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CHEMICAL COMPOSITION AND COMPARATIVE ANALYSIS OF THE WOOD OF TWO VARIETIES OF *Bambusa vulgaris* SCHRAD. EX J.C. WENDL

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Abstract

Determining the variation of chemical properties of the two varieties of Bambusa vulgaris is important to provide the information on the similarity and comparison of the chemical constituents for appropriate utilization. This study was therefore conducted to determine the chemical properties of the two available Bambusa vulgaris in Nigeria. Samples were collected from the two varieties of B. vulgaris at the base (5%), the middle (50%) and the top (90%) along the stem of the two varieties of the species. The chemical constituents evaluated includes: Cellulose, Hemicellulose, Holocellulose, Lignin and Ash content following standard procedure. The mean cellulose, Hemicellulose, Holocellulose, Lignin and Ash content for wamin and vitata respectively are: 45.94% and 46.19%, 38.38% and 38.33%, 74.86 and 74.61, 27.64% and 27.60%, and 0.72% and 0.82%. all the parameters except Holocellulose decrease from the base to the top. There was no significant difference in all the parameters between the varieties and among the sampling height. Most of the chemical characteristics of the varieties of reduced from base to top. The chemical constituent of the two varieties of Bambusa vulgaris compared favourably with some other wood species

Keywords: *Chemical Constituents, Bambusa vulgaris, Cellulose, Hemicellulose and ash*

Introduction

Chemical composition of a woody plant gives an idea of how feasible the plant is, as a raw material for construction, papermaking and other uses (Keller *et al*., 2001; Mediavilla *et al*., 2001). The fibrous constituent is the most important part of the plant. Since plant fibres consist of cell walls, the composition and amount of fibres is reflected in the properties of cell walls (Firdous and Gilani, 2001). Generally, lignocellulose materials from wood and non-wood plant consist of cellulose, hemicelluloses, lignin, extractive and some inorganic matter (Ververis *et al*., 2004). Information on the chemical composition of bamboo is important in deciding the techno-commercial suitability, pulping method and paper properties (Voulgaridis *et al*., 2000; Pahkala and Pihala, 2000; Ververis *et al*., 2004; Ates *et al*., 2008; Hadjazi *et al*., 2009; Abdul-Khalil *et al*., 2010).

The chemical composition of bamboo determines its properties and influences its utilization. The main chemical constituent of bamboo are cellulose, hemicellulose and lignin, which amount to over 90% of the total mass. The minor constituents of bamboo amount to about 10%, which are composed of resins, tannins, waxes and inorganic salts, (Chaowana, 2013). The selection of bamboo species for various applications is not only related to physical and mechanical properties but also to the chemical composition Tomalang *et al.* (1980), in their study found that the main constituents of bamboo culms are holocellulose (60-70%), pentosans (20-25%), hemicelluloses and lignin (each amounted to about 20-30%) and minor constituents like resins, tannins, waxes and inorganic salts. The proximate chemical compositions of bamboo are similar to those of hardwoods, except for the higher alkaline extract, ash and silica contents. The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo against mold, fungal and borers attack is strongly associated with the chemical composition (Abd.Latif and Abd.Razak, 1991).

The study by Chew *et al.* (1992) found out that *Bambusa vulgaris* contains glucose 2.37%, fructose 2.07% and sucrose 0.5%. Bruno *et al*. (2009) reported that, the culms exhibit different chemical composition in the contents of extractives, holocellulose, Alpha-cellulose, lignin and ash between the bamboo species, location in the culms and position at the nodes and internodes. This study therefore aimed at determining the chemical properties in the wood of the two varieties of *Bambusa vulgaris* available in Nigeria with a view to assessing its potentials for appropriate utilizations.

Bambusa vulgaris, also known as Golden Bamboo is a species of the large genus Bambusa of the clumping bamboo tribe Bambuseae. The Bambuseae are a group of perennial evergreens in subfamily Bambusoideae, characterized by having three stigmas and tree-like behavior that are in turn of the true grass family Poaceae. The *Bambusa vulgaris* is an open-clump type bamboo species. Among bamboo species, it is one of the largest and most easily recognized. It forms moderately loose clumps and has no thorns. There are two varieties of the species, namely *Bambusa Vulgaris* 'vittata' having yellow culms (stems) with green stripes and *Bambusa Vulgaris* 'wamin', having green culms and dark green leaves. Stems are not straight, not easy to split, inflexible, thick-walled and initially strong. The culm diameter is between 50-100mm with a height of 20000mm. This species has a culm-wall thickness of 15mm with an internode length ranging from 250-350mm (Akinlabi *et al.,* 2017).

Materials and Methods

Study Site

Bamboo culms: *Bambusa vulgaris* (Wamin and Vitata) of about 12 years old were harvested from bamboo groove at Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State, located on longitude 07°23′18″ to 07°23′43″N and Latitude 03°51′20″ to 03°23′43″E. Samples were collected from the two varieties of *B. vulgaris* at the base (5%), the middle (50%) and the top (90%) along the stem of the species.

Experimental Design

The experimental design adopted was a two-factor factorial experiment in a Completely Randomized Design. The first factor was the Bamboo varieties (Wamin and Vitata) and second is Sampling height (Base, Middle and top). The experiment was replicated ten (10) times. The data obtained were subjected to Analysis of Variance (ANOVA) under 0.05 level of probability

Determination of Chemical Properties of Bamboo

This test was carried out at Nigerian Institute of Science Laboratory Technology, Ibadan, Nigeria. The internodes of each height location were cut for chemical analysis, the samples were milled. Milled bamboo was placed in a shaker with sieves to pass through a No. 60 mesh sieve (250-µm). The resulting material was placed in glass jars labelled with appropriate code for chemical analysis. The epidermis of the strips was first removed with a fine blade. The milled samples were kept for chemical analysis. The grinding process was the same as above described for all the chemical analysis. There was a minor modification for extractive content test. Instead of benzene solutions, toluene solution was used.

Determination of Klason Lignin Content of Bamboo Samples

A one-gram, oven-dried sample of extractive-free bamboo was placed in a 150 ml beaker. Fifteen ml of cold sulphuric acid (72%) was added slowly while stirring and mixing. The reaction was allowed to proceed for two hours with frequent stirring in a water bath maintained at 20 °C. When it was two hours, the specimen was transferred by washing it with 560 ml of distilled water into a 1,000 ml flask, diluting the concentration of the sulphuric acid to 3%. A condenser was attached to a flask. The apparatus was placed in a boiling water bath for four hours. The flasks were removed from the water bath and the insoluble material was allowed to settle. The contents of the flasks were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was washed free of acid with 500 ml of hot tap water and then oven-dried at 103±2 °C. Crucibles were cooled in a desiccator and weighed until a constant weight is obtained. ASTM D 110656 (1978).

The following formula was used to obtain the Klason lignin content of bamboo:

Lignin content in bamboo (percent) $=\frac{(W4-W3)}{(100\times W2)}(100-W1)$ 1

W_1=alcohol-toluene extractive content (percent).

W_2=weight of oven-dried extractive-free sample (grams). W_3=weight of oven-dried crucible (grams).

W_4=weight of oven-dried residue and crucible (grams)

Determination of Holocellulose Content of Bamboo Samples

A two-gram sample of oven-dried extractive-free bamboo was weighed and placed into a 250 ml flask with a small watch glass cover. The crucibles were then oven-dried at 103 ± 2°C, then cool in a desiccator, and weigh until a constant weight was reached ASTM D 110656 (1978)

The following formula was used to determine the holocellulose content in bamboo:

Holocellulose content in bamboo (percent) $\frac{(W4-W3)}{(100xW2)}X(100-W1)$ (2)

W_1=Alcohol-toluene extractive content (percent)

W_2=Weight of oven-dried extractive-free sample (grams)

W_3=Weight of oven-dried crucible (grams)

W_4=Weight of oven-dried residue and crucible (grams)

Determination of Alpha-Cellulose Content of Bamboo Samples

A three gram oven-dried sample of bamboo was placed in a 250ml

Erlenmeyer flask with a small watch glass cover. The flasks were placed into water bath that was maintained at 20 °C. The sample was treated with 50 ml of 17.5 percent NaOH and thoroughly mixes for one minute. After which the specimen was allowed to react with the solution for 29 minutes, 50ml of distilled water was added and mixed well for another minute. The following formula was used to obtain the alpha-cellulose content in bamboo. ASTMD 110360 (1978).

Alpha-Cellulose (percent)

$$=\frac{(W4-W3)}{(100xW2)}X(W1) \qquad (3)$$

Where,

W_1=Holocellulose content (percent)

W_2=Weight of oven-dried holocellulose sample (grams)

W_3=Weight of oven-dried crucible (grams)

W_4=Weight of oven-dried residue and crucible (grams)

Determination of Ash Content of Bamboo Samples

An empty crucible was ignited and covered in the muffle at 600 °C then later cooled in a desiccator, and weighed to the nearest 0.1 mg. Two (2) grammes sample of air-dried bamboo was placed in the crucible, then the weight of crucible plus specimen was determined, then placed it in the drying oven at 103±2°C.The sample was removed with the crucible cover removed, then cooled in a desiccator and weighed until the weight was constant. The crucible and contents were placed in the muffle furnace and ignited until all the carbon was eliminated. The content was heated slowly at the start to avoid flaming and protect the crucible from strong drafts at all times to avoid mechanical loss of test specimen. The temperature of final ignition was 580 °C to 600 °C. Then the crucible with its contents was removed and place in a desiccator to cool, the cover was replaced loosely, then content was cooled and weighed accurately. The heating was repeated for 30 min periods until the weight after cooling was constant to within 0.2 mg. The following formula was used to obtain the ash content in bamboo ASTM D 110284(1990).

$$\text{Ash content (percent)} =\frac{W2/W1}{100} \qquad (4)$$

Where,

W_1=weight of ash (grams)

W_2=weight of oven-dried sample (grams)

Results and Discussion

Alpha Cellulose Content

The variation in mean value of percentage cellulose content of the varieties of *Bambusa vulgaris* is presented in table 1, the cellulose content in wamin was 45.94% and vitata has 46.19%. Atthe base, middle and top, it was 47.46%, 46.81% and 43.56%, respectively for wamin, while vitata has 46.99% for the base, 46.41% for the middle and 45.16%for the top. There is no significant difference between the two varieties and among their sampling positions, this may be as a result that the bamboo is the same species but different varieties. The cellulose is the innermost chemical constituents in the cell wall of fibres, as such; it requires high temperature to intensely impact cellulose content in a wood (Rowell 2013). There was a slight percentage difference in the cellulose content of the bamboo culm varieties between the varieties and from the top to the base, notwithstanding statistically, there was no significant difference in the cellulose content There is an increasing trend in the percentage of cellulose content value from base to top (fig 1). This view was reported by Bremer *et al.* (2013) on the chemical composition of two Vietnamese bamboo species; namely *Dendrocalamus barbatus* and *Dendrocalamus asper*,

Their percentages cellulose content ranged from 50.7 to 46.13% for *Dendrocalamus barbatus*, ranged from 49.41 to 47.01% for *Dendrocalamus asper*. Cellulose is fairly impacted by thermal modification compared with the other chemical constituents in bamboo this is in agreement with the studies of Xiaomeng *et al.* (2021), Comparing thermal treated with untreated samples, it was observed that the contents of cellulose and hemicellulose in treated bamboo decrease. With the increase of heat treatment temperature, the contents of cellulose and hemicellulose decrease gradually. The decrease of cellulose content is mainly due to the volatilization of small molecular degradation products during oil heat treatment (Tong *et al.*, 2019).

Cellulose as the main component exhibited a higher thermal stability than hemicellulose because of its crystallinity, this could be attributed to a shortening of cellulose chains. This is the chief component of plant fibres used in pulping and the most abundant natural polymer in the world. It is estimated that 830 million of cellulose is produced each year through photosynthesis (Azizi-Mossello *et al*., 2010). Paper strength depends on the cellulose content of a fibrous raw material. Holocellulose defined the total content of carbohydrate materials and as a whole adds to the overall strength of a paper (Singh *et al*., 2011).

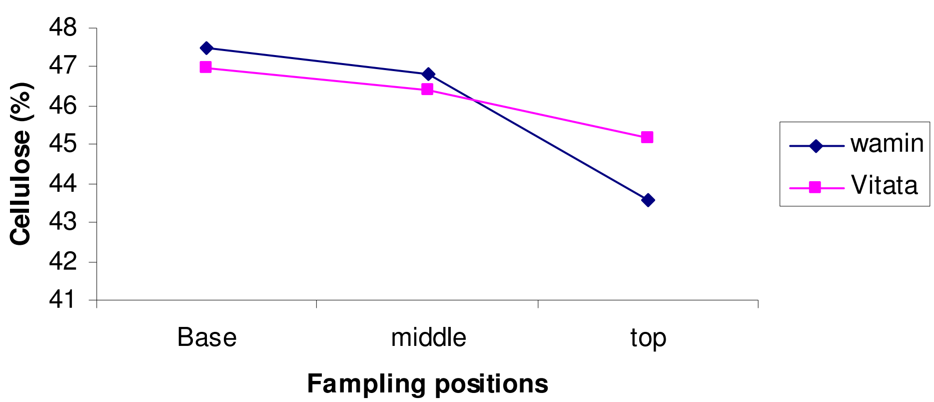

Fig. 1: Alpha Cellulose content for the two varieties of *Bambusa vulgaris* in relation to sampling positions

Table 1: Mean Values obtained for chemical properties of the two varieties of *Bambusa vulgaris*

Bamboo varieties	**Sampling positions**	**Mean**				
		Cellulose (%)	Hemicellulose (%)	Holocellulose (%)	Lignin (%)	Ash (%)
Wamin	Base	47.46	38.89	74.49	29.81	0.81
	Middle	46.81	38.75	74.99	27.54	0.70
	Top	43.56	37.51	75.10	25.56	0.64
Total		45.94	38.38	74.86	27.64	0.72
	Base	46.99	39.17	74.15	28.92	0.90
Vitata	Middle	46.41	38.11	74.57	28.11	0.86
	Top	45.16	37.72	75.11	25.77	0.70
Total		46.19	38.33	74.61	27.60	0.82

*Represents significance at 5% level of probability, while superscript letter represents difference between each factor

Hemicellulose

The variation in hemicellulose percentage content between the two varieties and in sampling height, were not significant at 5% level. Hemicellulose content mean values variation is presented in table 1. The wamin samples have the least at top likewise vitata and the highest percentage of hemicellulose content of 36.89% and 39.17% were recorded for wamin and vitata, respectively. The values of percentage hemicellulose content of the two varieties of *Bambusa vulgaris* at the base varied from 36.89% and 39.17%, at the middle samples the mean value ranged from 38.51 to 38.11%, while at top samples ranged from 37.51 to 37.72%. In this study, the percentage of hemicellulose content was highest at the base, there was a decreasing pattern from top to base, and the least percentage hemicellulose content values were recorded at the top (Fig 2). This is a general trend with bamboo according to Bremer *et al.* (2013), this is because different factors cause a lot of changes to physical properties of the bamboo such as Equilibrium Moisture Content (EMC), colour and mass, all of which are adversely affected by changes in chemical composition, most especially hemicellulose content Bremer *et al.* (2013). Species with higher hemicellulose content might present a substantial increase in hydrophobicity. In addition to changes in the hydrophobic character, the densification of lignin chain is also a factor to explain the variation in the hemicelluloses in the woods (Duchez and Guyonnet, 1998).

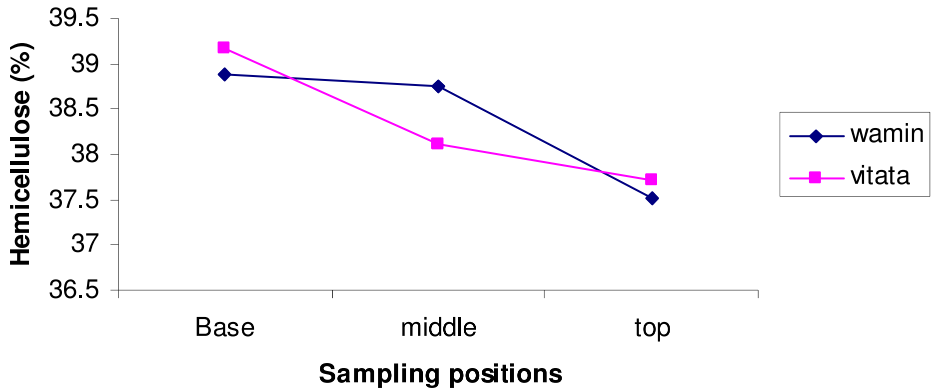

Fig. 2: Hemicellulose content for the two varieties of *Bambusa vulgaris* in relation to sampling positions

Holocellulose Content

The result of analysis of variance shows that there was no significant difference between the varieties and in the sampling height, at 5% level of probability as shown in table1. The mean value of Holocellulose content percentage ranged from 74.49 to 74.15% at the base, while at the middle samples ranged from 74.99 to 74.57%, the mean value for the top samples varied from 75.10 to 75.11% for wamin and vutata respectively. The highest Holocellulose content percentage was recorded at the top samples with percentage value 75.10 to 75.11%, there is a decreasing trend in the percentage holocellulose content ranging from top to base. this result is in agreement with the studies by Nguyen *et al*. (2012). Bamboo hemicelluloses contain about 7% acetyl groups (Liese, 1985). These groups were separated from the chains by thermal exposure and formed acetic acid. This compound has a catalytic effect on the decomposition of the glycosidic bonds of holocellulose. Holocellulose includes cellulose and hemicelluloses, which have different thermal stabilities. The main components; holocellulose and lignin, have an important influence on the physical and mechanical properties of Bambusa vulgaris (Nguyen *et al*., 2012). The relatively high holocellulose content of the stalk is a qualitative indication of the suitability of the bamboo for paper making. High holocellulose content is considered desirable for pulp and paper industry because of its correlation with higher pulp yield (Shakhes *et al*., 2011). The higher the holocellulose content of a material, the better the swelling behaviour of the pulp produced from it (Singh *et al*., 2011). Similarly, Nevell and Zeronian (1985) established a positive relationship between holocellulose content and mechanical strength properties of handsheets including tensile, burst indexes, and double folds.

High holocellulose content, therefore, is considered desirable for pulp and paper production. Alpha-cellulose is equally important in the overall assessment of a plant material for paper production. According to the rating system designated by Nieschlag *et al*. (1960), plant materials with alpha-cellulose content ≥34% are characterized as promising for pulp and paper manufacture from chemical composition point of view.

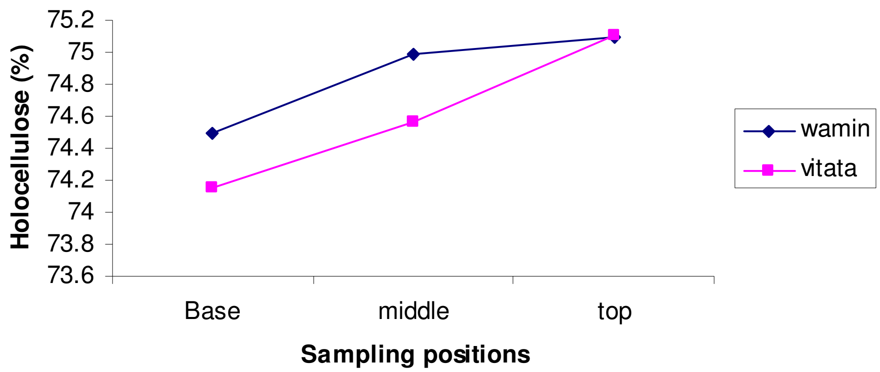

Fig. 3: Holocellulose content for the two varieties of *Bambusa vulgaris* in relation to sampling positions

Klason Lignin Content

The mean value percentage of lignin content of Bambusa vulgaris are 27.64% and 27.60% for wamin and vitata, respectively. At the base, it was 29.81% and 28.92%, middle (27.54% and 28.11%) and top (25.56% and 25.77%) for wamin and vitata, respectively (table 1).

Lignin content varied consistently in decreasing order from base to top (Fig 4). This increase in the Lignin percentage content is as a result of hydroxyl linkage of lignin as the bamboo grow. Though statistically, there was no significant difference between the varieties and among the sampling positions.

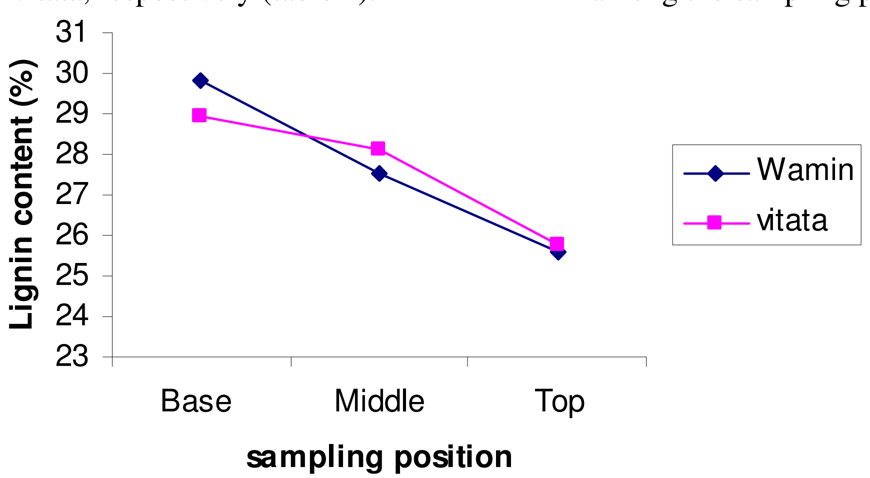

Fig. 4: Lignin content for the two varieties of Bambusa vulgaris in relation to sampling positions

Based on the results, the percentage lignin variation is in line with other chemical constituent of the two varieties of Bambusa vulgaris except holocellulose that decrease from the top to the base, the highest lignin content is recorded at the base samples. The increasing pattern of the percentage lignin content of the bamboo varied from top to base, this is in line with the Bremer *et al*. (2013) whose findings on the chemical composition variations of the Vietnamese bamboo species, namely *Dendrocalamus barbatus* and *Dendrocalamus asper.* Their percentage cellulose content ranged from 25.19 to 37.22% for *Dendrocalamus barbatus*, ranged from 34.89 to 24.94% for *Dendrocalamus asper*, this is because by means of Klason lignin analysis, all components are not soluble in concentrated Sulphuric acid, and bamboo lignin has a high content of unsaturated aromatic acids, as is typical for grass. These components can react with various decomposition products of hemicellulose. Furthermore, polymerisation of decomposition products of hemicelluloses is possible; the hydrophilic character will be weakened by a reduction of hydroxyl groups during decomposition of holocellulose.

Lignin provides plant tissue and individual fibres with comprehensive strength and stiffens the cell wall of the fibres, to protect the carbohydrates from chemical and physical damage (Abdul Khalil *et al*., 2006). In pulp and paper production, lignin is an undesirable polymer and one of the main reasons for pulping is to remove it from wood and other lignocellulosic materials. Because of its importance, several advances have been made to remove lignin. Some of these include the use of 75% sulphuric acid to isolate lignin (Klason lignin), the use of either sodium hydroxide or in conjunction with sodium sulphide (soda lignin or kraft lignin) and isolation through the use of organo-solvent (Milled wood lignin) (Upendra and Shukkla, 2010). Meanwhile, the average lignin content obtained for the two varieties of the bamboo (Bambusa vulgaris) compared favourably with 17.7% reported for elephant grass (Madakadze *et al*., 2010), 20.92% for reed (Shatalov and Pereira, 2006), 24.5% for Cramble orientalis, 20.59% for *Cramble tataria* (Tutus *et al*., 2010), 18.50% for hemp, 19.20% for kenaf (Dutt et al., 2009), 18.6% for banana stem (Abdul Khalil et al., 2006), 25-32% for softwoods and 17-26% for hardwoods (Eroglu, 1998). (Table 2)

Ash Content

There was no significant difference at 5% level of probability in sampling height and varieties of bamboo, The average mean variation value Ash content percentage of the two varieties of the bamboo is presented in the table 1. The mean value ranged from 0.72 to 0.82%for wamin and vitata, respectively. It ranges at the base between0.81 and 0.90, also, the mean ranged from 0.70 to 0.86% at middle while from 0.64 to 0.70% at the top for wamin and vitata, respectively.

The percentage ash content was highest at the base samples; which decrease to the top (Fig 5). The ash content of wood is made up of inorganic minerals, primarily calcium, potassium, and magnesium. Manganese and silica are two other common minerals. The inorganic constituent of lignocellulosic material is generally indicated as ash content which is considered as residue remaining after combustion of organic matter at a temperature of 525±25^{o}C (Rowell et al., 1997). The ash content consists mainly of various metal salts such as silicates, carbonates, oxalates and phosphates of potassium, magnesium, calcium, iron and manganese as well as silicon (Shakhes *et al*., 2011). Normally, they are deposited in the cell walls, libriform fibres and luminar of parenchyma cells, resin canals and ray cells (Sjostrom, 1993).

The low percentage ash accumulated in the wood of the two varieties of *B. vulgaris* compared well with other non-wood raw materials sourced for pulp and papermaking, such as, 1.40% obtained in kenaf, 1.40% in hemp (Dutt *et al.*, 2009), 2.40% in Jute (Marques *et al.*, 2010) and 3.5% in matured bamboo (Ogunsile and Uwajeh, 2009) (Table 2). This presents another good indication of its suitability for pulp and papermaking since it is expected that chemical recovery from the pulping liquor will be high.

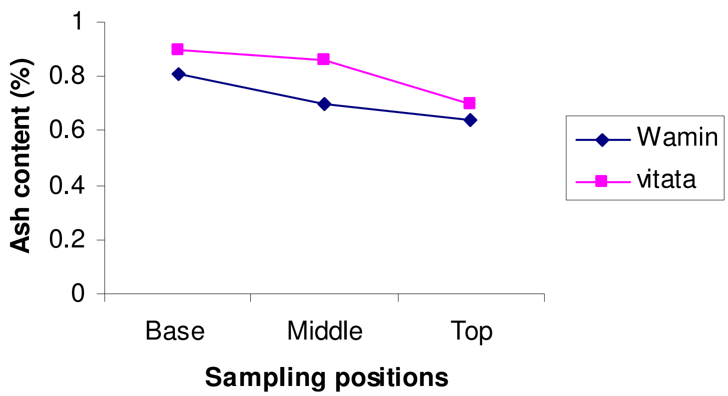

Fig. 5: Ash content for the two varieties of Bambusa vulgaris in relation to sampling positions

Table 2: Percentage Chemical Composition of Some Non-Wood Fibres

Species	Lignin	Holocellulose	cellulose	Ash	Reference
Bambusa vulgaris (wamin)	27.64	74.86	45.94	0.72	Present study
Bambusa vulgaris (vitata)	27.60	74.61	46.19	0.82	Present study
T. daniellii	13.05	66.80	39.00	2.79	Sotannde 2015
Switchgrass	23.89	-	41.20	4.83	Madakadze *et al.*, 2010
Elephant grass	17.7	-	45.6	4.23	Madakadze *et al.*, 2010
Reed (node)	20.92	61.21	29.18	4.77	Shatalov *et al.*, 2001
Sunflower stalk	10.8	66.9	37.6	-	Lopez *et al.*, 2005
C. orientalis	24.5	70.5	50.65	7.83	Tutus *et al.*, 2010
C. tataria	20.59	75.0	50.42	9.31	Tutus *et al.*, 2010
Hemp	18.50	71.80	46.75	1.56	Dutt *et al.*, 2009
Kenaf	19.20	71.4	48.60	1.40	Dutt *et al.*, 2009
Pineapple leaf	10.5	80.5	73.4	2.0	Abdul Khalil *et al.*, 2006
Banana stem	18.6	65.2	63.9	-	Abdul Khalil *et al.*, 2006
Jute	2.9	92.0	-	2.4	Marques *et al.*, 2010
Sisal	5.9	85.0	-	1.0	Marques et al., 2010
Bamboo	26.5	-	-	3.5	Ogunsile and Uwajeh, 2009
Wheat straw	15.3	74.5	38.2	4.7	Deniz *et al.*, 2004
Corn stalk	17.4	64.8	35.6	7.5	Usta *et al.*, 1990
Tobacco stalk	19.5	67.6	37.5	7.3	Usta *et al.*, 1990
Rice straw	17.2	70.9	35.6	16.6	Tutus *et al.*, 2004
Bagasse	21.70	71.03	42.34	2.10	Agnihotri *et al.*, 2010
Softwoods	25-32	68-74	40-45	< 1	Eroglu, 1998
Hardwoods	17-26	70-80	38-49	< 1	Eroglu, 1998

Conclusion

The result of this study shows the variation in chemical contents of the two varieties of *Bambusa vulgaris*, (wamin and vitata) as available in Nigeria, the percentage cellulose, hemicellulose ash content and lignin contents decreased consistently from base to top samples except for holocellulose which is other way round. All the parameters were highest at the base except holocellulose for the two varieties of the bamboo. The cellulose (45.94% and 46.19%), hemicellulose (38.38 and 38.33%), lignin (27.64% and 27.60%), ash (0.72% and 0.82%) were obtained for the two varieties of *Bambusa vulgaris* (wamin and vitata), respectively. According to this result, tappering reduced the chemical compositions of the species which at long on makes different portion of the bamboo to be useful for different purposes.

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