Physico-Mechanical Properties of (*Agave Sisalanaia*) Leaves Fibre for Engineering Application

BY

[1]HUSSAINI MUSA SULEIMAN, [1]ABUBAKAR YAHAYA and [2]YAHAYA ABDULHAMID

[1]Department of Agricultural and Bio-Environmental Engineering

Federal Polytechnic, P.M.B. 35, Mubi Adamawa State, Nigeria.

Email; musaspp2013gmail.com.

[2]Department of Agric and Natural resources, Potiskum Local Government Yobe State.

ABSTRACTS

Fibre was extracted from Agave sisalana leaves obtained locally in Adamawa state, Nigeria using water retting extraction procedure. Studies were carried out on its physical and mechanical properties. The parameters evaluated were fiber diameter which was found to range between (1.933 µm to 2.50 µm), lumen width ranged between (1.00 µm to 1.50 µm), from a wall thickness of (0.50 µm). Derived properties computed includes runkle ratio which was found to be within (0.867 to 1.784), slenderness ratio (106.3 to 128.3), and coefficient of flexibility of (56.01 to 74.55), the moisture absorption ranging from 3.00 % to 3.17 % and density ranging from 0.610 g/cm^3 to 3.167 g/cm^3. Mechanical properties determined were force at peak, elongation at break, tensile stress, tensile strain, modulus of elasticity and point of rapture which were found between 3.700 kgf to 8.600 kgf, 2.882 mm to 8.98 mm, 4.88 (kgf) to 5.92 (kgf), 0.0282 to 0.0899, 65.9 (kgf/mm^2) to 206 (kgf/mm^2) and 2.513 kgf to 8.198 kgf respectively. Data obtained were subjected to statistical analysis and graphs were plotted using Matlab R2007b. Statistical package for social sciences (SPSS) was used to determine significantly different means, and the (ANOVA) tables were constructed from which observations and conclusions were made. The results shows that agave sisalana leaves fiber were characterized by high tensile strength, low density, and low moisture absorbency in comparison with other leave fibers in its category. Therefore it is recommended for possible utilization in pulp and paper making, leather embroidery, textile, and automobile product such as break pad, car bumper, and car interior.

Keywords; *Physico-mechanical, Properties, Agave sisalana leaves, Fibre, Engineering application.*

Split Ginger Bread (Hyphaene Thebiaca) Truck as a Reinforcement Member in Concrete short Beams

Introduction

Natural fiber reinforced polymer composites (NFRPCs) have gained a worldwide acceptance as a potential substitute for glass filled composites over past few years especially in the automotive sector. As natural fibers are lesser in weight, easier to handle, nonabrasive and cost effective, composites made from them are also sustainable and economical. Every natural fiber has its own surface morphology which decides the interfacial matrix-fiber adhesion. Brindha, *et al*., (2012). described that the shortage of fibers is due to the fact that, in recent years the research for alternative source of fibres has been increased due to growing shortage of fibres from the wood of forest trees for paper making in many countries. The importance of increasing wood consumption and raw materials availability for the paper industries have resulted in a renewed attention on the benefits inherent in several non-wood fibre plant with annual or biannual harvest (Jorge, et al., 2011).

Materials and Methods

The materials used in this research work include the following; Sisal (*agave sisalana)* leaves obtained locally in Maiha local Government Area of Adamawa State, sisal fibre from the leave, NaOH, H_2SO_4, potassium Sulphate, Safranin red, potassium chromate, HCl, HNO_3, distilled water and water. Tools and equipment used was electronic oven dryer M/C NO.11/084 Mod., Motic electric microscope, material tensile testing machine (Cusson p5030), weighing balance, veneer caliper, sharp knife, water bath and camera.

Fiber extraction

The sisal (*agave sisalana)* leaves was cut from the main stock using a sharp knife object at the base of the stalks at matured leaf length. The leaves were tied in bundles, weighed and submerge in a water pond for a period of three (3) weeks to allow the bacteria and fungi in the environment to remove non cellulose substance. The fiber was extracted from the core by hand stripping, clean and dries as describe by Sahay and Singh (2001), Narendra and Yang (2005) and Paridah *et al*., (2011) and adopted by TAPPI (1980)

Chemical treatment of fibre

After the extraction of the fiber, 400 g of sodium hydroxide (NaOH) was dissolved in 8 $ of distilled water which is equivalent to 5 % preparation of NaOH solution, about 990 g of fibre was immersed into the solution for 48 hours at room temperature as a method described by Ray *et al* (2001) and Mishra *et al* (2001). The fibre was removed from the solution and then dried for 48 hours at room temperature, followed by oven drying at 100°C for 6 hours.

Dimensional analysis of the fibres

In accordance with Ververis *et al.,* (2004), Sharma *et al.,* (2011), for fibre length dimension, small silver was obtained and macerate with 10ml of 67% HNO_3 and boil in a water bath (100

Table* 1. *Determined Fibre dimensional P s

Fibre Length FL (µm)	Fibre Diameter FD (µm)	Fiber Lumen Width FLN (µm)	Fibre Wall Thickness FWT (µm)
153.0	2.167 ± 1.444	1.267 ± 0.844	0.50 ± 0.333
190.0	2.00 ± 1.333	1.00 ± 0.667	0.50 ± 0.333
243.3	2.033 ± 1.356	1.067 ± 0.711	0.50 ± 0.333
265.3	1.933 ± 1.289	1.00 ± 0.667	0.50 ± 0.333
316.7	2.50 ± 1.667	1.50 ± 1.00	0.50 ± 0.333

arameter

Fibre diameter

The mean values of fibre diameter at different stages of fibre length as in Table 1 were 2.167µm, 2.00µm, 2.033µm, 1.933µm, and 2.50µm for the length of 153.0µm, 190.0µm, 243.3µm, 265.3 µm and 316.7µm respectively. The diameter at all stages of length evaluated was higher than that of corn husk fibre ranged between 0.021 µm to 0.15 µm (Taiwo *et al.,* 2014). The result shows that the diameter increases with an increase in fibre length.

Fibre lumen width

The mean values of fibre lumen width of agave sisalana leave fibre evaluated at different stages of fibre length as in Table 1, were 1.267µm, 1.00µm, 1.067µm, 1.00µm and 1.50µm for the length of 153.0µm, 190.0µm, 243.3µm, 265.3µm and 316.7µm respectively. The result in shows that, in all stages of fibre length investigated the lumen width was lower than that of rice husk fibre and wheat straw fibre (Agu *et al.,* 2002). This is also lower than that of corn husk which has short fibres similar to various hard woods, whose length is <2mm, fibre diameter (21.89±5.1µm), lumen width (6.63±3.5µm) and cell wall thickness (7.63±2.3µm) (Taiwo *et al.,* 2004). This is in contrast with the result reported by Sharma *et al.,* (2011) that, lager fibre lumen width produces better in beating of the pulp due to penetration of the liquid in fibre lumen, but in agreement with the report of (Ogbonnaya *et al.,* 1997) that, fibre length, lumen width and wall thickness were not enough to justify the strength of the papers produced from the plant fibres.

Fibre wall thickness

The mean values of fiber wall thickness of agave sisalana leave fibre evaluated at different stages of fibre length were the same at all stages investigated as 0.50±0.333 for length of 153.0µm, 190.0 µm, 243.3µm 265.3µm and 365.7µm respectively. The analysis result in table 1, shows that, the fibre wall thickness in all stages of fibre length investigated were the same irrespective of changes of fibre diameter due to increase in length. This is in agreement with the report of (Msahli *et al.,* 2006) that, the fibre with uniform characteristic perform well where instantaneous force act on the fibre during the use of end product. The result in all cases were higher than that of castor plant fibre and cotton fibre (Maduako *et al.,* 2011), but lower than bambusa tulda (Sharma *et al.,* 2011). Istek, (2006) reported earlier that cell wall thickness governs the fibre flexibility, and thick walled fibre affect the bursting strength and folding endurance of the paper produced from the fibre.

Table 2: Fibre Derived Parameters

Fibre Length (µm)	Runkle ratio (r)	Fslenderness ratio (z)	Coefficient of Flexibility (c)
153.0	**0.867±0.578**	**106.3±70.866**	**56.01±37.34**
190.0	**0.897±0.598**	**110.9±73.90**	**59.04±19.36**
243.3	**1.040±0.690**	**112.4±74.93**	**62.35±41.57**
265.3	**1.250±0.834**	**120.1±80.067**	**72.72±48.48**
316.7	**1.784±1.189**	**1 2 8.3±85.57**	**74.55±49.70**

arameter

Fibre Derived Parameters

Fibre runkle ratio

The values of runkle ratio of the extracted *agave sisalana* leave fibre at different stages of fibre length was presented in Table 2 and were found to be 0.867, 0.897, 1.040, 1.250 and 1.784 for the length of 153.0µm, 190.0µm, 243.3µm, 265.3µm and 316.7µm respectively. This is in agreement with Yang and Saheh, (1998) and Dutt, *et al.* (2009), who investigated on the fibre quality related to runkle ratio and reported that, fibre with runkle ratio less than one (<1) are good for paper making because they are more flexible, collapse easily and form a paper with large bonded area while fibre with runkle ratio more than one (>1) are stiff, difficult to collapse and form bulkier paper with less bonded area. It was observed that, the fibre length of 153.0 µm and 190 µm with runkle ratio 0.867 and 0.897 were good for paper making.

Fibre slenderness ratio

The mean values of slenderness ratio of the extracted agave sisalana leave fibre at different stages of fibre length was presented in Table 2 and were found to be 106.3, 110.9, 112.4, 120.1 and 128.3 for 153.0µm, 190.0µm, 243.3µm, 265.3µm and 316.7µm respectively. This is higher than corn husk ranged between 0.021 µm to 0.15 µm (Taiwo et al., 2014). The result pointed out that *agave sisalana* leaves fibre have excellent slenderness ratio of greater than (>70) due to long length and thin cells of fibre. The slenderness ratio of fibre depends on length and diameter, short and thick fibre do not have good surface contact and fibre bonding (Obonnaya et al., 1997). Maduoko, (2011) pointed out that, the higher the slenderness ratio, the stronger the resistant of tearing paper sheet. It has been observed from the result indicates that the slenderness ratio were ranged between 106.3 to128.3 in all stages of length investigated, and this is in line with the standard of technical association of pulp and paper industries (TAPPI, 1980). It is also in agreement with Xu et al. (2006) that, the slenderness ratio of more than 33 for fibrous materials are considered good for pulp and paper production. It was also observed that, the slenderness ratio of *agave sisalana* leaves fibre increase with increase in length of the fibre.

Fibre coefficient of flexibility

The computed values of coefficient of flexibility of the extracted *agave sisalana* leave fibre at different stages of fibre length were found to be 56.01, 59.04, 62.35, 72.72 and 74.55 for the length of 153.0 µm, 190.0 µm, 243.3 µm, 265.3 µm and 316.7 µm respectively. The values at all stages of length were higher than cotton fibre with 0.015 to 0.025 (Maduako, et al., 2001). The values also fall within the standard rating of elastic fibres (50 – 80) in accordance with Ogbonnaya *et al*. (1997), and Namessan, (2008) who earlier pointed out that, flexibility coefficient of fibre makes fibre processing easy without breakage, and the fibre with low coefficient of flexibility will have negative effect on the tensile and bursting strength as well as folding endurance. It has been observed from the result that fibre at all stages evaluated was highly flexible and satisfies the requirement for suitability in pulp and paper making. This is in agreement with Bektas *et al*. (1999) that, reported earlier that, there are four (4) groups of fibre; High elasticity fibre having coefficient of flexibility >75, elasticity fibre with coefficient between 50-75, rigid fibre between 30-50 and high rigid fibre with <30, in accordance with elasticity rating. Rigid fibres do not have efficient elasticity, therefore unsuitable for paper production, but suitable for fibre plates, rigid cardboards production.**Fibre Moisture regain and Density**

***Table 3*: Determined Fibre moisture absorption and density**

ENGTH (µm)	Mean Moisture absorption (%) (µm)	Mean Density g/cm^3
153.0	3.0 ± 2.000	0.667 ± 0.445

190.0	3.0 ± 2.000	0.654 ± 0.436
243.0	3.0 ± 2.000	0.621 ± 0.414
265.3	3.167 ± 2.111	0.647 ± 0.431
316.7	3.133 ± 2.089	0.610 ± 0.407

arameter

Moisture absorption

The mean values of moisture absorption evaluated at different stages of fibre length was presented in Table 3 and were found to be 3.0 %, 3.0 %, 3.0 %, 3.2 % and 3.1 % for the length of 153.0 µm, 190.0 µm, 243.0 µm, 265.3 µm and 316.7 µm respectively. It was observed that the moisture absorption at all stages investigated were lower than cotton fibre of 8.0 – 25.0 % (Naveen *et al.,* 2014), flax of 6.2 – 7.0 % (Brindha, *et al.,* 2013), and *Agave Americana* with moisture absorption ranged between 8-9% (Ashish *et al.,* 2015). This is in agreement with the report of (Saheb, 1999) that, fibre with low moisture absorption capacity is suited for different application as composite due to its moisture resistance. The analysis of variance (Table 4) shows that moisture absorption is not significant at 5 % probability level.

Fibre density

The density values measured at different stages of length as presented in Table 3, were 0.667 g/cm^2, 0.654 g/cm^2, 0.621 g/cm^2, 0.647 g/cm^2 and 0.610 g/cm^2 for length of 153.0 µm, 190.0 µm, 243.0 µm, 265.3 µm and 316.7 µm respectively. The results revealed that the density of sisal fibre ranged between 0.610 ±0.407 to 0.667±0.445. The results were in agreement with the studies investigated on natural fibres by (Pai, *et al.,* 2015) and reported that, good quality natural fibres most possess good thermal insulation properties, low density, noon abrasive nature, easily available from replenish able sources, recyclable in nature and sustained good application as composite for structural and non-structural applications. The analysis of variance (Table 4) indicates that the density of the fibre investigated at all stages of length were significant at $p \leq 0.05$ level for the replications and not significant for the treatments.

***Table 4*: Analysis of variance (Mean Square) for fibre moisture absorption and density**

Sources of Variation	DF	Moisture Absorption (%)	Density (g/cm^3)
Replication	2	297.295^{ns}	30.045*
Treatment	4	73.492^{ns}	18.075^{ns}
Error	8	10.256	6.013
Total	14		

Fibre Mechanical Properties

***Table 5.* Determined Fibre Mechanical Properties**

FIBRE THICKNESS LEVEL (mm)	FORCE AT PEAK (kgf)	ELONGATION AT BREAK (mm)	TENSILE STRESS (kgf)	TENSILE STRAIN	MODULUS OF ELASTICITY (kgf/mm	POINT AT REPTURE
0.27	3.700±2.4667	2.882±1.8817	5.81±1.3560	0.0282±0.0188	206±1.1092	2.513±1.6757
0.3	85.633±3.7557	3.995±2.6637	4.88±1.1380	0.0400±0.0266	122±1.8103	2.810±1.8733
0.39	6.633±4.4223	7.869±5.2463	5.55±1.2947	0.0787±0.05	2570.5±0.7150	6.286±4.1913
0.41	7.233±4.8223	7.811±5.2073	5.48±1.2787	0.078±0.0520	70.3±2.4200	4.780±3.1867
0.4	48.600±5.7333	8.989±5.9927	5.92±1.3813	0.0899±0.0599	65.9±0.0013	8.198±5.4653

Force at peak

The summary of results for mechanical analysis of *agave sisalana* leaves fibres at different levels of fibre thickness were presented in Table 5. The take-off force at peak for different levels of thickness were 3.700 kgf, 5.633 kgf, 6.633 kgf, 7.233 kgf and 8.600 kgf for the thickness of 0.27 mm, 0.38 mm, 0.39 mm, 0.41 mm and 0.44 mm respectively. The results of forces at peak at all levels of fibre thickness investigated were higher than that of Roselle, Kenaf and Okra (Modibbo *et al.,* 2009). The analysis of variance (Table 6) indicates that, the force at peak was significant at $p \leq 0.05$ probability level. ***Elongation at break***

The load elongation of the fibre investigated at different levels of thickness was presented in Table 5. The elongation at break for different levels of thickness were 2.882 mm, 3.995 mm, 7.869 mm, 7.811 mm and 8.989 mm, for the thickness levels of 0.27 mm, 0.38 mm, 0.39 mm, 0.41 mm and 0.44 mm respectively.

The result showed that the elongation increases with increase in sample thickness of the fibre and viceversa. The result also revealed that load and the braking elongation of the fibre samples increase from 0.200 mm to 2.200 mm and correspond to increase in load, and the point correspond to 0.5400 mm is referred to as yield point. It is in agreement with the reports of (William *et al.*, 1997) that, higher elongation at breaking behavior improved the modulus of elasticity of the fibre in different application, and higher modulus makes fibre stiff and suitable for use as composite materials (Narendra *et al.,* 2009). The analysis of variance (Table 6) indicates that, the fibre elongation at break was not significant at $p \leq 0.05$ level of probability.

Tensile stress-strain properties

The mean values of tensile stress evaluated at different levels of thickness presented in Table 5 and were found to be 5.81 kgf, 4.88 kgf, 5.55 kgf, 5.48 kgf and 5.92 kgf. The strain evaluated were 0.0282, 0.0400, 0.0787, 0.078 and 0.0899, for the thickness levels of 0.27 mm, 0.38 mm, 0.39 mm, 0.41 mm and 0.44 mm respectively. The result shows that, the stress- strain increase and decrease to a certained point, due to fluctuation of cellulose content in the fibre, and this is in agreement with the reports of (Steyn *et al*., 2006) that, tensile properties of agave fibres are not uniform, this can be explain by the fact that, it is a natural fibres and natural fibre are subject to growth irregularities to the extent that fibres from the same plant are not uniform in size and properties. It was also in agreement with (Young *et al*.,1986) that, the outer leaf sheaths of natural fibres produces the strongest fibre while the sheaths produces the weakest fibre, and the innermost fibre have high fracture strain while the peripheral fibre have lower tensile strength. The result also revealed that, the initial stress (5.81 kgf) decrease to 4.88 kgf with an increase in sample thickness and finally increases to 5.92 kgf, while the strain increase with an increase in thickness levels. The analysis of variance (Table 6) indicates that, stress was significant while strain was not significant at $p \leq 0.05$ probability levels.

Modulus of elasticity

The mean values of modulus of elasticity for the fibre at all levels of thickness were presented in Table 5 and were found to be 206 kgf/mm^2, 122 kgf/mm^2, 70.5 kgf/mm^2, 70.3 kgf/mm^2 and 65.9 kgf/mm^2 for the thickness of 0.27 mm, 0,38 mm, 0.39 mm, 0.41 mm and 0.44 mm respectively. The result shows that modulus of elasticity of the fibre at all levels of thickness mentioned were greater than that of flax (18 kgf/mm^2), jute (17.2 kgf/mm^2), cotton (5 – 10 kgf/mm^2) and polyester (13.2 kgf/mm^2) fibres (Ashish *et al.,* 2015). This is also in agreement with the result reported earlier by (Narendra *et al.,* 2009) that, higher modulus of elasticity in fibre makes fibre the stiff and suitable for application as composites and carpet materials. It was observed that, the modulus decrease with increase in thickness level of the fibre sample. The analysis of variance (Table 6) indicates that the modulus of elasticity of the fibre were not significant at $p \leq 0.05$ level of probability.

Point of rapture

The mean values of fibre point of rapture evaluated were presented in Table 5. The rapture at different levels of fibre thickness were 2.51 mm, 2.81 mm, 6.29 mm, 4.78 mm and 8.20 mm for the thickness levels of 0.27 mm, 0.38 mm, 0.39 mm, 0.41 mm and 0.44 mm respectively. The result shows that the fibre point of rapture increase with an increase in thickness level of the fibre sample, and the rapture at all levels ranged between 2.51 mm to 8.19 mm elongation, and load (force) of between 3.700 kgf to 8.600 kgf respectively. The analysis of variance indicates that the fibre point of rapture were not significant at $p \leq 0.05$ level of probability (Table 6).

***Table 6*; Analysis of Variance (Mean Square) for Mechanical Properties**

Sources of Variation	DF	Force at Peak (kgf)	Elongaton at Break (mm)	Tensile Stress (kgf)	Tensile Strain	Mod. Of Elasticity (kgf/mm^2)	Point at Rapture
Replication	2	1214.998^{ns}	1228.771^{ns}	0.6101^{ns}	0.1230^{ns}	2.869^{ns}	753.132^{ns}
Treatment	4	333..654*	365.893^{ns}	0.4842*	0.0363^{ns}	8.595^{ns}	232.804^{n}
Error	8	465.362	472.815	0.8574	3.0402	9.761	^{s}290.64
Total	14						

the leaves obtained locally from Maiha L.G.A of Adamawa state, were studied for its Physico-Mechanical Prop[erties for engineering application. The fibre was extracted using water retting procedure and treated with alkaline (NaOH), from which the following conclusions were drawn;

The fibre runkle ratio in some stages of length (153.0 and 190.0) were less than one (<1) while slenderness ratio in all stages of fibre length were greater than seventy (>70) which is considered good for paper production. It was fond that the fibre has moisture absorption is 3.1 % and the density of 0.64 %, cellulose ranged between 70 – 83 % and this can be used in many applications due to its moisture resistance ability and is within the standard rating system of fibre with 34 % and above.

The mechanical properties determined were force at peak, elongation at break, tensile stress and strain, young's modulus and point of rapture. They were found to range between 3.700 – 8.600 kgf, 2.882 – 8.989 mm, 4.88 – 5.92 kgf, 0.0282 – 0.0899, 65.9 – 206 kgf/mm^2 and 2.51 – 8.198 kgf for force at peak, elongation at break, tensile stress, tensile strain, modulus of elasticity and point of rapture respectively. The results obtained shows that the fibre exhibit high tensile strength and can be used in the production of nets, carpets, rugs, door mats and other woven objects.

Recommendations

Based on this study conducted for characterization of sisal hemp (*agave sisalana*) leaves fibre at different stages of fibre length and thickness, the following recommendations were made;

1. Large scale production of sisal plants should be encouraged to replace the imported fibres and safe the country from foreign exchange.
2. It was recommended for application in piteado technique for leather embroidery and plaster of paris (POP) due to its high tensile strength and low density.

3. Acetylation, acrylation and other chemical treatment should be carried out to evaluate the effectiveness of different fibre treatments that will be suitable for its other applications.
4. Further studies on thermal properties of (*agave sisalana)* leaves fibre should be carried out to suit its ability in other applications in thermoplastic automobile parts and civil engineering works.
5. Based on these finding, the design and construction of machine for processing of sisal fibre should be carried out.

References

Agu, C. V., Njoku, O. U, Chilaka, F.C, Okorie, S. A and Agbiogwu, D. (2012). Physico- chemical characterization of Lignocelluloses fibre from Ampelocissus cavicaulis. (Electronic Version). *International Journal of Basic and Applied Science Vol. 12(3) PP. 68-77.*

Aisha, U, Aleiro, Shehu, B. L., Hauwa, K., Summayya, B., Shuaibu, B. L. and Abubakar M. B. (2013). Seed characterization and proximate analysis of wild castor from Sokoto state. (Electronic Version). *Journal of Environmental Science, Toxicology and food technology (JESTFT) Vol. 3(4); pp. 59-63.*

Ashish, H., Kadole, P. and Pooja, K. (2015). Agave Americana leaves fibers. Open access fiber journal, vol. 3, 64-75. ISSN 2079-6439, www.mdpi.com/journal/fiber.

Avinash, R. Pai, Ramanand N. Jagtap (2015). Surface Morphology and Mechanical Properties of some Unique Natural Fibers Reinforced Polymer Composites. *Journal of Material and Environmental Sciences Vol. 6 (4) PP 902-917.*

Batra, S. K. (1985), Other Long Vegetables Fibres, *Hand book of fibre science and technology. Vol. (4) fibre chemistry. PP. 727- 809.*

Bektas, I., Tatus, A. and Eroglu H. (1999). A study of the suitability of calabrian pine (pinus bruliaten) for pulp and paper manufacturing Turkish. Journal of Agriculture Vol. 23; 589-601.

Brindha D. Vinohini, Alarmelumangai, K. and Malathy, N.S.(2012). Physico-Chemical Properties of fibre from Banana Varieties After scouring. International Journal of Fundamental and Applied Life Science. [Electronic Version] Vol 2(1):217-222.

Brindha, D., Vinodhini, S. and Alarmelumangai, K. (2013), Extraction and characterization of fibre from tree plants species of the genus cleome L. (Electronic version). *Asian Journal of experimental biological science Vol.4 (1); pp. 69-73.*

Drambi, U. (2011). The study of some physic-mechanical properties of African Mohogany (khaya senengalensis). *Unpublished Master's Degree Thesis. Modibbo Adama University of Technology, Yola.*

Dutt, D. Upadhyaya, J. S., Sing, B. and Tyagi C. H. (2009). Studies on Hibiscus canabinus and Hibiscus sabdarifa as alternative pulp blind for soft wood; *An optimization of craft delignification process: Industrial crop produce. Vol. 29. PP.16-27.*

Ishak, M. R.., Leman, Z., Sapuan, S. M., Saleh M. Y. (2009). The effects of Sea water treatment to impact and flexural strength of sugar palm fibre reinforced Epoxy Composite. *International Journal of Mechanical and Material Engineering* Vol. 4; 315-321.

Jorge, G. and Helena, P. (2001). *Cynara Carduncul*us. New fibre crop for pulp and paper production. *Industrial crops and Products* Vol (13) 1-12.

Kolte, P.; Daberao, A.; Sharma, A. (2012), Agave Americana: The natural leaf fibre. Text. Rev. 7, PP 1–5.

Maduako, J. N., Igbanugo, A. B., Mudiare, O.J. and Asota C. N. (2001). Characterization of selected varieties of cotton plant grown in Nigeria for Utilization in paper making. Nigerian Journal of Education Technology. Vol. 2 (2) 46-52.

Mishra, Antaryami, Narayan C. N. (2013), Development and Mechanical Characterization of Palmyra fruit fibre reinforced epoxy composites. Journal of Production Engineering Volume 16 (2). November, 2013.

Mishra S., Misra M., Tripathy S.S., Nayak S.K., Mohanty A.K. (2001). Macromol Mater Eng. 286:107

Modibbo, U. U, Aliyu, B. A. and Nkafamiya, I. I. (2009). The effect of molarization Media on the physical properties of local plant Best fibre. (Electronic Version). *International Journal of Physical science. Vol. 4(11); pp. 698-704.*

Morton, J.F., Ledin, R.B. (1952). 400 plants of south Florida. Text House (Florida) Inc., Coral Gables.

Msahli, S.; Sakli, F.; Drean, J.Y. (2006), Study of textile potential of fibres extracted from Tunisian Agave Americana L. AUTEX Res. Journal ,6, 9–13.

Msahli, S.; Chaabouni, Y.; Sakli, F.; Drean, Y. (2007), Mechanical behavior of Agave Americana L. Fibres: Correlation between fine structure and mechanical properties. J. Appl. Sci. 7, 3951–3957.

Mwaikambo L.Y. and Ansel M.P. (2015), Effects of chemical treatments on the properties of hemp, sisal,jute, and kapok for composite reinforcement, *Journal of Indian Academy of wood science Nov. 2015.*

Namessan, N. O. (2008). Use of kenaf *(hibiscus canabinus)* as base friction material in production of Automobile brake pads. Unpublished Phd. Thesis Modibbo Adama University of Technology, Yola.

Narendra, R. and Yang Y. (2005). Bio-fibre from Agricultural by product for Industrial Application Textile, Clothing and Design publication. *University of Nebraska Lincoln, USA PP. 22-28.*

Naveem, J., Sathishkumar, T. P. and Satheesh, K. S. (2014). *International Journal of Innovative research and Engineering Technology Vol. 3. PP 1091-1095.*

Ogbonnaya, C. and Bosade, A. (2011). Determination of some selected engineering properties of soya beans (Glycine max) Related to design of processing machine. (Electronic version). *Journal of Agriculture, food and technology 1(6); 68-72.*

Ogbonnaya, C., Macauley, R. H. and Nwalozie M. C. (1997). Physical and Historical properties of kenaf, grown under water deficit on a sandy soil. *Industrial crops production* (7), 8-19.

Paridah, M., Tahir, A. B. Syeed, O. A. and Zakiah, A. (2011). Retting process of some Bast plant fibre and its effect on quality; A Review of Bast fibre retting. (Electronic Version). *Journal of Bioresources. Vol. 6 (4) pp 5260-5281.*

Ray D., Sarkar B.K., Rana A.K., Bose N.R. (2001). Bull Mater. Science 24:129.

Sahay, K.M. and Singh K. K. (2001). Unit operation of Agricultural processing. *Vikas publication. House PVT Ltd. New Delhi, India pp. 6-359.*

Sahin, H. and Young R. A. (2008). Auto-catalyzed acetic acid pulping of juice. Industrial crops and products. 28, 24-28.

Saheb D. N. and J. P. Jog (1999). "Natural fibre polymer composites: a review," Advances in Polymer Technology, vol. 18, no. 4, pp. 351–363. *View at Google Scholar*

Sharma, A. K, Dharm, D., Upadhyaya, J. S. and Roy, T. K. (2011). Anatomical, Morphological and Chemical Characterization of Bambusa Tulda Dendrocalamus Hamiltonii, Bambusa Balcooa, Malocana Baccifera, Bambusa Arundinacea and Eucalyptus Tereticorinis. [Electronic Version]. *Journal of Bioresources 6 (4); 5061-5074.*

Steyn, H.J.H. (2006), Evaluation of Conventional Retting versus Solar Baking of Agave Americana Fibres in Terms of Textile Properties. Master's Thesis, University of Free State, Bloemfontein, South Africa.

Taiwo, K. F.,Fagbemi, O. D., Otiojun, D., Mgbachivuzor, E. and Igwe, C.(2014). Pulp and Paper Making Potential of Corn Husk. International Journal of Agricultural Science Vol. 4(4); 129-145.

Tappi, (1980). Standard and Suggested Method. Technical Association of Pulp and Paper Industries, New York, USA. 2(1) 1-19.

Ververis, C., Georhiou, K., Christodoulaku, N., Santas, P. and Santas, R. (2004). Fibre Dimension, Lignin and Celluloses Content of Various Plant Materials and their Suitability to Paper Production. [Electronic Version]. *International Journal of Crops and Products Vol. 19. PP 244-255.*

Xue Li; Lope G. Tabil; Satyanarayan Panigrahi; (2007); *Journal of Polymer Environment, Volume 15, 25–33.*

Yang P. and S. Kokot, "Thermal analysis of different cellulosic fabrics," *Journal of Applied Polymer Science, vol. 60, no. 8, pp. 1137–1146, 1996. View at Google Scholar · View at Scopus.*

Young, R.A.; Rowell, R.M. (1986), Cellulose Structure, Modification and Hydrolysis; Wiley-Inter-Science Publication: New York, NY, USA. pp. 188–189.