

Industrial Applicability of Wood Anatomical, Mechanical and Physical Properties of Diverse Tree Species in Sudan

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ABSTRACT

Wood density, fiber dimensions and hardness strength of the studied species are in the normal range for hardwoods. In general wood basic density and fiber characteristics of the study species are compatible for pulp and paper industries. However, it is recommended to mix the pulp produced from the study species wood with soft-wood or recycled paper pulps to improve their properties. Also their hardness strength as well as air dry density are compatible for flooring industry. The suitability of the study species for such advanced industries would not only reduce imports, but also would provide an economic incentive to the forestry and industrial sectors of Sudan.

KEYWORDS

Balanites aegyptiaca; Development; Forests based industries; Sudan.

1. Introduction

Sudan is a country rich in forest including a large number of tree species; it encompasses about 3156 species belonging to 1137 genera and 170 families (Broun and Massay 1929, Andrews, 1950, 1952, 1956, and El Amin 1990). Nevertheless the utilization of wood resources has traditionally concentrated to a few numbers of species, due to the lack of information about the wood properties of many indigenous species growing in Sudan. Despite the richness of Sudan in most of the basic factors required to establish pulp and paper and flooring industry, it is still dependent on import to satisfy its needs for pulp and paper. There is currently no flooring industry in Sudan. It is therefore evident that there is an urgent need to assess the suitability of local fibrous raw materials for paper and flooring industries. Domestic sources of such industries would not only reduce imports but also provide an economic incentive to the forestry and industrial sectors of Sudan.

Wood density is the most significant property in determining wood end uses. It is strongly effect on the yield, strength, and general quality of most of the products produced from wood. It is considered the best single index for pulp yield and quality (Bendtsen 1978).

Wood anatomy is described as fundamental basis of timber utilization. A wood anatomist can suggest uses, especially for woods that are not in a commercial demand. Previous studies have shown that fiber morphology is an important indicator for end-use. For instance, the fibers dimension and their derived values correlate with most of the strength properties of pulp. Sadiku and Abdulkareem (2019) have successfully used the fibers dimension and their derived values to assess the suitability of some nigerian tropical timber species for pulp and paper making. Ajuziogu and Ojua (2020) in their Study on the wood and bast fibres of *Gmelina arborea* have used the fiber morphology to assess the suitability of their studied species bark and wood for pulp and paper making. While, Ajala and Noah (2019) have used the fibers dimension and their derived values of *Anigeria robusta* wood to assess its suitability for paper making. Many Other researchers like Saikia et al. (1997), Ogbonnaya et al. (1997), Ververis et al. (2004), Ajuziogu et al. (2010), and Ekhuemelo and Tor (2013) have also successfully used the fibers dimension and their derived values to assess the suitability of various fiber raw materials for pulp and paper manufacture. According to Haygreen and Bowyer (1996), mechanical properties are usually the most important characteristics of wood product to be used in structural applications such as flooring and rafters, structural panel roof, wall sheathing, etc...

Wood properties studies have a special significance in countries like Sudan where only a few timbers are well known. After the oil extract in Sudan, great amounts of wood will be available for uses other than energy because oil will gradually replace wood, the main energy resource. This research is an attempt to provide basic information on some anatomical, mechanical and physical properties of *Balanities aegyptiaca* wood in order to assess its suitability for pulp and paper and flooring industries. *Balanities aegyptiaca* is a common wild tree belonging to the family *Balanitaceae*. It is an evergreen, multi-branched and armed tree species that varies in height from 8 to 10 m (El Amin 1990) or 15 m and in diameter from 30 to 50 cm (Thirakul 1984). The wood makes excellent firewood and good quality charcoal (Thirakul 1984); it is also used for local furniture and agricultural implements. The fruit is edible and is used against constipation and as anti-diabetic. The sapogenin, yamogenin, and diosogenin, can be extracted from all parts of the plant (Vogt 1995). The general feature of *Balanities aegyptiaca* tree species is illustrated in (Figure 1).



Figure 1. *Balanities aegyptiaca* general features.

Balanities aegyptiaca tree is an indigenous species in Sudan with a wide range of natural occurrence over diverse climatic and edaphic conditions (Suliman and Jackson 1959). It grows in sand, clay, cracking clay and gravel soils (Suliman and Jackson 1959 and Orwa et al. 2009). So, the tree is widely distributed in the Sudan (see Figure 2).

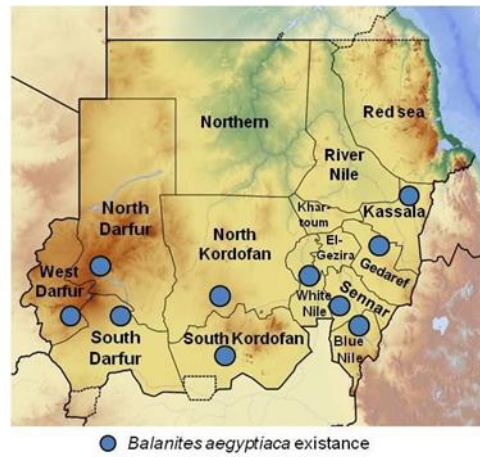


Figure 2. *Balanites aegyptiaca* distribution in Sudan.

2. Materials and Methods

2.1 Materials

The wood raw materials were collected randomly from 10 forests located in four states in Sudan namely: North Kordofan State, South Kordofan State, Blues Nile State and White Nile State. According to the mean annual rainfall for ten years (2000-2009), the study areas were divided into two zones; zone one: with a relatively low rainfall (273mm annually, mean average rainfall), and zone two: with relatively high rainfall (the mean average rainfall is 701 mm annually).

The location and characterization of the study areas are summarised in (Figure 3), while sampling procedure is presented in (Figure 4).

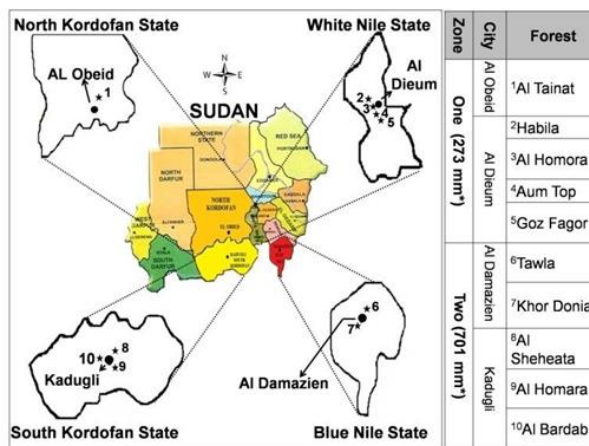


Figure 3. Location and characterization of the study areas.

Three healthy and straight trees were selected randomly and cut down from each forest give a total of 30 trees. The tree total height, merchantable height and diameter at breast height (DBH) were measured for each tree. Two discs of 30 cm thick were obtained from each tree at 10% and 90% of the merchantable height. Afterwards the discs were cut into small samples or strips include tree’s pith with 3 x 3 x tree diameter in cm. Three free of defect strips were taken from each 90% disc and four from 10% disc given a total of 7 strips foreach tree. Then each strip was cut into small samples and used for wood properties investigations (for more details see Figure 4).

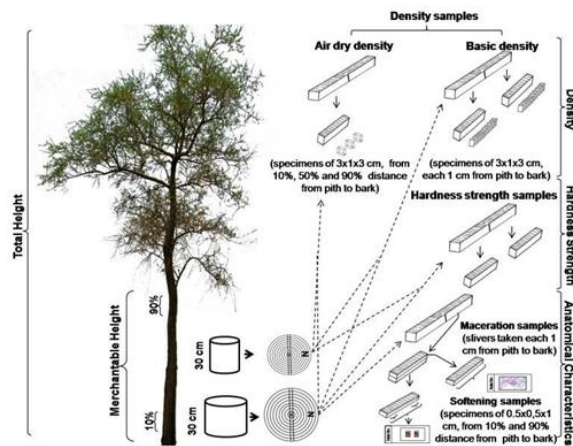


Figure 4. Sampling procedure.

2.2 Methods

2.2.1 Wood density

Two wood density types were measured in the current study: basic density as well as air dry density. The wood basic density was measured as oven-dry mass/green volume. One wet sample (strip) from each stem height (10% and 90%) was taken and was cut from the pith (center) into two parts and each part has been sawn into small specimens of 3×1×3 cm. The specimens green volume was determined by water replacement method. Then were immediately transferred into an oven and dried for 48-72 hours until the constant mass was attained. The dry weight was measured using sensitive digital balance.

The wood air dry density was measured as air dry mass/air dry volume. One sample was chosen from each height (10 % and 90%). The samples were then cut from the pith (centre) into two parts (radiuses). One radius was chosen for air dry density determination. Small specimens of 3×1×3 cm were cut from each radius. The air dry gravimetric method was conducted on the basic of DIN 52 182 (Anonymous 1991) the samples were conditioned to a constant mass at 20 °C air temperature and 65 % relative humidity. The specimen's weight was measured using a sensitive digital balance. The volume was measured using micro callipers (Mitutoyo Digimatic Model CDNP30).

Two anatomical tests were conducted, maceration test to measure fiber length, and the softening test to measure fiber diameter and lumen diameter. One air dry sample or strip from stem height 10% was selected from each tree of the study species and was separated from the pith localization into two samples (radiuses). One radius was taken to perform the anatomical properties investigations as illustrated in (Figure 4).

The maceration procedure developed by Shultze as cited in Jane (1970) was adopted to macerate the woody materials. Small slivers of wood were placed in test-tubes, to which 65% nitric acid with a few crystals of potassium chlorate (KClO₃) was added and then warmed up in a water bath for about 5-10 minutes. The macerated material is washed, stained, rewashed, fixed in slides and then left left 24 hours to dry. A number of 40 fibers length were measured randomly from each sample using light microscope (model: Variant Jenamed) with an 10x ocular lens provided with a measuring scale graduated into ten equal segments and each segment is graduated into ten sub-segments (Figure 5).

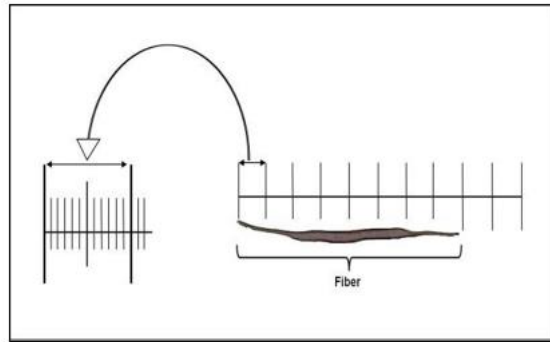


Figure 5. Fibre length measurement using measuring scale.

Concerning the softening test, one sample of 0.5 x 0.5 x 1 cm was cut from each sampling point (10% and 90% distance from pith to bark). The samples were softened by boiling in water for about 8-10 hours. Transverse (cross) sections 10-15µm in thickness were cut using GSL1 microtome (invented by H. Gaertner, F.H. Schweingruber & S. Luccinetti). The prepared sections were dehydrated in a graded ethanol series (25%, 50% and absolute, respectively), stained and dehydrated again. The sections were fixed in slides and left 24 hours to dry.

Nikon coolpix 990 Camera fixed in light microscope (model: Variant Jenamed) which in turn was connected with PC were used to take photos from the prepared slides. The image j software was used to measure the fibers's dimension from the photos. A number of 40 fibers were selected randomly to measure fiber diameter and lumen diameter (Figure 6).

Three derived values were also calculated using fiber dimensions:

- Slenderness ratio as fiber length/fiber diameter,
- Flexibility coefficient as (fiber lumen diameter/ fiber diameter) × 100 and
- Runkel ratio as (2 × fiber cell wall thickness)/lumen diameter.

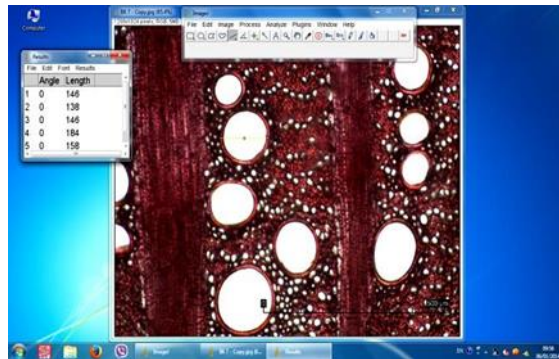


Figure 6. Fibres diameter and lumen diameter measurements using ImageJ software.

2.2.2 Hardness strength

Brinell hardness test was conducted on the basis of DIN EN 1534 to measure the hardness strength of the studied species. One conditioned at 20 °C air temperature and 65% relative humidity sample (stripe) from each stem height (10% and 90%) were selected. Each stripe was split from the pith (center) into two radiuses. In order to obtain soft surface, the four sides of each radius were sanded using sanding machine. The TIRA test 28100 machine provided by a hardened steel ball with a diameter of 10 ± 0.01 mm was used to perform the hardness test in the transverse and radial sections (See Figure 7).

3. Results and Discussion

3.1 The Suitability for Pulp and Paper Making

(Table 1) shows the mean values for the investigated fiber characteristics as well as wood basic density of the study species compared with the acceptable values for Pulp and paper making (PPM) and those of *Gmelina arborea* which is used commercially in pulp and paper making in the world.



Figure 7. Hardness test methodology

Table 1. The study species Fiber Characteristics and wood Basic density compared with the acceptable values for pulp and paper making (PPM) and those of *Gmelina arborea* as reference species.

| Property | <i>Balanites aegyptiaca</i> | Acceptable values for PPM |
|------------------------------------|-----------------------------|---------------------------|
| Basic density (kg/m ³) | 660 | 350-650 ¹ |
| Fibre length (mm) | 1.15 | ≥ 1 ² |
| Flexibility Coefficient (%) | 41 | > 60 ³ |
| Runkel ratio | 1.48 | 0.25-1.5 ⁴ |
| Slenderness ratio | 88 | >33 ⁵ |

¹Casey (1980), ²Source 2, ³Petri (1952), Okereke (1962), Rydholm (1965), ⁴Valkomer (1969), ⁵Xu et al. (2006) and ⁶Ogunkunle and Oladele (2008).

The average basic density of *Balanites aegyptiaca* (660kg/m³) was in the range of tropical hardwoods of 400-900 kg/m³ (Tissot 1985). It could be graded as medium according to Melo et al. (1990) classification. Khristova et al. (1997) found the wood basic density of *Balanites aegyptiaca* to be 619 kg/m³ which is more or less comparable with those obtained in the current study (660 kg/m³). *Balanites aegyptiaca* basic density is almost within the range for commercial temperate pulpwood of 350-650 kg/m³.

The fiber length of the study species is in the range of hardwood of 0.7-2.0 mm (Ilvessalo- Pfaffli 1995) and considered as short according to Wagenführ (1984), and Medium according to IAWA (1989) classifications. They are also comparable with the acceptable value for PPM. Many authors confirmed the suitability of species with equal and even shorter fiber length than the studied species for pulp and paper making. Good examples are the species studied by Khristova et al. (1997, 1998), Khristova and Karar (1999), Khristova et al. (2004) and that of Dutt and Tyagi (2011). The fibers were of good slenderness ratios (88), much more than the acceptable value for papermaking of < 33. It is much bigger than almost all those of hardwood using in papermaking and also bigger than some soft wood species like *Pinus kesiya* (56.51) as sited in Dutt and Tyagi (2011). This enhances their suitability for pulp and paper making.

Acceptable range of papermaking (0.25-1.5) as sited by Valkomer (1969). Khristova et al. (1997, 1998) confirmed the suitability of species with higher Runkel ratio for papermaking (2.9-2.5 respectively). Nevertheless, the flexibility coefficient of the study species are much lower than the acceptable value for papermaking of

preferably >60. But they are comparable to those of the species studied by other authors (Khristova et al. 1997, 1998 and Khristova and Karar 1999). In comparison with *Gmelina arborea* wood properties shown in (Table 1), the study species has comparable fibre length, lower flexibility coefficient, higher Runkel and slenderness ratios and higher wood density. Therefore, it is considered compatible for pulp and paper making. However, it is recommended to mix the pulp produced from the study species wood with soft-wood or recycled paper pulps to improve their properties.

3.2 The Suitability for Flooring Industry

In flooring industry, the most important wood properties which determine the suitability of the wood for such industry is the hardness. Wood density is acknowledged to affect most mechanical properties (Haygreen and Bowyer 1996, Barnett and Jeronimidis 2003, Bowyer et al. 2003, Kiaei and Samariha 2011). Therefore, this section assess the suitability of the study species for flooring industry by comparing its air dry density and Brinell hardness strength mean values by those of the American's flooring industry benchmark Red oak (*Quercia rubra*) and by those of *Robinia pseudoacacia* (which is widely used in flooring industry) as reference species (Table 2).

Table 2. The study species air dry density and hardness strength compared with the reference species.

| property | <i>Balanites aegyptiaca</i> | References species* | |
|--|-----------------------------|-----------------------------|----------------------|
| | | <i>Robinia pseudoacacia</i> | <i>Quercia rubra</i> |
| Air dry density (g/cm ³) | 0.789 | 0.77 | 0.7 |
| Hardness strength (N/mm ²) | | | |
| Transverse surface | 87 | 78 | 53-66 |
| Radial surface | 46 | 34 | 29-36 |
| *Wagenführ (2007) | | | |

Based on the Malaysian Grading Rules for Sawn Hardwood Timber (Anonymous 1984), *Balanites aegyptiaca* wood air dry density can be classified as medium (from 0.720 to 0.800 g/cm³). The study species wood can be classified as very hard, according to the Brinell hardness strength classifications provided by Mörath in Lohmann (1991). The estimated hardness strength (in transverse and radial surface) and air dry density of the study species are bigger than those of *Robinia pseudoacacia* as well as *Quercia rubra* which commercially used in flooring industry. Therefore, the study species is considered compatible for flooring industry.

4. Conclusion

Wood density, fiber dimensions and hardness strength of the studied species are in the normal range for hardwoods. In general wood basic density and fiber characteristics of the study species are compatible for pulp and paper industries. However, it is recommended to mix the pulp produced from the study species wood with soft-wood or recycled paper pulps to improve their properties. Also their hardness strength as well as air dry density are compatible for flooring industry. The suitability of the study species for such advanced industries would not only reduce imports, but also would provide an economic incentive to the forestry and industrial sectors of Sudan.

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