Evaluation of *Prosopis juliflora* properties as an alternative to wood shortage in Kenya

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Wood from *Prosopis juliflora*, which was introduced in Kenya in the 1970s as a means of slowing desertification, is being used for both fuel and construction. The results of our evaluation show that the wood has high resistance to white and brown rot pathogens, a high degree of impregnability making it suitable for use under severe conditions, and low susceptibility to termites. Its dimensional stability and mechanical properties are comparable to those of native Kenyan timber species. Its calorific value is similar to that of comparable fuelwood species. *P. juliflora* could help to remedy the wood scarcities currently prevailing in Kenya.

Photo 1.
The semi-arid lands of Kenya-Marigat, Baringo.
Note the young stand of *P. juliflora* in the foreground.
Photo P. K. Sirmah.

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RÉSUMÉ

ÉVALUATION DES PROPRIÉTÉS DE *PROSOPIS JULIFLORA* COMPARÉES À CELLES D'ESSENCES AUTOCHTONES EXPLOITÉES AU KENYA

L'étude a pour objectif d'évaluer la durabilité et les propriétés technologiques d'une espèce exogène du Kenya, *Prosopis juliflora*, introduite au début des années 1970 pour augmenter le couvert forestier et lutter contre la désertification. La durabilité du duramen vis-à-vis des champignons, testée dans des conditions de laboratoire, indique que le bois présente une bonne résistance aux agents de pourriture blanche et de pourriture brune. Le bois contient une teneur importante d'extractibles, qui semble présenter un effet limité sur l'inhibition de la croissance des champignons. De plus, le bois est facilement imprégnable, permettant d'envisager son utilisation dans des classes d'emploi élevées après traitement adéquat. La résistance aux termites évaluée dans des conditions de laboratoire et de champ indique une faible susceptibilité du bois de *P. juliflora*, qui semble fortement liée à la présence des substances extractibles. Le bois présente une bonne stabilité dimensionnelle et les propriétés mécaniques supportent la comparaison avec celles d'essences comme *Pinus patula* abondamment utilisée au Kenya pour la construction. Le pouvoir calorifique est similaire à celui d'autres essences du genre *Prosopis* utilisées actuellement comme bois de chauffage. L'ensemble de ces résultats montre que l'utilisation de *P. juliflora* comme source de bois d'énergie ou de bois de construction peut être une bonne alternative à la pénurie de bois existant au Kenya, permettant de réduire les pressions environnementales sur les forêts naturelles ou cultivées traditionnelles.

Mots-clés: extractible, durabilité, propriété mécanique, *Prosopis juliflora,* valorisation, bois.

ABSTRACT

EVALUATION OF *PROSOPIS JULIFLORA* PROPERTIES AS AN ALTERNATIVE TO WOOD SHORTAGE IN KENYA

This study aimed to assess the durability and technical properties of *Prosopis juliflora*, an exogenous tree species in Kenya, which was introduced in the early 1970s to improve biomass cover and rehabilitate arid and semi arid land. Laboratory tests to assess heartwood resistance to fungi indicated that the wood was resistant to both white rot and brown rot fungi. The heartwood had a high content of extractives, which have been demonstrated to have a limited effect on fungal growth inhibition. Moreover, *P. juliflora* wood was easily impregnated using a standard vacuum pressure plant, so that additional preservation treatments can be considered for use under severe conditions. Laboratory and field tests to assess termite resistance indicated low susceptibility of *P. juliflora* wood, which seems correlated to the presence of extractives. The wood is dimensionally stable and its mechanical properties compared well with those of *Pinus patula*, a Kenyan wood species widely used for construction. Calorific value was consistent with that of other *Prosopis* wood species currently used as fuelwood. Taken together, these data indicate that *P. juliflora* wood for fuelwood and construction can be a valuable alternative to help remedy the wood shortage in Kenya and reduce pressures on natural and plantation forests.

Keywords: extractive, durability, mechanical property, *Prosopis juliflora,* economic value, wood.

RESUMEN

EVALUACIÓN DE LAS PROPIEDADES DE *PROSOPIS JULIFLORA* COMPARÁNDOLAS CON LAS DE ESPECIES AUTÓCTONAS EXPLOTADAS EN KENIA

Este estudio tiene por objetivo evaluar la durabilidad y las propiedades tecnológicas de una especie exógena de Kenia, *Prosopis juliflora*, introducida a principio de los setenta para aumentar la cubierta forestal y luchar contra la desertización. La durabilidad del duramen a los hongos, probada en condiciones de laboratorio, indica que la madera presenta una buena resistencia frente a la acción de los agentes causantes de pudriciones blancas y pardas. La madera tiene un contenido importante de extraíbles, que parece presentar un efecto limitado en la inhibición del crecimiento de los hongos. Además, la madera es de fácil impregnación, lo que permite prever su utilización en clases de uso altas tras un tratamiento adecuado. La resistencia frente a las termitas, evaluada en condiciones de laboratorio y de campo, indica una susceptibilidad baja de la madera de *P. juliflora*, que parece estrechamente asociada a la presencia de substancias extraíbles. La madera presenta una buena estabilidad dimensional y sus propiedades mecánicas son comparables a las de especies como *Pinus patula,* muy empleado en Kenia para la construcción. El poder calorífico es análogo al de otras especies de del género *Prosopis* actualmente usadas como leña. Estos resultados demuestran que la utilización de *P. juliflora* como fuente de leña o madera de construcción puede ser una buena alternativa a la escasez de madera en Kenia y permitiría reducir las presiones ambientales sobre los bosques naturales o cultivados tradicionales.

Palabras clave: extraíble, durabilidad, propiedad mecánica, *Prosopis juliflora,* valorización, madera.

Context of the study

Forest ecosystems make up a complex natural resource that provides environmental goods and services supporting social, cultural and economic development. It is therefore important for national development that this resource is conserved, protected and sustainably used. Kenya and other developing countries are facing the challenge of over-reliance on natural resources. It is for this reason that *Prosopis juliflora* was introduced into Kenya's arid and semi-arid lands in the early 1970s, in order to remedy environmental problems, improve biomass cover and rehabilitate disused quarries (Choge *et al.,* 2007). The species was valued initially for its ability to prevent soil erosion and to grow where nothing else could (photograph 1). Over the years, it spread rapidly and colonized agricultural lands and pastures (Choge *et al.,* 2007). Its suckering ability after cutting made it difficult to control. Today it has colonized a large proportion of Kenya's arid lands, such as the Taita Taveta, Wajir, Mwingi, Marsabit, Isiolo, Mandera, Baringo and Turkana Districts (figure1). Inhabitants in these areas are complaining about the trees forming impenetrable thickets and about injuries due to thorns. Moreover, problems with livestock feeding on its pods have been reported. In one unprecedented case, local communities took the matter to the National Environmental Management Authority. *P. juliflora* has been reported in the print media (Daily Nation, 22nd February 2007) as gradually diverting the Tana river from its course, thus affecting the Bura irrigation scheme as well as overgrowing a large proportion of the road network in the 70 km² Kerio Delta (photograph 2).

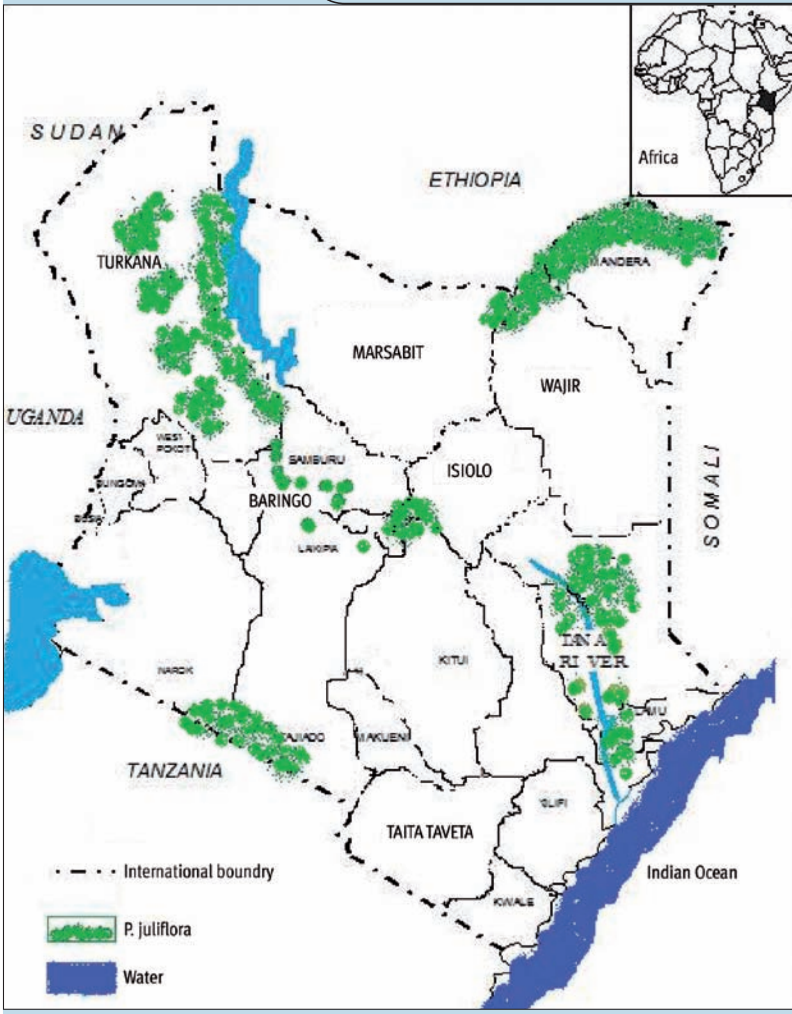

Figure1.
Distribution of *P. juliflora* in Kenya.

P. juliflora is a fast-growing and drought resistant plant originating from South and Central America. It grows in all kinds of soil conditions, including wastelands, at altitudes ranging from 0 to 1,500 m above sea level, under mean annual temperatures of 14 to 34 °C and annual rainfall of 50 to 1,200 mm (Pasiecznik *et al.*, 2001). Mature trees grow to 17 m in height. The species is characterised by its twisted, greenish-brown stem, with axial thorns on both sides of the nodes and branches. It is reported to dry out the soil and to compete with grasses, particularly in dry areas, and is therefore considered in some areas as a weed (Choge *et al.,* 2007). Uses of *P. juliflora* pods, beans and gum as food supplements and medicines for animals and humans have been described (Barba *et al.,* 2006; Choge *et al.,* 2007). A chemical characterization of *P. juliflora* gum by Lopez *et al.* (2006) has indicated an arabinogalactan protein with potential uses for beverages and pharmaceutical products, while fatty acids and free sugars in the seeds and pods enhance its use as a food supplement (Sawal *et al.*, 2004; Silva *et al.,* 2002). Antifungal and plant growth inhibiting alkaloids have been isolated from its leaves (Nakano *et al.*, 2004; Kishore, Pande, 2005) and associated with its allelopathy. Bark and bark extracts have been shown to exhibit antifungal properties (Càceres *et al.,* 1995). *P. juliflora* wood has been described as a source of lumber, firewood, activated carbon and barbecue charcoal (Kailappan *et al.*, 2000; Goel, Behl, 2001). There is considerable potential for *P. juliflora* as a source of fibre for the paper, paperboard and hardboard industry. The heartwood of different *Prosopis* species contains significant amounts of wood extractives and polyphenol compounds (Goldstein, Villareal, 1972). A reddish-amber gum, with properties similar to the gum arabica produced by *Acacia senegal*, often exudes from the stem and older branches.

Photo 2.
P. juliflora growing wild and blocking a road in the Turkana Delta, Kenya.
Photo P. K. Sirmah.

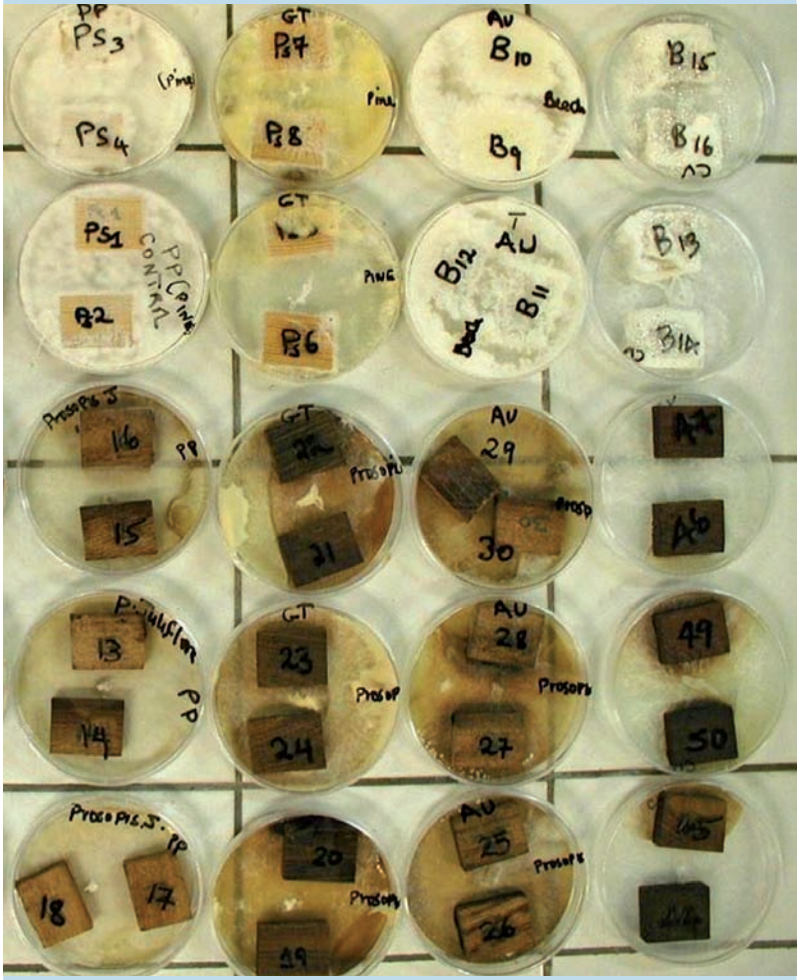

Photo 3.
Fungal test with *P. juliflora* in a sterile chamber.
Photo P. Gérardin.

Timber demand in Kenya is rising each year, outstripping supply so that a deficit of 6,841,000 m^3 is forecast by the year 2020 (Mburu *et al.*, 2005). State forests consisting of 31% pine, 45% cypress, 10% eucalyptus and 14% of other species cover about 1,405,000 ha (some 2.4% of the total land area) while privately owned plantations, consisting of Acacia and *Grevillea robusta*, cover about 70,000 ha. This evaluation of the technical properties of the wood of *P. juliflora* as an underexploited exogenous species in Kenya's arid and semi arid regions was carried out with a view to its use as an alternative to other declining wood resources.

Materials and methods

Determination of extractive content in the wood

Mature *P. juliflora* wood was cut in Baringo (latitude 0°, 20' N, longitude 35°, 57' E), Kenya. The heartwood and sapwood were separately ground to fine sawdust powder using a vibrating hammer mill, passed through a 115-mesh sieve and dried at 60 °C before soxhlet extraction with hexane, dichloromethane, acetone, toluene/ethanol mixture (2/1 v/v) or water. 10g of wood powder were extracted with 180ml of the solvent for 15 hours at a rate of 10 to 12 cycles per hour. After extraction, the solvent was evaporated under reduced pressure and the residue was vacuum-dried over P_2O_5 before weighing. Two methods based either on direct determination of extractives after solvent evaporation (direct methods, DM) or on the difference between the dry weight of sawdust before and after extraction (indirect method, IM) were used to evaluate extractive contents.

The percentage of extractives was evaluated according to the formula:

$$\%\ \text{DM} = \frac{m_e}{m_s} \times 100$$

$$\%\ \text{IM} = \frac{(m_s - m_d)}{m_s} \times 100$$

where m_e is the weighed mass of extracts after solvent evaporation, m_s is the dry mass of the sawdust before extraction, and m_d is the dry mass of extracted sawdust.

Resistance to fungal decay

Heartwood samples measuring 35 mm x 25 mm x 5 mm (L, R, T) were conditioned to a constant weight (m_u) at a temperature of 20 ° to 22 °C and a relative humidity of 60 to 70%. The theoretical dry mass (m_t) of the test samples was determined from the averaged percentage moisture (μ) obtained from similar samples dried at 103 °C according to the formula:

$$m_t = \frac{100\ m_u}{100 + \mu}$$

In a sterile chamber, two UV-sterilized samples were introduced into malt-agar cultures of the white rot fungus *Coriolus versicolor* (CV) strain CTB 863A and the brown rot fungi *Poria placenta* (PP) strain FPRL 280 *Glocophyllum + trabeum* (GT) strain EBW 109 and *Antrodia species* (AN) strain CIRAD/2304/1. Each experiment was repeated three times. Beech wood (*Fagus sylvatica*) was used as control for white rot fungi and *Pinus sylvestris* for brown rot (photograph 3). Incubation was carried out for three months at 25 °C and 70% RH. Decay was assessed by determining the loss of mass using the following formula:

$$\text{Mass loss (\%)} = \frac{(m_t - m_f)}{m_t} \times 100$$

where m_f is the final weight of dry samples after attack.

To understand the contributions of extractives to resistance to wood decay, fungal mycelium was grown in 9 cm Petri dishes filled with 20 ml of malt-agar medium (30 grams malt, 40 grams agar in 1 L) treated to 50, 100, 500 and 1000 ppm of extracts. Control dishes were not treated with the extract. The extracts were introduced after sterilization of the medium (20 min, 120 °C, 1 bar) by adding the necessary quantity of extract dissolved in 5ml of ethanol. The dishes were inoculated in the centre of the malt-agar with a 10 mm portion of a healthy fungal colony. Incubation was carried out at 25 °C and 85% RH. Growth was assessed every 2 or 3 days by measuring the diameter of the colony estimated from the mean of two perpendicular diameters and expressed as a percentage of available room for growth. Growth inhibition was calculated when the diameter of the control culture reached 9 cm, according to the formula:

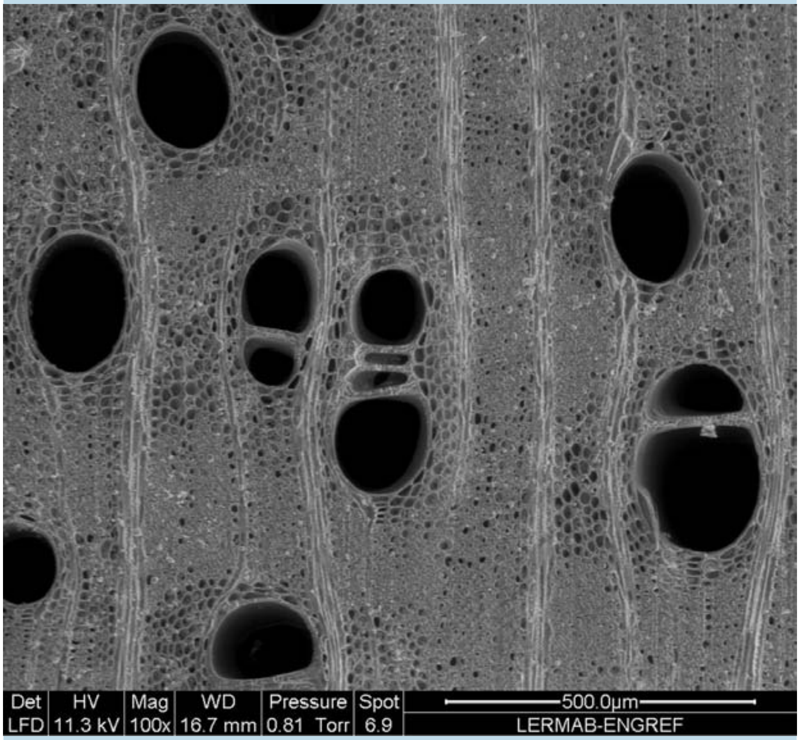

Photo 4.
Electron microscope scan of a heartwood section, showing vessels (dark spots).
Photo F. Huber.

$$\text{growth inhibition (\%)} = 100 \times (1 - d_1/d_0)$$

where d_0 is the diameter of the control culture and d_1 the diameter of the culture in the presence of extracts. All experiments were duplicated.

Resistance to termite damage

Wood samples measuring 50 mm x 15 mm x 15 mm (longitudinal, radial, tangential) were exposed to *Macrotermes natalensis* termites in the field in accordance with a modified AWPA E7-93 (1993) field test standard using stakes. Eighteen samples previously Soxhlet extracted or not (see Table III) were exposed at a distance of 0.3 m from the termite nest and randomly placed 30 cm apart. Every month for six months, three blocks, extracted or not, were assessed for weight loss. Resistance to *M. natalensis* in the laboratory was also assessed with the AWPA E1-97 (1997) standard method. Two test blocks measuring 30 mm x 10 mm x 20 mm (L, R,T) were placed in sterile glass jars with two corners against the side of the container. The jars, measuring 80 mm in diameter and 100 mm in height, contained 150 grams of sterile sand and 30 ml of distilled water. Four hundred termites were added to each jar at a ratio of 360:40 workers to soldiers respectively and incubated at 25 °C for 28 days. The percentages of living termites and weight loss (WL) in the blocks were determined after the experiment as follows:

$$\text{WL (\%)} = \frac{(m_1 - m_2)}{m_1} \times 100$$

where m_1 is the dried initial weight of the block and m_2 the dried weight after exposure to the termites. *Pinus sylvestris* was used as the control.

Anatomical features

Microscopic observations were performed with an environmental scanning electron microscope (ESEM Quanta 200) for sapwood and heartwood samples. The transverse surface of test samples was microtomed and analyzed without further preparation. Photomicrographs were taken at different magnifications.

Physical and fuel characteristics

Moisture content was determined using the oven-dry method. Basic density was determined from freshly cut wood samples using the water displacement method:

wood density = w_o / v_o , where v_o is the volume of displaced water and w_o is the oven dried weight of the sample.

Ash content was determined as per ASTM D 3174-89 (1989). 1 g of wood sample in a tared porcelain capsule was subjected to a temperature of 815 °C in a muffle furnace and the amount of ash generated was measured. Higher heating value was determined as per ASTM D 2015-93 (1993). 1 g of ground wood was pressed into a pellet and charged into a calorimetric bomb standardised by benzoic acid with a heat value of 26.453 MJ/kg.

Moisture content

A freshly cut piece of *P. juliflora* wood was weighed (mi) and then dried in an oven at 103 °C until its mass stabilized(md). Moisture content (MC) was calculated as follows:

$$MC\ (\%) = \frac{(mi-md)}{md} \times 100$$

Table I.
Extractives from *P. juliflora* heartwood and sapwood (%).

Solvent	Heartwood		Sapwood	
	DM	IM	DM	IM
Hexane	2.4	2.7	1.8	1.9
Dichloromethane	3.4	3.7	1.9	1.9
Acetone	7.6	7.7	2.0	2.1
Toluene/ethanol	8.9	9.6	6.0	6.4
Water	10.6	10.8	6.2	6.6

DM: direct method; IM: Indirect method.

Table II.
Percentage weight loss in wood samples after 3-month exposure to fungi.

Wood species	Fungi			
	C. versicolor	*P. placenta*	*G. trabeum*	*Antrodia*
P. juliflora	1.5	2.3	3.1	2.5
P. sylvestris	-	20.5	21.2	-
F. sylvatica	30.1	-	-	24.5

Determination of dimensional stability

Twenty four samples of *P. juliflora* were cut into 20 mm x 20 mm x 20 mm (L, R, T) pieces and dried at 103 ± 2 °C. Dimensions were measured to the nearest 0.01 mm using Veneer callipers and their dry volume determined (v_1). The samples were then put in a desiccator containing a saturated copper sulphate solution. The weight of these blocks was measured every two days until they stabilised to a constant mass, indicating that the wood blocks had reached their maximum moisture level. Their dimensions were measured again and the wet volume determined (v_2). The swelling coefficient (s) was determined according to the formula:

$$s\ (\%) = \frac{v_2 - v_1}{v_1} \times 100$$

Mechanical strength test

Specimens from freshly cut mature *P. juliflora* were extracted from billets cut at breast height. Clear-wood specimens were sampled and tested according to British Standard BS 373:1957 using specimens obtained along and across the grain. The specimens were dried to approximately 12% moisture content. Bending strengths (compression and shear parallel to the grain) and hardness were tested. Their rupture and elasticity modulus and Janka hardness were evaluated. A calibrated universal strength testing machine (USTM) was used.

Treatability

Industrial-quality CCA was used at a concentration of 6% m/m (Tanalith-C, Arch Timber). Air-dried roundwood samples 140-150 mm in diameter and 2 m in length were vacuum-pressure treated with an initial vacuum of 66,708 Pa for 15 min, a pressure of 150,000 Pa for 4 hours and a final vacuum of 66,708 Pa. Retention and penetration were determined using the following formula:

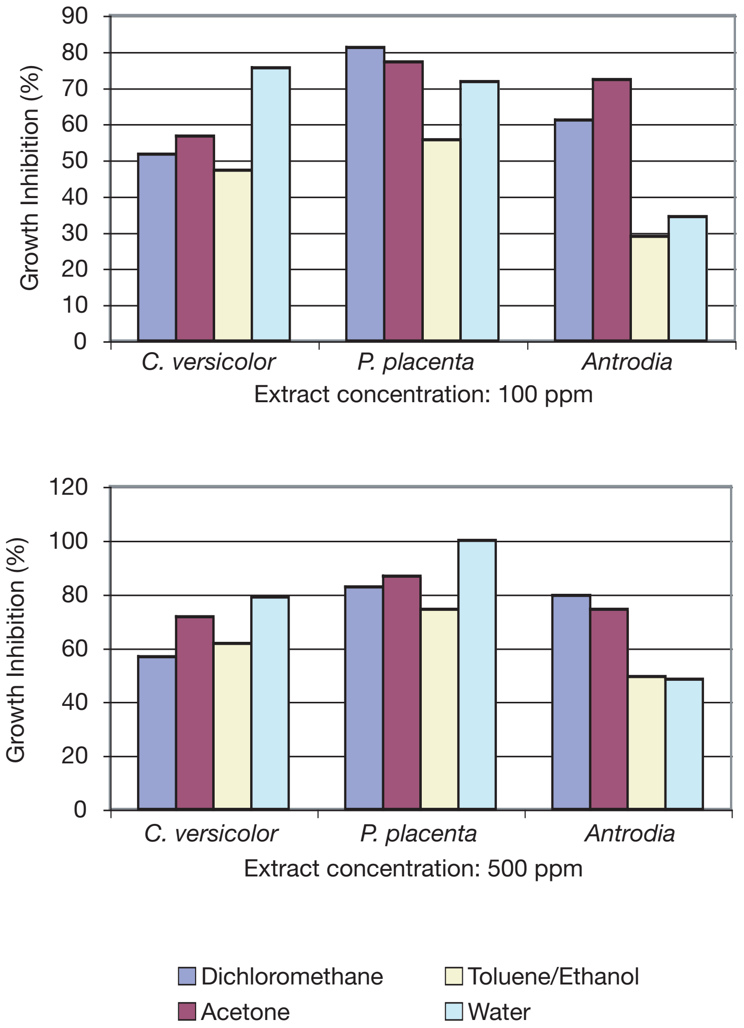

Figure 2.
Fungal growth inhibition by extracts at different concentrations.

retention = $(w_2 - w_1) \times c/v$

where w_1 is the mass of the air-dried untreated wood (kg), w_2 is the mass of the pressure-treated wood (kg), c is the solution concentration (%) and v is the sample volume.

Penetration was determined by measuring the depth (mm) impregnated by the chemical, radially from the periphery at mid-length.

penetration = $[1-(r-r_1)/r] \times 100$

where r_1 is the depth of preservative penetration (cm) evaluated visually and r is the sample radius.

Results

Anatomical characteristics

There is a marked difference between the yellowish sapwood of *P. juliflora* and its dark brown heartwood. The annual growth rings are distinct, with marginal parenchyma bands. The vessels are either solitary or in clusters of 2 to 3 with a diffuse porous pattern. Earlywood and latewood vessels had a mean diameter ranging from 110 to 130 µm. Mean vessel density was assessed at 6/mm² (photograph 4). The diameter and density of vessels in *P. juliflora* can be described as usual for this species. Villalba (1985) reports vessel diameters in *P. flexuosa* of 130 µm in earlywood and 40 µm in latewood. Other authors do not distinguish between earlywood and latewood vessels and give medium diameters ranging from 40 µm for *P. argentina* (Villagra, Roig, 1997) up to 140 µm for *P. pallida* (Lopez *et al.*, 2005). The density of vessels per square millimetre was assessed as 10 in *P. laevigata*, 12 in *P. kunzei* and 5 in *P. palida* (Lopez *et al.*, 2005).

Extractive content

The quantities of extractive contained in the wood of *P. juliflora* are reported in table I. The two methods used, based either on the weight of extracts after evaporation of the solvent or on the mass loss of extracted sawdust, gave close values indicating that practically no products were lost during vacuum evaporation. The quantity of extracts in both sapwood and heartwood increased with solvent polarity. In the heartwood, the lowest percentage of 2.4% extract was recorded with hexane, followed by dichloromethane with about 3.4%. The highest values, of 10.6% and 8.9% respectively, were recorded with water and a toluene/ethanol mixture.

Resistance to fungus attacks

Non-extracted non-dried heartwood samples were exposed to fungal action for 3 months, under sterile conditions, to evaluate natural resistance. The results showed high natural resistance to all tested fungi. In all cases, no significant weight losses were observed (table II), while beech and pine controls were heavily degraded. The effect of heartwood extractives on the growth of fungi was investigated on a malt-agar

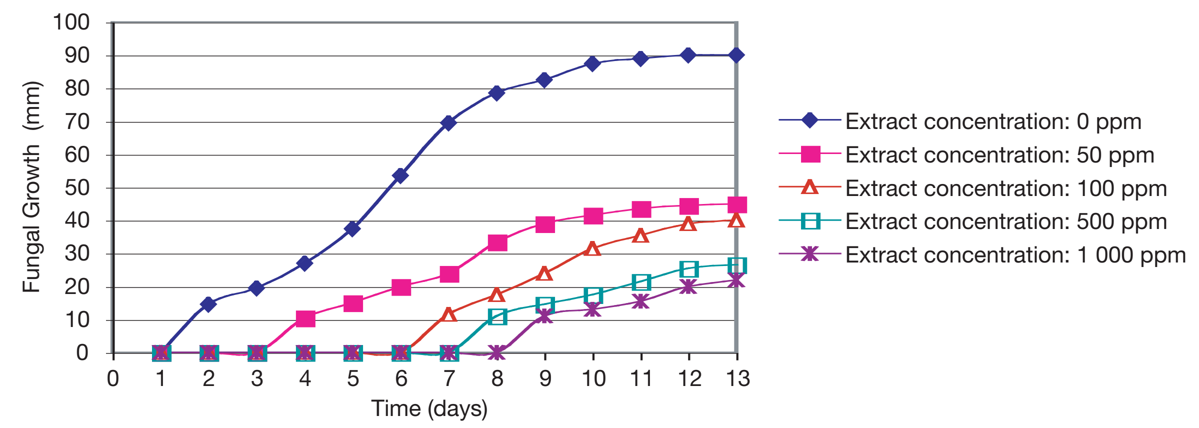

Figure 3.
Fungistatic effects of acetone heartwood extractive against *C. versicolor*.

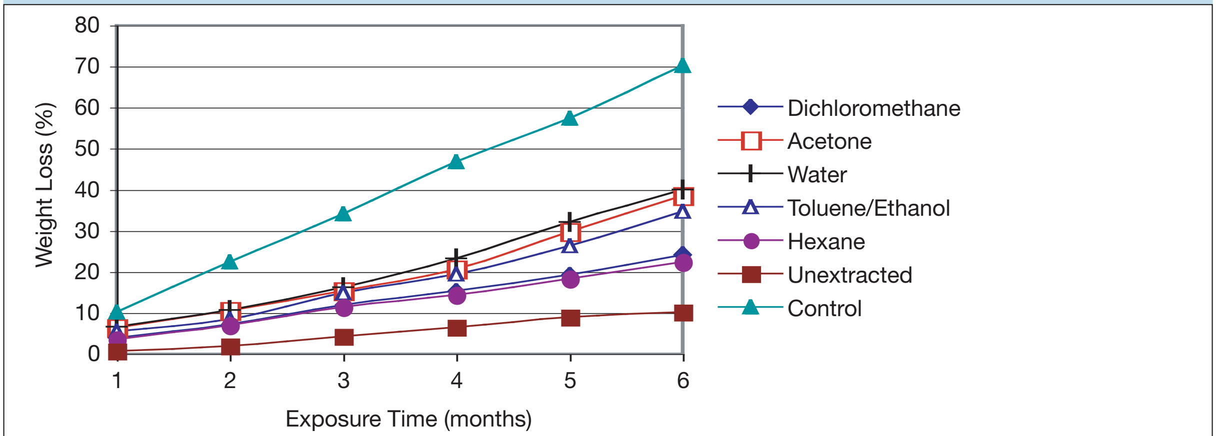

Figure 4.
Effects of removing and retaining extractives on the resistance of *P. juliflora* heartwood to termites.

medium to assess their effects on wood durability. The results showed that in all cases, the extracts were more or less efficient as fungal growth inhibitors at the tested concentrations (figure 2). However, their action seems to stem from a fungistatic effect rather than a fungicidal effect: development of the mycelium on the treated medium started after a more or less lengthy inhibition period (figure 3). During this period, fungal activity was detected by the formation of a coloured area around the fungal inoculate. This behaviour is probably associated with detoxification of the medium by fungal enzymes, allowing further development of the fungus. Increasing the extract concentration increased the inhibition period. Similar observations were made for all the extracts and fungi.

Resistance to termites

To assess resistance to termites and check the influence of extractives, blocks (extracted or not) were subjected to termite action in the field for 6 months and in the laboratory for 28 days. The results are reported in figure 4 and table III respectively. Independently of the nature of the extraction and the test method, weight losses in the test blocks were low for the unextracted blocks and rose with increasing solvent polarity, while the pine blocks were heavily degraded. These results suggest that extractives play an important part in natural wood durability.

Physical and fuelwood characteristics

Moisture content, swelling coefficient, ash content, density and heating values of *P. juliflora* and *Pinus patula*, a Kenyan species widely used in construction, are shown in table IV. The results indicate that *P. juliflora* wood is dimensionally stable with higher heating values consistent with those of other *Prosopis* wood species currently used as fuelwood. Ash content is relatively high but consistent with those generally found in tropical wood species (Goel, Behl, 1996). These results suggest that *P. juliflora* is suitable as fuelwood (photograph 5) or for charcoal production (photograph 6), mainly using traditional earth kilns (photograph 7). These traditional earth kilns could be an interesting alternative to produce charcoal for local populations. The dimensional stability and density of *P. juliflora* wood could also be of interest for parquetry.

Mechanical properties

The elasticity and strength properties of *P. juliflora* and *P. patula* are shown in Table V. The elasticity modulus of *P. juliflora* is relatively high compared to that of *P. patula*, but similar to that reported in the literature. The rupture modulus of *P. juliflora* was higher than for *P. patula,* indicating good resistance under load and, consequently, valuable strength properties. Compression and shear strength parallel to the grain corroborate MOR measurements. The values found were higher than those reported, but consistent with those of other *Prosopis* species. Janka hardness was lower than that reported in the literature, but significantly higher than that of *P. patula,* indicating resistance to indentation. All these results indicate that *P. juliflora* wood possesses the mechanical properties required for construction purposes.

Wood treatability

Even though most European countries have banned or severely restricted the use of CCA treated woods, such treatments are still in use in Kenya (Venkatasamy, 2005).

Table III.
Effect of extract removal or non-removal on the resistance of *P. juliflora* heartwood to termites in the laboratory.

Solvent	Workers surviving (%)	Soldiers surviving (%)	Weight loss (%)	Classification of attack
Hexane	0	0	0.3	sound
Dichloromethane	8.5	4.5	2.5	light
Acetone	9	10	8.4	light
Toluene/ethanol	6	4	4.7	light
Water	8	7	12.8	moderate
Non-extracted	0	0	0.15	sound
Control	62	53	29.8	heavy

Photo 5.
Mature *P. juliflora* used for fuelwood in Baringo District, Kenya.
Photo P. K. Sirmah.

Table IV.
Values of physical and fuel wood characteristics.

Species	Physical properties			Fuel wood characteristics	
	Moisture content (%)	Density (g/m³)	Dimensional stability (%)	Ash content (%)	Higher heating value (kJ/g)
P. juliflora	32.6	0.828	2.3	2.84	21.50
P. patula	46.3	0.696	14.5	0.4	20.11

Table V.
Mean mechanical property values.

Species	Compression parallel to grain (kPa)	MOR (kPa)	MOE (MPa)	Shear parallel to grain (kPa)	Hardness (N)
P. juliflora[1]	73 320	124 100	15 200	20 100	7 300
P. juliflora[2]	62 050	113 700	14 200	15 030	13 000
P. patula	56 930	82 100	4 900	13 100	2 000

[1]Found; [2]reported (http: www2.fpl.fs.fed.us/Techsheets/hardwoodNA/pdf-files/prosoeng.pdf).

Sapwood penetration in *P. juliflora* (46.4%) is only half that of *P. patula* (100%) but higher than in other tropical hardwood species in the literature, while retention ranged from 36 kg/m^3 in *P. juliflora* to 49 kg/m^3 in *P. patula*. Sapwood is generally more vulnerable to biological degradation than heartwood in most wood species (Grace, 1996). Both heartwood and sapwood are susceptible to fungi, termite and powder-post-beetle infestation, depending on durability (Kamweti, 1992). According to the Food and Agriculture Organization (FAO), the recommended CCA retention for interior timber not in ground contact, such as trusses or rafters, is 6 kg/m^3, and 8 kg/m^3 for exterior timber not in ground contact, such as doors and windows. Timbers in ground contact, such as fence posts, railway sleepers and bridges, need a retention of 12 kg/m^3, timbers permanently immersed in fresh water require 16 kg/m^3, and timbers immersed in seawater, for jetties and boat building for example, require 24 kg/m^3 (Fao, 1986). The relatively high retention and higher sapwood treatability indicate that this species could be a potential alternative source of construction material for use under severe conditions, for railway sleepers or fencing posts for example. Moreover, it can be assumed that the use of more environmentally acceptable preservatives could lead to similar results and reduce the impact of treated wood on human health and the environment.

Photo 6.
Charcoal made from *P. juliflora* wood using traditional earth kilns.
Photo P. K. Sirmah.

Photo 7.
P. juliflora in a traditional earth kiln for charcoal production, Baringo, Kenya.
Photo P. K. Sirmah.

Photo 8.
A one-year-old *P. juliflora* in Baringo District, Kenya.
Photo P. K. Sirmah.

Conclusion

Our study shows that *P. juliflora* (photograph 8) can be an alternative to declining plantation timber in Kenya for fuelwood, light construction work and furniture manufacture. The wood properties tested are consistent with those of other *Prosopis* species grown in other parts of the world, with the exception of a high extractive content not previously reported. The heartwood shows high resistance to fungi, and a lesser degree of resistance to termites. The high extractives content seems to be directly connected to termite resistance. Further studies are under way to characterize the chemical components of the wood, bark, pods and leaves, with a view to fully realising the potential of this tree species.

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References

ASTM D 3174-89, 1989. Standard test method for ash in the analysis sample of coal and coke.

ASTM D 2015-93, 1993. Standard test method for gross calorific value of coal and coke by the adiabatic bomb calorimeter.

AWPA E1-97, 1997. Standard method of laboratory evaluation to determine resistance to subterranean termites.

AWPA E7-93, 1993. Standard method of evaluating wood preservatives by field tests with stakes.

BARBA A. P., FRIAS J. T., OLALDE V., CASTANEDA J. G., 2006. Processing, nutritional evaluation and utilization of whole mesquite flour (*Prosopis laevigata*). Food Science, 71 (4): S315- S320.

BS 373: 1957, 1957. Methods of testing small clear specimens of timber.

CÀCERES A., MENÉNDEZ H., MENÈNDEZ E., COHOBON E., SAMAYOA B. E., JAUREGUI E., PERALTA E., CARILLO G., 1995. Antigonorrhoel activity of plants used in Guatemala for the treatment of sexually transmitted diseases. Ethnopharmacology, 48 (2): 85-88.

CHOGE S. K., PASIECNIK N. M., HARVEY M., WRIGHT J., AWAN S. Z., HARRIS P. J. C., 2007. Prosopis pods as human food, with special reference to Kenya. Waters SA, 33 (3): 419-424.

FAO, 1986. Wood Preservation Manual. Italy, Food and Agriculture Organization.

GOEL V. L., BEHL H. M., 2001. Genetic selection and improvement of hard wood tree species for fuel wood production on sodic soil with particular reference to *Prosopis juliflora*. Biomass and Bioenergy, 20 (1): 9-15.

GOEL V. L., BEHL H. M., 1996. Fuelwood quality of promising tree species for alkaline soil sites in relation to tree age. Biomass and Bioenergy, 10 (1): 57-61.

GOLDSTEIN I. S., VILLARREAL A.,1972. Chemical composition and accessibility to cellulase of Mesquite wood. Wood Science, 5 (1): 15-20.

GRACE J. K., 1996. Susceptibility of compressed fiber to termite attack. Forest Products, 46 (9): 76-78.

KAILAPPAN R., GOTHANDAPANI L., VISWANATHAN R., 2000. Production of activated carbon from Prosopis (*Prosopis juliflora*). Bioresource Technology, 75 (3): 241-243.

KAMWETI D. M., 1992. Growth and utilization of *Grevillea robusta* around Mt Kenya. *In: Grevillea robusta* in Forestry and Agro forestry. Nairobi, Kenya, C. E. Harwood (ed.), ICRAF.

KISHORE G. K., PANDE S., 2005. Integrated management of late leaf spot and rust diseases of groundnut (*Arachis hypogaea* L.) with *Prosopis juliflora* leaf extract and chlorothalonil. International Journal of Pest Management, 51 (4): 325-332.

LOPEZ B. C., SABATÉ C. A., GRACIA C. A., RODRIGUEZ R., 2005. Wood anatomy, description of annual rings and responses to ENSO events of *Prosopis pallida* H.B.K., a wide- spread woody plant of arid and semi-arid lands of Latin America. Journal of Arid Environments, 61: 541-554.

LOPEZ Y. L., GOYCOOLEA F. M., VALDEZ M. A., BARCA A. M. C., 2006. Mesquite gum: Alternative of industrial use. Interciencia, 31 (3): 183-189.

MBURU F., MUISU F., SIRMAH P., GERARDIN P., 2005. Impregnability of *Grevillea robusta* using the sap displacement method. Bois et Forets des Tropiques, 286 (4): 65-72.

NAKANO H., NAKAJIMA E., HIRADATE S., FUJII Y., YAMADA K., SHIGEMORI H., HASEGAWA K., 2004. Growth inhibitory alkaloids from Mesquite (*Prosopis juliflora* [Swartz] D.C) leaves. Phytochemistry, 65 (5): 587-591.

PASIECZNIK N. M., FELKER P., HARSH G., HARRIS L. N., CRUZ J. C., TEWARI K., MALDONADO L. J., 2001. The *Prosopis juliflora-Prosopis pallida* complex, a monograph. *In:* HIDRA. United Kingdom, Coventry.

SAWAL R. K., RATAN R., YADAV V. S., 2004. Mesquite (*Prosopis juliflora*) pods as a feed resource for livestock – a review. Asian-Australasian animal Sciences, 17 (5): 719-725.

SILVA J. H., OLIVEIRA J. N. C., SILVA E. L., JORDAO F. J., RIBEIRO M. L., 2002. Use of Integral Mesquite (*Prosopis Juliflora* (Swartz) D.C.) pods meal in the Japanese quails feeding. Revista Brasileira de Zootecnia, 31 (4): 1789-1794.

VILLALBA R., 1985. Xylem structure and cambial activity in *Prosopis flexuosa* DC. IAWA bulletin 6: 119-130.

VILLAGRA P. E., ROIG F. A., 1997. Wood structure of *Prosopis alpataco* and *P. argentina* growing under different edaphic conditions. IAWA, 18: 37-51.

VENKATASAMY R., 2005. Industrial wood preservation in Kenya. Present status-Future prospects. IRG/WP 05-30385.