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Chemical Composition of Lowland Bamboo (*Oxytenanthera abyssinica*) Grown around Asossa Town, Ethiopia

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ABSTRACT

The selection of bamboo species for various applications in the chemical and biochemical related industry is related to the chemical composition. This research was carried out to study the major chemical compositions of bamboo culms grown around Assosa town in Ethiopia. Lowland bamboo (*Oxytenanthera abyssinica*) samples were harvested, sorted, dried, milled using Wiley Mill, sieved and all chemical characteristics were determined in accordance with the standards outlined in ASTM except Kurchner-Hoffer and Alkali extraction method for cellulose and hemicellose determination, respectively. From the study it showed that the average results of the main chemical composition (Cellulose, Hemicelluloses and Lignin) were 52.06, 16.90 and 22.47%, respectively. The Ash content of *Oxytenanthera abyssinica* was 5.30% while the extractives content (Hot-water & Alcohol-toluene solubility) was 6.80 and 5.60%, respectively.

***Keywords*:** Chemical composition, Cellulose, Hemicelluloses, Lignin, *Oxytenanthera abyssinica*

1. INTRODUCTION

Worldwide more than 1,500 species and 90 genera of bamboos are found, covering 36 million hectare (ha) of land which is distributed in the tropical and sub-tropical belt between 46° north and 47° south latitude at elevations as high as 4000 m above sea level (FAO, 2007; Ohrnberger, 1999). Africa has about 43 species of bamboo covering about 1.5 million hectares (Kigomo, 1988). Forty of these species are primarily distributed in Madagascar while the remaining three species are found in mainland Africa. Bamboo forest in Ethiopia is the largest in Africa and it has two indigenous bamboo species: the highland bamboo (*Yushania alpina*) and the lowland bamboo ***(****Oxytenanthera abyssinica*) (Fig. 1). Out of which the high land bamboo comprises about 130,000 ha and low land bamboo covers over 850,000 ha (Ensermu et al., 2000; Kassahun, 2003). This means that 86% of the African bamboo resource is found in Ethiopia, corresponding to approximately 7% of the global bamboo resource. The country can sustainably produce three million cubic meters of dry weight annually from its two commercially important bamboo species: *Yushania alpina* and *Oxytenanthera abyssinica* (FAO, 2005 and 2013).

The selection of bamboo species for various applications is not only related to physical and mechanical properties but also to the chemical composition. The bamboo cell walls mainly consist of between 90 to 98% cellulose, hemicelluloses and lignin, while the other 2 to 10% are mainly of extractives, resins, tannins, waxes and inorganic salts (Razak et al., 2009; Liese, 1985, 1992; Tomalong et al., 1980). Compared with wood, however, bamboo has higher alkaline extractives, ash and silica contents (Malanit et al., 2009; Amu and Babajide, 2011).

The chemical composition of bamboos also has an influence on deciding what kinds of bamboos with which kind of material in combination is suitable for the utilizations. The difference lies in the percentages of each component and their micro structures. Some variation in chemical composition changes according to the type of bamboo species, geographical location, the age (maturity) and the parts of bamboo. The variation of bamboo's chemical composition has a big influence on the physical and mechanical properties of bamboos and therefore the treatment and utilization of bamboos (Liese, 1985). The hemicelluloses and cellulose are actually made of the carbohydrate polymers which made up of simple sugars monomer to form the linear structure of cellulose and the short and branched forms of hemicellulose (Browning, 1975 and Fengel, 1983).

Cellulose is a polymeric carbohydrate, a polysaccharide with repeating units of glucose or it is a linear polymer of D-glucose units linked by β-1, 4-linked glucose. Cellulose molecules are relatively linear and have strong tendency to form intra and intermolecular hydrogen bonds. Bundles of cellulose molecules are thus aggregated together in the form of micro-fibrils, in which highly ordered (crystalline) regions alternate with less ordered (amorphous) regions. As a consequence of its fibrous structure and strong hydrogen bonds cellulose has a high tensile strength and is insoluble in most solvents. Orientation of the linkages and additional hydrogen bonding makes the polymer rigid and difficult to break (Hamelinck et al, 2005; Sjostrom, 1981; O'Sullivan, 1997).

Hemicelluloses are heterogeneous polymers of pentoses (Xylose, Arabinose), hexoses (mannose, glucose, and galactose) along with acetyl groups (CH_3CO) and sugar acids (uronic acids) (Theliander et al., 2002).

Figure 1. *Oxytenanthera abyssinica*

Among softwood hemicelluloses there are galactoglucomannans, arabinoglucuronoxylan, and arabinogalactan, meanwhile hardwood hemicellulose comprises mainly glucronoxylans and glucomannan (Saha and Bothast, 1997).

Lignin is the cementing substance between fibres and tissues and is concentrated mainly in the region of the middle lamella and imparts rigidity to wood tissue. Lignin exists in plant as branched chain polymer molecules. Hardwood lignin consists of coniferyl and sinapyl structures whereas coniferyl structure is the dominating softwood lignin component. Isolated lignin, in general, are amorphous and non-crystalline, and show definite softening points at elevated temperatures (Sjodahl, 2004).

Extractive along with cellulose, hemicelluloses and lignin solid material of bamboo includes less than 3%-5% which contribute to properties such as colour, smell, decay resistance, density and flammability. Extractives can be classified as lipophilic or hydrophilic organic compounds, which can be extracted from the samples by using neutral (non-polar), organic solvents (methyl-tert-butyl ether, acetone, benzene, tetrahydrofuran) or water, respectively. Water soluble extractives are, among others, some carbohydrate of non-cell wall structural components and tannins. In contrast lipophilic extractives are classified into aliphatic hydrocarbons, fatty alcohols, fatty acids, resin acids and sterols as well as fats and waxes (Harinen, 2004).

Ash is a term generally used to refer to inorganic substances such as silicates, sulfates, carbonates, or metal ions (Rydholm, 1965). The fraction of inorganic compounds also called ash constitutes of Ca, K, Mg, P, Mn, Fe, Si, Al and Na salts and the actual composition varies between wood species and is also influenced by the local compositions of the soil (Theliander et.al., 2002).

The present study was conducted to evaluate the major Chemical components of *Oxytenanthera abyssinica* for holistic production and utilization use of the materials in the forest industry sector and help to boost their utilization in the chemical and biochemical related industry.

2. MATERIALS AND METHODS

2. 1. Sample Collection and Preparation

Oxytenanthera abyssinica, the main raw material for the present study is available in Ethiopia grows in the western part along major river valleys and in the lowlands bordering Sudan. The representative *O. abyssinica* samples used for this study were collected from Gembeshere, Afasezim and Abrhamo kebeles around Assosa town of Benishangul Gumuz region.

Bamboo stems from 3 years old of lowland bamboo samples were harvested from Assosa areas. Then the harvested bamboo culms were dried. The bamboo culms for chemical analysis were cut into small strips with knife. The strips were small enough to be placed in a Wiley Mill. Bamboo chips were ground in the Wiley mill and the size of the samples must be small to make sure the reaction reagent and fibres are occurring with optimum during the analysis. The powder was then placed in a shaker with sieves to pass through a No. 40 mesh sieve (425 μm) yet retained on a No. 60 mesh sieve (250 μm). The resulting material was stored in glass bottles labeled with appropriate code for chemical analysis. The chemicals composition analysis was used on the bamboo fibre. This method were divided into five (6) stages namely, the material preparation, determination of extractive (hot-water and alcohol-toluene), hemicellulose, cellulose, lignin and ash contents.

2. 2. Characterization of *Oxytenanthera abyssinica* Chemical Composition

Following standards of American Society for Testing and Materials (ASTM) shown in the below table, Alcohol-toluene soluble and Hot-water extractive content, Ash content, and Lignin content were determined. While Hemicellulose and Cellulose content was determined according to alkali extraction and Kurchner-Hoffer method (Brown, 1975), respectively and there was a minor modification for alcohol-toluene solubility of bamboo extractive content test. Toluene was used instead of benzene and reported as alcohol-toluene extractives. The amounts were expressed on a percentage basis of the starting oven-dry mass. The exact standard that was followed for each chemical property performed is presented in Table 1.

Table 1. Standards methods used for chemical analysis of bamboo culms

Property	Standard
Alcohol-toluene solubility *	ASTM D 1107-56
Hot-water solubility	ASTM 1110-56
Klason lignin	ASTM D 1106-56
Hemicellulose	Akali Extraction
Cellulose	Kurchner-Hoffer
Ash Content	ASTM D 1102-84

Each test was conducted using 3 replications. It was necessary to conduct additional experimentation when analyzing for alcohol-toluene extractive content. Since, both the lignin and Hemicellulose content test are performed with extractive-free bamboo that is derived from the alcohol-toluene extractive test.

3. RESULTS AND DISCUSSION

3. 1. Chemical Composition of *Oxytenanthera abyssinica* Culms

Table 2. The chemical composition of (*Oxytenanthera abyssinica*) from Assosa (Ethiopia).

Property	Assosa site, Ethiopia	Africa*
Hot-water solubility %	6.80	6.5
Alcohol-toluene solubility %	5.60	2.7
Cellulose %	52.06	n.a
Hemicelluloses %	16.90	12-33
Lignin %	22.47	15-27
Ash %	5.30	1-4

n. a not available and *Source: Louppe, et al., (2008) A Comprehensive knowledge and information on the chemical composition of bamboo is important as far as its utilization for chemical and biochemical is concerned. Similar to other lignocellulosic materials, the primary components of *Oxytenanthera abyssinica* are cellulose, hemicelulose, and liginin. The average values for the chemical composition of *Oxytenanthera abyssinica* from Assosa, Benishangul gumuz region are given in Table 2. (The results were based on average values of three replicates, errors lower than 1% in all components, weight percent on dry basis). In general, non-woods differ somewhat from woods in their chemical composition and properties.

In this section, the results of *Oxytenanthera abyssinica* culms chemical composition was investigated and discussed in detail here under.

3. 1. 1. Hot-water solubility

The hot-water extraction removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars and starches, present in bamboo. The results of hot water soluble extractive of *Oxytenanthera abyssinica* (6.8%) is in good agreement compared to that from Africa (6.5%). The results of *Oxytenanthera abyssinica* agreed with that reported by Dhamodarn et al., (2003) 3.1-7 % but higher than bamboo 5.8% by Karar (2004). Soluble hot water extractive of *Oxytenanthera abyssinica* from Ethiopia is higher than from Africa. Such variations in plants exist with geographical location and plant portion.

3. 1. 2. Alcohol-toluene extractives

The alcohol-toluene extractives of bamboo consist of the soluble materials, not generally considered part of cell structural components bamboo substance. These are primarily the waxes, fats, resins and some gums as well as some water soluble substances. No single organic solvent is capable of removing all these substances, and different solvents remove only soluble components in their solubility range of polar to non-polar. The mixture, ethanol-toluene, appears to provide the most complete removal of residual solvent-extractable substances in bamboo.

The result of alcohol-toluene soluble in *Oxytenanthera abyssinica* (5.6%) are higher than those in wood, such as poplar with the benzene-alcohol extractive content of 2.14% (Gong, 2007) and Africa (2.7%), but lower than that in grasses, such as rice straw with the benzene-alcohol extractive content of 7.45% (Liu et al. 2003). This results agreed with that reported by Dhamodarn et al (2003) 0.3-7.8 %, but higher than Karar (2004) 3.2 %. This indicated that *Oxytenanthera abyssinica* contained more substances like waxes, fats, resins, phytosterols, non-volatile hydrocarbons, low-molecular weight carbohydrates, salts, and other water-soluble substances. Wax material attached to the inner layer also contributed to the higher alcohol-toluene extractive content relative to the middle and outer layers. Higher alcohol toluene extractive in bamboo may be advantage for anti-decay and it will provide good strength in fiber processing because of its higher specific gravity. Generally the higher soluble extractive content (tannins, gums, sugars, starches and coloring matter) present in bamboo and indicated easy access and penetration of chemicals to the cell wall materials. Extractives may be converted into pitch, which can adversely affect the runnability of process equipment by choking the wire. Therefore, more attention should be given to the extractives in *Oxytenanthera abyssinica* during the manufacturing of like dissolving pulp.

3. 1. 3. Cellulose content

Understanding the cellulose characteristics of bamboo is fundamental to its use as a feedstock. Cellulose is the main constituent of bamboo. Approximately 40-55% of the dry substance in bamboo is cellulose. Cellulose is a homopolysaccharide composed of β-D-glucopyranose units which are linked together by (1→4)-glycosidic bonds. Cellulose molecules are completely linear and have a strong tendency to form intra- and intermolecular hydrogen bonds. Bundles of cellulose molecules are thus aggregated together in the form of microfibrils, in which crystalline regions alternate with amorphous regions. Many cellulosic materials consist of crystalline and amorphous regions in different proportions, and these crystalline and amorphous regions affect the accessibility and chemical reactivity (Ciolacu et al., 2011).

The results of cellulose of *Oxytenanthera abyssinica* was high (52.06%) which indicate that bamboo species can be acceptable raw material for cellulosic based products. The result of cellulose content of *Oxytenanthera abyssinica* agreed with the results of Schott (2006) 50-70 %, but higer than that reported by Robert (1996) 50% and lower than by Judt (1993) 57-66%, Hurter (2001) 57-66%, Okubo et al., (2004) 60.8% and Yang et al., (2008) 57-66%. The thick cell wall cause for the increase of holocellulose content which is one of the major components of cell wall. The range of cellulose contents implies that bamboo can be regards as a suitable raw material for pulp and paper industry (Li et al. 2007).

3. 1. 4. Hemicelluloses content

Hemicelluloses are heterogeneous polysaccharides, unlike cellulose, most hemicelluloses function as supporting materials in the cell walls. The result of hemicellulose of *O. abyssinica* was (16.9 %). This result showed that it is in the range (12-33) of *O. abyssinica* of Africa. The result of hemicellulose of *Oxytenanthera abyssinica* agreed with Judt (1993) 15-26 %, Hurter (2001) 15-26% and Dhamodarn et al., (2003) 16-21%, but disagreed with Schott (2006) 20-30% and Yang et al., (2008) 20-25%.

3. 1. 5. Klason Lignin Content

Lignin is one of the structural components of cell wall and is polymer of phenylpropane units. Many aspects in the chemistry of lignin still remain unclear. Klason lignin is obtained after removing the polysaccharides from extracted (resin free) wood by hydrolysis with 72% sulfuric acid. The Lignin in *O. abyssinica* isolated from extractive free sample as an insoluble residue after hydrolytic removal of the polysaccharides. Bamboo lignin is built up from three phenyl-propane units, p-coumaryl, coniferyl and sinapyl alcohols interconnected through biosynthetic pathways (Liese, 1987). Determination of lignin content in raw materials provides information for evaluation and application of the processes. The results of lignin content in *Oxytenanthera abyssinica* was 22.47 % which, place bamboo at the high end of the normal range or 11-27% reported for non-woody biomass (Bagby, 1971) and closely resemble the ranges reported for softwoods (24-37%) and hardwoods (17-30%) (Li et al., 2007; Fengel, 1984 and Dence, 1992). This results agreed with and found in the range reportes of Judt (1993) 21-31%, Hurter (2001) (21-31%), Dhamodarn et al., (2003) 20-30%, Schott (2006) 20-30% and Yang et al., (2008) 20-30%, but disagreed by Okubo et al., (2004) 32.2%. The high lignin content in bamboo contributes to its structural rigidity, making it a valuable building material (Scurlock et al., 2000).

3. 1. 6. Ash content

Ash is a term generally used to refer to inorganic substances such as silicates, sulfates, carbonates, or metal ions. It has been suggested that the higher ash content in bamboo chips is mainly due to the fact that almost all silica is located in the epidermis layers (Satish et al., 1994). The inorganic components of wood are generally expressed as percentage of ash, based on dry weight of the sample. Briefly, the ash constituents had a detrimental effect on the processing and quality of chemical and biochemical products. Consequently, the amount of ash in the raw material will indicate the measure to be taken during processing.

The results of the ash content of *Oxytenanthera abyssinica* was higher (5.3%) compared to that from Afirca (1-4 %). This result is within the range of reports made by Liese (1998) 0.8-9.7 % and Dhamodarn et al., (2003) 1.0-9.0 %. However, the result of ash content of *O. abyssinica* is higher with Judt (1993) 1.7-4.8 %, Hurter (2001) 1.7-5% Karar (2004) 4.6 % and Yang et al., (2008) 1-3 %. This result indicates the soil was rich in mineral salts and inorganic matter.

4. CONCLUSIONS

This work was intended to study the chemical composition of *Oxytenanthera abyssinica* grown around Asossa Town of Benishangul Gumuz region. The potential use of *Oxytenanthera abyssinica* that it is a fast growing plant, with short harvesting time and good chemical composition properties like cellulose content make it cost effective and sustainable feedstock for chemical and biochemical industrial application.

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References

[1] Amu, O.O., Babajide, S.S. (2011). Effects of bamboo leaf ash on lime stabilized lateritic soil for highway construction. Research Journal of Applied Sciences, Engineering and Technology, 3(4), 278-283.

[2] Bagby, M.O., Nelson, G.H., Helman, E.G., Clark, T.F. (1971). Determination of lignin in non-wood plant fiber sources. Tappi. 54, 1876-1878.

[3] Browning, B.L. (1975). The Chemistry of Wood. Robert E. Krieger Publishing Co., Huntington, NY, 689, p.

[4] Ciolacu, D., and Popa,V. I. (2010). Cellulose Allomorphs: Structure, Accessibility and Reactivity. Nova Science Publishers Inc., United States, pp. 43-45.

[5] Dence, C.W. (1992). The determination of lignin. In: Lin S.Y. and Dence, C.W. (eds). Methods in lignin chemistry. Springer-Berlin Heidelberg New York, pp. 33-61.

[6] Dhamodarn, T.K, Gnanaharan, R. and Sankara Pillai, K. (2003). Bamboo for Pulp and Paper A State of the Art Review With Annotated Bibliography. Page (38)

[7] Embaye, K. (2003). Ecological aspects and resource management of bamboo forests in Ethiopia. Doctoral Thesis, Swedish University of Agriculture Sciences, Uppsala.

[8] FAO. (2005). Global Forest Resources Assessment: Food and Agriculture Organization of the United Nations Rome.

[9] FAO. (2007). World Bamboo Resources. A Thematic Study Prepared in the Framework of the Global Forest Resources Assessment 2005. Rme, Italiy, Rome, 73p.

[10] FAO. (2013). Food and Agricultural Organization of the United Nations. Global Forest Assessment, 200 Available online: http://www.ftp.fao.org/docrep/fao/008 /A0400E/ A0400E00. pdf (accessed on 6 May 2013).

[11] Fengel, D. and Wegener, G. (1983). Wood: Chemistry, Ultrastructure, Reactions, Walter de Gruyter, Berlin, Germany, Publishers. pp. 613.

[12] Gong, H. R. (2007). Wood characteristics and storage methods of poplar residue, China wood-based panels 14(3), 29-30.

[13] Hamelinck, C.N., Van Hooijdonk, G. and Faaij, A.P.C. (2005). Ethanol from lignocellulosic biomass: tecno-economic performance in short-, middle- and long-term. Biomass Bioenergy.

[14] Harinen, S. (2004). Analysis of the top phase fraction of wood pyrolysis liquids. Masters Thesis, Department of Chemistry Laboratory of Applied Chemistry, university of Jyvaskyla.10p.

[15] Hurter, W. R. (2001). Non wood Plant Fiber Uses in Papermaking. Agricultural Residues, TAPPI 1997 .Non wood Fibers Short Course Notes.

[16] Judt, M. (1993). Non-wood plant fibers, will there be a comeback in paper-making? Industrial Crops and Products 7(2): 51-57.

[17] Karar, I.G. (2004). Environmentally Friendly Pulping and Bleaching of Bamboos and Bagasse from Sudan. Doctor of Philosophy (Ph.D). University of Khartoum. Sudan.

[18] Kelbessa, E., Bekele, T., Gebrehiwot, A., and G. Hadera. (2000). A Social-Economic Case Study of the Bamboo Sector in Ethiopia: An Analysis of the Production-to-Consumption system.

[19] Kigomo, B.N. (1988). Distribution, cultivation and research status of Bamboo in Easter Africa. Ecol. Ser. Monograph (1)

[20] Li, X.B., Shupe, T.F., Peter, G.F., Hse, C.Y., and Eberhardt, T.L. (2007). "Chemical change with maturation of the bamboo species *Phyllostachys pubescens*," Journal of Tropical Forest Science 19(1), 6-12.

[21] Liese, W. and Hamburg, F.R.G. (1987). Research on Bamboo. Wood Science and Technology, 21(3): 189-209.

[22] Liese, W. (1985). Anatomy and properties of bamboo. Recent research on bamboos. Proceedings of the International Bamboo Workshop. Hangzhou, China.

[23] Liese, W. (1998). The Anatomy of Bamboo Culms, INBRA Techanical Report (Book 18), Internation Network for Bamboo and Rattan, Beijing, Chaina.

[24] Liese,W. (1992). The structure of bamboo in relation to its properties and utilization: Bamboo and its use. Proceedings of the International Symposium on Industrial Use of Bamboo, Beijing, China, 7-11 December 1992. Published by the International Tropical Timber Organization: Chinese Academy of Forestry, Beijing, China. Pp. 96-100.

[25] Liu, B. Y., Shi, H. Q., Li, X.Q., and Xu, L.q. (2003). Analysis of lignin content in waste liguor of rice straw pulp by ultraviolet spectrometer. China pulp and paper 22(6), 19-22.

[26] Louppe, D; Oteng-Amoaka, A.A; Brink, M; Lemmens, R. H; Oyen, L.P and Cobbinah, J.R. (2008). Plant Resources of Tropical Africa 7(1). Timber 1. Wageningen, Netherlands.

[27] Malanit, P., Barbu, M.C. And Fruhwald, A. (2009). The gluability and bonding quality of an Asian bamboo (*Dendrocalamus asper*) for the production of composite lumber. Journal of Tropical Forest Science, 21(4)- 361-368.

[28] O'Sullivan, A. (1997). Cellulose: The structure slowly unravels. Cellulose 4(3), 173-207.

[29] Obolenskaya A.V., Elitskaya Z.P., Leonovich A.A., 1991. Laboratory Manual on Wood and Cellulose Chemistry, Ecologia, Moscow, 250-254.

[30] Ohrnberger D. (1999). The bamboos of the world: annotated nomenclature and literature of the species and the higher and lower taxa. Elsevier, Amsterdam.

[31] Okubo,K; Fujii, T and Yamamoto, Y. (2004). Development of bamboo- based polymer composites and their mechanical properties. Elsevier, Composites: 7(2) 377–383.

[32] Razak, W., 1998. Effect OD selected preservatives on the durability of *Gigantochloa scortechinii*. A Ph. D. Thesis, University of London, London.

[33] Razak, W., A. Mohammed, M.T. Mustafa and A. Hassan. (2009). Physical characteristics and anatomical properties of cultivated bamboo (*Bambus vulgariss* chrad) culms. J. Biol. Sci., 9(7): 753-759.

[34] Rydholm, S.A. (1965). Pulping Processes. Inter science Publications, New York. pp. 1049.

[35] Saha, B.C. and Bothast, R.J., 1997. Enzymes in liginocellulosic biomass conversion. ACS Symp. Ser.666 45-56.

[36] Satish, K., Shukla, K. S., Tndra, D. & Dobriyal, P. B. (1994). Bamboo Preservation Techniques: A Review. Published jointly by International Network for Bamboo and Rattan (INBAR) and Indian Council of Forestry Research Education (ICFRE). P.19.

[37] Schott, W. (2006). Bamboo in the Laboratory, A few observations on heat-treating of bamboo for rod making purposes. Page (4) 29.

[38] Scurlock, J. M. O., Dayton, D. C., and Hames, B. (2000). Bamboo: An overlooked biomass resource? Biomass and Bioenergy 19(4), 229-244. DOI: 10.1016/S0961-9534(00)00038-6

[39] Sjodahl R. (2004). The influence of dissolved wood components and sodium ion concentration on kraft pulping (licentiate Thesis). Royal Institute of Technology, Stockholm, Sweden.

[40] Sjostrom E. (1981). Wood Chemistry: Fundamental and Applications, Academic Press, New York, 169-189.

[41] Theliander H., Paulsson M., Brelid, H. (2002). Introduktion till massa-ochpappers framställning. Chalmers Institute of Technology, Göteborg, Sweden.

[42] Tomalang, F. N., Lopez, A. R., Semara, J. A., Casin, R. F. and Espiloy, Z. B. (1980). Properties and utilization of Philippine erect bamboo. In International Seminar on Bamboo Research in Asia held in Singapore, 28-30 May, 1980. Proceedings edited by Lessard, G. and Chouinard, A. Singapore: International Development Research Center and the International Union of Forestry Research Organization. pp. 266-275.

[43] Varghese M., Vishnu K. N. S., Bennt S. S. R., Jaghdes S. (1995). Genetic effect on wood and fiber traits of *Eucalyptus grandis* provenances. In Eucalypt Plantations: Improving fiber Yield and Quality. CRCTHF-IUFRO Conference: Hobart, Australia 19-24 February 1995. pp. 64-67

[44] Wan Rosli, W. D., Leh, C.P., Zainuddin, Z., and Tanaka, R. (2003). Optimization of soda pulping variables for preparation of dissolving pulp from oil palm fire. Holzforschung 57(1), 106- 114.

[45] West, T. O. and Marland, G. (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States, Agricultural Ecosystems & Environment, 91, 217-232.

[46] Yang Z., Xu S., Ma X. and Wang S. (2008). Characterization and acetylation behavior of bamboo pulp. Wood Science and Technology 12(2) 621-632.

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