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ANATOMICAL, PHYSICAL AND MECHANICAL PROPERTIES OF SALT TOLERANT TREE SPECIES GROWN IN PUNJAB, PAKISTAN

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Abstract

Some anatomical, physical and mechanical properties of four tree species were studied. Twelve wood logs each of *Eucalyptus camaldulensis, Acacia nilotica, Prosopis juliflora and Tamarix aphylla*, collected from two saline sites near Lahore and Faisalabad, were analyzed in both green and air-dry (12% moisture) conditions. The tested tree species differed greatly with respect to different wood quality parameters. Maximum density (842 kg m^{-3}) was observed in *P. juliflora* followed by *E. camaldulensis* (817 kg m^{-3}), *A. nilotica* (701 kg m^{-3}) and *T. aphylla* (635 kg m^{-3}). Static bending strength was found maximum (1240 kg cm^{-2}) in *A. nilotica* and minimum (778 kg cm^{-2}) in *T. aphylla*. The modulus of elasticity ranged from 53735 to 86977 kg cm^{-2} with maximum value in *A. nilotica* and minimum in *T. aphylla*. The crushing strength parallel to grain was observed maximum in *P. juliflora* (610 kg cm^{-2}) and minimum in *A. nilotica* (321 kg cm^{-2}). Cleavage value was observed maximum (40 kg cm^{-1}) in *P. juliflora* and minimum (31 kg cm^{-1}) in *E. camaldulensis.*The results of impact bending indicated that the wood of *P. juliflora* has maximum (4.35 kg m^{-1}) tendency to absorb sudden shocks and minimum in *T. aphylla* (1.47 kg m^{-1}). Calorific value was observed maximum in *E. camaldulensis* (4900 kcal kg^{-1}) and minimum in *T. aphylla* (4607 kcal kg^{-1}). Overall, it is concluded that all tested tree species have strength properties comparable with *Dalbergia sissoo* wood and thus have good utilization potential for different wood products.

Key words: Saline environments, Tree species, Wood properties, Calorific value.

Introduction

Higher rate of population growth coupled with increased demand for wood has caused a dramatic decrease in forest resources. It is therefore necessary to use appropriate production techniques to meet the demand for getting higher yield of forest products (Ates *et al.*, 2009). Hence, managing plantations of fast growing tree species is of prime importance for sustainability of industrial wood raw material production (Samariha, 2011).

Being diverse in nature, some tree species have high potential to produce large volumes of straight branches and trunks as important fuel sources for local populations (Tewari *et al.*, 2003). The wood materials have variations in physical, anatomical and mechanical properties. Inherent characters like good strength to weight ratio and aesthetic appearance make the wood suitable for pulp, packing, building construction, furniture, sports goods and numerous industrial uses.

One of the most economically and ecologically important tree species in arid and semi-arid zones of the world is *Prosopis juliflora*. *Prosopis* species vary widely in their productivity and relative use for timber, fuel wood, pods for food and fodder. Consequently, their plantation has been continuously promoted as valuable multi-purpose species of dry zones (Pasiecznik *et al.*, 2001). The first record of *P. juliflora* introduction to West Africa and pacific island was in 1820s, to India and Pakistan was in 1870s, and to Australia and South Africa was before 1900 (Pasiecznik *et al.*, 2004).

Acacia nilotica is an exotic species native to India, Pakistan and much of Africa. Its nine subspecies are recognized and widely distributed in tropical and subtropical Africa (Brenan, 1983).This species has high potential for nitrogen fixation and is considered as one of the fast growing species of the wastelands and agroforestry systems for providing strong timber, fodder for goats and sheep, and high quality fuel wood (Toky *et al.*, 1994).

Some *Eucalyptus* species have higher priority for plantation due to their adaptation capability to wide ecological conditions, ready for harvesting in short time and sources of wood fiber and pulp.
The uses of *Tamarix aphylla* wood are diverse. In the USA, it is used for fuel and is capable of taking a high polish and has been proposed for fence posts (Tesky, 1992). Moreover, it has been found to be a suitable raw material for making particle boards and can be used as biomass for sugar production (Zheng *et al.*, 2007). Its wood may also be suitable for making ploughs, wheels, carts, tool handles, brush-backs, ornaments, turnery and fruit boxes (Orwa *et al.*, 2009).

The fore mentioned tree species have good growth potential under stress environments. Biomass production of these species with reference to salinity of soil and irrigation water has been reported earlier (Mahmood *et al.*, 2016). This paper reports on wood properties of selected salt tolerant tree species to evaluate their suitability for different uses as substitute of standard wood (*Dalbergia sissoo*).

Materials and Methods

Experimental sites: A survey was conducted to select established salt tolerant plantations of different ages in different ecological zones of Pakistan (*latitude* between 24^o and 37^{o}N and *longitude* 61^o and 76^{o}E) to study their wood properties. For this purpose, two sites in Punjab province, Lahore and Faisalabad were selected.

Biosaline Research Station-I, Lahore of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, comprises of 60 hectares of saline wasteland located at a distance of 18 km from Lahore city (*31º.30'N, 74º.20'E*). The climate is semi-arid with rainy, long and extremely hot summers, dry and warm winters, a monsoon and dust storms. The average monthly temperature is 21°C with warmest average temperature 41°C and coolest average temperature 11°C. From late June till August, the monsoon seasons starts, with heavy rainfall throughout the study area. The annual average rainfall is 350 mm.

Biosaline Research Station-II, Pakka Anna of NIAB, Faisalabad, comprises of 400 hectares of salt-affected wasteland located at a distance of 50 km in South-West of Faisalabad (*lat. 31º.24'N, long. 73º.05'E*). The climate is semi-arid with average rainfall 200 mm and evaporation more than 1600 mm. In summer, mean maximum and minimum temperature are 39ºC and 27ºC and in winter 21°C and 6°C, respectively.

Wood properties: In order to study wood properties, four salt tolerant tree species *Acacia nilotica*, *Eucalyptus camaldulensis*, *Prosopis juliflora* and *Tamarix aphylla* were selected and harvested. Total 12 tree logs of each species were collected (6 from each site) and analyzed for anatomical, physical and mechanical properties. Calorific values of these tree species were also determined.

Anatomical properties: The anatomical characteristics were measured from the disc cut from the end face of butt log of each species. Two blocks were cut from each disc. The blocks were boiled in water for softening and permanent slides were prepared for cross, radial and tangential sections from each block and studied under the microscope with help of an eye piece micrometer. The features measured at different magnifications included fiber length, fiber diameter, fiber wall thickness, fiber lumen width, vessel frequency, vessel diameter, height of ray, height of ray cell, width of ray, width of ray cell, no. of rays in tangential section and no. of rays in cross section. The observed anatomical features were based on IAWA Committee List (Wheeler *et al.,* 1989).

For the measurement of fiber length, small chips of wood from each species were heated in a solution of 20% nitric acid (HNO_3) and a small amount of potassium chlorate ($KClO_3$) until the fibers started separating from one another. The fibers were taken on a slide after thoroughly washing them with water and stained in a solution of methylene blue. The length of 100 fibers was measured on these slides for each wood species. Other anatomical characteristics were recorded on 50 measurements.

Physical properties: A disc of 7 cm thickness was removed from each log of each species for determination of moisture content, density and shrinkage. Remaining portions of all logs were used for determination of mechanical properties.

Mechanical properties: The logs of four hardwoods were converted in to planks for determination of mechanical properties. Half of the material from each log was used for strength determination in green condition while the remaining proportions were used for tests in air-dry condition. The planks to be tested in green condition were surfaced to 2 cm thickness without letting them dry. Specimens of 2 cm × 2 cm cross section area were sawn starting from side of the plank up to the pith. One set of specimens of the following sizes were sawn from each plank:

Property	Dimension (cm)*
Static bending	30 × 2 × 2
Impact bending	30 × 2 × 2
Compression parallel to grain	6 × 2 × 2
Tensile strength perpendicular to grain	7 × 2 × 2
Cleavage	4.5 × 2 × 2
Hardness	10 × 2 × 2

*Longitudinal x radial x tangential direction

Strength properties including static bending, compression strength parallel to grain, tensile strength perpendicular to grain and impact bending were determined by using ASTM D-143-94 and ASTM D-2395-93 procedures (Anon., 1996). Similar procedure was followed for preparing specimens for tests in air-dry condition adjusted to those at 12% moisture content using the formula given in standard methods. The tests were performed on Amsler Universal Wood Testing Machine with a loading capacity of 4000 kg. Effort was made to use only defect free specimens for determination of mechanical properties.

Calorific values measurement: For the measurement of calorific/heat values, the saw dust of four hardwoods samples was oven dried and 1 g weight of the sample of each wood species was used in oxygen bomb calorimeter for measuring the heat of combustion of the samples. The bomb cylinder and bucket were mounted in the calorimeter. The bomb is completely surrounded by a bucket chamber, sealed co-axially with the bomb head. After the bomb and bucket are closed and sealed, the bomb is filled with oxygen, the bucket chamber is filled with water, initial equilibrium is established, the bomb is fired and the temperature rise is monitored and recorded under all automatic microprocessor control. Then, at the completion of a test, automatic control releases the residual pressure in the bomb rinses the bomb, cool in system and empties the bucket.

Results and Discussion

Anatomical properties: Results indicated that *A. nilotica* fibers length was observed maximum in length (1.47 mm) and thickness (3.09 µ) while minimum fiber length (0.789 mm) observed in *T. aphylla* and minimum fiber wall thickness (2.62 µ) in *P. juliflora* (Table 1). On the basis of fiber length and fiber wall thickness, *A. nilotica* wood is better in strength followed by *P. juliflora, E. camaldulensis* and *T. aphylla*. In *A. nilotica* vessels are lower (4.23 per mm^2) in frequency but medium in diameter (175µ) due to which wood can be seasoned and preserved without any difficulty. Maximum vessels frequency (11.7 per mm^2) was observed in *T. aphylla*. In *E. camaldulensis*, the wood rays both in tangential and cross section were found maximum (111 per mm^2 and 14.9 per mm, respectively) but minimum in ray's height (7.7 µ) and width (1.4 µ) because of which its wood may be non- durable. In *P. juliflora,* fibers were observed longer and narrow lumen (7 µ) which provide better strength but rays were also medium in frequency and larger in size, make the wood non-durable and chemical treatment is necessary before its utilization. Krisdianto and Damayanti (2007) concluded that the fiber quality of *A. nilotica* is in the second class quality which means wood fiber is moderately thick with narrow lumen diameter. Sadegh and Kiaei (2011) reported average fiber length 0.89 mm in *E. camaldulensis* while in current study, the average value calculated as 0.96 mm.

Anatomical properties describe the internal structure of wood on the basis of which various technological properties and behavior of wood can be assessed and its better utilization is suggested. These properties also help identification of a wood species. Anatomical properties include growth rings, structure, frequency and dimensional measurements of different wood elements such as vessels, wood rays, fibers and parenchyma cells. The growth rings can be observed on the cross surface of wood which help determine the age and growth rate of the tree. The vessels are thin walled wide lumen tube like structures, similar to drain pipes through which moisture can move lengthwise and sidewise in wood. The wood rays are ribbon like aggregates radiate from pith to bark in wood, composed of parenchyma cells and influence durability of wood. The fibers are thick walled and narrow lumen cells which occupy major volume of wood and provide mechanical strength to wood.

Physical properties: Physical properties are manifested without any change in size or shape of a test sample. Moisture content, growth rate, density and shrinkage are the common physical properties. Moisture content in the ratio of the amount of water lost relative to the oven dry weight of wood substance. Density of wood is the ratio of weight of a sample to equal volume of that sample at 4ºC. Shrinkage of wood is the measure of reduction of a test sample in each direction when excessive moisture is removed from green to air-dry or oven-dry condition. Wood density is an important property for solid wood and fiber products in conifers and hardwoods (De Guth, 1980) and is affected by cell wall thickness, cell diameter, early wood to late wood ratio and chemical content of the wood (Cave & Walker, 1994). The values of wood density and shrinkage decreased along stem from the base upwards (Kiaei & Sadegh, 2011).

Results indicated that maximum density (842 kg m^{-3}) was observed in *P. juliflora* followed by *E. camaldulensis* (817 kg m^{-3}), *A. nilotica* (701 kg m^{-3}) and *T. aphylla* (635 kg m^{-3}) which classify the wood from heavy to medium dense wood. The moisture content of freshly removed samples in all wood species ranges from 95-100%. The volumetric shrinkage from green to air-dry condition was calculated maximum in *T. aphylla* (4.42%) followed by *A. nilotica* (4.11%), *E. camaldulensis* (4.02%) and *P. juliflora* (2.59%) as presented in Table 2. Similarly, volumetric shrinkage from green to oven-dry condition was maximum in *T. aphylla* (6.63%) followed by *A. nilotica* (6.23%), *E. camaldulensis* (5.59%) and *P. juliflora* (4.82%), clearly indicated that *P. juliflora* wood has less tendency to shrink during its processing and *A. nilotica* wood is moderately liable to shrink while making article from it.

Mantanis & Birbilis (2010) determined *Tamarix* wood's air and oven dried densities as 0.73 and 0.66 g cm^{-3} while maximum tangential and volumetric shrinkage approximately 10.8 and 14%, respectively. For pulp and paper manufacturing, *Eucalyptus* wood in the basic density range of 400-600 kg m^{-3} is preferred (Downes *et al.*, 1997).

Table 1. Comparison for anatomical properties of tested salt tolerant wood species.

Microscopic features	*A. nilotica*	*E. camaldulensis*	*P. juliflora*	*T. aphylla*
Fiber length (mm)	1.47 ± 0.51	0.96 ± 0.38	1.02 ± 0.30	0.79 ± 0.39
Fiber diameter (µ)	17.2 ± 2.38	16.1 ± 3.23	12.2 ± 4.13	19.4 ± 4.55
Fiber wall thickness ((µ)	3.09 ± 0.71	2.69 ± 0.88	2.62 ± 0.74	2.75 ± 0.81
Fiber lumen width (µ)	11.1 ± 3.12	10.7 ± 2.95	7.0 ± 1.61	13.9 ± 3.52
Vessel frequency (per mm^2)	4.23 ± 0.95	10.6 ± 0.71	6.2 ± 0.58	11.7 ± 0.84
Vessel diameter ((µ)	175 ± 18.3	125 ± 11.5	152 ± 14.5	111 ± 10.8
Height of ray (µ)	300 ± 21.6	130 ± 13.6	260 ± 16.8	1138 ± 45.8
Height of ray (Cell)	32.3 ± 5.41	27.7 ± 3.95	24.6 ± 3.55	57.5 ± 9.45
Width of ray (µ)	40.1 ± 6.45	22.6 ± 3.74	36.6 ± 4.78	16.0 ± 2.98
Width of ray (Cell)	4.1 ± 0.99	1.45 ± 0.48	3.23 ± 0.81	11.7 ± 1.94
No. of rays in tangential section (per mm^2)	19.2 ± 3.89	11.1 ± 2.04	24.4 ± 4.15	10.8 ± 3.16
No. of rays in cross section (per mm)	6.25 ± 1.33	14.9 ± 2.51	5.16 ± 1.08	2.56 ± 0.67

Values are averages of twelve tree log samples ± standard deviation

Table 2. Comparison for physical properties of tested salt tolerant wood species.

Property	*A. nilotica*	*E. camaldulensis*	*P. juliflora*	*T. aphylla*
Density (air-dry) (kg m^{-3})	701 ± 41.7	817 ± 35.4	842 ± 52.1	635 ± 33.2
Basic density	0.61 ± 0.12	0.72 ± 0.25	0.74 ± 0.22	0.55 ± 0.10
Longitudinal shrinkage (%)				
From green to air-dry	0.11 ± 0.04	0.11 ± 0.06	0.09 ± 0.03	0.11 ± 0.07
From green to oven-dry	0.25 ± 0.07	0.30 ± 0.09	0.21 ± 0.04	0.30 ± 0.07
Radial shrinkage (%)				
From green to air-dry	1.41 ± 0.25	1.50 ± 0.16	0.72 ± 0.21	1.71 ± 0.46
From green to oven-dry	2.51 ± 0.36	2.48 ± 0.45	1.96 ± 0.33	2.82 ± 0.54
From the air-dry to oven-dry	1.11 ± 0.21	1.06 ± 0.35	0.61 ± 0.14	1.13 ± 0.41
Tangential shrinkage (%)				
From green to air-dry	2.54 ± 0.64	2.49 ± 0.51	1.77 ± 0.63	2.60 ± 0.49
From green to oven-dry	3.47 ± 0.47	2.81 ± 0.33	2.65 ± 0.65	4.51 ± 0.77
From the air-dry to oven-dry	1.25 ± 0.24	1.29 ± 0.15	1.31 ± 0.30	1.63 ± 0.41

Values are averages of twelve tree log samples ± standard deviation

Table 3. Mechanical properties of tested wood species (in green condition), collected from Punjab, Pakistan.

Property	*A. nilotica*	*E. camaldulensis*	*P. juliflora*	*T. aphylla*
Modulus of rupture-MOR (kg cm^{-2})	815 ± 39.8	950 ± 17.1	1039 ± 33.6	662 ± 24.3
Modulus of elasticity-MOE (kg cm^{-2})	48615 ± 2248	65742 ± 8863	78575 ± 7210	49337 ± 2892
Max. compression parallel to grain	321 ± 16.5	360 ± 8.85	397 ± 5.31	232 ± 4.79
Tensile strength perpendicular to grain	40 ± 3.30	31 ± 3.51	45 ± 5.62	29 ± 2.60
Side grain hardness (kg)	802 ± 15.5	616 ± 2.88	800 ± 43.6	490 ± 7.07
End grain hardness (kg)	930 ± 21.6	670 ± 36.1	876 ± 55.1	530 ± 18.3
Cleavage (kg cm^{-1})	59 ± 2.44	24 ± 1.70	42 ± 1.70	33 ± 0.81
Impact bending per 4-cm^2 (kg m^{-1})	3.25 ± 0.67	3.37 ± 0.21	3.87 ± 0.28	1.10 ± 0.06

Values are averages of twelve tree log samples ± standard deviation

Table 4. Comparison for strength properties of tested wood species in dry condition (12% moisture) with standard wood (*Dalbergia sissoo*).

Property	*A. nilotica*	*E. camaldulensis*	*P. juliflora*	*T. aphylla*	*D. sissoo*
Modulus of rupture (kg cm^{-2})	1240 ± 35.5	994 ± 25.6	1165 ± 54.7	778 ± 41.6	1122 ± 47.8
Modulus of elasticity (kg cm^{-2})	86977 ± 7738	74905 ± 1259	86524 ± 5221	53735 ± 636	85790 ± 1098
Max. compression parallel to grain	456 ± 4.64	496 ± 17.7	610 ± 8.99	361 ± 9.48	560 ± 15.3
Tensile strength perpendicular to grain	38 ± 2.40	34 ± 2.80	42 ± 2.20	32 ± 4.10	36 ± 3.71
Side grain hardness (kg)	843 ± 7.63	830 ± 8.16	1028 ± 25.6	524 ± 16.4	650 ± 13.6
End grain hardness (kg)	1113 ± 21	947 ± 33	1183 ± 12	666 ± 15	800 ± 21
Cleavage (kg cm^{-1})	34 ± 0.81	31 ± 0.95	40 ± 0.57	39 ± 1.15	22 ± 1.11
Impact bending per 4-cm^2 (kg m^{-1})	2.85 ± 0.12	2.77 ± 0.20	4.35 ± 0.12	1.47 ± 0.17	1.79 ± 0.20

Values are averages of twelve tree log samples ± standard deviation

Mechanical properties: The term strength is often used to refer all mechanical properties. Strength is the ability of a material to carry applied loads or forces. Some of the important mechanical properties are modulus of rupture, modulus of elasticity, cleavage, tensile strength, impact bending and hardness. Modulus of rupture determines the load as a beam. Modulus of elasticity is the stress at elastic limit. Compression parallel to grain (crushing strength) determines load a beam will vertically carry. Cleavage is the ability of a wood sample to offer resistance against splitting. Tensile strength perpendicular to grain is important in designing of connection between wood members in building. Impact bending (toughness) is the resistance offered by wood specimens to sudden shocks. Hardness is related to the resistance to indentation as its determination is carried out as side hardness and end hardness.

Results indicated that in green condition, the maximum bending strength (1039 kg cm^{-2}) was observed in *P. juliflora* followed by *E. camaldulensis* (950 kg cm^{-2}), *A. nilotica* (815 kg cm^{-2}) and *T. aphylla* (662 kg cm^{-2}) (Table 3), while in air-dry condition at 12% moisture level; maximum (1240 kg cm^{-2}) in *A. nilotica* and minimum (778 kg cm^{-2}) in *T. aphylla* (Table 4). The modulus of elasticity ranged from 48615 to 78575 kg cm^{-2} in green condition and 53735 to 86977 kg cm^{-2} in air dry condition with maximum value in *A. nilotica* and minimum in *T. aphylla* which means that the wood of *T. aphylla* and *E. camaldulensis* is hard and brittle and has less tendency to bear fiber stress at elastic limit in air-dry condition while both have more tendency than *A. nilotica* in green condition. The crushing strength parallel to grain was observed maximum in *P. juliflora* both in green (397 kg cm^{-2}) and air-dry condition (456 kg cm^{-2}). In green condition, cleavage value was maximum (59 kg cm^{-1}) in *A. nilotica* and minimum (24 kg cm^{-1}) in *E. camaldulensis* while in air-dry condition, maximum value (40 kg cm^{-1}) in *P. juliflora* and minimum (31 kg cm^{-1}) in *E. camaldulensis* which means the wood of *A. nilotica* and *P. juliflora* has better nail/screw holding power (Table 4). Awan *et al.* (2012) reported wood density, static bending-MOR, maximum compressive strength parallel to grain and perpendicular to grain, maximum tensile strength, impact bending and nail holding capacity of *E. camaldulensis* as 0.681 g cm^{-3}, 1046 kg cm^{-2}, 88 kg cm^{-2}, 56 kg cm^{-2}, 610 kg cm^{-2}, 578 kg cm^{-1} and 129 kg cm^{-1}, respectively.

The hardness both side and end grain was found maximum (1028 and 1183 kg) in *P. juliflora* followed by *A. nilotica* (843 and 1113 kg), *E. camaldulensis* (830 and 947 kg) and *T. aphylla* (524 and 666 kg) in air-dry condition which indicates that the wood of *P. juliflora* and *A. nilotica* has better properties when used against knives of lathe or other machines so their wood is good for carving work. The results of impact bending indicated that the wood of *P. juliflora* has maximum (4.35 kg m^{-1}) tendency to absorb sudden shocks and minimum in *T. aphylla* (1.47 kg m^{-1}) in both green and air-dry condition.

Wood is an anisotropic material having differential dimensional changes in different structural directions. The magnitude of shrinkage and swelling is affected by the moisture gained or lost by wood (Usta & Guray, 2000). Shukla *et al.* (1990) reported mechanical properties of *P. juliflora* as modulus of rupture 883 kg cm^{-2} (green) and 1060 kg cm^{-2} (dry), modulus of elasticity 77700 kg cm^{-2} (green) and 90000 kg cm^{-2} (dry), compression parallel to grain 237 kg cm^{-2} (green) and 301 kg cm^{-2} (dry) and compression perpendicular to grain 136 kg cm^{-2} (green) and 182 kg cm^{-2} (dry). Mantanis & Birbilis (2010) reported different mechanical properties of *T. aphylla* as modulus of rupture 88.5 N mm^{-2}, modulus of elasticity 7533 N mm^{-2}, compression strength parallel to grain 40.9 N mm^{-2} and hardness value 33.7 N mm^{-2}. Krisdianto & Damayanti (2007) concluded that *A. nilotica* timber is not recommended for construction materials due to small log diameter with branches but suitable for carved and turnery products.

Comparison with standard wood (*Dalbergia sissoo*): *D. sissoo* is the finest wood used for high class furniture and cabinet work. It is also good constructional wood employed in house building, flooring, journey and carpentry works. Thus, there is tremendous pressure on it's over utilization. Its supply does not meet the demand. Under these circumstances it is essential to use the alternative wood species which are not commercially used. The purpose of testing of hardwoods from target areas is to compare these species with *D. sissoo* wood.

Results revealed that *P. juliflora* is superior to *D. sissoo* as it has about 9% more crushing strength, 82% greater cleavability, 143% more toughness, 58% more side hardness and 48% more end hardness. Similarly, *A. nilotica* is better than *D. sissoo* wood in strength properties; modulus of elasticity, cleavage, impact bending and side and end hardness. However, *A. nilotica* has lesser crushing strength parallel to grain than *D. sissoo* wood. *E. camaldulensis* has greater resistance to indentation both side grain and end grain, cleavage and impact bending while compared with the reported values of the same properties with *D. sissoo* wood. However, shisham wood is superior to *Eucalyptus* wood considering modulus of rupture, modulus of elasticity and crushing strength parallel to the grain. While comparing *T. aphylla* with *D. sissoo* wood it is found that it has high resistance to splitting while all the remaining properties are inferior to *D. sissoo* wood.

Suitability of hardwoods for different purposes: The four hard woods have been tested and evaluated for different purposes. The evaluation is based on structural features, physical and mechanical properties. The suitability is given in the following Table 5.

Caloric values of tested hardwoods: Results indicated that maximum heat value 4900 kcal kg^{-1} was observed in *E. camaldulensis*, followed by *A. nilotica* (4870 kcal kg^{-1}), *P. juliflora* (4850 kcal kg^{-1}) and minimum in *T. aphylla* (4607 kcal kg^{-1}). Calorific values of all tested wood species were lower than the calorific value of standard wood *D. sissoo* i.e.5000 kcal kg^{-1}. Wood has inherent advantages as natural fuel. The heating power or caloric value related to the quantity of heat emitted during the process of combustion. Basic factors which affect the heat value of wood include dryness, anatomical structure, soundness, presence of extraneous substances and size of piece of wood. *Prosopis* species produce a high quality fuel wood, having a high calorific value of approximately 5000 kcal kg^{-1} (Anon., 1997). Anon., (1980) reported that calorific value of *P. juliflora* is between 4200-4800 kcal kg^{-1}. Carter (1994) reported that calorific value of *A. nilotica* is around 4800 to 4950 kcal kg^{-1}. Patil *et al*. (2000) termed *A. nilotica* timber as high quality charcoal due to properties like fixed carbon 82%, volatile material 15% and ash content 5%.

Table 5. Matrix showing suitability of tested hardwoods for different uses.

Uses	*A. nilotica*	*E. camaldulensis*	*P. juliflora*	*T. aphylla*
Athletic and sports goods	+	-	+	-
Axles/Beams	+	+	+	-
Bearing blocks	+	+	+	-
Boat building	+	+	+	-
Cross arms	+	+	+	-
Crates/Boxes	+	-	+	+
Columns, posts, struts	+	+	+	-
Packing cases	+	-	+	-
Furniture	+	+	+	-
Sleepers	+	+	+	-
Flooring	+	+	+	-
Paving blocks	+	+	+	-
Tool handles	+	+	+	+
Wedges	+	+	+	-
Agricultural implements	+	+	+	-
Carts and carriages	+	+	+	-
Mine work and pit props	+	+	+	-
Rural construction	+	+	+	-
Walking sticks	+	+	+	+
Bed legs	+	+	+	-
Fuel wood	+	+	+	+
Rollers/Mallets	+	+	+	-
Carving	+	-	-	-
Bolted timber	+	+	+	-
Spokes	+	+	+	+
Shuttles	+	-	-	+
Carpentry work	+	+	+	+

+ Suitable / may be used; - Not recommended

Conclusions

On the basis of results of anatomical, physical, mechanical and calorific values, the following conclusions are made:

- *P. juliflora* is better to standard wood of *D. sissoo* as it has 9% more crushing strength, 82% greater cleavability, 143% more toughness, 58% more side hardness and 48% more end hardness.
- *A. nilotica* is also better to *D. sissoo* for some properties like modulus of rupture (MOR), modulus of elasticity (MOE), cleavage and both side and end hardness values.
- *E. camaldulensis* has greater resistance to indentation both side and end grain, cleavage and impact bending but *D. sissoo* wood is superior while considering MOR, MOE and crushing strength parallel to grain.
- *T. aphylla* has high resistance than *D. sissoo*.

Overall, it is concluded that all tested species have strength properties comparable with *D. sissoo* wood and thus have good utilization potential for wood products.

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