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Properties of particleboard based on Date palm fronds as renewable Egyptian lignocellulosic materials

Salem E. Zayed[1], A. A. Adam[2], Entesar A. Hassan[3], and M. A. Elkady[4]

[1]Professor, Chemistry dep., South Valley University, Faculty of science, Quena, Egypt

[2]Nag Hamady Fiberboard co., Quality manger & WBP consultant, Egypt

[3]Lecturer, Chemistry dep., South Valley University, Faculty of science, Quena, Egypt

[4]MSc. Student, Chemistry dep., South Valley University, Faculty of science, Quena, Egypt

ABSTRACT: The main objective of this study was to evaluate the suitability of Egyptian biomass based on Date palm fronds, (Phoenix dactylifera L) for full-scale manufacturing to produce particleboard of requested quality. For the evaluation, Date palm rachises (DPR) and sugarcane bagasse (SCB) were compared for some of the chemical properties, such as holocellulose, Alfa-cellulose, lignin and ash contents, alcohol–benzene extractives, solubility in dilute alkali (1%NaOH), and hot water solubility. In addition, DPR fiber physical properties such as fiber length diameters, cell wall thickness, scanning with SEM, estimate of α-cellulose degree of polymerization (DP) and pH of DPR fibers were determined.

Particleboards were made from DPR and SCB as surface and core layer were prepared and mixed with different percentages of urea-formaldehyde (UF) as a binder. The mechanical properties of produced boards such as density, thickness swelling (TS), bending strength (BS), modulus elasticity (MOE), and internal bond (IB) were measured.

Chemical composition of DPR is slight better than SCB. Moreover, the values of DPR fiber lengths, diameters and cell wall thickness are also in the range of hardwoods values. The results indicated that all the panels met the requirements for Load-bearing boards for use in dry conditions type (P4) of European standard (EN 314: 2010).

KEYWORDS: Alphacellulose; bending strength; Holocellulose; Klason Lignin; modulus elasticity; thickness swelling.

1 INTRODUCTION

The shortage in natural wood resources due to deforestation and the increasing demand for the wood products due to population growth on the other hand, make the international attention is focusing on utilization of agro-residues and recycling of wood waste for manufacture of wood based panel.

In Egypt, with its poor forests resource, high demanding of wood products and high cost price of imported wood, The wood based panel production was started in 1963 based on sugarcane bagasse raw materials in Aswan governorate by Komombo company for particleboard to try solving a part of this problem, But medium density fiberboard (MDF) was started in 1996 to introduce a new type of wood based panel based on sugarcane bagasse raw materials in Quena governorate by Nag-Hamady Fiberboard company (NFB). Recently, due to expansion in other industries based on sugarcane bagasse raw material like paper industry, bio-fuel production, organic materials synthesis like alcohols, vinegar,…etc, All of those make the use of alternative fiber such as agricultural residues like date palm fronds more attractive and feasible to produce wood boards suitable for using in the furniture and construction industries. There are suitable quantities of lignocellulosic residues that are available all over Egypt; where **F.A.O. 2012** reported that the annual production of dates in Egypt equal to 1,470,000 tons, and the total aria cultivated 42,500 hectares (101192.5 feddans) **[1]**.

In addition, lignocellulosic residues are naturally abundant and attractive renewable alternative raw materials for wood board industries because their manufacturing processes can be easily adapted to various types and forms of wood board. Finley from both the economical and environmental point of view, Using of lignocellulosic residues can help to protect the environment and add a money value to this residues.

1.1 CHEMICAL COMPOSITION OF LIGNOCELLULOSIC MATERIALS

Date Palm fronds are Lignocellulosic materials, which can be used as raw materials for many chemical industries especially for manufacturing of wood based panels. The cell wall of any plant composites from three important components, cellulose, hemicellulose, and lignin, add to some cell wall chemicals called extractives.

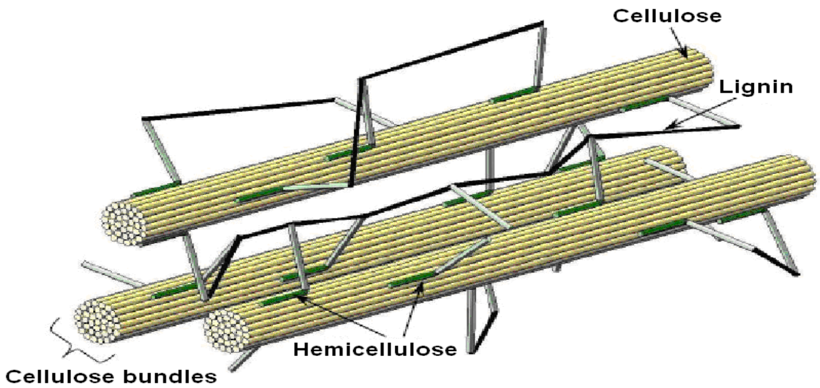


Figure1: Location and Arrangement of cellulose, hemicellulose and lignin in the lignocellulosic material [2], [3].

1.2 CELLULOSE

Cellulose is a high molecular weight linear homopolymer of repeated units of cellobiose (two anhydrous glucose rings joined via a β 1,4- glycosidic linkage) **[4]** (Dabhi, B.K. et al 2014)**.** Most of these polymer chains arrange in parallel and form a crystalline structure, and the rest form a non crystalline regions. The number of glucose units in a cellulose molecule is referred to the degree of polymerization (DP).Wood cellulose has an average DP of at least 9,000 – 10,000 or higher as 15, 000, Thus molecular weight for cellulose ranging from about 10,000 to 150,000 .

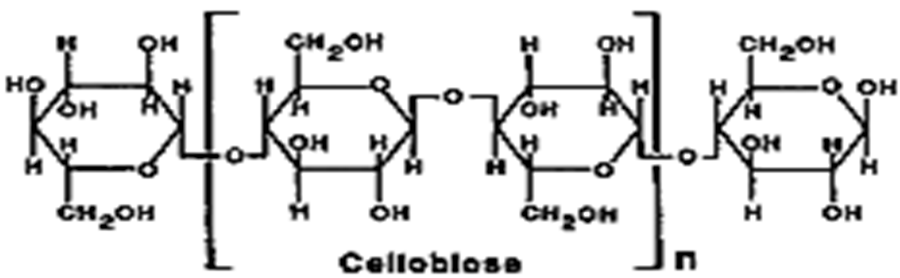


Figure 2. Structure of cellulose

1.3 HEMICELLULOSE

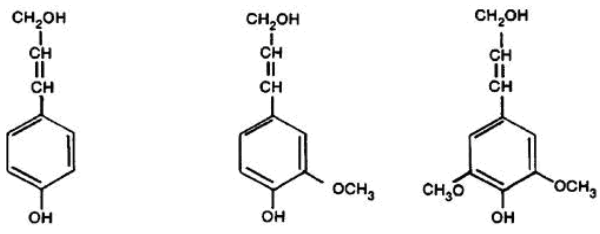
Hemicellulose is a linear and branched heterogeneous polymer typically made up of five different sugars. There are a slightly difference in hardwoods and softwoods hemicelluloses composition. In hardwood, the main hemi cellulose is O-acetyl-4-O-methylglucuronoxylan, called glucuronoxylan or simply xylan. The content of xylan in hardwood wood fibers is about 15-30 %, depending on the species **[5]** (Sjostrom, 1993a). In softwood, the main hemicelluloses are O-acetyl-galactoglucomannan and arabino-(4-O-methylglucurono) xylan, simply called glucomannan and xylan, respectively. The content of glucomannan and xylan in softwood is 20 % and 10 %, respectively. The hemicellulose polymers in wood are much smaller in size than the cellulose, as the hemicelluloses have DPs of 100-200 **[5]** (Sjostrom, 1993b).

1.4 PENTOSAN

Pentosan is polysaccharide compound of pentose sugar units. nonstarchy polysaccharide, hemicellulose and flour gums are the names that have been used to refer to them **[6] (Lehtonen M., Aikasalo R., 1987)**. Mainly pentosan consists of D-xylose and L-arabinose pentose sugars.

1.5 LIGNIN

Lignins are amorphous, highly complex, mainly aromatic polymers of phenylpropane units that are considered to be an encrusting substance. The three-dimensional polymer is made up of C–O–C and C–C linkages. The precursors of lignin biosynthesis are *p*-coumaryl alcohol (Figure 3-a), coniferyl alcohol (Figure 3- b), and sinapyl alcohol (Figure 3-c). Structure (3-a) is a minor precursor of both softwood and hardwood lignins, structure (3-b) is the predominate precursor of softwood lignin, and structures (3-b) and (3-c) are both precursors of hardwood lignin **[7]** (Alder, 1977).



3-a 3-b 3-c

Figure 3. Chemical structures of lignin precursors: (3-a) p-coumaryl alcohol, (3-b) coniferyl alcohol, and (3-c) sinapyl alcohol.

Lignins can be classified in several ways, but they are usually divided according to their structural elements **[5]** (Sjostrom 1993c). Softwood has a range of (28.8 ± 2.6 %) lignin content **[8]** (Rowell M. Roger, 2005a); it is mainly a polymer of coniferyl alcohol called guaiacyl lignin. Hardwood has a range of (23.0 ± 3.0 %) lignin content **[8]** (Rowell M. Roger, 2005b); it is mainly a syringyl-guauacyl copolymer.

1.6 EXTRACTIVES

Wood extractives can be defined as the chemical compounds that are extractable from wood with various neutral solvents **[9] (Monica, Ek, et al 2009)**. Due to they are a group of cell wall chemicals, different specific types of solvents including of water, benzene, alcohol, etc or combination of more than one solvent can be used. They mainly consisting of fats, fatty acids, fatty alcohols, phenols, terpenes, steroids, resin acids, rosin, waxes, and many other of minor organic compounds. These chemicals exist as monomers, dimers, and polymers. In general, softwoods have higher extractives content than hardwoods. Some of these extractives are responsible for the color, smell, and durability of the wood.

2 MATERIAL AND METHOD

This research has been carried out at NFB laboratories and research pilot plan according to the following experimental work.

2.1 SAMPLES COLLECTION AND PREPARATION

The tested Palm fronds raw materials were collected in spring season from local areas in Quena governorate, South of Egypt. To preparing the samples for chemical analysis, Date palm rachises (DPR) were cleaned from leaves and spines. Only rachises were cut into small strips then cut into small chips to be placed in an electrical fiber mill. Bagasse samples were collected from bagasse depither located at NFB. The samples were then placed in a shaker with sieves to pass through a 500-µm sieve. The resulting material was placed and labeled with appropriate code for physical or chemical analysis then samples were subject to the following work.

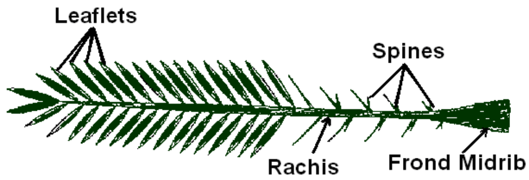


Figure 4. Date Palm frond components

2.2 METHODS

Moisture Content was determined using the oven-drying method according to (ASTM **D4442-92**) **[10]**. Extractives was Determined in two-step extraction process to remove water soluble and ethanol soluble material according **NREL [11]** but it was founded that it was more useful to use mixture of benzene-ethanol 1:1 (**V/V**) instead of ethanol alone, as it is reported in **[12]** (**T 204 cm-97**) the ethanol - benzene mixture appears to provide the most complete removal of residual solvent-extractable substances in pulp. Hot alkali solution extracts (NaOH 1% solubility) was done according **TAPPI, T 212 om-02 [13]**. Holocellulose content & α-Cellulose content were determined according method that descried by **Rowell M. Roger, (2005) [8].** Acid-insoluble lignin (Klason lignin) was determined according **T 222 om-11 [14]**. pentosan was determined according the procedure was describe by **Herbert F. Launer and William K. Wilson (1939) [15]. α-**cellulose degree of polymerization (DP) was determined in Cadoxen soln; The method & Cadoxenn prepation was done according to the procedure described by **Dupont,A-L (2003**) **[16]**. The pH of lignocellulosic fibers was measured by a previous calibrated JENWAY 3505 pH meter with a glass electrode; Five grams of oven dried fiber sample were soaked in a glass beaker with 100 ml of distilled water for 10 minutes at 20 °C. The mixture were stirred from time to time, and then filtered to check the pH value of filtrate. Density of lignocellulosic fibers was determined based on the oven dry weight as Kg/m ^{3}. Observation with SEM was done by using (JEOL, Japan) Instrument, JEOL - JSM-5500 LV scanning electron microscope. The sample introduce to SEM observation as it is with no preparation and it also introduced as pretreated sample. Two types of preparation was used, extractive free simple, or the sample was pretreated with sodium hydroxide 1%.

2.3 PARTICLEBOARD MANUFACTURING

Date palm rachises (DPR) were air dried in sun light for 48 hours, and then cut to 25x25x5 mm chips that suitable size for grinding in mill. Particles for three-layered particleboard were prepared by using laboratory attrition mill; for particle classification a screen shaker with six layers, particles left behind 4 mm and 3 mm screens were reground. The particles that remain on 2 mm and 1 mm sieves were used in core layer while particles on 0.5 and 0.250 mm sieves were used for surface layer .the particles were then dried to a target 3% MC. Constant weight of both core and surface particles were weighted to get target density as shown in table 1.

Three-layer particleboards 400 × 400 × 12 mm with computed density 680 kg/m^3 were produced. For the production of these particleboards, (surface and core particles) from SCB at different variants of resin addition ratio A1, A2 and A3, and compared with these particleboards from DPF at different resin addition variants B1, B2 and B3, were produced under laboratory conditions according to trials parameters, materials for surface and core layer ratio, board density , Urea formaldehyde resin addition , press cycle and press temperature are listed in table 1.

Three Particleboards were pressed from each variant at specific pressure 35 kg/cm^2 by using laboratory press of NBF research plant. After air-conditioning, these boards were cut according to standard sawing pattern into test specimens serving for the subsequent determination of basic physical and mechanical properties. Eighteen test specimens to determine density, swelling.

Table 1: Board manufacturing parameters

sample	Material	SL	CL	BD	BT	SL resin	CL resin	PT	PC
		%	*%*	*Kg/m3*	*mm*	*%*	*%*	*°C*	*Sec*
A1	**SCB**	30	70	680	12	8	6	177	144
B1	**DPR**	30	70	680	12	8	6	177	144
A2	**SCB**	30	70	680	12	10	7	177	144
B2	**DPR**	30	70	680	12	10	7	177	144
A3	**SCB**	30	70	680	12	11	8	177	144
B3	**DPR**	30	70	680	12	11	8	177	144

SL= surface layer particles, Cl= core layer particles, BD= board density, BT= board thickness, PC= press cycle, and PT = press temperature.

2.4 PARTICLEBOARD MECHANICAL PROPRIETIES

Bending strength or modulus of rupture (MOR) and modulus of elasticity in bending test (MOE) were performed according EN 310 **[17]**, but internal bond (IB) and swelling in thickness test were performed according EN 319 [18] & EN 317[19] respectively.

3 RESULTS AND DISCUSSION

The chemical & Physical Characterization of Date Palm rachises (DPR) were compared with those of Sugarcane bagasse (SCB), the conventional raw material, which utilizes in Particleboard and MDF production.

3.1 CHEMICAL CHARACTERIZATION OF FIBERS

DPR have slight low polysaccharides (holocellulose) and lignin content and similar to that of SCB Table 2. The hot water solubility of DPR are higher than those of bagasse and most of hardwoods. The alpha cellulose content of **DPR** are slightly lower than those bagasse and most of hardwoods. In addition, the solubility of **DPR** fiber in hot alkali is lower than that of bagasse.

Table 2: Chemical composition of Date Palm rachises

Test / Material	H.Cell %	α- Cell%	Hemi Cell%	Lignin %	Pentosan %	Water Ex.%	Solvent Ex.%	Total Ex.%	NaOH %	C.W%	Ash %
DPR	69.96	38.99	30.97	18.55	24.79	14.16	1.6	15.76	29.26	13.9	5.82
SCB	74.14	42.58	31.56	18.22	29.22	3.97	1.82	5.79	34.5	3.4	2.85

H.Cell= holocellulose %, α-cell= α-cellulose %, Water Ex & Solvent Ex = water & solvent extractives respectively, NaOH %= solubility in 1 % NaOH, C.W= Cold water solubility.
N.B. hemicellulose content = (H.Cell %) – (α-cell %),Total Extractives = Water Ex% + Solvent Ex %

Date palm rachises are a lignocellulosic material that contains a high level of holocellulose, this high content allows Date palm rachises fibers act as fiber-reinforced materials. Thus, the boards made from date palm rachises composite have suitable mechanical properties and can be introduce as a competitive product in the market.

Date Palm rachis have suitable lignin content (18.55%), which is nearest to Sugarcane bagasse content (18.22%), this lignin content just makes it a building material with higher strength suitable for particleboard manufacturing without undesirable proprieties.

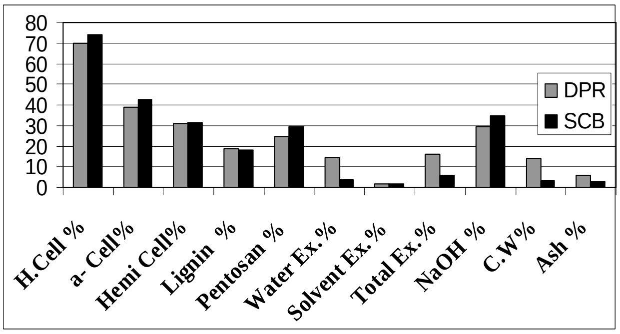


Figure 5: Chemical composition of Date Palm rachises based on data in table 2

Date palm rachis fiber have a suitable hemicellulose and pentosan content (30.97% & 24.79% respectively) comparing with bagasse fibers that are explain the good mechanical properties of produced boards, where they were considered as very important factors for MOR, which is direct proportion with IB.

Date Palm rachis have suitable total extractives content 15.76% where water extractive was 14.16 %and solvent (benzene –ethanol) extractive was 1.6%.This means that the fiber will loss some of undesirable colored materials in during the manufacturing process spatially in the digester sector.

Ash content consider to be an indicator to non-organic materials in a Lignocellulosic fiber which maybe undesirable matter if it presence in very high levels. However, Date Palm rachis has suitable ash content 5.82% and this result was in agreement with those arising from other Lignocellulosic materials.

3.2 PHYSICAL CHARACTERIZATION OF FIBERS

The physical Characterization of **DPR** were compared with those of SCB. As indicated in Table 3, **DPR** are slight higher pH, density & D.P. than SCB.

Table 3: physical composition of Date Palm rachises

Raw material type	pH	Density Kg/m^3	D.P
DPR	5.7	166.8	1200.25
SCB	5.5	160	1099
D.P= degree of polymerization.			

DPR like SCB fiber has suitable pH value, according **[20]** (Maloney T. M, 1989) the increase in acidity of fiber (pH= 4.8 to 4.4) is an undesired in the drying process of the fiber, where acidity of fiber is accelerating the curing of blinder material with the lignocellulosic fiber (pre-curing of glue), therefore the part of the resin content is lost in this process, hence during the hot press, obtained lower mechanical properties and standard non-conformity.

DPR Fiber has density equal to 166.8 Kg/m^3 which is in the Lignocellulosic materials range 190 - 220 Kg/m^3 according **[21]** (**Xanthos M, 2010**).

As listed in Table 4, it was significantly clear that the most DPR fiber properties are similar to those of SCB, conventional raw material, which utilized in production of particleboard and MDF. However, fiber length and cell wall thickness of DPR is some higher than those of bagasse. In addition, DPR lumen width was lower than those of most hardwood and bagasse.

Table 4: fiber Date Palm rachises

Raw material type	Fiber length µm	Fiber width, µm	Lumen width , µm	Cell wall thickness , µm
DPR	1654	29.2	8.6	5.0
SCB	1564	18.17	10.21	2.89

3.3 Observation with SEM

By using Instrument JEOL - JSM-5500 LV scanning electron microscope (JEOL, Japan), the best result is obtained when the sample was pretreated with sodium hydroxide 1% before SEM observation. Figure 5 (SEM microphotograph) explains the surface features of Date Palm rachis. A: general surface scanning view with magnification 35 X .B: showing fiber wood cell with magnification 700x.C: showing fibers, vessel members and ray parenchyma with magnification 500 X. D: showing a longitudinal section of vessel with magnification 300 X.

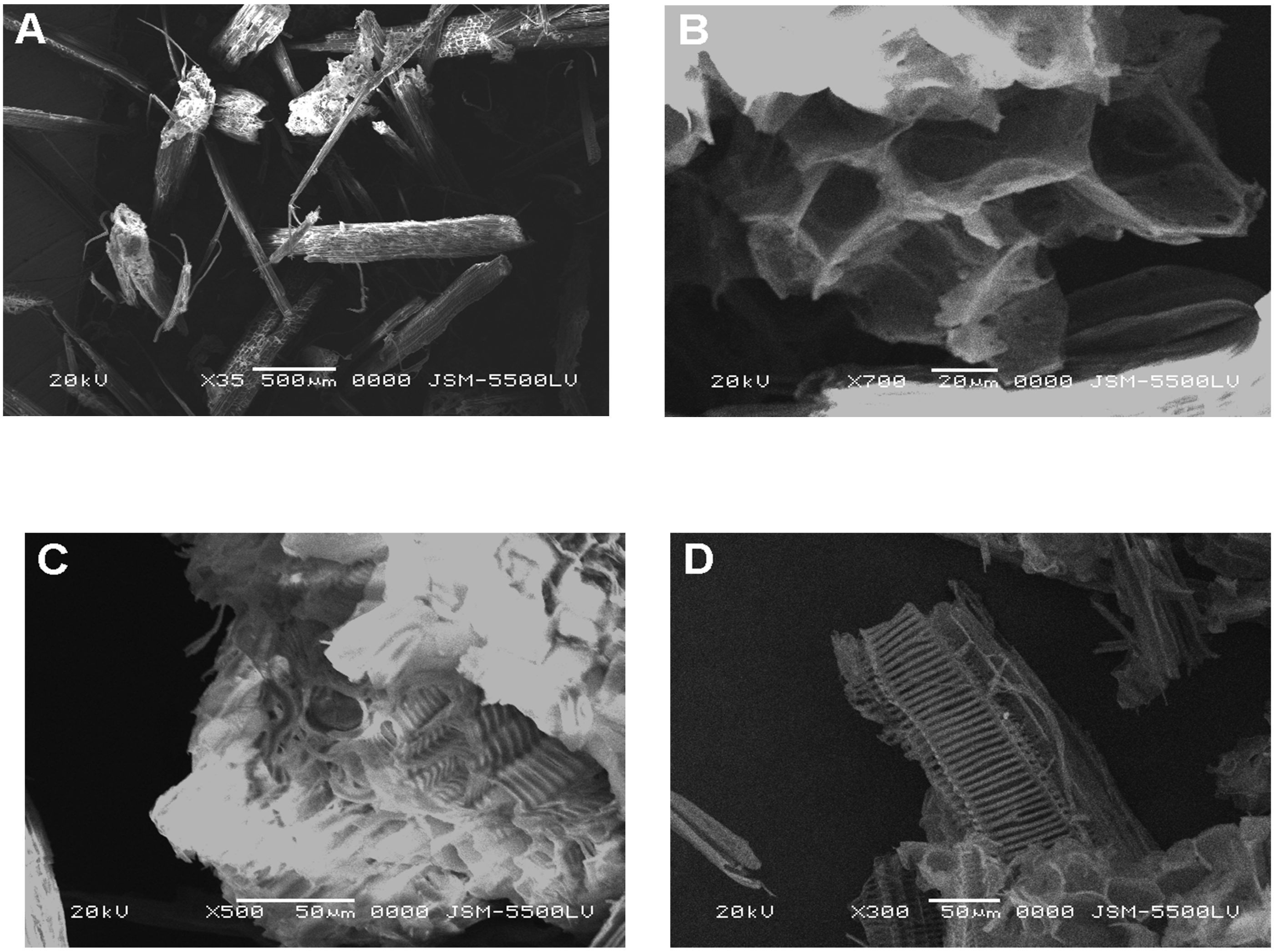


Figure.5: SEM of microphotograph of Date Palm rachis

3.4 MECHANICAL PROPERTIES OF TESTED PANELS

The physical and mechanical of particleboards made from SCB and DPR at different resin levels types A1-A3 and B1-B3 types are presented in Table 5. The results indicate that mechanical properties of DPR boards are slightly higher than those made of SCB and it was clear that the increase in MOR, MOE and IB is related to raw material type and increase in resin level. Nevertheless, both cases, the mechanical properties are satisfied the standard requirements **[17]** (**EN314, 2010**). Results are showed that there is no major difference in thickness swelling and slight enhancement is due to such reasons related to resin level, wax level and board density and both board types are met the standard requirements.

Table 5: Mechanical properties of tested panels

Sample		MOR	MOE	IB	Swelling(24h)
Unit		N/mm^2	N/mm^2	N/mm^2	%
DPR	B1	18.36	2012.33	0.6	9.05
	B2	20.57	2264.33	0.76	8.67
	B3	28.47	3049	0.90	8.44
SCB	A1	16.45	1738.33	0.46	11.47
	A2	21.34	1738.33	0.57	11.41
	A3	27.00	2865.00	0.78	9.43
standard		16	2300	0.4	16

MOR = modulus of rupture , MOE = modulus of elasticity in bending, IB = internal bond , Swelling = swelling in thickness test, & standard = EN 314 standard Type P4**,** with board thickness 10:13 mm. N.B all produced board thickness = 12 mm

4 CONCLUSION

Date palm rachis, which is a residue accumulated in suitable amounts in Egypt; can be a potential material for particleboard manufacturing. Using date palm fibers for manufacturing particleboards are a good solution for raw materials shortage in the Egyptian particleboard industry sector. The mechanical evaluations of UF-bonded particleboards indicate that the product is complied with the European standard requirements **[17]** (**EN 314, 2010**) for Evaluating Properties of particleboard. Finally using renewable materials like date palm rachis for manufacturing particleboards, not only could contribute to reduce the shortage of raw materials for particleboard industry but also add a money value to Palm fronds.

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