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Wood Property – Use Relationships for Four Secondary, Lesser-Used Wood Species Growing in Blue Nile State, Sudan.

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Abstract

Most of Sudan forests are degraded natural forests which have been creamed. The remaining stock is composed of some secondary species which are not used even for firewood or charcoal. Therefore the objective of the present study is to determine some basic properties and quality attributes for four secondary species growing in Blue Nile State and assign the different species to the recommended uses according to their properties and quality attributes. This is to increase the number of wood species in use and make it more economical to harvest and exploit natural forests sustainably.The basic properties determined included some anatomical fiber characteristics. Fiber length and cell proportionswere determined using stereological techniques,Physical and mechanical properties were carried out in accordance to standard testing procedures. Analysis of variance and Duncan's Multiple Range Test revealed significant variations in almost all properties between the species studied. The details are given in the first paper. (tables 1-4). However, for the purpose of this paper Correlation analysis was also carried out to find relationships between wood basic properties (anatomical and density) and wood quality attributes for the different uses like wood strength, dimensional stability, permeability, gluability and appearance. These attributes represent the characteristics needed to sort the different species for the most suitable uses. According to its properties and quality attribute goghan was found suitable for structural uses, high quality furniture internal decorations, carving, handcraft, veneer and high quality plywood. kakamut on the other hand, had similar quality attributes to goghan and can be used for the same uses with preference to goghan. Talh was assigned for structural uses, fixed furniture for student seating and at camping sites. It can also be used for fiberboard and pulp and paper production. Tarar, however, was found suitable for non –load bearing partitions and as an insulating material in sandwich construction as well as for fiberboard and pulp and paper manufacturing. Its low density also makes it suitable for the manufacture of particleboard.

Key Words: Talh, Goghan, Kakamut, Tartar, Basic properties, Quality attributes

Introduction

Although experience and availability have often dictated which species of timber should be used for a particular purpose, a much more detailed knowledge of the properties of timber is required for efficient utilization, for the exploitation of unfamiliar timbers and to aid in the selection of species for afforestation projects (Forest Products Research,1969).Timber quality is that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for the intended use. In this definition, the intrinsic quality of the wood is evaluated solely in terms of its suitability for various products or end uses (Schilz, 1963). To illustrate the concept of timber quality more clearly, consider the elements that it is composed of. According to the accepted definition of timber quality, the wood for specific end uses possesses are those attributes which make it suitable for those uses.

The mechanical properties of wood are such properties that determine the use of wood for structural and building purposes and innumerable other uses of which furniture, vehicles, implements, and tool handles are a few common examples. Macroscopically, wood can be described as an orthotropic or anisotropic material with three main directions: longitudinal direction (L), while radial (R) and the tangential (T) directions are in the transverse plane. The mechanical properties of wood in the radial direction slightly higher than in the tangential direction, and both radial and tangential properties are about one order of magnitude lower than the properties in the longitudinal direction.(Mishnaevsky and Qing , 2008).The maximum compressive strength parallel to the grain is a measure of the strength of wood when used as a stud or column (Moore, 2011). High strength in longitudinal compression is required of timber used as columns, props and chair legs, Nearly 50% of world forest land is covered with secondary species and they contribute less than 20% of the total world use of industrial wood and consequently contribute far less than their potential to the economic development of the countries in which they occur- mainly developing countries. The situation in Sudan is even worse than this average. The percentage of these species may reach more than 80%. (Nasroun, 2017). Due to the dwindling supplies of prime species in Europe and other factors the industry will focus on tropical forest resources.In pulp and paper successful large scale operations based on mixed tropical hardwoods – no general solution each available species mix has to be studied economically and technically.

Wood is a natural variable and versatile material which can be used for thousands of productsfrom purely structural purposes to purely decorative purposes; from high technology industrial products to small scale cottage industries and handcrafts. Each end use for wood has unique set of quality attributes which are affected by basic wood properties, and in turn affect the value recovery chain from tree to product (Zhang, 2003).

The utilization of secondary hardwood species is a global problem, due to the absence of the technical information and properties needed for sorting these species for the most suitable uses. The main objective of this study is, therefore, to use the anatomical, physical, mechanical and technological properties of the four secondary hardwood species and others to come forassigning each species to the recommended uses according to their properties and quality attributes. This, in turn will increase the number of wood species in use and make it more economical to harvest and exploit natural forests.

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Materials and Methods

Material

Four of the lesser used wood species which are available in reasonable numbers in Blue Nile State and other parts of Sudan were selected for this investigation. The selected species comprised:

Sterculia setigra (tartar), *Acacia polyacantha subsp. Campylacantha*(kakamut), *Acacia seyal* var.*seyal* and *Diospyros mespiliformis* (goghan) .

Methods

Determination of Anatomical Properties

The anatomical properties determined included fiber characteristics, namely:the proportions of the different cell types and their components, fiber diameter (FD), lumen diameter (LD), double cell wall thickness (DCWT), rankle ratio (RR), Coefficient of fiber rigidity (CR) and fiber flexibility (FF), as well as fiber length (FL). Mostof these properties were determined from macerated fibers, where wood chips from the different species were boiled in concentrated nitric acids in a water bath for ten minutes; the liberated fibers were washed in alcohol and water before staining them with safranin for five minutes and mounting them on temporary glass slides using Canada balsum. Using these slides FL was determined using stereological techniques, while the cross-sectional measurements were determined by an image analyzer in Giad Material Research Laboratory. Cell proportions (Pp) of cell types and their components (cell walls and cell lumens), on the other hand, were determined from cross sections prepared by standard procedure and measured using stereological techniques.

Physical and Mechanical Properties

Shrinkage

Both of tangential and radial shrinkage were determined according to Sudanese standard 1748: 2013, *Wood – determination of radial and tangential shrinkage*. Shrinkage values taken from fiber saturation point (30%) to oven dry condition (0% moisture content). Values of longitudinal shrinkage were not estimated because they are usually very slight.

Density

Wood density was determined according to the Sudanese standard 5174: 2012, *Wood – determination of* *density for physical and mechanical tests*. The density was determined for air dry samples at equilibrium moisture content (7%).

Permeability

Ten samples measuring 50×50×20 mm were selected randomly from sapwood of the different species at 7% moisture content. The weight of the samples was recorded before soaking in test solution using fuchsin acid dissolved in water giving a dark red color to facilitate measurement of liquid penetration .Then the test solution containing the test samples was heated in a water bath for two hours; after that the solution and the samples were allowed to cool down over night. The test specimens were weighed again to determine the absorption percent and measure the depth of lateral penetration.

Compression Parallel to the Grain

Compression parallel to the grain was carried out in accordance to ISO 3787: 1976 standard: *Wood-Determination of Ultimate Stress of Compression Parallel to the Grain.* The test was carried out using Universal testing machine. The test specimens were at equilibrium moisture content (7%).

Technological Properties

Gluing properties

Ten specimens were tested for their adhesion strength according to Sudanese standard 1339: 2015, *Adhesives - Wood-to-wood- Determination of shear strength by compressive strength*. The adhesive used was an ordinary thermoplastic resin commonly used in furniture industry.

Texture;

Ten clear samples measuring 20×20×60 mm each were randomly selected from samples prepared for compression test. The samples were visually evaluated for their texture, grain uniformity and smoothness. The evaluation was based on arbitrary numerical values given to each specimen based on the quality of the above mentioned parameters. The numerical values varied in the range 1- 10; ten being the finest texture and the best surface quality while one represented the roughest surface. The specimens used were clear specimens – without any defect to confine the evaluation on textural features and touch smoothness of the wood surface.

Pulp and Paper

Pulp and paper quality is closely associated with fiber characteristics. Nasroun (1978) working on this relationship established some mathematical models to quantify these relationships and using them to predict paper properties from wood anatomical properties. An attempt was made to use some of the fiber characteristics obtained from this investigationfor the four studied species (table1) to estimate the expected paper properties for paper to be produced from the four species.

Statistical Analysis

Analysis of variance was carried out followed by Duncan's Multiple Range Test seaking significant differences in all properties studied between the species and for separating the means. Correlation analysis was also carried out to find relationships between wood basic properties (anatomical and density) and wood quality attributes for the different uses like wood strength, dimensional stability, permeability, gluability and appearance. All these parameters will be used as indicators to assign the different species to the recommended uses.

Results and Discussion

Anatomical properties

Table 1 shoows the mean values for fiber characteristics for the four species under investigation. These anatomical properties showed significant differences between the four species. FL was highest in tartar (1.75mm) and lowest in kakamut (1.35mm). FD, however, ranged between kakamut (20.85 µm) and talh (12.94µm). LD was highest in kakamut (14.02µm) and lowest in talh (4.97µm). DCWT Ranged between talh (7.94µm) and tartar (6.60µm). Whereas the ratios (RR, CR) were highest in talh (1.75µm), (0.31µm) respectively and lowest in kakamut (0.52µm), (0.17µm), the opposite was the case with FF. CR for talh was higher than that reported by Nasroun (1978), while FF for talh was lower than that obtained by Nasroun (1978).

Spp	Dimensions				Ratios		
	FL(mm)	FD(µm)	LD(µm)	DCWT(µm)	RR	CR	FF
Di	1.52B	15.05 B	7.81B	7.25AB	0.98B	0.24B	0.52B
PO	1.35 C	20.85 A	14.02A	6.85B	0.52C	0.17C	0.67A
Se	1.59 B	12.94 C	4.97C	7.94A	1.75A	0.31A	0.39C

St	1.75 A	14.34 BC	7.74B	6.60B	0.90B	0.23B	0.54B

Table 1. The mean values of fiber characteristic for the four species.

FL= Fiber length, FD = Fiber diameter, LD = Lumen diameter, DCWT =Double cell wall thickness, RR = runkle ratio, CR = coefficient ofRigidity, FF = Fiber flexibility, Spp = Species, Di = *Diospyrosmespiliformis** PO= *Acacia polyacantha** Se = *Acacia seyal var. seyal** St = *Sterculiasetigera*

Table 2 shows the volume fractions for cell types and their components (cell walls and cell lumens). These proportions also showed significant difference between the four species.

Table(2)The mean values of volume fractions for cell types and their components

Spp	**Pp V**	**Pp F**	**Pp P**	**Ppcw**	**Pp cl**	**Pp FL**
Di	**0.08A**	**0.81A**	**0.10D**	**0.70A**	**0.31C**	**0.09B**
Po	**0.08A**	**0.62B**	**0.30C**	**0.62B**	**0.39B**	**0.13B**
Se	**0.05A**	**0.54C**	**0.42B**	**0.51C**	**0.50A**	**0.10B**
St	**0.07A**	**0.34D**	**0.59A**	**0.52C**	**0.48A**	**0.18A**

PpV = Volume fraction of vessels* PpF = volume fraction of fiber* PpP = volume fraction of Parenchyma* Ppcw = Volume fraction of cells wall* Ppcl= Volume fraction of cells lumen* PpFL = Volume fraction of fiber lumen*Spp = Species* Di = Diospyrosmespiliformis* PO= Acacia polyacantha* Se = Acacia seyal var. seyal* St = Sterculiasetigera.

PpV was highest in gughan and kakamut 0,08) and lowest in talh (0.05). Pp F was also highest in gughan (0.81) but lowest in tartar. PpP, on the other hand, was highest in tartar (0,59) and lowest in gughan (0,10), PpCWwas highest in in gughan (0.70) and lowest in talh and tartar, while PpCL was the opposite. PpFL was highest in tartar (0.18)and lowest ingughan. This is reflected in the density where tartar has the lowest density among the four species and the highest PpFL, while gughan has the lowest PpFL and the second highest density in the group.

Physical and Mechanical Properties

Physical and mechanical properties also showed significant differences between the species studies (table 3).Talh had the highest density (0.82g/cm³) while tartar had the lowest density (0.38g/cm³). The density value for talhwas close to that obtained by Nasroun (2005). Tangential and radial shrinkages were highest in goghan (10.19%), (5.41%), respectively and lowest in talh (6.02%), (3.06%) respectively. Shrinkage values obtained for talh were also close to those obtained by Nasroun (2005). Liquid absorption (AB) ranged between tartar (207.94%) and talh (57.85%). Most of the absorption in tartar was along the grain and very little across the grain. Depth of penetration (PD) was deepest in gughan (1.94cm) and smallest in Tartar (0.21cm).

The analysis of variance also showed slightly significant differences in compression parallel to the grain where talh, goghan and kakamut had the highest values (838, 840 and 838 MPa, respectivly)with no significant difference between them, while tartar was the weakest (210 MPa) with significant difference from others. The value obtained for talh was higher than that obtained by Nasroun (2005).

Table 3. The means separation for physical and mechanical properties studied

Spp	DEN g/cm³	Com Kg/cm²	Shrinkage (%)		Permeability	
			T	R	AB (%)	PD(cm)
Di	**0.74 B**	**840.00 A**	**10.19 A**	**5.41 A**	**82.510 B**	**1.9400 A**
PO	**0.74 B**	**838.94 A**	**6.76 B**	**3.43 BC**	**78.820B**	**1.7500 B**
Se	**0.82 A**	**838.94 A**	**6.02 B**	**3.06 C**	**57.850 C**	**1.7500 B**
St	**0.38 C**	**210.70 B**	**7.70 B**	**4.33 B**	**207.940 A**	**0.2100 C**

DEN = density* Com = compression parallel to the grain* T = tangential * R = Radial* AB = Absorption* PD = Depth of penetration* Spp = Species* Di = Diospyrosmespiliformis* PO= Acacia polyacantha* Se = Acacia seyal var. seyal* St = Sterculiasetigera.

Table 4 shows the mean values of glue bond strength and wood texture. Glue bond strength (BS) ranged between gughan (27.141Mpa) and tartar (0.751Mpa), indicating that only gughan and kakamut gave adequate bond strength. With regards to texturegughan had the finest texture and grain uniformity, followed by kakamut and talh while tartar had a moderately course texture. Both kakamut and talh were also figured.

Table 4. The mean values of glue bond strength and texture for the four species

Species	Glue bond strength(MPa)	Texture
Di	27.141 A	8.50 A
PO	24.956 A	7.20 A B
Se	3.959 B	6.40 BC
St	0.751 C	5.10 C

Spp = Species* Di = Diospyrosmespiliformis* PO= Acacia polyacantha* Se = Acacia seyal var. seyal* St = Sterculiasetigera

Correlation analysis relating all studied properties

Table 5shows the correlation matrix relating all studied properties. Each cell contains the correlation coefficient (R) and the significance level. It is well known that wood processing and utilization are directly affected by basic wood characteristics. The results of the correlation analysis aimed at relating some wood quality attributes, like strength, dimensional stability, gluability, permeability and surface appearance with basic properties, namely anatomical properties and density. The table shows only the significant correlations. Some of the expected correlations did not appear in the table because they were not significant. This is why some indirect relationships were described. For instance, double cell wall thickness was positively and highly correlated to rankle ratio (RR), fiber coefficient of rigidity (CR) and density, while density was positively and highly correlated to compressive strength parallel to the grain ($R = 0.9338$ at $P< 0.0001$); compressive strength being one of the wood quality attributes for structural utilization. This is due to the fact that density and double cell wall thickness are the best indicators for the percentage of solid wood material compared to the cavities in wood. For the same reason density was negatively and highly correlated to the amount of liquid absorbed (A B) ($R = - 0.9579$ at $P<0.0001$). Double cell wall thickness was also negatively correlated to liquid absorption which is one measure of wood permeability, which, in turn is another quality attribute for glue bonding, wood treatment with preservatives and finishing of furniture parts. Permeability will also be negatively correlated to rankleratio and coefficient of fiber rigidity which were highly correlated to double cell wall thickness.

Glue bond strength was positively correlated to lumen diameter and fiber flexibility, both of which are indicators of permeability due to the high proportion of cavities compared to cell walls. This will allow the glue to penetrate into the wood and result in joints as strong as the shear strength of wood. Lumen diameter and fiber flexibility are negatively and highly correlated to rankle ratio and fiber coefficient of rigidity and double cell wall thickness the three of which should be negatively correlated to permeability and glue bond strength. Glue bond strength is an important quality attribute in furniture and plywood manufacturing as well as any wood products where strong adhesion is needed.

Table 5. Correlation matrix relating all studied properties

	LD	DCWT	RR	CR	FF	FL	DEN
LD	1.000	N.S	-0.7490 P<0.0001	-0.8931 P<0.0001	0.8922 P<0.0001	-0.5999 P=0.0053	N.S
DCWT	N.S	1.000	0.6170 P<0.0001	0.5565 P<0.0001	-0.5581 P<0.0001	N.S	0.2247 P=0.0450
RR	-0.7490 P<0.0001	0.6170 P<0.0001	1.000	0.9352 P<0.0001	-0.9352 P<0.0001	N.S	0.2013 P=0.0733
CR	-0.8931 P<0.0001	0.5565 P<0.0001	0.9352 P<0.0001	1.000	-0.9987 P<0.0001	0.5047 P=0.0232	N.S
FF	0.8922 P<0.0001	-0.5581 P<0.0001	-0.9752 P<0.0001	-0.9957 P<0.0001	1.000	-0.4983 P=0.0253	N.S
FL	-0.5999 P=0.0053	N.S	N.S.	0.5047 P=0.0232	0.4983 P=0.0253	1.000	-0.5563 P=0.0109
FD	0.9136 P<0.0001	0.2242 P=0.0456	-0.4881 P<0.0001	-0.6561 P<0.0001	0.6547 P<0.0001	-0.4867 P=0.0295	
Com	N.S	N.S	N.S	N.S	N.S	-0.7369 P=0.0002	0.9338 P<0.0001

DEN	NS	0.2247 P=0.0450	0.2013 P=0.0733	NS	NS	-0.5563 P=0.0109	1.000
AB	NS	-0.2436 P=0.1290	NS	NS	NS	0.6657 P=0.0014	-0.9579 P<0.0001
PD	NS	NS	NS	NS	NS	-0.7220 P=0.0003	NS
BS	0.5208 P=0.0185	-0.2149 P=0.3628	-0.3928 P=0.0866	-0.4927 P=0.0273	0.4830 P=0.0310	-0.7621 P<0.0001	NS
GD	NS	NS	NS	NS	NS	-0.6682 P=0.0013	0.6359 P=0.0026

LD = Lumen diameter* DCWT = Double cell wall thickness* RR = Rancle ratio* CR = Coefficient of fiber rigidity* FF = fiber flexibility* FL = Fiber length* FD = Fiber diameter* Com = Compression parallel to the grain* DEN = Density* AB = Absorption* PD = Depth of penetration* BS = glue bond strength* GD =Service quality (grade)
Spp = Species* Di = *Diospyrosmespiliformis** PO= *Acacia polyacantha** Se = *Acacia seyal*var. seyal* St = *Sterculiasetigera.*

Property- Use Relationship

Wood is a natural variable and versatile material which can be used for thousands of productsfrom purely structural purposes to purely decorative purposes; from high technology industrial products to small scale cottage industries and handcrafts. It is well known that wood processing and utilization are directly affected by wood properties (Pashin and de Zeeuw, 1980). In recent years there has been interest in combining studies on wood properties and wood products quality to start solving the unresolved problem of utilization of the so-called secondary wood species.

Each end use for wood has unique set of quality attributes which are affected by basic wood properties, and in turn affect the value recovery chain from tree to product (Zhang, 2003)..The basic properties were matched with quality attributes for some important current end-uses such as structural uses, different qualities of furniture, wood flooring, paneling, wood molding, turning, pallets as well as important manufactured products such as pulp and paper, veneer, plywood and other panel boards.

Structural uses

Engineering or structural use requires strength, stiffness, dimensional stability and durability as main quality attributes. The different wood species under investigation were different in meeting these requirements.*Acacia seyalvar. seyal* (talh) is the most abundantly naturally occurring tree in Sudan which can be easily naturally regenerated togive sustainable productionhas been used only for the production of charcoal and for women's sounas. This is due to the fact that talh is very vulnerable to attack by insect borers immediately after it is felled. This is not a big problem since the wood can be treated with preservatives.

The results of this study showed that talhwood is moderately permeable to fluids and can be treated with the hot-and –cold open tank method. But because this wood is attacked by insect borers immediately after it is felled and because the longitudinal permeability of wood in the direction parallel to the grain is much higher than the lateral permeability across the grain, it may be better to treat the green logs by the sap displacement method in the forest immediately after it is felled. The density and mechanical properties (wood strength) as represented by compression parallel to the grain for talhsatisfy the strength requirement for structural and similar uses. The compression parallel to grain value (838.94 kg/cm²) puts talh in the forth highest strength group among six groups of our local structural timbers according to Sudanese standard 5332 (2012).

The high density (0.82 g/cm³) which is close to what was obtained by Nasroun (2005) (0.80g/cm³) as a strong indicator of wood strength shows that other strength properties are also high. This shows that talhcan safely be used in load bearing structures provided that it is treated with preservatives and dried to the equilibrium moisture content before using it. Because the glue bond strength was very low for talh glued joints should be avoided in joining structural components. Instead mechanical fastener such as nails, screws, bolts and metal plate connectors should be used. The strength of these connectors is positively and highly correlated to wood density. The high density of talh will ensure strong mechanically fastened joints. Talh can therefore be used safely for wood- frame buildings,if properly seasoned and treated with preservatives. Smaller pieces can be used for other load-bearing product like pallets, tool handles for agricultural implements and similar products which require strength. Preservative treated talh poles or studs can also be used as pit props in gold or coal mines.

Shrinkage values are useful in estimating roughly the dimensional allowances necessary in converting green timber. Because talh hasthe lowest shrinkage valuestolerances will not be high when used for constructions. In general, no significant dimensional changes will occur if wood is fabricated or installed at a moisture content corresponding to the average atmospheric conditions to which it will be exposed. When incompletely dried material is used in construction, some minor dimensional changes can be tolerated if the proper design is used.) (Forest Product Laboratory,2010)

For*Diospyrosmespiliformis*and *Acacia polyacantha*also the density and mechanical properties (compression parallel to the grain) satisfy the strength requirement for structural uses. The values of compression parallel to the grain (840.00kg/cm²) for goghanand (838.94kg/cm²) for kakamut put goghan and kakamut in the same (forthhighest) strength group as talh among our local structural timbers, according to the same standard mentioned above. goghan and kakamut densitieswere medium high (0.74g/cm³) that is good index of all strength properties shows that also goghan and kakamut canbe used in load bearing structures after being dried to equilibrium moisture content.

The glue bond strength was high for goghan and kakamut so they can be used safely for wood-frame buildings if properly seasoned. With their fine textures and figured appearance they can be used in wall paneling and internal decorations.The results of this study showed that goghan wood is permeable and kakamut is moderately permeable.Thereby they can be treated with preservatives if the need arises. Permeability of goghan and kakamut is an indication for drying rate, meaning that these two species can be dried at a reasonably rapid rate without much degradation. It also facilitates treatment with preservatives and will positively affect finishing properties.Being of low density and low strength tartar wood can be used in non-load bearing positions. For the same reason it will have a low thermal conductivity and therefore suitable for insulation as in cold stores and as covers in sandwich constructions. Its lightness also makes it suitable for rafts lifebelts, fairing, filling and bulkheads in aero-planes manufacture where weight is an important factor.

Furniture and similar uses

For furniture other characteristics like machinability, surface quality, dimensional stability, gluability and permeability become more important. These important quality attributes for customers and manufactures are determined to varying degrees by basic wood characteristics for example durability depends on extractives, appearance determined by anatomical structure and chemical properties. These service related characteristics need to be considered with other quality attributes (Zhang, 2003). Among the studied wood species goghan is the most qualified to meet these attributes. Furniture is associated with daily living and personal use. It remains a reminder of the usefulness, durability and beauty of wood.

Goghan has a fine texture, smooth surface and straight grain as indicated by the high score (8.50 out of 10) obtained from visual appearance grading carried out in this investigation. This wood also showed a strong glue bond which will ensure that bonded furniture parts will hold for a long time. The results also indicated that this wood is permeable to liquids, which means that it can be treated with preservatives to prolong its life in service and results in good finish. All these attributes make goghan an ideal wood for high quality furniture, cabinetry, doors and similar household and office items. Associated with furniture are the wood panel boards. Due to its fine texture, straight grain and its glue bond strength the wood is good for manufacturing strong good quality plywood which can be used in furniture making and paneling. The veneers which are not used for making plywood can be used to cover furniture parts made from lower quality woods. Smaller sizes of goghan can be used for turned or molded furniture parts and antique furniture. As goghan wood has medium high density and strength, the sizes of furniture parts should be much smaller the sizes usually used.

Kakamut showed similar properties to goghan in density, gulability and slightly lower in permeability. The wood is motley with moderately fine texture. The wood is also figured as appeared from the visual appearance grading. These things make the wood suitable to different qualities of household and office furniture from specialty furniture to custom furniture, as well as doors and turned furniture components. Again smaller dimensions should be used for furniture parts due to the medium high density. The wood could also be used for manufacturing veneers and high quality plywood.

Talh has a high density, moderately fine texture and figured, low glue bond strength, moderatelyresistant to impregnation,that is, low permeability. Therefore it can be used for cheaper furniture, such as school furniture and at camping sites. Because talh has high density the dimensions for furniture parts should be smaller than those usually used. Mechanical fastener should be used in jointing furniture parts due to it’s low glue bond strength. Wood should be treated before it used. Talh has low permeability so it can be treated by the sap displacement method in the forest. Tartar has low density, moderately course texture and low glue bond strength. According to lateral permeability tartar was extremely resistant to impregnation but longitudinal absorption of water was quite high compared with other species. All these things make tartar suitable to use in concealed parts of the furniture.

Manufactured products

Particleboard

The factor of raw material used is by far the most important parameter affecting the quality of particleboard because it interacts with every other variable mentioned. It governs the type of particles generated; the material used also determines the formulation of the urea resin, the pressure level and pressing temperature to be used.The most important species variable governing particleboard properties is the density of the wood raw materials; it has been the main factor determining which species to use for manufacturing composition boards. In general terms, the lower density woods will produce panels within the present desired density ranges, usually with strength properties superior to boards made from higher density species. Light density woods can be easily compressed to a wide range density particleboard with the assurance that sufficient interparticle contacts and good bonding is achieved during pressing (Nasroun and El-Wakeel, 2003).Softwoods and medium-density hardwoods (0.40 - 0.60 g/cm³) are preferred, but heavier hardwoods are not excluded (Tsoumis, 2009). Board density is a major factor considering that wood will be compressed to produce boards having a density 5-20% higher than that of the wood in order to obtain maximum bond and sufficient strength and durability according to intended use (Mitlin, 1969). According to the results of this investigation and the obtained density values only Tartar can be used for the manufacture of particleboard. The other three species under investigation are too heavy to give strong boards. This in addition to the fact that both goghan and kakamut are too valuable to be used for particleboard.

Plywood

In decorative plywood (for decorative wall, furniture and cabinet panels) appearance is more important than strength (Tsoumis, 2009) (Forest Product Laboratory, 2010). Both of goghan and kakamut which have high bonding strength, fine texture and good surface quality can be used for manufacturing high quality plywood, which can be used for high quality furniture cabinetry, paneling, internal decorations and joinery. They can also be peeled and used as veneers.

Pulp and Paper

With the increasing demand on pulp and paper a shift of supply to the developing countries is indispensible. In pulp and paper industry successful large scale operations are based on mixed tropical hardwoods. Each available species mix has to be studied economically and technically. Technically the anatomical properties studied (tables 1 and 2) were used in mathematical models obtained by Nasroun, (1978) working on the suitability of seven hardwoods grown in Sudan for pulp and paper manufacturing to estimate some expected paper properties for paper to be produced from the species under investigation. The results obtained are given in table 6.

Table 6. Results of some expected paper properties obtained from the above mentioned models

Spp	B L		T F		S B	
	Unbeaten pulp	30min beating	Unbeaten pulp	30min beating	Unbeaten pulp	30min beating
Di	2978		17.217	81.50	1.98	2.46
Po	2993		21.825	71.33	1.97	1.42
Se	2978		12.674	85.68	2.09	2.67
St	2990		40.60	95.25	1.47	1.63

BL = Breaking length, T F = Tear factor, S B = Sheet bulk, Spp = Species, Di = *Diospyrosmespiliformis*, PO= *Acacia polyacantha*, Se = *Acacia seyalvar. seyal*, St = *Sterculiasetigera*

The breaking length obtained for the four species were higher than the values obtained by Nasroun (1978) for *Acacia nilotica* and *A. seyal* var. seyal, but slightly lower than four other species including *Eucalyptus spp.* tested by the same author for unbeaten pulp. The tear factor results for unbeaten and beaten pulp for 30 minutes were also comparable with the results of the above mentioned study.The same with sheet bulk. According to these results all species can be recommended for pulp and paper manufacturing. But again goghan should not be used for this purpose because it is too valuable for that, except for residues from other processes. These results and others to come will enable us to group similar species for integrated paper industries use mixed hardwoods. Some of these results are higher than what was obtained by Nasroun 1978. This can be explained by the fact that fiber length obtained in this investigation (table 2) was greater than what was obtained in the previous study.

Fiber board

Fiber board manufacturing is species tolerant and does not have any specific requirements with regards to raw material and almost any wood species can be used. This means that all species studied can be used for this industry. However, goghan is too valuable to be used for this industry and therefore should not be used for this purpose.

Conclusions and recommendations

Conclusions

The quality attributes for assigning the different species to the correct uses included; wood strength, stiffness, dimensional stability, gluability, permeability, texture and some fiber anatomical characteristics.

Goghan acquired all the quality attributes for structural utilization, paneling, internal decorations, other decorative uses in addition to high quality furniture, veneer, decorative plywood, carving, handcrafts and others.

Kakamut had similar quality attributes as goghan and can be used for all the above mentioned uses with slight preference to goghan.

Talh with its high density and high strength value can be used for structural purposes. However, it must be treated with preservatives before use as it is susceptible to attack by insect borers. It can also be used for fixed furniture for student seating and at camping sites using mechanical fasteners as its gluing properties are poor. It can also be used to some species tolerant uses such as the manufacture of different types of fiberboard including MDF. It can also be used for pulp and paper as well as different forms of bio-energy. This, in addition to other load bearing items like pit props, pallets, tool handles..etc.

Tartar with its low density and low strength can only be used in non-load bearing partitions and as an insulating material in sandwiched construction. Its density makes it a good raw material for different types of particleboard. It can also be used for manufacturing different types of fiberboard. It also has long fibers which makes it suitable for the production of pulp and paper. This in addition to the production of toys and other small items.

Recommendation

More than 95% of Sudan forests are natural degraded forests. They are stocked with secondary species which are not in use. When the time comes for the rehabilitation of these forests for sustainable management, these species will be removed. Therefore this kind of study should continue to determine the quality attributes for these species and assign each species to the appropriate uses with added value instead of burning them.

For future work we need to continue characterizing these secondary lesser-used species and assign them to suitable uses and thereby increase the number of wood species in use and make it more economical to harvest natural forests and avoid the expected shortage of wood resources for the promotion to sustainable development.

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