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Technological Properties of *Calotropis procera* (AIT) Wood and its Relation to Utilizations

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Abstract: Because Saudi Arabia suffers from a shortage of wood necessary for certain industrial uses and therefore depends primarily on imported wood, there is a need to develop alternative non-wood resources. The aim of this study was to investigate the feasibility of using *Calotropis procera* wood by evaluating the basic technological properties required for proper utilization. This study is the first attempt to provide basic information regarding the physical, chemical and anatomical characteristics of *Calotropis procera* tree wood growing wild in arid and semi-arid regions. A brief description of the anatomical characteristics of *Calotropis procera* wood was provided and the results indicate that it belongs to the diffuse porous type of hardwoods. The basic specific gravity of the wood was 0.345 and it can be classified as light wood, which makes it suitable for particleboard manufacturing. The total volumetric shrinkage of the wood ranged between 14.21% and 16.98%. The cellulose and hemicellulose content of *Calotropis procera* wood fall in the range typical for either softwoods or hardwoods (47.88 and 27.08%, respectively). According to the properties determined in the present study, we conclude that most properties of *Calotropis procera* wood are similar to other non-woody materials, softwoods and hardwoods. Furthermore, this wood is characterized by a low lignin and high extractive and hemicellulose contents. Further investigations are required before it can be used in industry. The evaluation of the properties of particleboard made from *Calotropis procera* wood is in progress.

Key words: *Calotropis procera* · Technological properties · Hardwood · Chemical composition · Anatomical characteristics

INTRODUCTION

Wood has been used by humans through history and it remains a raw material for a large number of products in modern times; however, other competitive materials, such as metals, cement and plastics, are now available. The value of wood has been preserved for many traditional uses and its use grows steadily as new products are developed to meet the increasing needs of man [1]. However, the increasing demand on forest resources, due to the increasing population and new applications, has led to shortages in the wood supply [2]. Furthermore, Saudi Arabia and similar arid and semi-arid countries suffer from shortages of the wood necessary for several industrial purposes and depend largely on imported wood. Consequently, there is a need to search for alternative resources to substitute for solid wood. Research efforts in the Plant Production Department at King Saud University have been directed towards the introduction of fast-growing tree species for firewood production [3, 4] by using agricultural residues [5]. It is important to search for alternative resources to substitute for solid wood. Non-conventional wood resources represent an advantageous solution for Saudi Arabia because of the low or absent forest coverage and the decreased rate of tree cutting in other forest-rich countries. Among some non-woody materials that have not yet been assessed as alternative raw materials for fuel, pulp and panel production is the wood from the giant milkweed tree (*Calotropis procera*). *Calotropis procera* (Ait), of the family Ascelpiadaceae, is locally known as Oshar with the English name of giant milkweed. It is a spreading, evergreen and perennial shrub or small tree growing to four meters and has few branches and leaves, which are concentrated primarily at the growing tip. A copious white milky sap flows where stems or leaves are cut. The native range covers southwest Asia and Africa [6]. It is considered to be one of the most drought tolerant desert plants and grows in arid and semi-

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rid regions [7]. The plant is widely distributed throughout Saudi Arabia and can be found growing in an open habitat with little competition. It also grows favorably in dry habitats [8, 9]. It has been reported to be both medicinal and toxic in animals [8, 10]. The woody parts of this plant are burned to produce charcoal, which was previously an ingredient in gunpowder [10].

Many animal and human pharmacological studies have been conducted using various aerial parts of *Calotropis procera* [11, 12, 13]. The effects of salinity on growth [14], some physiological activities [14] and photosynthetic pigment [15] were also studied. In addition, the influence of the allelopathic effect [16] and the impact of environmental stress on certain characteristics and plant composition have been investigated [7, 15, 17]. However, basic research is still needed to investigate important physical, chemical and anatomical characteristics of wood to assess their suitability for industry. Increased demand for woody raw materials in composition panel industries has led to the investigation of biomass from non-wood plants for use in these industries. Many agricultural residues and non-wood plants have been investigated for use in composition panel production. Some of these materials have included cotton stalks [18], vine prunings [19], wheat and rice straw [20], date palm midribs [5], sunflower stalks [21], kiwi prunings [22], castor stalks [23] and eggplant [24]. Before suggesting the proper utilization of wood from any plant, it is essential to evaluate the wood's technological properties. These properties are classically used to select lignocellulosic materials for the forest production industry [25] and include physical, chemical, anatomical and mechanical properties. The use of *Calotropis procera* wood for paper, pulp, composition panels and fuel is limited because no information regarding their technological properties exists.

This study is the first effort to provide basic information regarding important technological properties of *Calotropis procera* wood. The objective of this study was to evaluate some technological properties of giant milkweed wood to assess their suitability for wood industry and to encourage more effective use of its wood.

MATERIALS AND METHODS

Plant Material: The plant material used in the current study was collected from the aerial part of wild-growing *Calotropis procera* shrubs. The study was conducted on the arid shrub community during the flowering stage in July of 2010 in the central desert region near Riyadh, Saudi Arabia. Five shrubs were randomly selected. The climate of this area is a sub-tropical desert where the average annual rainfall is less than 250 mm, most of which is received from December to March. In summer, the temperature rises as high as 51.6°C and in winter it falls below the freezing point [3].

Biomass Estimation: After cutting the shrub, the total green weight of the above-ground portion was obtained by weighing each component in the field using a balance. Samples approximately 30 cm long were cut along the grain at the base of each branch. The samples were covered with moist cloth inside an ice-box to reduce dehydration and were transferred to the Forestry and Wood Technology Laboratory at the College of Food and Agricultural Sciences at King Saud University, Riyadh for further analysis. The samples of branches and foliage were weighed in the green state to the nearest 0.1 g. They were then oven-dried at 70°C to constant weights. The oven-dried to green weight ratio was calculated for each sample. This ratio was multiplied by the actual green weight of each component to calculate its oven-dried weight. The percentages of each biomass component to the total above-ground biomass in either green or oven-dried states were calculated accordingly. In addition, each branch in the green state was separated into four parts, the outer bark, inner bark, wood and pith. The fresh weight of each part was recorded, the samples were oven dried at 70°C for 48 hours and the oven-dried weights were calculated. The green and oven-dried weight proportions for each part were calculated.

Physical Properties of Wood: For each shrub, the density at each condition (green, air-dried and oven-dried), the fiber saturation point (FSP), the maximum moisture content (MMC) and the total volumetric shrinkage were determined by the following formulas, respectively: $D_g = W_o/V_g$, $M_f = \beta_v/D_g$, $M_{max} = 1.5\text{-}D_g)/(1.5 \text{ x } D_g)$, where D_g is basic specific gravity, W_o is the oven-dry weight, V_g is the green volume, M_f the FSP and β_v is the total volume of shrinkage (as a percentage). The total shrinkage of the wood (from green to oven-dried) was calculated based on the green volume, which was determined by water displacement. The oven-dried volume of the samples was determined by water displacement after immersing the samples in wax.

Anatomical Structure: For anatomical studies, stem discs were collected from the base of the branches in the early hours of the day and immediately fixed in formalin-acetic acid- alcohol "FAA" [26]. After one week, the fixed stem pieces were preserved in an alcohol-glycerol solution for softening (50% ethanol + 50% glycerol, v/v). Permanent mounts were made after cutting fine sections (8-10 µm) on a sliding microtome (AO 860, USA) in transverse, tangential and radial planes, staining in double combinations of hematoxylin/safranin, hematoxylin/Bismark brown[27] (Johansen, 1940) and ferric chloride/lacmoid [28] and dehydration in an ethanol series. The anatomical wood structure was thoroughly studied and the data were collected for the vessel density per square inch, tangential diameter and radial diameter in cross section using the micrometer scale on an Olympus Cx41 (Japan) microscope.

Fiber Length Determination: For fiber measurement, wood samples were taken from two opposite sides of the outer part of the base disc used for specific gravity determination and were macerated following the modified method described by Franklin [29]. Match stick-sized specimens were cooked in a test tube containing a solution of equal amounts of glacial acetic acid and hydrogen peroxide (35%) at 70°C for 24-48 hours in a water-filled beaker until the specimens became white. The treated specimens were then washed thoroughly with tap water and the fibers were separated by gentle shaking. The macerated fibers were stained with safranin and two hundred fibers were measured from each specimen to the nearest 0.01 mm using a projection microscope.

Chemical Analysis of Wood: To prepare samples for chemical analysis, various samples from each branch were air-dried and individually ground in a Wiley mill to pass through a #40 mesh screen and be retained on a #60 mesh screen. The percentage of extractive content based on the oven-dried weight was determined according to the ASTM D1105 [30]. The contents of the three primary chemical components of wood (cellulose, hemicelluloses and lignin) were then determined using wood meal free-extractive based on the oven-dried weight according to the standard methods described in the ASTM designations [31-33], respectively. In addition, ash content was determined according to the ASTM-D1102 [34].

Statistical Analysis: The data for each of the five selected trees were analyzed using a nested design [35]. In addition, mean values, standard deviations and ranges (minimum and maximum values) are used to describe the data.

RESULTS AND DISCUSSION

Growth Characteristics: The growth parameters of *Calotropis procera* shrubs, including total height, diameter at the branch base outside the bark (D_{OB}) and the crown diameter (CD) are presented in Table 1. It can be seen from the results that the height of the *Calotropis procera* shrubs ranged between 3.8 to 5.1 m with an average of 4.47 m, while the D_{OB} ranged between 9.15 and 14.4 cm with an average of 11.73 cm. The maximum diameter and the upright of the crown were 444 and 447 cm, respectively. The numbers of branches varied between 9 and 13 with an average of 11 per shrub. These wide variations in the shrub growth parameters studied may be due to the nature of the tree growth in the natural habitat, which is in the form of individual trees. Indeed, the tree stock in the studied area was determined to be less than 215 shrubs per hectare.

Biomass Production and Allocation: The values of total above-ground biomass (green and dry weight), allocation pattern and the various tree components of *Calotropis procera* trees are presented in Table 2 and Fig. 1. For oven-dried tree components, the biomass ranged between 6.63 to 10.1 kg tree^{-1} with an average of 8.65 kg/tree. However, the range for fresh weight samples was 24.8 to 34.0 kg/tree. This wide range in the biomass yields from the different trees obtained in this study may be attributed to the varied responses of trees to prevailing soil or edaphic conditions in the location [36, 37]. It may also be attributed to the genetic potential of individual trees to produce a higher or lower biomass than their neighbors [38, 39]. Aref *et al.* [3] studied the effect of stand density on *Leucaena leucocephala* trees and they reported that the proportion of biomass allocated to branches increased from 25 to 45 percent with increasing space from 0.70 to 2.1 m. The allocation of branches based on dry samples gave a higher value (67.64%) than the foliage (32.36%) and the ratio between them was nearly 1:2 (Fig. 1). However, for fresh samples, the biomass production was 52.14% and 47.84% for branches and foliage, respectively, with an approximate ratio of 1:1. This large difference in branch allocation between fresh and dry samples mat be attributed to the increase in the moisture content of the harvested trees, which was higher in the foliage (410.31%) than the branches (167.24%). The structure of *Calotropis procera* branches in cross-section is shown in Figure 2. It consists of four parts in the radial direction from the center to the periphery, namely pith, wood, inner bark and outer bark. As shown in the figure, the outer bark of the

Table 1: Sample *Calotropis procera* trees

			Crown diameter (cm)		
Tree No.	Height (cm)	D_{OB} (cm)	1	2	No. of branches
1	460	12.30	360	395	10
2	380	9.15	410	390	9
3	510	14.40	515	505	12
4	495	11.65	470	465	13
5	390	11.15	480	465	11
Mean	447	11.73	447	444	11
SD	60	1.9	62	50	1.58

D_{OB} is diameter outside bark
CD measured in two directions
SD is the standard deviation

Table 2: Biomass production and allocation of *Calotropis procera* trees

			Allocation of above-ground (%)			
	Biomass production (kg/tree)		Fresh weight basis		Dry weight basis	
Tree No.	Fresh	Oven-dried	Branches	Foliage	Branches	Foliage
1	31.5	9.93	53.97	46.03	70.39	29.61
2	28.0	7.79	55.36	44.64	68.93	31.07
3	24.8	6.63	42.34	57.66	58.67	41.33
4	30.1	8.78	53.82	46.18	69.02	30.98
5	34.0	10.1	55.29	44.71	71.19	28.81
Mean	29.68	8.65	52.14	47.84	67.64	32.36
SD	3.49	1.46	5.52	5.53	5.10	5.11

D_{OB} is diameter outside bark
CD is crown diameter, which measured in two directions, 1 and 2 (upright)
SD is standard deviation

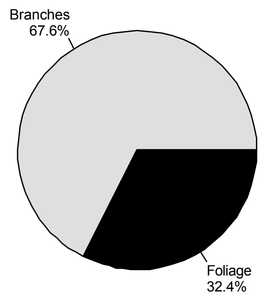

Fig. 1: Allocation of biomass (dry weight) to branches and foliage of *Calotropis procera trees*

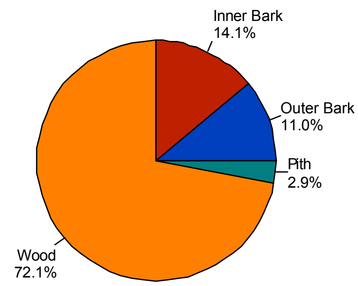

Fig. 3: Dry weight proportion of outer and inner bark, wood and pith of *Calotropis procera* branch

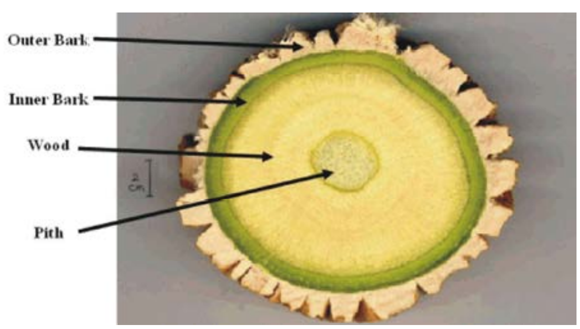

Fig. 2: Cross-section of *Calotropis procera* branch

giant milkweed is corky, furrowed and light yellow in color and it has longitudinal grooves. The woody parts will be described briefly here. The inner bark is soft, light green and has high moisture content. Based on the oven-dried weight, it can be noted from Fig. 3 that among the four basic parts of the branches, the woody part was the most predominant tissue in the branches, with a proportion of 72.15%. The proportions of the other three parts were 11.0%, 14.1 and 2.9% for outer bark, inner bark and pith, respectively. According to the results of the current study

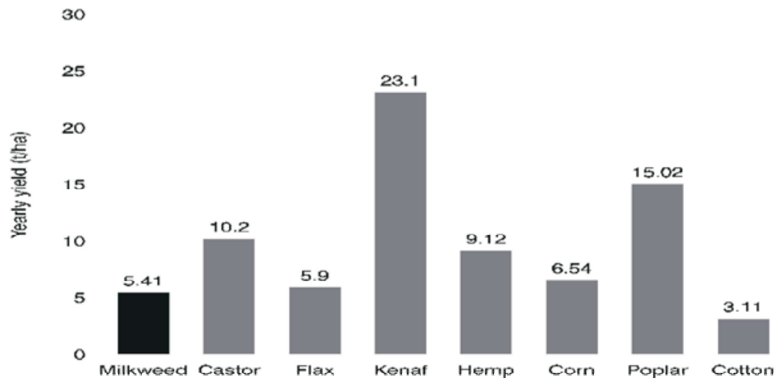

Fig. 4: Branch yield of *Calotropis procera* compared to other plants
Sources: Data for milkweed from the current work and for castor from Grigoriou and Ntalos[23], the other data were adapted from Grigoriou and Ntalos [23]

and assuming that the tree population at the site may reach 625 per hectare, the predicted branch yield of the giant milkweed may be 5.41 tons per hectare. As shown in Fig. 4, the average branch yield of giant milkweed trees was different than kenaf (23.1 t/ha) and poplar wood (15.02 t/ha), but closer to flax (5.9 t/ha) and corn (6.54 t/ha). It compares favorably to those of the other crops and was comparatively higher than the average yield from cotton stalks (3.11 t/ha).

Physical Properties of *Calotropis procera* Wood: The results for the physical properties of giant milkweed wood are presented in Table 3. These properties include specific gravity, density, fiber saturation point, maximum moisture content and total volumetric shrinkage.

Density and Specific Gravity: Density is defined as the mass or dry weight per unit of fresh volume in g/cm^3, while the specific gravity of wood is usually expressed as a ratio of the oven-dried weight of the sample to the weight of an equal volume of water and is abbreviated as sp gr. Density was the first wood property to be scientifically investigated. The specific gravity of wood is one of the most important physical properties because of its direct or indirect relationship with many properties, such as strength, shrinkage and swelling, calorific value, permeability and acoustic insulation. The specific gravity is also related to the thermal and electrical properties of wood, which largely determine the suitability of these materials for wood industries, such as wood pulping, paper making, composition panel manufacture and charcoal production. The basic specific gravity of giant milkweed wood ranged between 0.336 and 0.354 with an average of 0.345. However, the mean density of dry wood (weight and volume in oven-dried samples) was 0.405 g/cm^3, while the air-dried wood density (based on oven-dried weight and volume in air-dried samples, at approximately 12% MC) was 0.39 g/cm^3 (Table 3). These results show that the density of milkweed is lower than the density (0.40-0.75 g/cm^3) of woody raw material [40] and kiwi '*Actinida sinensis* Planch.'-0.502 g/cm^3 [22], but it is close to wingnut wood '*Pterocarya fraxinifolia* LAM.' (-0.35 g/cm^3) and cotton stalks (0.364 g/cm^3 [41]. However, *Calotropis* has specific gravity much higher than that of hazelnut stalks-0.23 g/cm^3 [42]. It is clear from the basic specific gravity values that giant milkweed wood can be classified as "light" wood according to Panshin and Zeeuw [39], who classified woods with basic specific gravities of 0.36 or less as light, 0.36 to 0.50 as moderately light to moderately heavy and above 0.50 as heavy.

Low specific gravity of giant milkweed wood may be due to the unusually high vessel volume or due to thin-walled fibers with wide lumen, which results in high total air space and lower specific gravity [43]. This makes it suitable for the manufacturing of particleboard or to improve the quality of particleboard made of wood with high density, such as of *Casuarina* wood [44]. In contrast, many wood species with low densities could result in low pulp yield producing from it [45] and low heating values when turned to charcoal or used for direct burning [46].

Fiber Saturation Point: The fiber saturation point (FSP) represents the point at which the cell wall is completely saturated with water, but no moisture is present within the cell lumen. This point varies between different native wood species because of variations in chemical organization, but generally falls between 25 and 30% of

Table 3: Some physical properties of *Calotropis procera* (L.) wood

Items	ρ_{od} (g/cm^3)	ρ_{ad} (g/cm^3)	SG_{Basic}	FSP (%)	M_{max} (%)	β_V (%)
Average*	0.405	0.390	0.345	45.90	223.83	15.80
Standard deviation	0.010	0.009	0.006	2.81	5.22	0.88
Minimum value	0.393	0.380	0.336	43.61	214.49	14.21
Maximum value	0.417	0.406	0.354	49.72	230.81	16.98

* Each value is an average of 12 specimens

FSP: Fiber saturation point; M_{max}: maximum moisture content

ρ_{od} is based on oven-dried weight and volume. ρ_{ad} is based on oven-dried weight and air-dried volume

SG_{basic} is calculated based on oven-dried weight and green volume

moisture content [39] and it can reach 35% in some species [47], such as alder (34.6%), beech (35.6%) and wingnut (47.5%). Variations among wood species depend on cell wall volume, density and the ratio of the heartwood to sapwood portions in the cross section [48]. This is a critical point, because below this point, the properties of wood are altered by changes in moisture content. The amount of moisture present in wood when used in environments that provide no contact with liquid water will always be less than the FSP [25].

The fiber saturation point (FSP) of giant milkweed wood was higher (45.9%, Table 3) than the most known wood species, such as poplar (28.9%), beech (35.6%) and birch (28.9%), but was lower than the FSP of wingnut wood (47.5%), as determined by Gungor *et al.*[48]. The high FSP values for giant milkweed wood compared to other wood species may be due to the lower content of extractive (7.11%), because the extractives occupy sites in the cell wall that would otherwise attract water. This result is in agreement with Haygreen and Bowyer [25], who reported that species with high extractive generally have low FSP values. Increases in the FSP values of giant milkweed may be linked to the higher wood shrinkage observed in the current study. The increase in the fiber saturation point of giant milkweed wood may indicate an increase in the effective range of the moisture content of wood in the green condition.

Total Volumetric Shrinkage: Shrinkage of the cell wall and therefore of the wood, occurs as bound water molecules escape from between long-chain cellulose and hemicellulose molecules [25]. The amount of shrinkage that occurs is generally proportional to the amount of water removed from the cell wall. The total wood shrinkage is an important property for wood industry because dimensional changes can cause distortion and collapse of semi-finished products. In general, the magnitude of shrinkage is greater with higher density. This indicates that the higher the density of the wood sample, the more it will tend to shrink. Shrinking is expressed as a percentage of the green dimension or volume. The total volumetric shrinkage is calculated from the change in moisture content from green to oven-dried and ranged between 8.5 and 18.8% for domestic and important wood species [25]. To avoid the shrinkage of giant milkweed wood after processing, it is necessary to dry the wood to a moisture content that is in equilibrium with the atmospheric relative humidity where the wood will be located. Total volumetric shrinkage of giant milkweed wood ranged between 14.21% and 16.98%, with an average of 15.8% (Table 3). These values were found to be in a range similar to most important wood species, which range between 8.5 and 18.8% [39]. The highest values for volumetric shrinkage of *Calotropis procera* wood indicated that their dimensional stability will not be as affected by changes in moisture. Therefore, to avoid the shrinkage of giant milkweed wood during utilization, it is necessary to dry the wood to moisture levels less than those that balance with the relative humidity in the atmosphere surrounding the timber.

Chemical Composition of *Calotropis procera*: Chemical composition of wood and any lignocellulosic material profoundly influences its utilization for pulp and particleboard industries, chemical feedstock and energy. Table 4 represents the analysis of variance of the chemical composition of *Calotropis procera* wood using a nested design. It can be noted from this table that the variations in extractive and hemicellulose content between trees were not significant, but the variations between the branches within individual trees were highly significant. However, for cellulose and lignin contents, no significant differences were observed between trees or branches within trees. The differences between trees and between branches within trees were highly significant for ash content, cold and hot water solubilities. These results indicate that the cellulose and lignin of *Calotropis* are stable chemical components and they did not vary between trees or between branches within trees. A comparison of the chemical composition of

Table 4: Analysis of variance of chemical components of *Calotropis procera* wood

	Mean square						
SOV	Extractive	Cellulose	Hemicellulose	Lignin	Ash	CWS	HWS
Tree	1.105 NS	32.31 NS	2.414 NS	42.07 NS	0.107 **	4.522**	4.649**
Branch/Tree	0.555**	24.29 NS	2.797 **	28.29 NS	0.012 **	0.435**	0.520**
Error	0.069	19.04	0.333	20.31	0.004	0.050	0.094

** Significant at 0.01 level of probability according to LSD test, NS: Not significant, CWS: Cold-water solubility, HWS: Hot-water solubility

Table 5: Chemical composition of *Calotropis procera* wood compared to other plants, hardwoods and softwoods

		Content (%) of					Solubility (%) in	
Items		Extractive	Cellulose	Hemicellulose	Lignin	Ash	Cold water	Hot water
Average		13.11	47.88	27.08	21.25	2.10	7.07	11.48
Minimum value		11.68	46.48	25.60	20.29	1.97	6.36	10.70
Maximum value		15.59	48.95	29.60	22.95	2.27	8.86	13.23
For comparison	Hardwood[1]	2-6	45-50	15-35	23-30	0.2-0.5	4-6	2-7
	Softwood[1]	2-8	45-50	20-32	25-34	0.2-0.5	2-3	3-6
	Kiwi[2]	6.24	38.38	32.19	26.27	2.05	9.97	18.43
	Wheat straw[3]	16.85	49.82	34.92	12.86	9.97	12.05	19.69
	Date palm[3]	21.52	46.41	25.89	17.75	7.91	15.28	21.65
	Vine stalks[4]	18.85	38.14	33.76	21.07	4.42	13.65	18.77

Source 1: Haygreen and Bowyer [25] and Fengel and Wegener [57]

Source 2: Nemli *et al.* [22]

Source 3: Al-Mefarrej and Nasser [5]

Source 4: Nasser *et al.* [58]

Table 6: Average values of wood anatomical characteristics for *Calotropis procera*

			Vessel diameter (µm)	
Items	Fiber length (mm)	Vessels per mm²	Radial	Tangential
Average	0.908	15.0	125.74	85.12
Standard deviation	0.085	1.7	43.83	23.77
Minimum value	0.742	12.0	39.27	44.03
Maximum value	1.167	18.0	236.80	157.08
N	50.000	15.0	50.00	50.00

Calotropis procera wood to other plants, softwoods and hardwoods is presented in Table 5. It is evident that cellulose and hemicellulose content falls within the range of either softwoods or hardwoods. The cellulose content of *Calotropis procera* wood (47.88%) was found to be much higher than the vine stalks (38.14%) and kiwi (38.38%), but close to wheat straw (49.82%) and date palm midribs (46.41%). The hemicellulose content of *Calotropis* (27.08%) was lower than kiwi (32.19%), vine stalks (33.76%) and wheat straw (34.92%) and close to date palm midribs (25.89%). From the results, it should be noted that the cellulose/hemicellulose ratio of *Calotropis procera* wood was 2.16. This ratio is important because of the capital role of hemicelluloses in papermaking [49]. Pulp yield is negatively correlated with the extractive content and water solubility [50]. Therefore, a lower pulp yield could be expected for this wood.

The lignin content of *Calotropis procera* wood ranged between 20.29 to 22.95%, with an average of 21.25%. It was much higher than wheat straw (12.86%) and date palm midribs (17.75%) and it was lower than kiwi stalks (26.27%) and close to vine stalks (Table 5). The relatively lower lignin content of giant milkweed in the current study compared to hardwoods (23-30%) and softwoods (25-34%) suggests that it may be advantageous for pulp manufacturing by lowering the pulp time and chemical charging, as compared to those of other non-wood raw materials. This suggestion is in agreement with the finding of Diaz *et al.*[50], who studied variations in fiber length and chemical properties in pulp from some *Leucaena* varieties. However, the highest extractive (13.11%) and hemicellulose content (27.08%) may decrease the pulp yield. The extractive content of *Calotropis* ranged between 11.68 to 15.59%, with an average of 13.11%, which was much higher than softwood, hardwood and kiwis stalks, but lower than others. The values for cold and hot water solubility for *Calotropis* were much higher than those observed in softwood and hardwood, but they were lower than other lignocellulosic materials (Table 5).

The ash content of *Calotropis procera* wood ranged between 1.97 and 2.27%, with an average of 2.1% (Table 5). These values were higher than most softwood and hardwoods, which does not exceed 2% in most species, but can reach 5% in some tropical species, such as *Tamarix aphylla* [46]. Ash content was close to that of kiwi (2.05%) and lower than the other materials. Generally, higher ash content in wood causes many problems for cutting edges during manufacturing [51] and decreases the suitability of material for charcoal production [52, 53] and chemical industry [54]. A comparison of the chemical composition of *Calotropis procera* with values observed in softwood and hardwood species indicate that it has lower lignin content and higher extractive content, ash content and hot and cold water solubility than common wood species. However, it has cellulose and hemicellulose contents similar to other wood species. These findings indicate that the woods produced from *Calotropis procera* are suitable as a source of fiber for the pulp industry and for composition panel production. In conclusion, the chemical composition of *Calotropis procera* wood is similar to other lignocellulosic materials. Furthermore, it is characterized by lower lignin content and higher extractive and hemicellulose content. Further investigations are necessary before using this wood in chemical industries.

Anatomical Characteristics: The present study is the first to describe the anatomy of *Calotropis procera* (Ascelpiadaceae). The wood from this plant is even-olored and yellowish. The pores are visible only with a lens at clear cross sections and the timber is of low weight (specific gravity range between 0.336 and 0.354). According to the data available from the current study and the results presented in Figures 5 and 6, we can offer a brief description of the anatomical characteristics of *Calotropis procera* wood grown in a natural habitat in the Riyadh region. The giant milkweed belongs to a hardwood group species. It is diffuse porous, growth mark indistinct, but characterized by 8-9 layers of comparatively thin walled, less lignified fibers and axial parenchyma cells. The vessels are diffuse solitary scanty and found primarily in long chains of radial multiples and in groups of irregular arrangements of large and small pores, which are circular and oval in cross section, thin walled (Fig. 5) with a simple transverse perforation plate (Fig. 6). In addition, there are 15 vessels per mm^2 (Table 6). Fibers occupying the bulk of the cross-sectional area are thin walled with wide lumens. The axial parenchyma is scantly scattered and inter-mixed with fibers. The rays are narrow, uniseriate to tetraseriate (Fig. 6), short to very long in height, heterogeneous and made up of upright and procumbent cells (Fig. 7).

As shown in Table 6, it can be seen that radial vessel diameters ranged between 9.27 and 236.8 µm, with an average of 125.74 µm, while tangential vessel diameters ranged between 44.03 and 157.08 µm, with an average of 85.12 µm. In addition, 77% of vessels have tangential diameters between 59 and 109 µm (Fig. 8a), while 84% of radial vessel diameters fall between 64 and 179 µm (Fig. 8b). This wide range of vessel diameter, in both directions, may be attributed to the environmental conditions and the nature of plant growth. It can be noted from the results in Table 7 that the fiber length of giant milkweed wood is in the range of tropical hardwood species, which range between 0.7 and 1.5 mm [55].

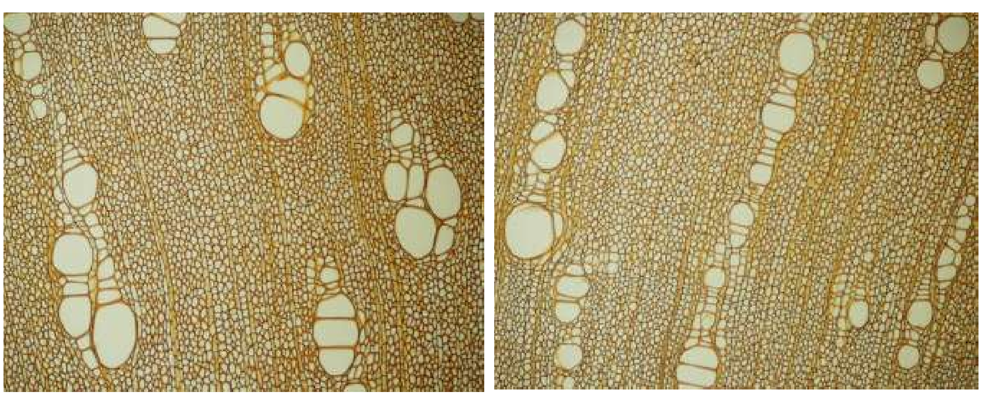

Fig. 5: Micrograph of *Calotropis procera* wood in cross-section showing vessel density (left) and the distribution of fibers and the axial parenchyma (right)

Fig. 6: Tangential view of *Calotropis procera* wood showing the structure and abundance of wood rays and the nature of the vessels

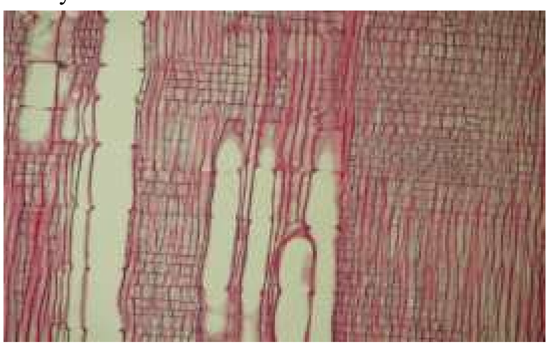

Fig. 7: Radial view of *Calotropis procera* wood showing composition of rays and simple perforation plates of the vessels

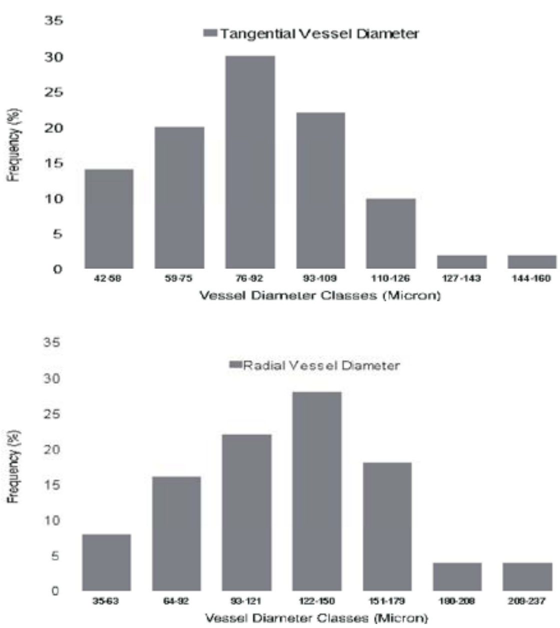

Fig. 8: Vessel diameter distribution of *Calotropis procera* in (top) tangential and (bottom) radial directions

However, it was seen that the fiber lengths were lower than the values observed in some species grown in Saudi Arabia. The wide range of giant milkweed wood fiber length values obtained in this study (0.742-1.167 mm) may be attributed to the changes resulting from the aging of cambium and modifications imposed on cambium activity by environmental conditions [39]. Based on the results concerning fiber length, we suggest that the wood produced from this species is suitable as a source of fibers for pulp, paper and fiberboards in arid and semi-arid regions. El-Osta [56] reported the same suggestion for the wood produced from young *Casuarina* species grown in Egypt, which had a weighted average fiber length of 0.81+0.17 mm, with a range of 0.09 to 1.01 mm for *Casuarina glauca*.

CONCLUSIONS

Several technological properties of *Calotropis procera* wood were investigated in the current study. The results indicate that it belongs to a hardwood group and is diffuse porous wood. The vessels are diffuse solitary scanty and found mostly in long chains of radial multiples and in groups. In addition, the fiber length is in the range of hardwood species, which suggested that this wood is suitable as a source of fibers for pulp, paper and fiberboard industries. The wood can be classified as light, which makes it suitable for the manufacturing of particleboard. The cellulose and hemicellulose contents are in the range of either softwoods or hardwoods (47.88 and 27.08%, respectively); however, it had a lower lignin content (21.25%), which suggests that it may be advantageous for pulp manufacture by lowering pulp time and chemical charging. In conclusion, the chemical composition of *Calotropis procera* wood is similar to other lignocellulosic materials. Furthermore, it is characterized by lower lignin content and higher extractive and hemicellulose content. According to the technological properties determined in the present study, we suggest that *Calotropis procera* is a convenient local raw material source available in Saudi Arabia and it is suitable for use in most wood industries.

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