Physical and mechanical wood properties of 14 timber species from Northeast Mexico

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ORIGINAL PAPER

Physical and mechanical wood properties of 14 timber species from Northeast Mexico

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Abstract

• *Background* Thornscrubs are a vegetation type from Northeast Mexico, consisting of 60 to 80 tree and shrub species that are used for a wide range of constructive, decorative and energy purposes. However, basic research of the physical and mechanical wood properties are still needed to establish additional uses and, thereby, increase their value in the timber industry.

• *Method* In this research, wood from fourteen native species were studied with regard to their basic density (BD), modulus of elasticity (MOE), and modulus of rupture (MOR), as well as the relationships between these three properties.

• *Results* Results showed that the BD range was 0.48 g cm^{-3}± 0.06 to 0.93 g cm^{-3}±0.07, the lowest being for *Leucaena leucocephala* and the highest for *Condalia hookeri*. MOE range was 6.42 GPa±1.23 to 15.13 GPa±2.72, corresponding to *Diospyros texana* and *Acacia schaffneri* respectively. MOR range was 101 MPa±16 to 207 MPa±33 for *Parkinsonia texana* and *Acacia schaffneri* respectively. Correlations between BD and MOE, BD and MOR, and MOE and MOR were as follows: r=0.67, r=0.64 and r= 0.87 respectively.

• *Conclusion* Values of modulus elasticity and rupture of studied species make them a promising general utility wood that can be recommended for a variety of structural and non-structural uses.

Keywords Density · Modulus of elasticity · Modulus of rupture · Thornscrub · Vegetation

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1 Introduction

The forests of Mexico are widely distributed, covering more than 0.6 million km^2, representing 32.75% of the total area of 1.979 million km^2 (SEMARNAT 2007). Tamaulipan thornscrub vegetation has an area of about 20 million ha, where around 60 to 80 shrubs and tree species are found, these species being those most used by people living in the rural areas, for either agriculture, livestock, or forest harvesting (Reid et al. 1990). The wood is mainly used for furniture, wagons, tool handles, and different kitchen utensils for rural households, as well as for firewood or charcoal (Folliott and Thames 1983; Meraz et al. 1998). A great number of studies on thornscrub have been reported, but a complete analysis of wood properties has been carried out for only a few species (Carrillo et al. 2011). The main objective of the present research is to reassess the available information such as basic density (BD), modulus of elasticity (MOE) and modulus of rupture (MOR) for 14 timber species from Northeast Mexico, and to establish a basis for better utilization of these species.

2 Material and methods

2.1 Species and sample trees

The 14 timber species used for this research were selected from those most preferred and used by the rural population because of their availability, natural durability, and good construction quality (Wolf and Perales 1985; Carrillo et al. 2008; Villalón and Carrillo 2010). Three straight trees from each species having no defect, insect, or mechanical damage, were randomly sampled from an area located at 99°11´56” and 25°08´59” in Linares, Nuevo León, Mexico. The material for physical and mechanical tests was obtained from heartwood in the bole zone of 0.3 m to 1.3 m above the tree base, according to Ramos-Alvarez and Díaz-Gómez (1981). The averages of tree height and diameter at breast height obtained in the sites of each species are presented in Table 1.

2.2 Sample preparation

After tree logging, wood samples were prepared and conditioned according to the German standard DIN 52180 (1994). A total of 30 samples, size 10 × 20 × 20 mm (longitudinal × radial × tangential directions respectively) were cut from each species (ten samples per tree) and tested to determine BD (dry mass divided by green volume) in accordance with DIN 52182 (1978). MOE was determined using also 30 specimens from each species (ten samples per tree), measuring 100 × 5 × 10 mm. The MOE test was performed on a universal Tinius Olsen machine once samples reached constant weight at 65% moisture content and 20±3°C, using three-point static bending where annual rings were orientated horizontally according to DIN 52186 (1978); the load (*F*) was applied at a uniform rate (5 mm min^{-1}) in the direction of the narrow side at the centre of the sample span. Also, MOR was determined during the same test using the maximum load at the break point as the condition of rupture. All calculations were performed using Statistical Analysis System (SAS ©2004, Version 9.1.2). BD, MOE and MOR of the species were compared, and correlations between BD and MOE, BD and MOR as well as MOE and MOR were developed.

3 Results and discussion

BD from the fourteen timber species is summarized and categorized in Table 2 following Echenique and Díaz (1969). Two species reached class 10, “extremely heavy”, corresponding to density higher than 0.86 g cm^{-3}: *C. hookeri* was the densest species (0.93 g cm^{-3}±0.07) and *E. ebano* the

Table 1 Tree characteristics of 14 timber species from Northeast Mexico

Latin name	Common name	Family	Use*	Average	
				Tree height (m)	DBH** (m)
Acacia amentacea DC.	Gavia	Leguminosae	L[1***]	3.5	0.20
Acacia farnesiana (L.) Willd.	Huizache	Leguminosae	L	4.5	0.35
Acacia schaffneri var. schaffneri (S. Watson) F.J. Herm.	Hizache chino	Leguminosae	L,C	3.5	0.25
Condalia hookeri M.C. Johnst.	Brasil	Rhamnaceae	L[1],C[1]	5.8	0.35
Cordia boissieri DC	Anacahuita	Boraginaceae	L[1]	4.4	0.30
Diospyros palmeri Eastw.	Chapote blanco	Ebenaceae	L[1]	5.7	0.30
Diospyros texana Scheele	Chapote obscuro	Ebenaceae	L	6.2	0.35
Ebenopsis ebano (Berl.) Barneby & Grimes	Ebano	Leguminosae	L[1],C[1]	6.9	0.35
Havardia pallens (Benth.) Britton & Rose	Tenaza	Leguminosae	L[1]	4.1	0.20
Helietta parvifolia (Gray) Benth.	Barreta	Rutaceae	L[1]	4.8	0.20
Leucaena leucocephala ssp. Glabrata (Rose) S. Zárate	Leucaena	Leguminosae	L	5.7	0.20
Parkinsonia texana (A. Gray) S. Watson var. Macra (I.M. Johnston) Isely.	Palo verde	Leguminosae	NR	6.4	0.28
Prosopis laevigata (Humb. & Bonpl. ex. Willd.) M.C. Johnst.	Mezquite	Leguminosae	L[1,2],C[1,2]	7.2	0.45
Sideroxylon celastrinum (Kunth) Pennington	Coma	Sapotaceae	L	4.7	0.25

*Uses: L=firewood, C=Charcoal, NR=Non reported uses,

** Diameter at breast height

*** Source: [1] Medina (2002), [2] Carrillo et al. (2011)

Table 2 Basic density, modulus of elasticity and modulus of rupture of 14 timber species of Northeast Mexico. Minimum (Min.), average (Ave.), maximum (Max.), standard deviation (S.D.), coefficient of variation (C.V. %) and classification (Class.) values are provided

SPECIES	Basic density (g cm^3)						Modulus of elasticity (GPa)						Modulus of rupture (MPa)					
	Min.	Ave.	Max.	SD	C.V. %	Class.*	Min.	Ave.	Max.	SD	C.V. %	Class.**	Min.	Ave.	Max.	SD	C.V. %	Class.***
A. amentacea	0.67	0.85	0.97	0.08	8.92	9	8.01	11.67	15.13	2.24	19.20	3	105	141	175	23	16.31	5
A. farnesiana	0.61	0.65	0.69	0.02	3.13	8	7.84	10.08	12.08	1.13	11.17	2	128	146	161	9	6.49	5
A. schaffneri	0.65	0.79	0.88	0.06	7.50	9	10.30	15.13	19.75	2.72	17.99	4	161	207	246	33	15.74	5
C. hookeri	0.76	0.93	1.06	0.07	8.01	10	8.02	11.32	15.68	2.13	18.84	3	120	152	194	23	14.94	5
C. boissieri	0.49	0.57	0.65	0.04	7.66	7	4.83	7.93	9.69	1.11	14.02	2	93	120	144	13	10.66	4
D. palmeri	0.56	0.58	0.62	0.02	2.94	7	4.42	7.26	10.12	1.44	19.79	1	81	107	133	14	13.38	4
D. texana	0.48	0.55	0.61	0.03	5.34	7	4.32	6.42	8.77	1.23	19.20	1	54	107	134	17	15.89	4
E. ebano	0.70	0.87	1.00	0.08	9.60	10	8.13	13.44	16.42	1.90	14.17	4	133	183	233	29	16.08	5
H. pallens	0.77	0.83	0.89	0.04	4.44	9	8.71	12.34	15.26	1.70	13.80	3	93	177	227	25	14.34	5
H. parvifolia	0.48	0.55	0.63	0.04	7.66	7	7.25	10.00	14.01	1.85	18.46	2	96	131	179	21	15.75	5
L. leucocephala	0.41	0.48	0.57	0.06	11.51	6	4.76	8.05	10.30	1.39	17.25	2	86	109	139	19	17.08	4
P. texana	0.53	0.55	0.58	0.02	2.82	7	4.36	6.59	8.96	1.04	15.77	1	65	101	142	16	15.83	4
P. laevigata	0.60	0.76	0.82	0.04	5.48	9	7.06	11.37	14.22	2.06	18.12	3	126	173	202	26	14.75	5
S. celastrinum	0.50	0.64	0.70	0.04	5.98	8	5.02	7.58	10.33	1.39	18.30	1	82	107	133	15	14.10	4

* Basic density classification according to Echenique and Díaz (1997): 10) extremely heavy, 9) too heavy, 8) very heavy, 7) heavy, 6) moderately heavy.

** Modulus of elasticity classification according to Dávalos and Bárcenas (1999:) 4) high, 3) medium, 2) low, 1) very low.

*** Modulus of rupture classification according to Dávalos and Bárcenas (1999): 5) Very High, 4) High.

second (0.87 g cm^{-3}±0.08). Four species were found for Class 9, "too heavy", with values from 0.72 g cm^{-3} to 0.86 g cm^{-3}: *A. amentacea* (0.85 g cm^{-3}±0.08), *H. pallens* (0.83 g cm^{-3}±0.04), *A. schaffneri* (0.79 g cm^{-3}±0.06) and *P. laevigata* (0.76 g cm^{-3}±0.04). Two species fell into Class 8, "very heavy" (0.60 g cm^{-3} to 0.72 g cm^{-3}): *A. farnesiana* (0.65 g cm^{-3}±0.02) and *S. celastrinum* (0.64 g cm^{-3}± 0.04). Five species were classified into Class 7, "heavy" (0.50 g cm^{-3} to 0.60 g cm^{-3}): *D. palmeri* (0.58 g cm^{-3}±0.02), *C. boissieri* (0.57 g cm^{-3}±0.04), *P. texana* (0.55 g cm^{-3}± 0.02), *H. parvifolia* (0.55 g cm^{-3}±0.04) and *D. texana* (0.55 g cm^{-3}±0.03). One species was labelled Class 6, "moderately heavy" (0.42 g cm^{-3} to 0.50 g cm^{-3}): *L. leucocephala* (0.48 g cm^{-3}±0.06). Information describing BD for these fourteen species is so far almost unavailable; only a few studies have been published. Correa-Méndez et al. (2008) worked with trees growing in a similar place to that used for this research, located northeast of the State of Tamaulipas. They stated basic density values higher than reported in this research for species such as *E. ebano* (0.97 g cm^{-3}), *H. pallens* (0.76 g cm^{-3}) and *C. boissieri* (0.58 g cm^{-3}). Carrillo et al. (2010) reported wood air-dry density for *P. laevigata* from four different sites at 12% moisture content ranging from 0.79 g cm^{-3} to 0.91 g cm^{-3}. Gillah and Ishengoma (1993) reported a value of 0.54 g cm^{-3} for *L. leucocephala* from plantations. According to basic densities detected in this research, the management of thornscrub species should be focussed on promoting their industrial use, especially those from classes 7 to 9. However, less dense species in class 6 such as *L. leucocephala* could be integrated into multipurpose plantations for wood biomass production.

Results of MOE are summarized and categorized in Table 2. This table shows a great MOE variation between thornscrub species. According to the classification for five classes of Mexican timber species developed by Dávalos and Bárcenas (1999), the Thornscrub species fall into four classes. For Class 4, "high", the species were *A. schaffneri* (15.13 GPa± 2.72) and *E. ebano* (13.44 GPa±1.90). For Class 3, "medium", four species were found: *H. pallens* (12.34 GPa± 1.70), *A. amentacea* (11.66 GPa±2.24), *P. laevigata* (11.36 GPa±2.06), and *C. hookeri* (11.32 GPa±2.13). Four species were labelled Class 2, "low": *A. farnesiana* 10.07 GPa±1.12): *H. parvifolia* (10.00 GPa±1.84); *L. leucocephala* (8.05 GPa±1.39), and *C. boissieri* (7.93 GPa± 1.11). In Class 1, "very low", four species were found: *S. celastrinum* (7.58 GPa±1.38), *D. palmeri* (7.26 GPa±1.44), *P. texana* (6.58 GPa±1.04), and *D. texana* (6.42 GPa±1.23). For MOE, values ranging from 6.58 GPa to 9.67 GPa for *P. laevigata* were reported by Carrillo et al. (2010).

Results of MOR are summarized and categorized in Table 2. Average values ranged from "high" to "very high" for the 14 species according to the classification system of Dávalos and Bárcenas (1999). For class 5, "very high", eight species were found: *A. schaffneri* (207 MPa±33), *E. ebano* (183 MPa±29), *H. pallens* (177 MPa±25), *P. laevigata* (173 MPa±26), *C. hookeri* (152 MPa±23), *A. farnesiana* (146 MPa±9), *A. amentacea* (141 MPa±23), and *H. parvifolia* (130 MPa±21).

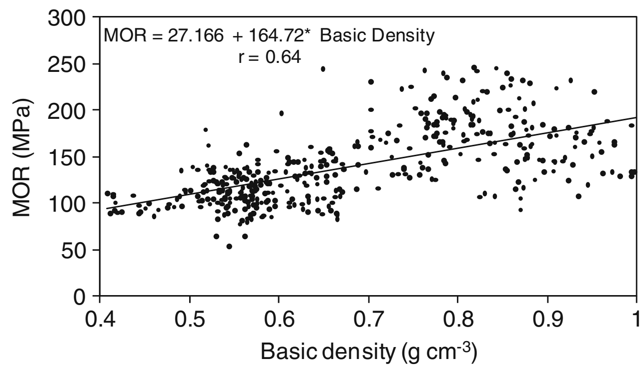

Fig. 2 Relationship between MOR and BD from 14 species of Northeast Mexico

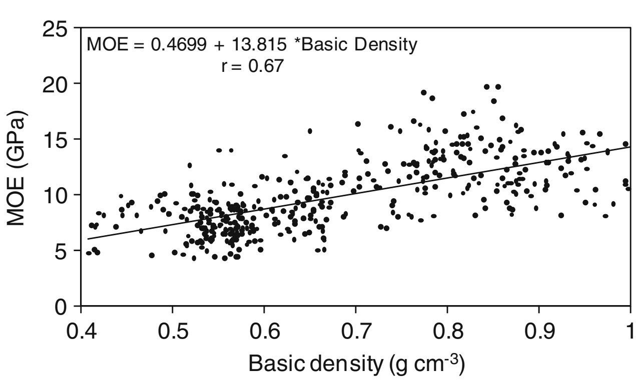

Fig. 1 Relationship between MOE and BD from 14 species of Northeast Mexico

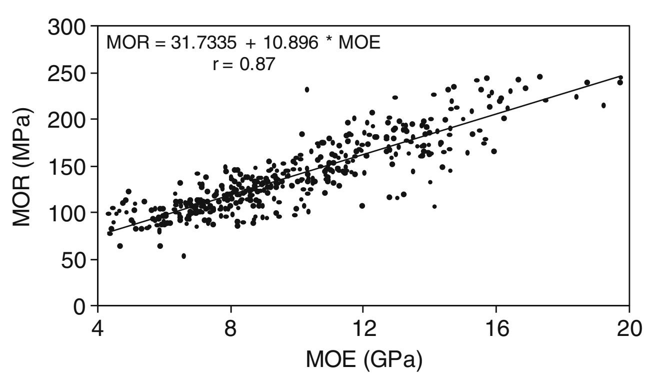

Fig. 3 Relationship between MOR and MOE from 14 species of Northeast Mexico

Six species were labelled Class 4, “high”: *C. boissieri* (120 Mpa±13); *L. leucocephala* (109 MPa±19), *D. texana* (107 MPa±17), *D. palmeri* (107 MPa±14), *S. celastrinum* (107 MPa±15), and *P. texana* (101 MPa±16). Values ranging from 97 MPa to 126 MPa for *P. laevigata* were reported by Carrillo et al. (2010).

Wood density is one of the most important wood characteristics, and it is used as an indicator of wood quality (Freyburger et al. 2009). Determination of some physical and mechanical properties is very time-consuming (Kokutse et al. 2010). The relationships of BD with MOE and MOR are shown in Figure 1. The model MOE=469.92+13.815 *BD, $p<0.05$ justifying the correlation coefficient of $r=0.67$ was found between the MOE and BD, a value of $r^2=0.50$ in this relationship was detected by Dávalos and Bárcenas (1999) after the evaluation of 119 Mexican timber species in dry condition. On the other hand, the relationship between MOR and BD (Fig. 2) was described based on the model (MOR= 27.116+164.72*BD, $p<0.05$) with a correlation coefficient of $r=0.64$. In this study, simple linear regression analysis showed that MOR was highly correlated with MOE for the fourteen thornscrub species ($r=0.87$, $p<0.05$), justifying the model MOR=31.7335+0.01090*MOE as is shown in Figure 3. The correlations found in this research were similar to those previously reported for hardwood species, showing high relationships between MOE and MOR for species such as *Eucalyptus camaldulensis, Khaya senegalensis, Tamarix articulate*, and *Casuarina* spp. (Ei-Osta et al. 1979).

4 Conclusion

Values of BD, MOE and MOR for the majority of species are reported here for the first time. The relatively high correlation between modulus of elasticity and rupture can be used for suitable prediction of bending strength based on modulus of elasticity.

The high density values found for some species such *Condalia hookeri, Ebenopsis ebano, Acacia amentacea and Havardia pallens* indicated the high quality in terms of mechanical properties of these species. High modulus elasticity and rupture for *Acacia schaffneri, Ebenopsis ebano, Havardia pallens* and *Acacia amentacea*, make these species a promising general utility wood that can be recommended for a variety of structural and non-structural uses. The establishment of an appropriate silvicultural management of the species mentioned above is highly recommended.

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