

PHYSICOCHEMICAL STUDIES OF EXTRACTED SISAL LEAVES FIBER (*Agave sisalana*) FOR SUSTAINABLE FOOD PACKAGING APPLICATIONS

HUSSAINI, MUSA SULEIMAN¹; GABI, NDANA MUHAMMAD²; ABDULHAMID, YAHYA³; & AYAGI, MUHAMMAD HADI⁴

¹Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic, P.M.B. 35 Mubi, Adamawa State, Nigeria. ²Department of Plant Resources, Agricultural Research Council of Nigeria Mabushi Abuja. ³Department of Agricultural and Natural Resources Potiskum Local Government Area, Yobe State, Nigeria. ⁴Department of Agricultural Engineering, Aliko Dangote University of Science and Technology Wudill, PMB 3244, Kano, Kano State, Nigeria.

Corresponding author: musaspp2013@gmail.com

DOI: <https://doi.org/10.70382/sjratr.v9i1.016>

Abstract

This paper evaluates some physical and chemical properties of extracted sisal hemp leaves fiber for its possible utilization in food packaging applications. The fiber was extracted from *Agave sisalana* leaves obtained locally in a government forest reserves Area, Adamawa state, Nigeria using water retting extraction procedure. Studies were carried out on its physical and chemical properties relevant to food packaging applications. The parameters evaluated were Moisture absorption ranging from (3.00 % to 3.17 %), density ranging from (0.610 g/cm³ to 3.167 g/cm³), fiber diameter which was found to range between (1.933 μ m to 2.50 μ m), lumen width ranged between (1.00 μ m to 1.50 μ m), from a wall thickness of (0.50 μ m). Proximate analysis was carried out for cellulose content, hemicelluloses, lignin and ash content which was found to range between 70.00 % to 83.33 %, 16.67 % to 23.33 %, 55.00 % to 75.00 % and 30.00 % to 30.50 % respectively. Statistical package for social sciences (SPSS) was used to determine significantly different means, and the (ANOVA) table and bar chart for chemical compositions were constructed from which observations, conclusions and recommendations were made. The results show that *agave sisalana* leaves fiber were characterized by low density, high cellulose content, 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, food packaging containers, textile, and automobile products such as brake parts, and car interior.

Keywords: Physico-chemical, sisal hemp, leaves fiber, packaging applications.

Introduction

Fiber is defined as flexible material having a high ratio of length to width and cross section (Herman and Raymond 1988). Fibers has been classified into natural and manufactured. Natural fibers have made a remarkable impact as a potential substitute for conventional synthetic fibers like aramid and glass fiber over decades. Owing to their mechanical properties, good thermal

insulation properties, low density, nonabrasive nature, easy availability from replenish able sources, cheaper prices and recyclability of natural fiber reinforced polymer composites have attracted the composite industry, both for structural and nonstructural applications. The chemical composition of lignocelluloses is inherent according to the particular needs of the plants. Celluloses, hemicelluloses and lignin are the three main constituent of any lignocelluloses source and proportion of these components in a fiber depends on the age, source of the fiber and the extraction condition used to obtain the fibers (Batra, 1985).

Materials and Methods

Materials

The materials used in this research work include the following; Sisal (*agave sisalana*) leaves obtained locally in Adamawa State, sisal fiber from the leave, NaOH, H₂SO₄, potassium Sulphate, Safranin red, potassium chromate, HCl, HNO₃, distilled water and water. Tools and equipment used was electronic oven dryer M/C NO.11/084 Mod., and Motic electric microscope.

Methods

Fiber extraction

The sisal (*agave sisalana*) leaves were 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).

Chemical treatment of fiber

After the extraction of the fiber, 400 g of sodium hydroxide (NaOH) was dissolved in 8 liters of distilled water which is equivalent to 5 % preparation of NaOH solution, about 990 g of fiber 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 fiber was removed from the solution and then dried for 48 hours at room temperature, followed by oven drying at 100°C for 6 hours.

Analysis of fibers physical properties

In accordance with Ververis *et al.*, (2004), Sharma *et al.*, (2011), for fiber length dimension, small silver was obtained and macerate with 10ml of 67% HNO₃ and boil in a water bath (100 ± 2° C) for 10minutes. The silvers were then washed and placed in a small flask with 50ml distilled water and the fiber bundles were separated into individual fiber using a small brush with a plastic end to avoid fiber breaking. The macerated fiber suspension was finally placed on a glass slide (7.5cm X 2.5cm) by means of a rubber pipette. For the fiber diameter, fiber lumen width and fiber cell wall thickness determination, cross sections were obtained from the same height as mentioned above and was stained with 1:1 aniline sulphite –glycerine /safranin red mixture to enhance cell wall visibility. Sisal fibre cell was viewed under calibrated motic electric microscope on ×10 objective lence.

Determination of the fiber Moisture absorption (Regain)

American society for testing and material (1997) standard testing method for moisture regain as reported by Brindha et al., (2013) was adapted to determine moisture absorption of sisal fiber at matured stage. Sisal fiber samples were conditioned for 24hours using ice blocked at $27 \pm 2^\circ\text{C}$ and the weight taken as (L). The conditioned fiber sample was oven dried at temperature of 105°C for 4hrs and the weight was taken as (W). Moisture absorption percentage of the sample was calculated according to equation 2 below;

$$\text{Moisture Absorption \%} = \frac{L-W}{L} \times 100 \quad (1)$$

Determination of the fiber density

Technical Association of Pulp and Paper Industries (TAPPI) standard method was adopted as reported in Modibbo et al., (2009). The density plant fiber at matured stage was determined by conditioning the fiber sample for 24hrs at $27^\circ\text{C} \pm 2^\circ\text{C}$ using water ice blocked before the test was carried. 2g of the sample was accurately weighed out for each fiber sample. The weight was immersed in toluene in a calibrated glass tube (30ml measuring cylinder) and volume of toluene displaced was determined and equal to the volume of sisal fiber immersed. The density of the fiber sample was calculated as follows;

$$\text{Density} = \frac{\text{Mass of fibre}}{\text{Volume of fibre}} \text{ in } g/cm^3 \quad (2)$$

Analysis of the Fiber Chemical Properties

Proximate analysis of the fiber was carried out to determine the percentage content of cellulose (alpha-cellulose), hemicelluloses (beta and gamma cellulose) lignin and ash as described by Technical Association of pulp and paper industries (AOAC 2016).

Determination of cellulose content

The alkali solubility test for Alpha – cellulose which involved treating 3g of sample with 100mls of 18% NaOH at $25^\circ\text{C} \pm 2^\circ\text{C}$, was carried out using water ice blocked. The weight of the undissolved residue which is the alpha-cellulose was expressed as a percentage of the initial weight of the dry ground sample (TAPPI, 1980).

Determination of hemicellulose content

Following the 18% alkali solubility test for the alpha cellulose, the dissolved cellulose portion (aliquot) was collected separately at the end of one hour and treated with 0.1N dilute H_2SO_4 . The treatment caused a precipitate form, which was the beta cellulose. The cleared portion (aliquot) was further oxidized with potassium chromate and potassium iodine was added. The aliquot was back treated with 0.1N solution of potassium thio-sulphate. The titration caused a precipitate form, which was the remaining dissolved gamma cellulose. The weight of the beta and gamma cellulose was added together and got the weight of the hemicelluloses which was then be expressed as a percentage of the initial dry weight of the ground fiber sample (TAPPI, 1980).

Determination of lignin content

The dry specimen of ground sisal fiber was chilled in ice beaker and treated with 38% concentrated HCL, stir and left to cool in the ice under a fume cupboard. Thereafter, concentrated H₂SO₄ was added drop wise to the mixture, stir and left over night at room temperature. The mixture was diluted with distilled water and boiled to coagulate the lignin which was then filtered hot and rinsed alternatively with concentrated HCL and water. The coagulated lignin was dried, weight and expressed as percentage of the initial weight of the dry specimen.

Determination of ash content

Proximate analysis as described by Aisha *et al.*, (2013) was adopted in determining the quality of ash content in the fiber, crucible was washed dried in an oven at temperature of 180°C for 30mins, cooled and then weight as M₀(g). 2g of the fiber sample was placed into the crucible and weighted again as M₁(g). Crucible with the fiber sample, transferred into the muffle furnace whose temperature set at 600°C and allow for 3hrs until the content becomes whitish in colour. Afterward, the crucible was brought out, cooled in the desiccators and weighted as M₂(g). The percentage of ash content was calculated as follows;

$$\% \text{Ash Content} = \frac{\text{Mass of ash (g)}}{\text{Mass of sample (g)}} \times 100 \quad (3)$$

Statistical Analysis

Statistical package for social science (SPSS) was used to determine the analysis of variance (ANOVA) and the means that were significantly different between the samples at 5% level of probability. The chemical properties were subjected to bar-chart and the percentages compositions were determined from which the observations, conclusions and recommendations were drawn for further studies.



Plate I: Sisal Matured Leaves for Fibre Extraction



Plate II: Extracted Fiber from matured sisal leaves.

Results and Discussion

Fiber Physical Properties

Moisture absorption

The mean values of moisture absorption evaluated at different stages of fiber length was presented in Table 5 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 fiber 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, fiber with low moisture absorption capacity is suited for different application as composite due to its moisture resistance. The moisture absorption increases to 3.16 % with further increase of fiber length (265.3 μm) but decrease to 3.133 % at fiber length of 316 μm . this might be due to the differences in fiber diameter from the bottom to the top. The analysis of variance (Table 2) shows that moisture absorption is not significant at 5 % probability level.

Fiber density

The density values measured at different stages of length as presented in Table 1, were 0.667 g/cm², 0.654 g/cm², 0.621 g/cm², 0.647 g/cm² and 0.610 g/cm² 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 fiber ranged between 0.610 ± 0.407 to 0.667 ± 0.445 . The results were in agreement with the studies investigated on natural fibers by (Pai, *et al.*, 2015) and reported that, good quality natural fibers most possess good thermal insulation properties, low density, non abrasive nature, easily available from replenish able sources, recyclable in nature and sustained good application as composite for structural and non-structural applications. It was observed that fiber density decreases with an increase in fiber length. The analysis of variance (Table 2) indicates that the density of the fiber investigated at all stages of length were significant at $p \leq 0.05$ level for the replications and not significant for the treatments.

Table 1. Determined Fiber Physical Properties

FIBRE LENGTH (μm)	Mean Moisture absorption (%)	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

Table 2. Analysis of variance (Mean Square) for fiber 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		

Table 3. Determined Fiber Chemical Properties

Parameters	Base T ₁	Middle T ₂	Top T ₃
Cellulose (%)	83.33±55.553	76.67±51.113	70.00±46.667
Hemicelluloses (%)	17.77±11.847	23.33±15.553	16.67±11.113
Lignin (%)	75.00±50.00	55.00±36.667	65.00±43.333
Ash (%)	30.50±20.333	30.50±20.333	30.00±20.000

Celluloses content

The mean values of cellulose content of *agave sisalana* leaves fiber as shown in Table 4 were 83.33%, 76.67% and 70.00% for the fiber length at base, middle and top respectively. The celluloses content decrease from the base to top level of the fiber as presented in Figure 1. The values in all stages were lower than seed flax, kenaf, ramie, jute, abaca, but fallen within the ranged of Henequen, fiber flax (Xue *et al.*, 2007), *Agave Americana* (Ashish *et al.*, 2015). The content in all stages investigated were 70% and above, this is in agreement with (Ververis *et al.*, 2004) and (Sharma *et al.*, 2011) that, investigated plant materials using standard rating system and recommended that plant material with 34% and above cellulose content were characterized as promising plant for pulp, paper manufacturing as well as good and biodegradable packaging of various kind from chemical composition point of view. It was observed from the results that the cellulose content was high in comparison with other plant fibers, and the higher the cellulose content the smaller the fiber diameter and proves that the fiber will be stronger in accordance with (Ishak *et al.*, 2009). Also, in agreement with the report of (Mohanty *et al.*, 2000) that, cellulosic fibers change their dimensions and properties with varying moisture content.

Hemicellulose content

The hemicellulose content of *agave sisalana* leaves fiber as shown in Table 4, were 17.77 %, 23.33 % and 16.67 % for the fiber length at the base, middle and top respectively. The hemicellulose content increases from the base level to the middle and decrease to top level. This is in agreement

with the reports of (Ebringerova *et al.*, 2000) that, hemicellulose content of plant fluctuate due to presence of sugar, glucose, xylems, galactose, arabinose in its composition. It was observed from the result in Figure 1 that, in all stages investigated the hemicellulose content was higher than henequen with 4-8 %, abaca with 15-17%, ramie 5-16.7 %. But lower than seed flax 30 – 45%, (Xue, *et al.*, 2007). It was also observed that, the hemicellulose content of the fiber was very low, and this is in agreement with (Agu *et al.*, 2012) that, low hemicellulose content in fiber is responsible for less water absorbing capacity which has advantages in utilization in different applications as composites.

Lignin content

The values of lignin content determined were presented in Table 4 and were found to be 75.00%, 55.00% and 65.00% for the fiber length at base, middle and top respectively. The result showed that the lignin content decreased from base to the middle and increase to the top level (Figure 1). But in all cases investigated the lignin was higher than pineapple crown leaves, rice straw, kenaf and bagasse (Khristova *et al.*, 2002; Tran, 2006; Huang, *et al.*, 2007). Lignin content in fiber improved the fiber strength and makes it suitable for paper making and other strong applications (Waranyou, *et al.*, 2010).

Ash content

The values of ash content determined as shown in Table 4 were 30.50 %, 30.50 % and 30.00 % for the fiber length at the base, middle and top respectively. The result shows that the ash content at the base and middle were the same, but decrease with 0.50 % at the top. The content was higher from the base to the middle and lower at the top level as presented in Figure 1. This is in agreement with (Steyn *et al.*, 2006) that, natural plant fibers are subject to growth irregularities to extent of the same plant possess different sizes and properties. The content in all stages investigated were higher than borassus fiber with 0.64 %, rice straw with 9.2 %, jute leaves with 8.8 % (Basak *et al.*, 1996), kenaf with 4 % (Khristova *et al.*, 2002) and bagasse with 1.5% (Khristova, *et al.*, 2006). Chemically sisal leaves fiber was rich in cellulose, and the higher the cellulose, the higher the ash content and vice versa (Waranyou, *et al.*, 2010). The higher the ash content, the easier the processing techniques of materials during application (Nameesan, 2008). It was observed that, sisal fiber has high ash content in comparison to other natural plant fibers, therefore, it will have good processing ability in most of its applications.

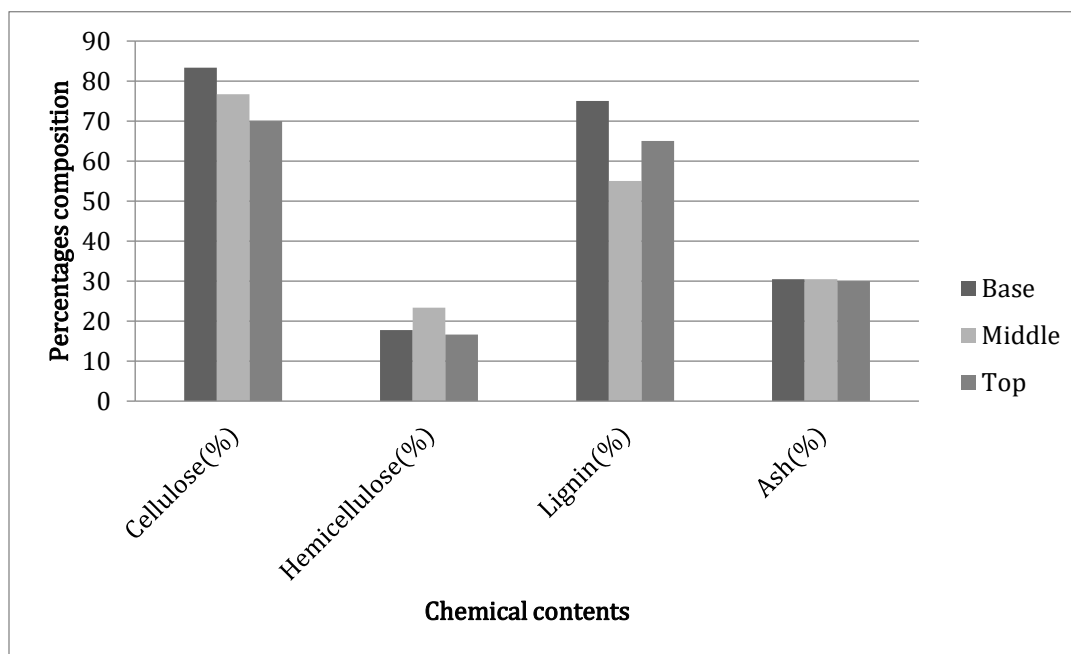


Figure1 Chemical Properties Distribution Chart

Conclusions and Recommendations

Conclusions

Agave sisalana leaves fiber extracted from the leaves obtained locally from Maiha L.G.A of Adamawa state, were studied for its physico-chemical properties for engineering application. The fiber was extracted using water retting procedure and treated with alkaline (NaOH).

The following conclusions were drawn; the fiber runkle ratio in some stages of length (153.0 and 190.0) were less than one (<1) while slenderness ratio in all stages of fiber length were greater than seventy (>70) which is considered good for paper production. It was found that the fiber 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 fiber with 34 % and above. Fiber cellulose content with this percentage is characterized as promising plant for pulp and paper manufacturing from the chemical point of view.

Recommendations

Based on this study conducted on Physico-chemical properties of sisal hemp (*agave sisalana*) leaves fiber at different stages of fiber length and thickness, the following recommendations were made;

- It was recommended for pulp and paper making, disposable packaging containers as well as combine mixtures in plastics packaging due to its high cellulose content $>70\%$.
- 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.
- Based on these findings, the design and construction of machine for processing of sisal fiber 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 fiber 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 Fibers, *Hand book of fiber science and technology. Vol. (4) fiber chemistry. PP. 727- 809*.
- Brindha D. Vinohini, Alarmelumangai, K. and Malathy, N.S.(2012). Physico-Chemical Properties of fiber 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 fiber from tree plants species of the genus *cleome L.* (Electronic version). *Asian Journal of experimental biological science* Vol.4 (1); pp. 69-73.
- Ebringerova, A. and Heinze, T. (2000). Xylan and Xylan Derivatives Biopolymers with valuable Properties. *Macromol Rapid Communication* 21; 542-556.
- Huang, G. L., Shi, J. X. Langrish, T. A. G. (2008). Environmentally friendly bagasse pulping with $\text{NH}_4\text{OH-KOH-AQ}$. *Journal of cleaner production*. Vol. 16, 1287-1293.
- 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.
- Khristova, P., Kordsachia, O., Pattb, R., Karar, I. and Khider, T. (2006), Environmental friendly pulping and bleaching of bagasse, *Industrial crops and products*,
- Khristova, P., Kordsachia, O., Pattb, R., Khider, T. and Karar, I (2002), Alkaline pulping with additives of kenaf from Sudan, *Industrial crops and products*, Vol. 15, PP 229-235.
- Maduako, J. N., Igbunugo, A. B., Mudiare, O.J. and Asota C. N. (2011). 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 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 fiber. (Electronic Version). *International Journal of Physical science. Vol. 4(11); pp. 698-704*.
- Mohanty, A. K, Misra, M. and Hinrichsen, G. (2000). Biofibres, Biodegradable polymers and Biocomposites; *An overview macromol mater Eng. 276/277 pp 1-24. Online.library.wiley.com*.
- Msahli, S.; Sakli, F.; Drean, J.Y. (2006), Study of textile potential of fibers extracted from Tunisian Agave Americana L. *AUTEX Res. Journal* ,6, 9–13.
- Namesan, N. O. (2008). Use of kenaf (*hibiscus cannabinus*) 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-fiber 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., 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 fiber and its effect on quality; A Review of Bast fiber 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 fiber 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 Tereticornis. [Electronic Version]. *Journal of Bioresources* 6 (4); 5061-5074.
- Steyn, H.J.H. (2006), Evaluation of Conventional Retting versus Solar Baking of Agave Americana Fibers 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.
- Tran, A. V. (2006). Chemical Analysis and pulping study of pineapple of crown leaves. *Industrial crops and products*. Vol. 24, PP 66-74.
- Raymond, B.S. and Herman, F.M. (1988), Application of polymers plenum publishing corporation 233 New York USA PP 5-13.
- Ververis, C., Georhiou, K., Christodoulaku, N., Santas, P. and Santas, R. (2004). Fiber 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.
- Waranyou, S. (2010), Songklanakarin Journal of Science and Technology Volume 32 (2) Pages 201-205.
- Xue Li; Lope G. Tabil; Satyanarayan Panigrahi; (2007); *Journal of Polymer Environment, Volume 15, 25-33*.
- Zwane, P.E.; Masarirambi, M.T.; Magagula, N.T.; Dlamini, A.M.; Bhebhe, E. (2011), Exploitation of Agave Americana L. plant for food security in Swaziland. *American Journal Food Nutrition*. Vol.1, PP. 82-88.