mm²]	6679	4163	11056	20
Shear parallel to the grain (N = 13)				
Shear strength [N/mm²]	9	7	13	21
Density at 12% mc [g/cm³]	0,58	0,55	0,65	4,5
Impact bending (N = 25)				
Impact bending strength [kJ/m²]	42	25	63	23
Density at 12% mc [g/cm³]	0,54	0,49	0,62	6
Hardness BRINELL/JANKA[1] (N = 25)				
Transverse [N/mm²]	39/10,2	31/7,6	53/14,7	14
Side [N/mm²]	20/4,2	14/2,2	27/6,4	23
Density at 12% mc [g/cm³]	0,51	0,48	0,57	11

[1]BRINELL values / mathematically converted to JANKA hardness (Schwab, 1990)

Table 3. Comparison of selected physical and mechanical properties of *Persea americana* branch wood with Mexican commercial timbers and other *Persea* species.

	Density [g/cm³] at 12% mc	Static bending [N/mm²]		Compression [N/mm²]	Tension [N/mm²]	Impact bending [kJ/m²]	Shear [N/mm²]	Hardness	[N/mm²]
		MOR	MOE	MOR					
Aguacate (*Persea americana*)	0,54	73	5937	35	63	42	9	39	20
Cedro (*Cedrela odorata*)[1,4]	0,34	37	5200	19	n.d.	37	5	n.d.	16
Parota (*Enterolobium cyclocarpum*)[2]	0,38	43	4596	24	41	34	6	27	15
Melina (*Gmelina arborea*)1	0,48	54	5900	26	n.d.	n.d.	9	145	17
Caoba (*Swietenia macrophylla*)[2,4]	0,50	83	8800	44	n.d.	51	13	38	17
Pino colorado (*Pinus durangensis*)[3]	0,53	98	11400	49	117	37	11	39	14
Habillo (*Hura polyandra*)[2]	0,60	94	9660	47	104	66	12	41	28
Persea spp.[6,7]	0,55	72-90	11500	43-48	n.d.	n.d.	11	n.d.	19-20

[1] Lavers (1983); [2] Bravo y Fuentes (1993); [3] v. Roth and Rechy (1986); [4] Sell (1989); [5]Rivero M. (2004); [6] Wood Explorer (2009); [7]USDA Forest Service (2009); n.d. = no data available

Compared to some of the more common structural timbers in Mexico such as pino colorado (*Pinus durangensis*) (v. Roth & Rechy, 1986), habillo (*Hura polyandra*) (Bravo & Fuentes, 1993), caoba (*Swietenia macrophylla*) (Richter & Oelker, 2002; Sell, 1989) and other *Persea* species (Wood Explorer, 2009; USDA Forest Service, 2009) in the same density range, avocado branch wood is below average in bending, compression and tension. However, the values obtained compare favorably with lighter weight nonstructural timbers such as melina (*Gmelina arborea*) (Obregón, 2009; Rojas *et al*., 2004; Fujiwara *et al*., 1996), cedro (*Cedrela odorata*) (Escobar *et al*., 1993; CIRAD-Forêt, 2009) and parota (*Enterolobium cyclocarpum*) (Bravo & Fuentes, 1993) (Table 3).

As for impact bending, shear and hardness, avocado branch wood possesses properties commensurate with its density comparable to those of the structural timbers listed in table 3. The dispersion of the values encountered and reflected in the coefficients of variation (CV; table 2), is of an acceptable magnitude and somewhat below the levels reported by the USDA Forest Service (1999) for some mechanical properties of clear wood. Taking into account that the studied material is branch wood, a higher variability of elastic and strength properties would have to be expected according to Bowyer *et al*. (2003).

Wood structure and natural durability

General macroscopic and microscopic features of *Persea americana* wood were reported earlier (Silva *et al*., 1999). In the context of the present study, observations focused on the presence or absence of tyloses in the investigated material. The results, obtained from radial strips extending from pith to bark, were negative throughout, *i.e.* no tyloses were detected. Since the formation of tyloses in heartwood is a mandatory character of all taxa pertaining to the family of Lauraceae (Richter, 1981), the lack of this feature indicates that the material obtained from coppicing operations in avocado orchards is essentially all sapwood.

This observation was confirmed by the accompanying bioassay in which the wood under study was tested under exposure to decay-producing fungi according to the European standard EN 350-1 (CEN, 1994). The mass losses recorded for the white rot fungi *Trametes versicolor* and *Phanerochaete chrysosporium* was 61% and 46%, respectively, that for the brown rot fungus *Postia placenta* 32% (Table 4). These mass losses are of the same magnitude as those recorded for the aile (*Alnus acuminata*) reference wood considered highly susceptible to fungal decay (Lomelí & Fuentes, 1997; Sachsse & Schulte, 1991). Accordingly, since mass losses are larger than 30% for all three fungi, the studied material is rated perishable (class V according to DIN-EN 350-1; CEN, 1994) and is expected to have a short service life under exterior and other decay-producing conditions unless preservative treated.

Analysis of possible end uses

In light of its fairly high hygroscopicity (Fuentes *et al*., 2002) and susceptibility to wood staining and decaying fungi, avocado branch wood generated from coppicing operations is unsuitable for exterior use unless properly protected.

Traditional uses of avocado wood include, for instance, sawn timber, firewood, turned articles, structural parts of guitar bodies (Rogel, 1982), light construction, flooring, furniture, general carpentry works and rotary veneer for plywood (Chudnoff, 1984). For the state of Michoacán, Guridi (1980) mentions wooden elements used in the manufacture of violins and guitars, whereas Pennington & Sarukhán (1998) refer to light construction and turned objects.

Some of these traditional uses can be confirmed, such as structural non-resonance elements for string instruments, turnery and furniture parts. On the other hand, to use avocado branch wood for structural members cannot be recommended for two reasons: *a)* its elastic and strength properties in bending, compression and tension are low and its load bearing capacity very limited; *b)* the dimensions (length, diameter) of the generally available material do not allow the manufacture of larger elements like beams, trusses and posts. Similarly, the low side hardness of avocado branch wood does not make it a commendable choice for flooring (parquet, solid wood and upper layer of prefab composites) as the wood surface is likely to deteriorate rapidly under the abrasive and compressive forces to which even light traffic floors are commonly subjected.

Low grade avocado branch wood can be converted into packaging materials (boxes, crates, etc.) or chipped for use in pulp and paper making (Vargas *et al*., 2006) and manufacture of wood composites (MDF, particle board). Given its good machining properties (Echenique & Plumtre, 1990; Martínez & Martínez, 1996), its moderate movement in service (Fuentes *et al.,* 2002; USDA Forest Service, 1999) and ease of gluing (Wood Explorer, 2009), good quality avocado branch wood has considerable utilization potential. It would be a natural choice to be adopted by the Mexican furniture industry as a substitute for costly imports from South and North America for the production of home furnishing items, chairs, small radio-stereo-TV cabinets, kitchen cabinets, etc. The manufacture of solid wood composites such as glue boards and glue-laminated scantlings would greatly increase the profitable utilization of the available raw material for value-added products such as fronts and sides of closets, larger cabinets, shelves, partitioning walls, interior paneling, door frames, etc. The required technology for primary conversion of small logs, drying, jointing

Table 4. Weight losses of *Persea americana* branch wood and *Alnus acuminata* (reference species) after a 12 to 16 week exposure to white rot (*Trametes versicolor, Phanerochaete chrysosporium*) and brown rot (*Postia placenta*) decay fungi.

	Weight loss [%]	*T. versicolor* [1]	*P. chrysosporium*	*P. placenta*	Controls
Persea americana	Mean	60.45	45.22	32.53	0.43
	Min	58.74	44.04	31.80	0.40
	Max	61.39	46.41	33.51	0.45
	CV	1.82	1.96	1.71	5.2
Alnus acuminata	Mean	60.91	45.57	36.10	––
(reference)	Min	58.49	43.91	35.40	––
	Max	63.19	46.97	37.46	––
	CV	1.99	2.50	2.06	––

[1] 12 week exposure time; for the other fungi and controls the exposure time was 16 weeks

and gluing is available in the market and the ensuing investments will no doubt pay off in the long run as has been proven with other wood byproducts from agricultural crops such as the sustainable, eco-friendly rubber wood (*Hevea brasiliensis*) emanating from latex producing plantations in Southeast Asia (Hong, 1996).

CONCLUSIONS

Persea americana (avocado) branch wood possesses strength properties in the low to medium range which largely limits its utilization to non-structural applications. It is also highly susceptible to biological degradation by decay fungi and should therefore be employed only under conditions protected from drastic moisture changes in order to guarantee a reasonable in-service performance.

By means of an adequate conversion technology, *i.e.* reduction and reconstitution to larger dimensions by appropriate jointing and gluing techniques, the raw material has considerable potential for general carpentry and, particularly, the Mexican furniture industry as a reasonable alternative for exotic timbers imported at high cost from other regions of the globe.

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