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PHYSICAL AND CHEMICAL FEATURES OF SOME AGRICULTURAL RESIDUES AND GRASSES AS ALTERNATIVE TO PULP AND PAPER PRODUCTION

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Abstract
The growing concern about the rising cost and diminishing supply of wood fibre has created a renewed interest in adopting alternative fibre sources in the manufacture of paper and paper products. This study investigated the suitability of selected agricultural residues (Sorghum bicolor, Panicum miliaceum, Abelmoschus esculentus and Hibiscus sabdariffa) and grass fibres (Oryza longistaminata and Hyparrhenia involucrata) obtained from the Federal University of Agriculture, Makurdi, Nigeria. Fibre dimensions of samples were determined by reducing samples into chips and placed into an equal volume of glacial acetic acid and Hydrogen peroxide in ratio 1:1. Macerated fibres were mounted on a slide in Reichert Visopan Microscope to determine fibre physical features. Proximate chemical analysis was done using Tappi Standard Method. Results show that Hyparrhenia involucrata had the longest fibre length of 2.23 mm while Oryza longistaminata had the least (0.24 mm). Abelmoschus esculentus had the least runkel ratio of 0.50 followed by Sorghum bicolor (0.73), Hibiscus sabdariffa and Panicum miliaceumwith 0.78, respectively. While Felting rate, Elasticity coefficient, Rigidity coefficient, and F ratio ranged from 134.76 - 24.76, 66.57% - 45.88%, 27.06% - 16.71%, and 51,111.27% - 9,211.07%, respectively. Results of chemical analysis shows that ash content, Hot water solubility, Ethanol Toluene solution, Cold water solution, lignin, Hemicellulose, Alkali, and Cellulose ranged from 3.86 % - 11.00 %, 0.58 % - 7.21%, 1.11 % - 22.30%, 0.46% - 12.06%, 5.86% - 25.90%, 15.70% - 57.43%, 3.01% - 23.22%, and 14.32% - 68.21%. The outcome of the study indicated that agricultural residues and grasses are propitious fibrous raw material for the paper production.

***Keywords**: Fibre, agricultural residues, grasses, pulp, paper*

Introduction
Paper and paper products in today's world play a very important role in everyday life. The consumption of paper per capita correlates closely with gross domestic products (Diesen, 2000), and also with the standard of welfare and education. It is said to be synonymous with development in the contemporary world. The manufacture of pulp and paper is basic to education, printing, publication and numerous packaging applications. At home, paper is used to clean, to dry things, and for so many other purposes. In short, paper is one of the most versatile and common products of modern societies (Gerboni, 2005).

World paper output increased from 0.8% to 410 million tons in 2017 (Euler, 2018). Essien, (2017) reported that as a result of the declining state of the three current paper mills in Nigeria, the country was losing over N400 billion every year because of paper products importation. About 4 billion representing 35% of the entire trees felled everywhere in the world are used in paper industries on every continent (Martin, 2011). World demand for paper has increased at an average annual rate of 4.7% over the past 40 years. Although future growth will reduce to 2 -3% because of the advent of internet and computers facilities, the existing wood resources may be inadequate to meet this growing demand for paper especially in the Asia-Pacific region and Eastern Europe (Talebizadeh and Rezayati, 2010). The total global consumption of paper was projected to increase from 316 million tons in 1999 and 351 million tons in 2005 to about 425 million tons in 2010 (García *et al*., 2008).

Wood is by far is the major raw material for global pulp and paper industry. It is, however, a relatively new raw material in papermaking. Historically, paper was made exclusively from nonwood plant fibres. According to Atchson and McGovern, (1993), the first made paper was from textile wastes, old rags and used fishnets, which consist of fibre of the true hemp and China grass (ramie). While nonwood was originally used for papermaking, in the seventeenth century, wood became the predominant fibre source in Europe. The seemingly inexhaustible supply and versatility of wood were the major causes of the shift. Currently, most modern pulp paper enterprises depend on wood material (Smook, 1992).

Paper industry is a forest based-industry. Depleting forest cover is a major cause of concern because of the adverse environmental implications of such activities (Vivek and Maheswari, 1998). In order to meet the increased demand for pulp and paper, researchers are looking for alternative sources of pulp supply that is both cost-effective and physically similar to traditional pulps. An added motivation to find new sources of wood pulp has risen out of environmental concern and regulations (Joey *et al.*, 1998).

All plants contain cellulose and any plant can be made into paper. Agricultural fibres are regularly used for the manufacture of paper products in developing countries. The agricultural pulp industry accounts for more than 50% of national pulp production in China and in India. There is a renewed interest to use agricultural-based fibres in place of wood for the production of pulp and paper in many developed countries. The alternative is driven in part, by the growing shortage of commercial wood supply as caused by the overcutting of the standing forest and accelerated re-allocation of forest land for ecological and recreational uses (Al Wong, 1995). Again, the growing concern about the rising cost and diminishing supply of wood fibre has created a renewed interest in the use of alternative fibre sources in the manufacture of paper products (Girouard, and Samson, 2010).

Agricultural straws are largely underutilized commercially in Benue State, Nigeria. Increased utilization of agricultural residues for pulp and paper manufacture would relieve society of loss and disposal problem of agricultural residues in many places. Poor disposal methods like burning with its attendant consequences would also be eliminated or at least minimized to a greater extent (Al wong, 1995). This study therefore investigated the physical and chemical properties of fibre of selected agricultural residues and grasses to ascertain their suitability for pulp and paper production.

Materials and Methods

Study Area

The study was conducted at the Federal University of Agriculture, Makurdi (FUAM), Benue State, Nigeria. The ecology of Benue State known as the Food Basket of Nigeria supports extensive arable cropping and livestock production as well as fruit, palm, grains, legumes, root and tuber production. Benue State lies within the coordinates 7°47' and 10°00' East, 6°25' and 8° 8' North. Sited on the bank of River Benue, and located about 300 km South of the Federal Capital, Abuja and 800 km North of the commercial city of Lagos(Gyang, 1997). The pulp and papermaking process was done at the Department of Forest Production and Products' laboratory.

Materials

Sample materials were obtained from agricultural wastes with long/tall stalks which include: Sorghum (*Sorghum bicolor* L.) straw and Millet (*Panicummiliaceum* L.) straw. Waste from crop residues with short straws were obtained from Okra (*Abelmoschusesculentus*) (L.) Moench stalks and Roselle Plant (Zobo) (*Hibiscus sabdariffa*) L. Stalks while grass materias were selected from *Oryzalongistaminata* A. Chev. and Roehr and *Hyparrheniainvolucrata*Stapf. The agricultural wastes and grasses were purposively collected from Federal University of Agriculture Teaching and Research Farm and within the university land. The stalk of each sample was chopped and chipped into small size of about 50 mm for the experimental procedure.

Fibre Dimension Determination

Fibre dimensions were determined by reducing some representative chips of the raw materials into the core and placed into an equal volume of glacial acetic acid and Hydrogen peroxide in ratio 1:1 in a covered bottle. The macerated cores were disintegrated by shaking the bottle to release the fibres. The fibre for each material was mounted on a slide and the fibre length (L), fibre diameter (D), lumen width (d), and cell wall thickness would be measured under a Reichert Visopan Microscope. The following morphological indices also called important criteria in papermaking were determined using the following five equations according to Kırcı, 2006.

$FR = FL/FD$ ………………… Equation i
$EC = LD/FD \times 100$ …………… Equation ii
$RC = CWT/FD \times 100$ …………... Equation iii
$RI = 2(CWT)/LD$ ……………… Equation iv
$Fr = FL/CWT \times 100$ …………. Equation v

Where:
FR - Felting rate
FL - Fibre length
FD - Fibre diameter
EC Elasticity (Flexibility) coefficient
LD - Lumen diameter
RC - Rigidity coefficient
CWT - Cell wall thickness
RI - Runkel index
Fr - F ratio

The derived values were compared with those of softwoods and hardwoods to assess the suitability of the plant raw materials for paper production. The Runkel ratio would show the pulpability of the raw material. The determination of fibre dimension was done at the Forest Research Institute of Nigeria (FRIN) Ibadan.

Proximate Chemical Analysis

The experimental samples were chipped and powdered in a Willey mill and portion was passed through 40 mesh and retained on 60 mesh. The proximate chemical analysis was carried out as per Tappi Standard Method. The raw materials were analyzed for lignin, ash content, hot and cold-water solubility, and cellulose contents using Tappi T 222 om-88, Tappi T 211 om-85, Tappi T 207 om-88, and Kurscher-Hoffer nitric acid method respectively (Tutus, *et al.,* (2010); Kurschner-Hoffer (1993); Sadiku*et al.,* (2016). This experiment was carried out at the Federal Institute of Industrial Research Oshodi (FIRRO) Lagos.

Data Analysis

Data from the study were subjected to one-way analysis of variance (ANOVA) and Ducan Multiple Range Test (DMRT) was used to separate means of the raw materials using the appropriate statistical software.

Results

Table 1shows fibre morphology of studied samples. The results indicate that *Hyparrhenia involucrate* had the highest fibre length of 2.23 mm while *Oryzalongistaminata* had the least (0.24 mm) and are significantly different at p<0.05. Other mean values of fibre length are, *Panicummiliaceum*stalk *(*0.98 mm) *Abelmoschusesculentus* stalk (0.93 mm), *Hibiscus sabdariffa* stalk (0.90 mm), and *Sorghum bicolor* stalk (0.77 mm). These means are not significantly different at p<0.05.

Abelmoschusesculentus stalk had the highest fibre diameter of 26.38µm followed by *Hibiscus sabdariffa* stalk (19.25 µm), *Hyparrhenia involucrate (*17.25 µm) and *Panicummiliaceum* stalk (15.56 µm). The means are significantly different at p<0.05. However, the fibre diameter of *Oryzalongistaminata* (9.94 µm) and *Sorghum bicolor* stalk (9.19 µm) are not significantly different p<0.05.

Mean value of fibre lumen width shows that, *Abelmoschusesculentus* stalk was highest (17.56 µm) followed by *Hibiscus sabdariffa* stalk (10.81 µm) and they are significantly different at p<0.05. *Panicummiliaceum*stalk had a mean value of lumen width 8.75 µm which is not significantly different from *Hyparrhenia involucrate* grass (8.00 µm). *Sorghum bicolor* stalk and *Oryzalongistaminata*grass had the lowest mean value of 5.31 µm and 4.56 µm respectively, and are not significant.

Mean values of fibre cell wall thickness of Hyparrhenia involucrate grass, Abelmoschus esculentus stalk and Hibiscus sabdariffa stalk (4.63 µm, 4.41 µm, and 4.22 µm) respectively are not significantly different but differ significantly from mean values of Panicummiliaceum stalk (3.41 µm), Oryza longistaminata grass (2.69 µm) and Sorghum bicolor stalk (1.94 µm).

Table 1: Fibre morphology of samples

S/No	Samples	Fibre Length (mm)	Fibre Diameter (µm)	Fibre Lumen Width (µm)	Fibre Cell wall Thickness (µm)
1	*Abelmoschus esculentus* stalk	0.93±0.19 ^{cde}	26.38±5.95^{f}	17.56±5.57^{e}	4.41±1.06^{e}
2	*Hibiscus sabdariffa* stalk	0.90±0.16 ^{cd}	19.25±4.61^{e}	10.81±2.16^{d}	4.22±1.61^{e}
3	*Panicum miliaceum* stalk	0.98±0.38 ^{cde}	15.56±4.09$_{d}$	8.75±2.56^{c}	3.41±1.29^{d}
4	*Sorghum bicolor* stalk	0.77±0.28 ^{bc}	9.19±2.82^{a}	5.31±2.18 ^{ab}	1.94±0.67^{ab}
5	*Hyparrhenia involucrate*	2.23±0.46 ^{g}	17.25±4.56^{e}	8.00±3.30^{c}	4.63±1.22^{e}
6	*Oryza longistaminata*	0.24±0.07 ^{a}	9.94±1.79^{ab}	4.56±1.30^{a}	2.69±0.46^{abcd}

The result of fibre morphology in Table 2 shows that *Abelmoschus esculentus* stalk had the least Runkel ratio of 0.50 followed by *Sorghum bicolor* stalk 0.73, Hibiscus sabdariffa stalk and *Panicummiliaceum*stalk with same mean value of 0.78respectively. These mean values are not significantly different. However, the values are significantly different from that of *Oryza longistaminata*grass (1.18) and *Hyparrhenia involucrate* grass (1.16) which are not significant at p<0.05.

The result also revealsthe mean values of felting rate(slenderness) of studied samples. The highest mean value was recorded for *Hyparrhenia involucrate* grass (134.76) followed by *Sorghum bicolor* stalk (90.66) and the means are significantly different. Nevertheless, the means differ significantly from the means of *Panicummiliaceum*stalk (66.70), Hibicus sabdariffa stalk (49.53), *Abelmoschus esculentus* stalk (37.35) and *Oryza longistaminata*grass (24.76). Mean values of elasticity coefficient were highest in *Abelmoschus esculentus* stalk (66.57 %) and it is significantly different from the means of *Sorghum bicolor* stalk (57.78 %), *Panicummiliaceum* stalk (56.23%) and Hibiscus sabdariffa stalk (56.16%). The means of *Hyparrhenia involucrate* grass and *Oryza longistaminata* grass (46.38% and 45.88%) respectively, were the lowest and are not significantly different.

Means of rigidity coefficient results show that *Oryza longistaminata*grass(27.06%) was highest followed by *Hyparrhenia involucrate* grass (26.84%) and are not significantly different from means of Hibiscus sabdariffa stalk, *Panicummiliaceum*stalkand *Sorghumbicolor* stalk (21.92%, 21.85%,and21.11%) respectively. The least mean rigidity coefficient was recorded for *Abelmoschus esculentus* stalk (16.71%) and is significant.

The F ratio values of *Hyparrhenia involucrate* grass and *Sorghum bicolor* stalk were 51,111.27% and 44,583.33%respectively and are not significantly different. Nevertheless, the values are significantly different from that others samples of *Sorghum bicolor* stalk(44,583.33%),*Panicummiliaceum*stalk(32,023.06%), Hibiscus sabdariffa stalk (25,056.79%), and *Abelmoschus esculentus* stalk (21,919.44%). However, F ratio for *Oryza longistaminata* grass was least (9,211.07%) and is significantly different from all other samples.

Table 2: Derived indices of agricultural residues and grasses

S/No.	Samples	Runkel ratio	Felting rate (Slenderness)	Elasticity (Flexibility) coefficient (%)	Rigidity coefficient (%)	F ratio (%)
1	*Abelmoschus esculentus* stalk	0.50±0.22[a]	37.35±0.01[ab]	66.57±00[d]	16.71±00[a]	21,919.44±5.39[b]
2	*Hibiscus sabdariffa* stalk	0.78±0.28[ab]	49.53±0.01b[c]	56.16±00[c]	21.92±00[b]	25,056.79±10.71[bc]
3	*Panicum miliaceum* stalk	0.78±0.43[abc]	66.70±0.03[c]	56.23±00[c]	21.85±00[bc]	32,023.06±13.37[bdc]
4	*Sorghum bicolor* stalk	0.73±0.32[ab]	90.66±0.04[d]	57.78±00[c]	21.11±00[b]	44,583.33±21.09[f]
5	*Hyparrhenia involucrate* grass	1.16±0.98[f]	134.76±0.03[f]	46.38±00[ab]	26.84±00[cd]	51,111.27±15.63[f]
6	*Oryza longistaminata* grass	1.18±0.43[def]	24.76±0.01[a]	45.88±00[ab]	27.06±00[cd]	9,211.07±3.70[a]

Mean value of cellulose solution was greatest (68.21 %) in *Panicummiliaceum* stalk and least (14.32 %) in *Abelmoschusesculentus* stalk. Other mean values are *Sorghum bicolor* (58.98 %), *Hyparrhenia involucrate* grass (58.65 %), Hibiscus sabdariffa stalk(37.82 %), and *Oryza longistaminata*grass (28.77 %). Means of all samples are significantly different at p<0.005.

The results of chemical characteristics of samples of in Table 3showed that*Hyparrhenia involucrate* grass had the highest (11.00 %)ash content followed by *Sorghum bicolor* stalk (10.12 %) while, *Panicummiliaceum*stalk and *Abelmoschusesculentus* stalk had 8.00 % respectively. Other values of %)ash contents were Hibiscus sabdariffa stalk (5.25 %) and *Oryza longistaminata*grass with the least of 3.86 %. Mean ash contents of all samples are significantly different at p<0.005.

The mean of hot water solution of samples was again maximum (7.21 %) in *Hyparrhenia involucrate* grass, greater than the one of Hibiscus sabdariffa stalk(7.09 %), *Sorghum bicolor* stalk (5.71 %), *Oryza longistaminata*grass (3.23 %). Also, *Abelmoschusesculentus* stalk had (1.01 %) while the least was 0.58% in *Panicummiliaceum*stalk. Hot water solution of samples is significantly different at p<0.005.

Hyparrhenia involucrate grass had the most (22.30 %) value of Ethanol Toluene solution. The values of other samples are as follows: *Sorghum bicolor* stalk (15.06%), Hibiscus sabdariffa stalk (12.44 %) and Oryza*longistaminata*grass (11.80 %). *Panicummiliaceum*stalk had (1.75 %) while *Abelmoschusesculentus* stalk had the lowest value of 1.11 %. Values of Ethanol Toluene solution were significantly different among samples at p<0.005.

Value of cold-water solutionwas again foremost (12.06 %) in Hyparrhenia involucrate grass. Panicummiliaceumstalk was next (10.03 %) in value followed by 10.03 %, 7.55 %, 7.40 %, 2.50 % and 0.46 %, for Panicummiliaceum stalk, Oryzalongistaminatagrass, Sorghum bicolor stalk, Abelmoschus esculentus stalk and Hibiscus sabdariffa stalk respectively. Mean values of cold-water solution were significant at p<0.005.

Lignin content of samples was maximum (25.90 %) in Sorghum bicolor stalk and minimum (5.86 %) in Hyparrhenia involucrate grass. Others include Hibiscus sabdariffa stalk (23.78 %), Panicummiliaceumstalk (16.82 %), Oryza longistaminatagrass (7.88 %) and Abelmoschusesculentus stalk (6.88 %). Means of lignin content of all samples are significantly different at p<0.005.

The mean value of hemicellulosewas highest (57.43%) in *Oryza longistaminata*grass. This was followed by Sorghum*bicolor* stalk (41.95 %), Hibiscus sabdariffa stalk (29.16 %), Hibiscus sabdariffa stalk (25.84%), *Panicummiliaceum*stalk (23.87%), and least (15.70 %) in *Abelmoschusesculentus* stalk. Means of all samples are significantly different at p<0.005.

Alkali value was foremost (23.22%) in *Hyparrhenia involucrate* grassand lowest (2.84%) in *Oryza longistaminata* grass. Others are *Abelmoschusesculentus* stalk (12.52 %), *Sorghum bicolor* stalk (11.10 %), Hibiscus sabdariffa stalk (9.09 %) and *Panicummiliaceum* stalk (3.01 %). Means of all samples are significantly different at p<0.005.

Table 3: Chemical properties of agricultural residues and grasses

S/No	Samples	N	Ash content (%)	Hot water solution (%)	Ethanol Toluene solution (%)	Cold water solution (%)	Lignin (%)	Hemi cellulose (%)	Alkali (%)	Cellulose solution (%)
1	*Abelmoschus esculentus*	5	8.00±0.00[c]	1.01±0.02[b]	1.11±0.02[b]	2.50±0.02[b]	6.88±0.13[b]	15.70±0.02[b]	12.52±0.02[b]	14.32±0.02[b]
2	*Hibiscus sabdariffa*	5	5.25±0.016[b]	7.09±0.02[f]	12.44±0.21[f]	0.46±0.20[f]	23.78±0.02[f]	29.16±0.02[f]	9.09±0.06[f]	37.82±0.02[f]
3	*Panicum miliaceum*	5	8.00±0.00[c]	0.58±0.02[a]	1.75±0.02[a]	10.03±0.02[a]	16.82±0.02[a]	23.87±0.02[a]	3.01±0.02[a]	68.21±0.02[a]
4	*Sorghum bicolor*	5	10.12±0.01[d]	5.71±0.02[d]	15.06±0.21[d]	7.40±0.02[d]	25.90±0.02[d]	41.95±0.02[d]	11.10±0.02[d]	58.98±0.00[d]
5	*Hyparrhenia involucrate*	5	11.00±0.00[e]	7.21±0.02[g]	22.30±0.02[g]	12.06±0.02[g]	5.86±0.02[g]	25.84±0.02[g]	23.22±0.02[g]	58.65±0.02[g]
6	*Oryza longistaminata*	5	3.86±0.02[a]	3.23±0.02[c]	11.80±0.02[c]	7.55±0.02[c]	7.88±0.02[c]	57.43±0.02[c]	2.84±0.02[c]	28.77±0.02[c]

Discussion

Physical Properties of Agricultural Residues and Grasses

Fibre Length

The quality of paper and paper products influence among other qualities the fibre length. The fibre length of *Hibiscussabdariffa* stalk, *Abelmoschusesculentus* stalk, *Panicummiliaceum*stalk, *and Hyparrhenia involucrate* whichranged between 0.90 mm - 2.23 mm,falls within fibres (0.7-1.6 mm) of hardwoods and far from 2.7-4.6 mm in softwoods as reported by Ates*et al*., (2008).This implies that these nonwood materials can produce a smoother paper of lower strength property compared to softwood fibres according to Biermann, (1996). However, the fibre length of *Hyparrhenia involucrate* was longest (2.23 mm) and is within the mean fibre length of 2.30 mm in Bambooreported by Deniz and Ates, (2002), 2.60 mm in Kenaf stalks as obtained by Atchison,(1993) and is higher than 1.52 mm and 1.59 mm reported by Eroglu *et al.,* (1992); Samariha and Khakifirooz, (2011) for Cotton and Bagasse respectively.

Fibre Diameter

Fibre diameter in this study ranged from9.19 µm - 26.38 µm with *Abelmoschusesculentus* being highest (26.38 µm). The mean fibre width of rice residues was reported by Kiaei and Veylaki (2011) to be 10.30 µm which is lower than 20.96 µm reported for Bagasse by Samariha and Khakifirooz, (2011). Enayati*et al.,* (2009) reported 23.02 µm for Canola while Eroglu *et al.,* (1992) recorded 26.8 µm for Tobacco as Deniz and

Ates (2002) obtained 15.1 µm for Bamboo. However, the fibre diameter in this study is lower than 32-43 µm for softwood fibres and fall within hardwood fibres (20-40 µm) as reported by Atchison (1987). Dutt and Tyagi, (2011) noted that the diameter and wall thickness of fibre influence fibre flexibility which affects the beating of pulp, bursting and tensile strengths as well as folding endurance of paper.

Fibre Lumen Width

The averagefibre lumen width ranged from4.56 - 17.56µm and maximum in *Abelmoschusesculentus* stalk. These values are within results obtained by Kiaei and Veylaki (2011) for rice residues (4.56 µm),Bamboo (6.9 µm) by Deniz and Ates (2002). Bagasse (9.72 µm) recorded by Samariha and Khakifirooz, (2011) and Canola (12.50 µm) and Tobacco (16.3 µm) reported by Eroglu*et al.,* (1992) respectively.

Cell Wall Thickness

The average cell wall thickness obtained in this research ranged from 1.94 µm - 4.63 µm with *Hyparrhenia involucrate*having the highest value.These values are within that of Bagasse (5.63 µm), rice residues (2.86 µm), Canola (5.26 µm), Tobacco (5.3 µm), Sunflower (3.3 µm), Cotton (3.6 µm), Bamboo (4.17 µm) and Corn (2 µm) as reported by Samariha and Khakifirooz (2011); Kiaei and Veylaki (2011); Enayati*et al.,* (2009); Eroglu *et al.,* (1992); Deniz and Ates (2002) respectively. Kiaei and Veylaki (2011)

observed that a decrease in cell wall thickness Ates (2002) obtained 15.1 µm for Bamboo. However, the fibre diameter in this study is lower than 32-43 µm for softwood fibres and fall within hardwood fibres (20-40 µm) as reported by Atchison (1987). Dutt and Tyagi, (2011) noted that the diameter and wall thickness of fibre influence fibre flexibility which affects the beating of pulp, bursting and tensile strengths as well as folding endurance of paper.

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Derived Properties of Test Samples

Runkel Ratio

The suitability of any fibrous material for pulp and paper production is determined using the Runkelratio values reported for agricultural waste and grasses in this study ranged from 0.50 in *Abelmoschus esculentus* stalk to 1.18 *Oryza longistaminata*grass. The mean values of *Hibiscus sabdariffa* stalk, *Panicummiliaceum* stalk,and*Sorghum bicolor* stalk indicate that will be very good for paper production with *Abelmoschus esculentus*being the best. Sharma *et al.,* (2013) reported 0.25 for *Solanumtorvum* and Sida*cordifolia* respectively. Kiaei and Veylaki (2011) reported runkel ratio of 1.38 for rice residues as Garay*et al., (*2009) documented 0.47 and 0.90 for wheat and corn respectively. However, Deniz and Ates (2002) reported 1.20 for Bamboo while Bagasses (1.15) was noted by Samariha and Khakifirooz, (2011). Runkel ratio value of 0.65, 0.42, and 0.31 was reported correspondingly for Tobacco, Sunflower,and Cotton by Eroglu *et al.* (1992).Runkel ratio as a derived value from the inverse of wall thickness of fibre to lumen width of fibre is regarded as one of the utmost significant and primary parameters required to finding the suitability of cellulose material for pulp and paper making (Ogunjobi*et al.,* 2014). Cellulose fibre materials having Runkel ratio < 1 are reported good for papermaking since fibres collapse easily, are better flexible, and produce paper with huge bonded area as, fibres with Runkelratio > 1 are rigid, hard to collapse and produce heavier paper with reduced bonded area (Sharma *et al.,* 2013).

Felting Rate (Slenderness)

The tearing features of paperare determined by felting rate. In this study, felting rate ranged from lowest of 37.35 in *Oryzal ongistaminata*to highest of 134.76 in *Hyparrhenia involucrate*. The low felting ratio in some of the species could be the presence of short fibres (Sharma, *et al.,* 2015). When the felting rate of fibresis high, it provides better and a well bonded formed paper (Sharma *et al.,* 2015). When the Felting rate of fibrous material is more than 33, it is regarded good for pulp and paper making (Xu *et al*., 2006). Ates*et al*., (2008) reported that, when fibrous material is lower than 70 in felting rate, it is considered useful for quality pulp and papermaking. Consequently, high felting rate gives lower strength properties of paper. The strength characteristics of papers have been found to positively correlate with its felting coefficient (Ates*et al*., (2008).

Elasticity (Flexibility) Coefficient (%)

Flexibility coefficient governs the rate of fibre bonding in paper sheet (Sharma et al., 2013). Valuesobtained ranged from a minimum of 45.88 % in *Oryza longistaminata*to a maximum 66.57 % in *Abelmoschus esculentus* stalk. Bektas*et al.* (1999) categorized cellulose fibres into four classes which include (i) Highly elastic to have flexibility coefficient >75% (ii) Elastic fibres when flexibility coefficient is 50 -70% (iii) Rigid fibres with flexibility coefficient between 30 - 50 % and, (iv) Very rigid fibres with <30% flexibility coefficient. Based on this classification, *Hibiscus sabdariffa* stalk, *Panicummiliaceum*stalk, *Sorghum bicolor* stalk, *Hyparrhenia involucrate* grass *Oryza longistaminata*grass fibres have rigid fibreswhile *Abelmoschusesculentus* stalk has elastic firbre.Ates*et al*., (2008) reported that when fibre elasticity coefficient is between 50 % and 70 %, the fibre would give a flat and good paper with high strength properties. It implies that *Abelmoschusesculentus* stalk will produce flat and good paper with high strength features. It is important to note that the lower the fibre diameter the lower the have flexibility coefficient(Hussin, *et al.,* 2014).

Rigidity Coefficient (%)

Rigidity coefficient regulates physical resistance characteristics of paper. The highest (27.06%) rigidity coefficient in this work was in *Oryza longistaminata* grass. This is in line with that of hardwoods (27.80%) reported by (Bektas *et al*., 1999). The least (21.11%) was noted in *Sorghum bicolor* stalk which is higher than 19.97 obtained in *Pinussylvestris,* a softwood by (Akkayan, 1983).Ekhuemelo and Udo (2016) noted that the high rate of rigidity coefficient distresses tear, burst, tensile, and double fold resistance of paper undesirably. So, it implies that the lower rigidity coefficient 'recorded in this study indicate that the samples would be good for pulp and paper production. It noted by Akgu and Tozluoglu (2009) that as the rigidity of fibre increases there is the corresponding decrease in fibre bonding.

F Ratio

F ratio mean value ranged from 9,211.07 to 51,111.27 which was highest in *Hyparrhenia involucrate* grass and lowest in *Oryza longistaminata*grass. This result is at variance with Akgul and Tozluoglu (2009) who reported 140.38 F factor for beech juvenile wood, and 240.55 in black pine juvenile wood. The F ratio result of this study also does not agree with Kar (2005)other studies, on hardwoods where F factor was reported to be 235.92 in *Populuseuramericana*and 206.78 in *Populustremula.*

Chemical Properties of Test Samples

Ash Content (%)

After the whole burning of the wood material at 575±25°C, the remain is ash content (Al-Mefarrej*et al.,* (2013). The ash content of his research ranged from 3.86 % in *Oryza longistaminata*to 11.00 % in *Hyparrhenia involucrate.* These values are higher than 2.35% - 2.86% of different age and position of *Bambusa. vulgaris* reported by Sadiku*et al.,* (2016). Tutus *et al.,* (2010) reported an ash content of 7.83% for *Crambeorientalis*and 9.3% for *Crambetataria.* respectively. Kristova and Karar, (1999) noted that high ash is not good for pulping because they influence usual alkali consumption and create difficulty in recovery of pulping chemicals and operational challenges in material handling, pulp washing and beating in addition to bleaching interference reported by Dutt*et al.,* (2009). Walia*et al.,* (2009) stated that the ash content of wood provides information on the idea of inorganic portion and non-volatile of raw material. Al-Mefarrej*et al.,* (2013) affirmed that there is a relationship between paper strength and ash content and as result, paper strength decreases as the ash content increases. So, it is expected that the strength of paper produced from *Oryza longistaminata*will be low.

Hot Water Solution (%)

Hot water solubility ranged from 0.58 % in *Panicummiliaceum*stalk to 7.21% in *Hyparrhenia involucrate* grass. These are higher than 4.05% - 11.96% reported by Sadiku*et al.,* (2016)for various ages and portions of *Bambusa vulgaris.* Water solubility of wood signifies the low molecular weight compounds and polysaccharides (Walia*et al.,* (2009). Generally, a wood material with lower cold and hot water soluble possess higher lignin content while the those with high values of cold and hot water soluble have more active cells Latib*et al.* (2014).

Ethanol Toluene Solution (%)

Ethanol Toluene solutionranged from 1.11 % for *Abelmoschusesculentus* stalk to 22.30 %in

Hyparrhenia involucrate. This agrees with 14.5% for banana stem reported by (Kumar and Kumar, (2011).

Cold Water Solution (%)

Cold water solutionranged from 0.46% in *Hibiscus sabdariffa* stalkto 12.06%in *Hyparrhenia involucrate* grass. These values agree with 1.76% - 6.63% for *Bambusa vulgaris* obtained by Sadiku*et al.,* (2016). Cold and hot water soluble are significant in the assessment of water-soluble extracts like sugar, tannin, pectin, starch, and phenolic compounds within any lignocellulosic material (Jamaludin, 2006).

Lignin (%)

In this study, lignin ranged from a minimum of 5.86% in *Hyparrhenia involucrate* grass to a maximum of 25.90%in *Sorghum bicolor* stalk. The result is consistent with 13.51% for *C*upressus sempervirens a softwood and16.31%for Populus alba, 12.15% for Eucalyptus camaldulensis, 17.56% for Acacia nilotica which are hardwood as by reported Solimanet al., (2017). Tutus et al., (2010) obtained 24.5% for *Crambeorientalis*. However, the values are below (29.24% - 45.90%) for *Bambusa vulgaris* obtained by Sadiku*et al.,* (2016). Ogunsile and Uwajeh, (2009) reported that high lignin value requires more penetrating delignification, high chemical consumption,and long cooking cycle. Low lignin content in materials requires slight conditions of pulping like reduce cooking time and temperature. Consequently, energy requirements and cost of production would be reduced (Omotoso and Ogunsile, 2009).

Hemicellulose (%)

Hemicelluloseranged from the least of 15.70% in *Abelmoschusesculentus* stalk to highest value of 57.43%in *Oryza longistaminata*grass. These values are the within the range of 34.43 to 35.97% in *Triticumaestivum*as reported by Al-Mefarrej*et al.,* (2013). These are higher than 4.13% - 10.58% reported by Sadiku*et al.,* (2016), 8.66% - 18.88% of *Eucalyptus* spp reported by Dutt and Tyagi, (2011) and lower than many annual plants and coniferous (68-74%) reported by Ates*et al.,* (2008). Tyagi *et al.,* (2004) stated that the higher the hemicellulose content; healthier the swelling behaviour of pulp, which results to a rise in mechanical strength properties, along with burst indexes, double folds tensile, and decrease in beating or refining energy.

Alkali (%)

Alkali in this research ranged from 3.01%in *Panicummiliaceum*stalk to 23.22%in *Hyparrhenia involucrate* grass. This agrees with an alkali-soluble of *Neolamarckiacadamba* which ranged from 17.50% - 18.83% reported by Latib*et al.* (2014). Jamaludin (2006) noted that high alkali soluble correspond to high degradation of cellulose and low polyphenol content. He further stated that in the pulping process, such property would give aid its high holocellulose content which however results in lower yield.

Cellulose Solution (%)

Cellulose is the be greatest significant part in fibre strength and afterward paper strength besides pulp yield (Al-Mefarrej*et al.,* 2013). Findings showed that cellulose content **r**anged from 14.32% in *Abelmoschus esculentus* stalk to 68.21%in *Panicummiliaceum* stalk. Sadiku*et al.,* (2016)recorded a slight higher of 68.38% to 75.68% for *Bambusavulgaris*at different ages and positions. Tutus *et al.,* (2010) recorded 40.1% in *Crambeorientalis,* 40.3% in *Crambetataria*, and *Bambusavulgaris* varied from 68.38% to 75.68%.

Conclusions

The following conclusions could be drawn from the results.

i. Although the analysis of variance of fibre length showed that means of studied samples are not significant, *Hyparrhenia involucrate* had the highest which falls within fibres of pulpable hardwood species.

ii. *Abelmoschusesculentus* stalk had the best runkel ratio followed *Sorghum bicolor Hibiscus sabdariffa* stalk and *Panicummiliaceum.* Their values indicate that it will be suitable for paper production.

iii. Felting rate of all fibrous material in this study indicates that they are good for pulp and paper making.

iv. *Hibiscus sabdariffa* stalk, *Panicummiliaceum* stalk, *Sorghum bicolor*, *Hyparrhenia involucrate* grass,*Oryza longistaminata*grass fibres have rigid fibreswhile*Abelmoschusesculentus* stalk has elastic firbre.

In conclusion, results based on the physical and chemical features indicated that Makurdi agricultural residues and grasses are propitious fibrous raw material for the paper production.

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