A STUDY ON MEA-PULPING OF TEN (10) NIGERIAN CULTIVATED AGRO-BASED FIBER FOR THE PRODUCTION OF PULP STOCK PAPER

Henry Okwudili CHIBUDIKE[1], Eze MGBACHIUZO[1], Nelly Acha NDUKWE[2], Nkemdilim Ifeanyi OBI[3], Olubamike Adetutu ADEYOJU[4] and Eunice Chinedum CHIBUDIKE[5]

[1]Chemical, Fiber and Environmental Technology Department, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O. Nigeria
[2]Department of Chemical Sciences, College of Basic & Applied Sciences, Mountain Top University, Magoki, Ogun State,Nigeria
[3]National Oil Spill Detection and Response Agency (NOSDRA), Abuja-Nigeria
[4]Production, Analytical and Laboratory Management, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O., Lagos-Nigeria
[5]Planning, Technology Transfer and Information Management, Federal Institute of Industrial Research, Oshodi, F.I.I.R.O., Lagos-Nigeria

Abstract

The objective of this research study is to examine the potentials of a novel environmentally friendly pulping process in converting some selected Nigeria cultivated agro-wastes into high yield paper pulp. The chemical and morphological characteristics of Ten (10) Nigerian cultivated agro-based fibers were investigated. Pulping trials were carried out using the monoethanolamine (MEA) process comparing the potentials of each agro-biomass in furnishing high yield pulp. The operating conditions such as the concentration of the cooking liquor (50%, 75%, 100%), the maximum cooking temperature (150, 160, 170ºC) and cooking time (60, 90, 120minutes) were applied systematically to establish optimal pulping conditions and optimum result. The lignin content of EFB (18.29%) was low; indicating that EFB should be easier to pulp. The optimum cooking conditions for MEA pulping were 75% MEA concentration, 90 minutes cooking time, and 150°C cooking temperature. The laboratory-scale experimental results indicated that MEA pulping process is particularly well suited for the pulping of agro-based fibers e.g. EFB of Oil Palm, which was de-lignified to a low kappa number value of 18.6, pulp yield of 49.93% and screen yield of 46.27% recording a reject of only 3.66%. It was observed that most of the materials with the exception of wheat straw and kenaf bast fiber showed a similar lignin content (around 18%), with rice straw and corn stalk showing slight variation. More variations were observed in the holocellulose and α-cellulose contents; also, sugar cane bagasse showed the highest percentage of α-cellulose with respect to total holocellulose. Comparing data on holocellulose, α-cellulose and lignin of the ten (10) agro base fiber investigated, it could be observed that EFB has slightly lower α- cellulose and holocellulose contents than all the agro-base fiber investigated with the exception of CFB, wheat and rice, but slightly similar in lignin contents only to pineapple leaves, bagasse and CBF. Based on these results, it seems appropriate to use EFB as a cellulose source suitable for the production of cellulose pulp and paper. MEA process is more economically attractive given its high pulp yield, despite the significant increase in chemical demand for bleaching. MEA pulping is a good alternative to soda pulping furnishing high pulp yield with less cooking temperature, i.e. 150ºC, thereby saving a considerable amount of energy with less odoriferous pollutants and pollution load associated with the soda process.

Keywords*: EFB, Monoethanolamine, Pulp Screen Yield, Kappa no, Lignin, Agro-wastes, Soda, kenaf*

Introduction

Pulp and paper production are one of the high demand sectors in the world of industrial production. The total global consumption from paper-making was projected to increase from 316 million tons in 1999 and 351 million tons in 2005 to about 425 million tons by 2010 **(García et al., 2008).** Today, the trend in total global consumption from paper-making is still rising. Consequently, the pulp and paper industry is one of the most polluting industries in the world facing social pressure related to its environmental and sustaining efficiency leading to the need for R & D to discover an efficient environmentally respectful pulping technology for converting lignocellulosic biomass (wood, non-wood and agro-fiber) to pulp stock paper.

Technology for pulp and paper production has advanced considerably and efforts are being made to reduce environmental impact of pulp and paper production processes through the use of organosolv pulping method developed to avoid environmental problems related to Sulphur emissions. In several countries of the world as it applied in F.I.I.R.O, kraft method was the dominant pulping process right from the inception of the pulp and paper laboratory in 1956 up till year 2011. The dominance of the kraft process was anchored upon its versatility to pulp almost any kind of wood successfully. But prominent are the emissions of some fowl smelling and malodorous pollutant such as mercaptans, p-cymols, chlorinated organic compounds e.t.c. In 2012, this method was substituted by the soda process because it is less polluting compared to the kraft process, but the fact remains that the soda process is still faced with severe drawbacks. Strongly alkaline cooking liquors dissolve carbohydrates to a great extent with negative impact on pulp yield. Most annual plants have a high content of silica, which is dissolved to a high extent in the strongly alkaline cooking liquor and thus creates serious problems in the evaporators, the recovery boilers and in the causticizing plant. These are the main reasons why soda pulping black liquor handling and recovery of chemicals is still problematic. The situation is completely different when monoethanolamine (MEA) as the main delignifying agent was investigated. Delignification by use of monoethanolamine (MEA) is an innovative, environmentally friendly chemical pulping process that works without the use of sulphur compounds, with a particular benefit of simple MEA recovery by distillation, allowing black liquor combustion to be dispensed and the dissolved lignin recovered **(Chibudike, 2019)**.

In the course of research investigation, we discovered that Shredded wood (natural fiber) from the forest is becoming increasingly scarce due to increasing urban requirement for wood especially in a world where virgin pulp sources are scarce and environmental concerns require reduction in cutting down green forest, a world where agricultural wastes constitute environmental nuisance and a nightmare to farmers who either landfilled or burned them to no beneficial purpose constituting a colossal loss of natural resources and environmental hazard. However, these known pitfalls can no longer be tolerated in a world were environmental friendliness is a law **(Chibudike et, al. 2009; 2011 and Chibudike, 2019)**. Substituting the use of wood for agro-wastes would help prevent environmental nuisance these wastes constitute during post-harvest, abate air pollution caused by unnecessary burning of these wastes and discourage the act of deforestation thereby converting wastes to wealth.

Experimental

Materials

Ten Nigeria-grown Agro-based Fibers generated during post- harvest treatments in various locations in Nigeria were used. These include: EFB of Oil Palm, wheat straw, rice straw, coconut fruit fiber, corn stalk, lemon grass, elephant grass, kenaf fiber, pineapple leaves and sugarcane bagasse.

Raw material characterization

Prior to chemical characterization and pulping, the raw material was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm and retained on a 0.40mm sieve to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12 – oS – 75. Particles larger than 0.40 mm are inefficiently attacked by the chemical reagents, whereas those below 0.25 mm can cause filtering problems. The sample was characterized by analyzing its content of moisture, hot water solubility, klason lignin, α-cellulose, 1% NaOH solubility, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in Table 1

Table 1: Standards used in the Chemical Characterization of the Agro-biomass

Biomass Characterization	Standards
Sample preparation	TAPPI Standard Test Method T 12 oS-75 (Anonymous, 2002)
Moisture	TAPPI Standard Test Method T 264 om-88 97 (Anonymous, 2009)
Hot water solubility	TAPPI Standard Test Method T 207 cm-99 (Anonymous, 1999)
Total Extractives	TAPPI Standard Test Method T 204 cm-97 (Anonymous, 2007)
Acid insoluble (klason) lignin	TAPPI Standard Test Method T 222 om-02
Alpha (α)-cellulose	TAPPI Standard Test Method T 203 os-74 (Anonymous, 1999)
1% NaOH solubility	TAPPI Standard Test Method T4 os-59 (Anonymous, 2002)
Ash	TAPPI Standard Test Method 211 om -02 (Anonymous, 2002)
Holocellulose	TAPPI standard Test method T-249, (Anonymous, 2004)

Determination of fiber morphology

Small slivers were obtained and macerated with 10 ml of 67% HNO3 and boiled in a water bath (100o ± 2oC) for 10 min (Ogbonnaya et al., 1997). The slivers were then washed, placed in small flasks with 50 ml distilled water and the fiber bundles were separated into individual fibers using a small mixer with a plastic end to avoid fiber breaking. The macerated fiber suspension was finally placed on a slide (standard, 7.5 cm × 2.5 cm) by means of a medicine dropper. For fiber diameter, lumen diameter and cell wall thickness determination, cross-sections were obtained from the same height/length as above and were stained with1:1 aniline sulfate–glycerin mixture to enhance cell-wall visibility (cell walls retain a characteristic yellowish color). All fiber samples were viewed under a calibrated microscope; a total of 25 randomly chosen fibers were measured. All samples were measured in a swollen condition.

Outline of the Production Process

Figure 1 illustrates the process of making paper from Empty Fruit Bunch (EFB). The EFB of Oil Palm was characterized chemically and morphologically and converted into brown pulp at a delignification degree of 18.2 kappa from MEA Process. The resulting pulps was fully bleached by the D1-Ep-D2 sequence and characterized for its beatability, drainability and physical-mechanical properties.

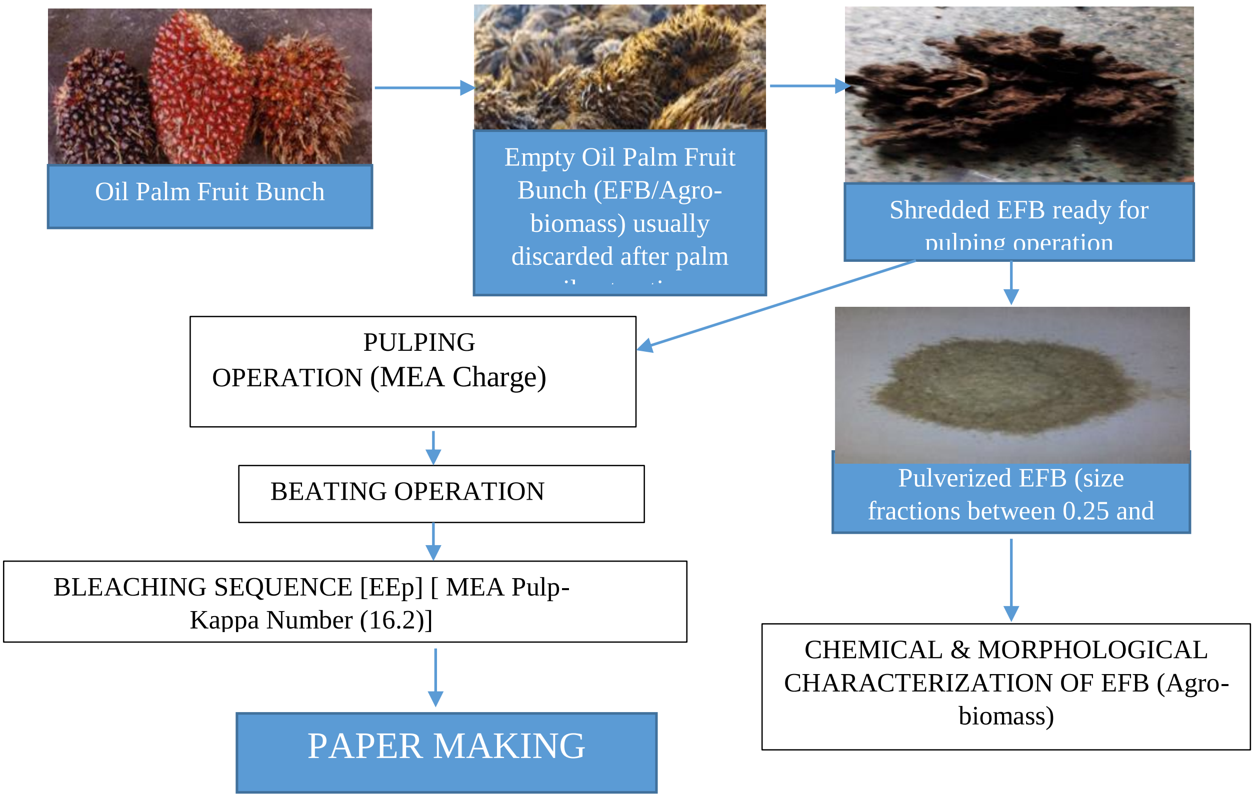


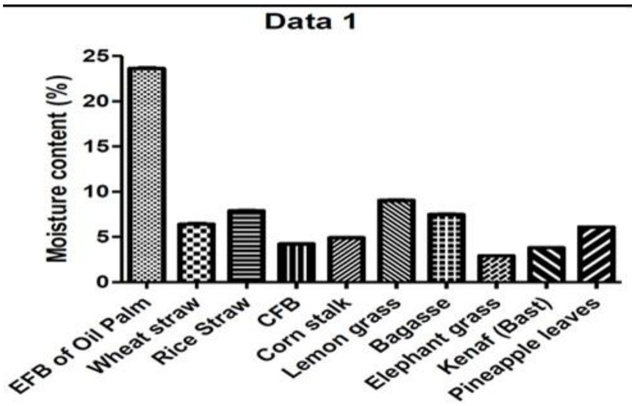
Figure 1: Figure 1: Steps in Agro-biomass (FFB) fractionation and conversion to paper

Description of the Pulp and Paper-making Process

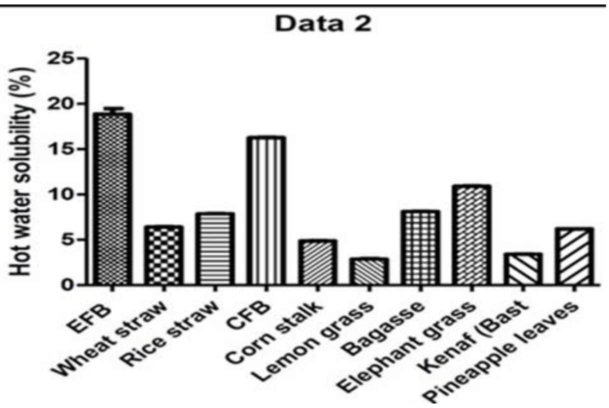
After the post-harvest treatment, the empty bunches of Oil palm were shredded and Prior to chemical characterization and pulping, a portion of the shredded sample was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm (because samples below 0.25 mm can cause filtering problems) and retained on a 0.40mm sieve (because particles larger than 0.40 mm are inefficiently attacked by the chemical reagents) to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12 – oS – 75. This portion of EFB sample was characterized by analyzing its content of moisture, hot water solubility, klason lignin, α-cellulose, 1% NaOH solubility, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in table 1. The second portion of the shredded EFB was subjected to a thorough cleaning process, 2kg of air-dry sample was loaded into a 15 L capacity batch reactor (digester) with eight (8) liter cooking liquor at liquor-sample ratio of 4:1. The digester mounted in the Pulp and Paper Research Laboratory of the Federal Institute of Industrial Research, Oshodi, (F.I.I.R.O.), Lagos-Nigeria is furnished with an outer electrical heating jacket. The lid of the digester was firmly bolted to prevent leakage, the digester was switched on and the time of rise of temperature and pressure was noted at intervals of five (5) minutes. The content of the digester was stirred while in operation by rotating the vessel via a motor connected through a rotary axle to a control unit, including measurement and control instruments of pressure and temperature, to facilitate attainment of the working temperature (5°C/min). The pulping temperatures gradually rose and allowed to be steady at varying maximum temperatures of 150, 160 and 170oC. The digester was switched off after varying maximum cooking periods of 60, 90 and 120 minutes from start of operation and allowed to cool below 60oC before the content were blown down. The digester's initial temperature, pressure and starting time were all noted, and the various changes in these parameters were also recorded. The resultant pulp was subjected to thorough washing with plenty of water. When it was observed that subsequent washing resulted in no further change in color, the pulp was transferred into the valley beater for processing into a more refined pulp before the bleaching operation.

Results and Discussion

The chemical analyses of Ten (10) Nigerian cultivated Agro-based fiber were conducted. Table 3 illustrates the results of the characteristics obtained. Figure 2 plot the results of moisture analysis of the ten agro-base fiber investigated as mentioned above. Amongst the raw materials investigated, Oil palm EFB is highest in moisture content and considerably higher than wheat and rice straw in lignin content. Both cold and hot water extractives were much higher for EFB and CFB than for Kenaf (Hibiscus cannabinus), bagasse and other Agricultural residues investigated in this research study, figure 3. It means EFB and CFB would require a slightly higher alkali dose to neutralize acidic extractive, which may affect the pulp yield adversely and create less digester corrosion caused by extractives.



Figures 2: Effect of Plant material on variation of Moisture Content



Figures 3: Effect of Plant material on variation of Hot Water Solubility

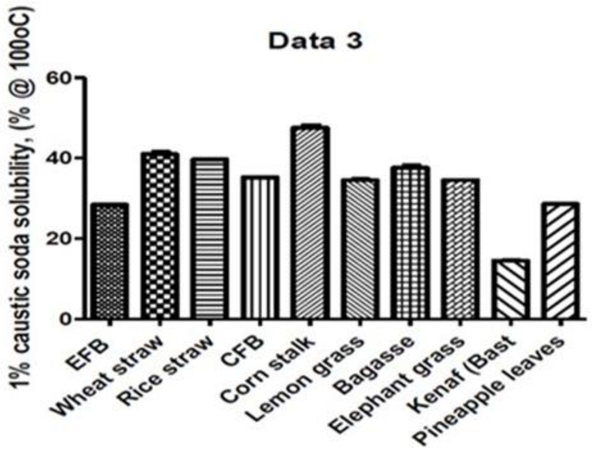
Table 2: Chemical Characterization of Ten (10) Nigeria-cultivated Agro-based fiber

Parameters	Agricultural Residues/ Non-wood Fibrous Materials									
	EFB	*Cereal Straws		**Coconut fruit fiber (cocos nucifera)	**Corn stalk (zea mays)	***Lemon grass (Cymbopogon citratus)	***Sugar Cane Bagasse	**Elephant grass	Bast Kenaf	***Pineapple leaves
		Wheat straw	Rice Straw							
Source of sample	Okiti pupa (Western Nigeria)	Minna (Northern Nigeria)	Minna (Northern Nigeria)	Badagry, Lagos Nigeria	Ebute-Metta (West), Lagos-Nigeria)	Oke-Ira, Lagos (Typically found in sub-Saharan tropical Africa)	Kaduna State (Northern Nigeria)	Ebute-Metta (West), Lagos-Nigeria)	F.I.I.R.OBotanical garden, Lagos.	Ebute-Metta (West), Lagos-Nigeria)
Moisture content (%)	23.63	6.40	7.90	4.2	4.90	9.04	7.5	2.9	3.8	6.08
Hot water solubility(%) @ 80–95oC for 0.5 h	18.90	6.40	7.90	16.3	4.90	2.90	8.12	10.9	3.4	6.2
1% caustic soda solubility, (% @ 100°C	28.3	41.0	39.7	35.2	47.6	34.60	37.67	34.6	14.5	28.6
Extractives (%)	13.65	3.70	7.90	6.6	4.10	16.89	5.40	3.9	5.2	6.21
Ash (%)	4.55	9.50	15.50	4.3	3.70	0.7	0.80	2.4	2.2	4.70
Alpha-cellulose, (%)	39.70	26.20	35.10	47.2	48.30	54.10	59.30	54.1	56.40	46.8
Lignin (%)	18.29	12.30	16.00	17.9	15.20	8.90	19.50	15.1	14.70	17.90
Holocellulose %	69.80	65.71	60.70	66.70	81.65	81.90	85.70	81.9	82.6	81.50

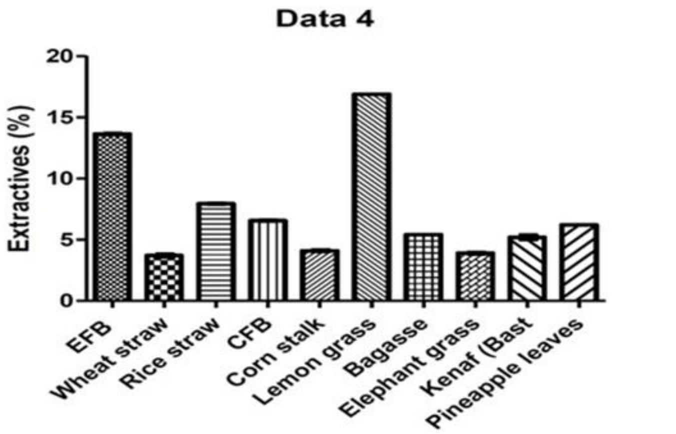
*Chibudike H.O. and Udohitinah J.S. (2009); **Chibudike et al., (2009); ***Chibudike et al., (2011)

Studies shows that 1% alkali solubility was distinct in wheat (41.0%) and corn stalk (47.6%), it was higher than values obtained for sugarcane bagasse, Kenaf (Hibiscus cannabinus), and rice straw, but much lower than in EFB, indicating compositional dissimilarities between EFB and the other raw materials investigated. It indicated that none of the agricultural residues could be stored for a longer period after harvesting, compared to sugarcane bagasse, wheat straw, rice straw, coconut and kenaf. EFB extractives are high when compared with other materials investigated, but lower than the other materials in alpha cellulose content with the exception of wheat and rice straw. The EFB contains 18.9% hot water solubles, 28.3% of 1% caustic solubles, 18.09% acid insoluble lignin, 69.8% Holocellulose, 13.65% extractives, and 4.55% ash. The extractive content in rice was 7.90% and was higher than those found in most of the agricultural residues. The extractive content was noted not to be higher than EFB of Oil Palm (13.65%). However, lemon grass (16.89%) recorded the highest extractive content amongst all the agro-based fibers investigated.

The high NaOH solubility of wheat straw was possibly due to the presence of low molar mass carbohydrates and other alkali-soluble materials. The extractives (solubles) in EFB (13.65%) were highest amongst the material investigated, while the least amount was found in wheat straw. This indicated that EFB, rice straw, coconut, and sugar cane bagasse contained more substances like waxes, fats, resins, phytosterols, non-volatile hydrocarbons, low molecular weight carbohydrates, salts and other water-soluble substances. A higher content of extractives would be converted into pitch, which would adversely affect the runnability of process equipment and the quality of paper, because of shadow marking. Papers made from this type of fibers might show reduced water absorbency.



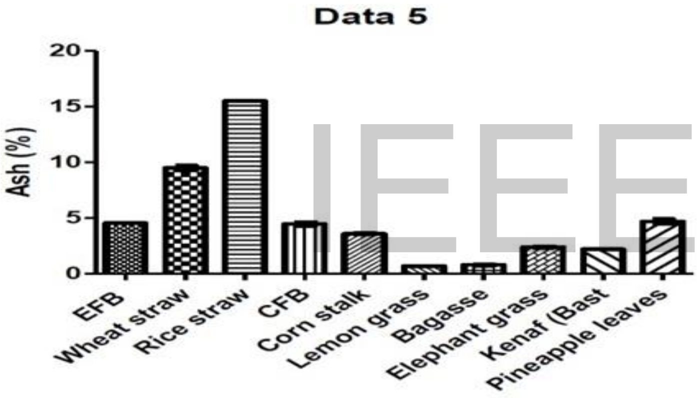
Figures 4: Effect of Plant material on variation of 1% Caustic Solubility



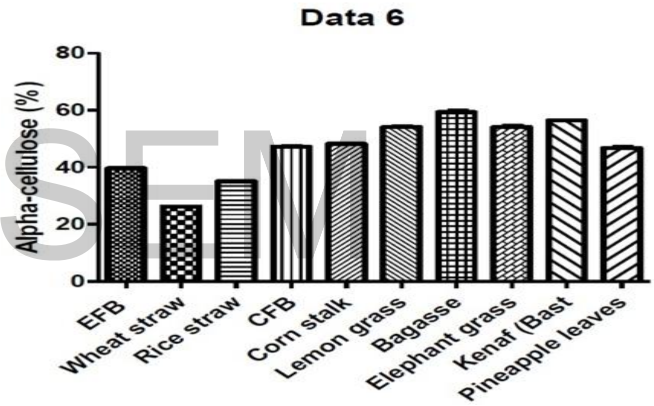
Figures 5: Effect of Plant material on variation of Extractives Content

The ashes are high, as in the case of cereal straws (wheat straw and rice straw) in comparison with other materials (Table 3). Although high ash contents were undesirable, as they would pass into the pulp. Ash contents in this study were in the typical range for non-wood plants and were not expected to have any significant effect on pulp mechanical strength properties.

As observed in Figure 6, Silica content in EFB (4.45%) was higher than that of Kenaf (2.20%) and was relatively low as compared to the cereal straws. Silica posed rather serious difficulties during pumping of black liquor and poor drainage during papermaking. At the same time, silica is suspected to play the role of inhibitor for O_2 delignification and bleaching with H_2O_2, thereby eliminating the need for additional inhibitors to mask transition metal ions during pulping/bleaching



Figures 6: Effect of Plant material on variation of Ash content



Figures 7: Effect of Plant material on variation of Alpha-cellulose Content

Figure 6 indicate that rice straw had significantly higher ash content than all the fibrous materials investigated. The value of α-cellulose content in EFB studied was lower compared to α-cellulose content in other agricultural residue investigated with the exception of wheat straw.

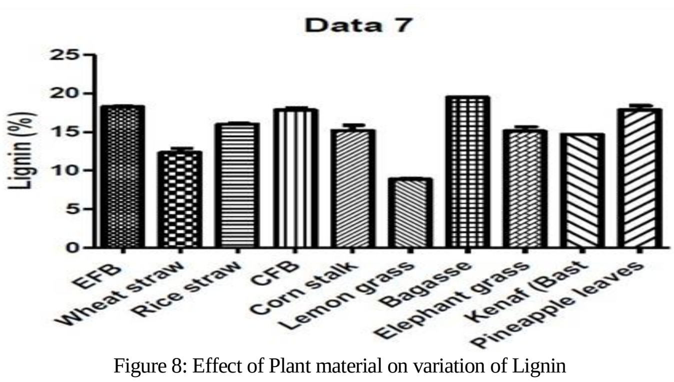


Figure 8: Effect of Plant material on variation of Lignin

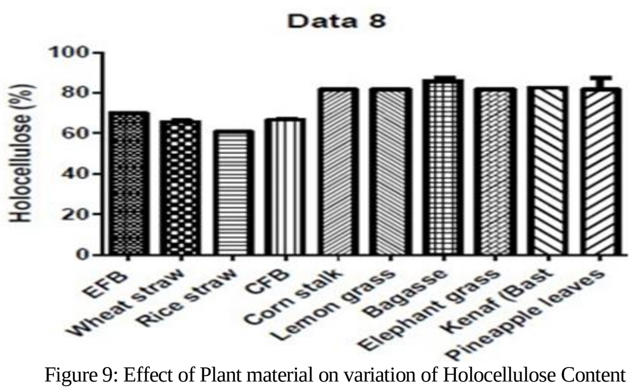


Figure 9: Effect of Plant material on variation of Holocellulose Content

The higher the lignin content, the greater the stiffness of fibers. Lignin contents in EFB were almost similar with that of the softwood and hardwood. As observed in Figure 8, Klason lignin contents in Kenaf (14.70%) and wheat straw (12.30%) were much lower than those in EFB, sugarcane baggase, rice and coconut. In practice, this means that these materials would need milder pulping conditions (lower temperatures and chemical charges) in order to reach a satisfactory kappa number. They would also undergo bleaching more easily and with the utilization of fewer chemicals. Alpha- cellulose content of EFB is 39.7% and the hemicellulose/α-cellulose ratio is appropriate to enhance swelling of the fiber, increase its plasticity, flexibility and link ability. This subsequently improves density and sheet properties.

Based on these results, it seems appropriate to use EFB as a cellulose source suitable for the production of cellulose pulp and paper. Comparing data on holocellulose, α-cellulose and lignin of the ten (10) agro base fiber investigated, it could be observed that EFB has slightly lower α- cellulose and holocellulose contents than all the agro-base fiber investigated with the exception of CFB, wheat and rice, but slightly similar in lignin contents only to pineapple leaves, bagasse and CBF. Figure 8 shows that most of the materials with the exception of wheat straw and kenaf bast fiber showed a similar lignin content (around 18%), with rice straw and corn stalk showing slight variation. More variations were observed in the holocellulose and α-cellulose contents; also, sugar cane bagasse showed the highest percentage of α-cellulose with respect to total holocellulose. Figure 10 Summarizes the chemical properties of the ten (10) agro-based fiber investigated. The holocellulose content in EFB was 69.8%% and it is higher than wheat straw (65.71%) and rice straw (60.7%), but lower than Corn stalk (81.65%) and Kenaf bast fibre (82.6%). Sugarcane bagasse (85.7%) recorded the highest holocellulose content. EFB has slightly lower α- cellulose than Kenaf but only lower in lignin content when compared to wheat straw, but very similar holocellulose contents.Besides the fiber length, these two fibers (EFB and kenaf) are also greatly different in chemical compositions, and thus they are not recommended to be pulp together. In summary, lignin is an undesirable polymer, and its removal during pulping requires high amounts of energy and chemicals. Wheat, kenaf, lemon, elephant grass, rice and corn stalk residues exhibited the lowest lignin content, which revealed that this material can undergo bleaching easier with the utilization of lower amounts of chemicals than other agricultural residues fibers.

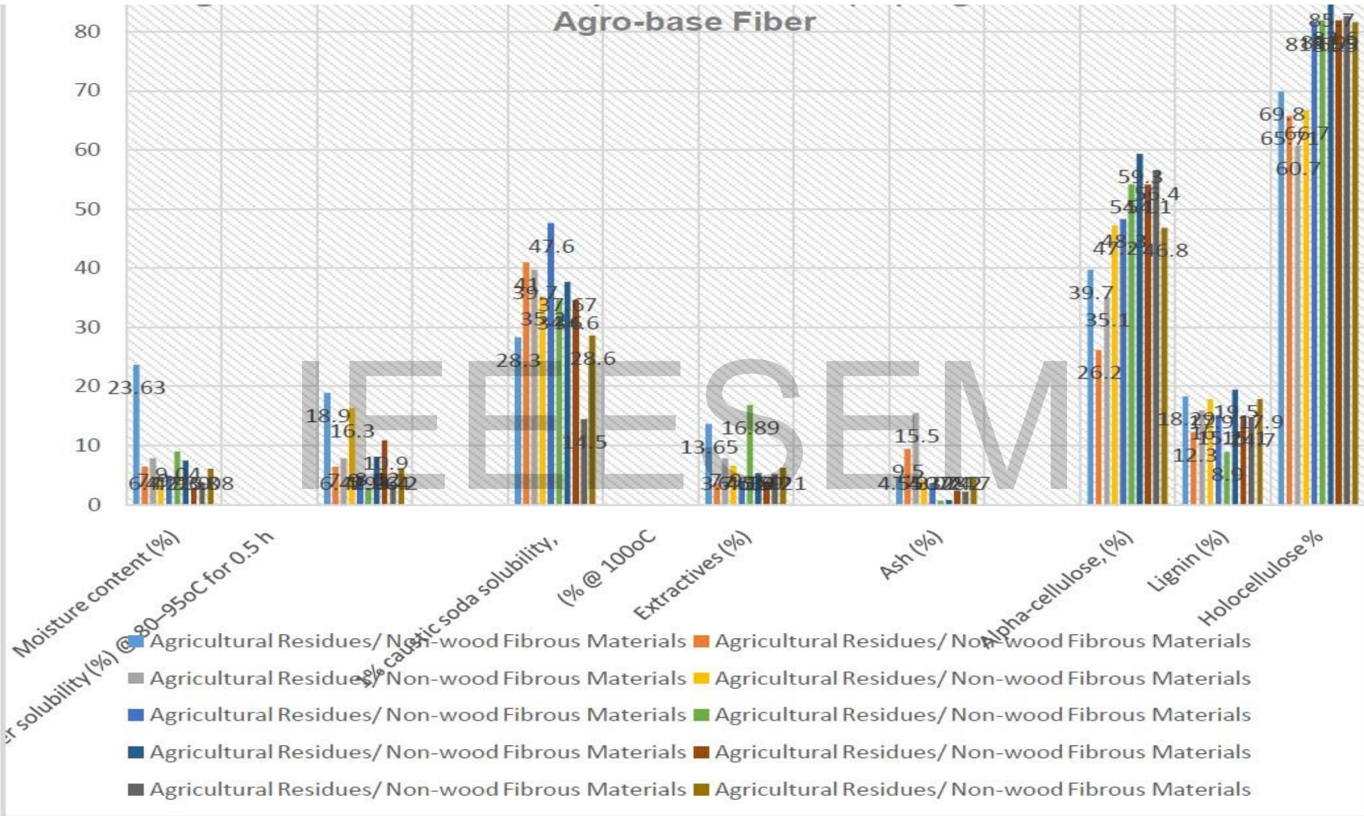


Figure 10: Chemical Composition of Ten (10) Nigeria-cultivated Agro-base Fibre

In producing paper, increasing the amount of cellulose and decreasing value of lignin, the extractive content, and ash caused increase of yield, decrease of chemical material consumption, and cooking time. The average fiber dimensions of the various types of agro- base fibers investigated in this research study are shown in Tables 4. The results of investigation indicate that the effects of materials on the fiber length were significant, so that the highest and lowest fiber length were found in Pineapple leaves and EFB residues. The fiber length of EFB averaged 0.7mm. The width of the EFB fibers was also measured, an average value of 14.16 µm being recorded (14.20 and 14.12µm were the maximum and minimum values obtained). The results also indicate that the effects of plant materials on the fiber diameter were significant, so that the highest and lowest of fiber diameter were found in rice and lemon grass. Going by these results and knowing that hardwood has a length of around width are, respectively, around 53.3% to 72.0% 1.5 mm to 2.5mm and a width of around 15 to 20µm, it can be estimated that EFB fibre length and is 5.6% to 29.2% lower (depending on the species) than hardwood.

Table 3: Morphological properties of Ten (10) Nigeria-cultivated Agro-based fiber

Plant materials	Fibre length, (L), (mm)	Fibre diameter, (D), (µm)	Fibre Lumen, (d), diameter (µm)	Fibre wall/Cell wall thickness, (w), (µm)
EFB of Oil Palm	0.70	14.16	5.97	4.04
Wheat straw	1.37	11.0	1.87	0.91
Rice Straw	1.45	8.5	0.36	0.25

Coconut fruit fiber (cocos nucifera)	1.17	18.4	8.5	5.3
Corn stalk (zea mays)	1.22	16.3	8.5	4.1
Lemon grass (Cymbopogoncitratus)	1.14	32.0	12.0	7.1
Sugar Cane Bagasse	1.70	21.0	11.9	6.2
Kenaf (bast))	1.29	22.1	12.7	4.3
Elephant grass	1.33	15.14	9.8	2.6
Pineapple leaves	2.93	12.10	7.6	3.4

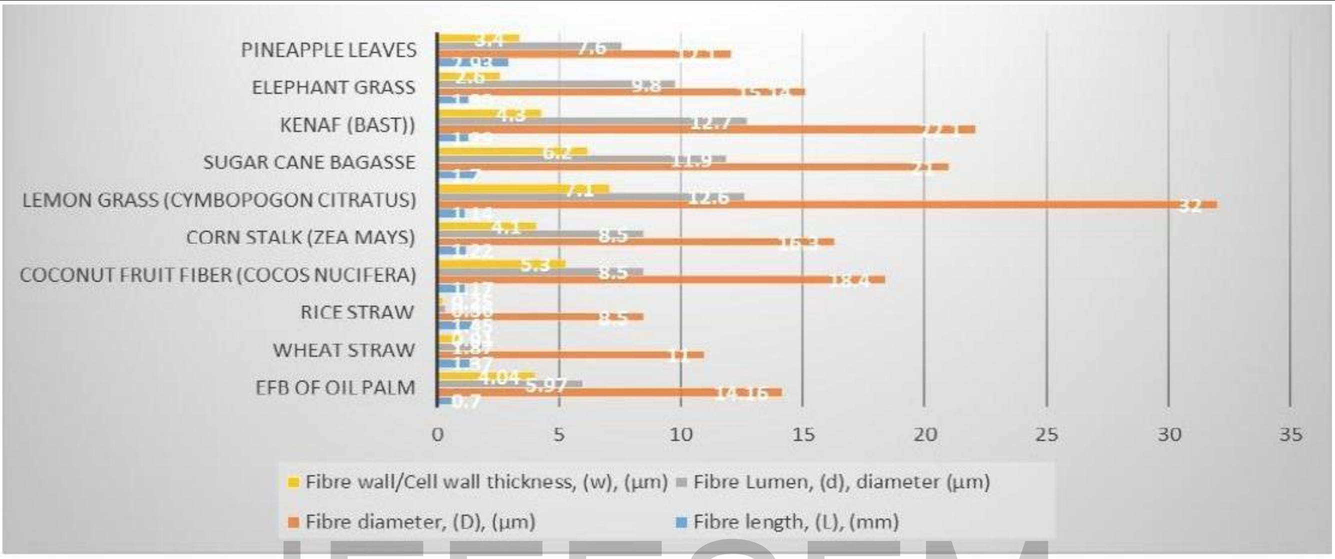


Figure 11: Summary of the Effect of Plant Materials on the Morphological Properties of Ten (10) Nigerian Cultivated Agro –based Fibers

On the other hand, softwood fibre is between 3-5 mm long and about 39 to 41 µm wide, meaning that EFB length and width are about 76.66% to 86.0% and 65.46% to 85.49% lower, respectively, than those of softwood. The Fiber lumen width amongst all of agricultural residues investigated followed the order given as: (Highest) Rice (0.36 µm)>wheat (1.87 µm)>EFB (5.97 µm) >Pineapple leaves (7.6µm) > corn (8.5 µm) > Coconut (8.5µm)>Elephant grass (9.8 µm) > Bagasse (11.9µm) >kenaf (12.7 µm) > Lemon grass (12.6 µm) > (lowest). The Fiber cell wall thickness amongst all of agricultural residues investigated also followed the order given as: (Highest) Rice (0.25 µm)>wheat (0.91 µm)>Elephant grass (2.6 µm) >Pineapple leaves (3.4µm) >EFB (4.04µm) > corn (4.1 µm) >kenaf (4.3 µm) > Coconut (5.3µm)> Bagasse (6.2µm) > Lemon grass (7.1 µm) (lowest).

Figure 12: EFB Fiber image on a projection microscope

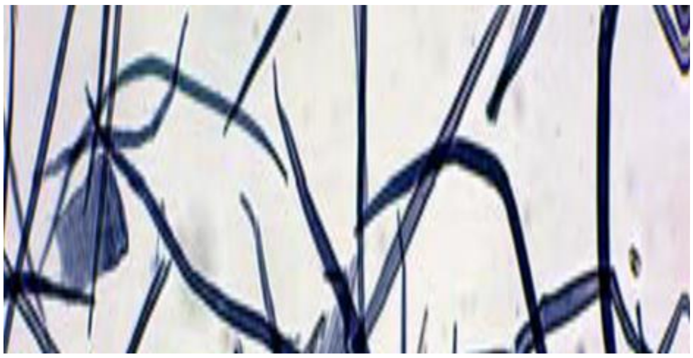


Figure 13: Kenaf Fiber EFB Fiber image on a projection microscope

On the other hand, softwood fibre is between 3-5 mm long and about 39 to 41 µm wide, meaning that EFB length and width are about 76.66% to 86.0% and 65.46% to 85.49% lower, respectively, than those of softwood. The Fiber length amongst all of agricultural residues investigated followed the order given as: (Highest) Pineapple leaves (2.9) > Baggase (1.7) > rice (1.45) > wheat (1.37) > Elephant grass (1.33)>kenaf (1.29)>corn (1.22)>coconut (1.17)> Lemon grass (1.14) >EFB (0.70) (lowest). The Fiber diameter amongst all of agricultural residues investigated followed the order given as: (Highest) Rice (8.5µm)>wheat (11.0µm)>Pineapple leaves (12.1µm)>EFB (14.16 µm) >Elephant grass (15.14µm)>corn (16.3µm) >Coconut (18.4µm)>Bagasse (21.0µm)>kenaf (22.1µm) > Lemon grass (32.0µm) >(lowest). The mean lumen widths of the plant materials investigated are also shown in Table 4.

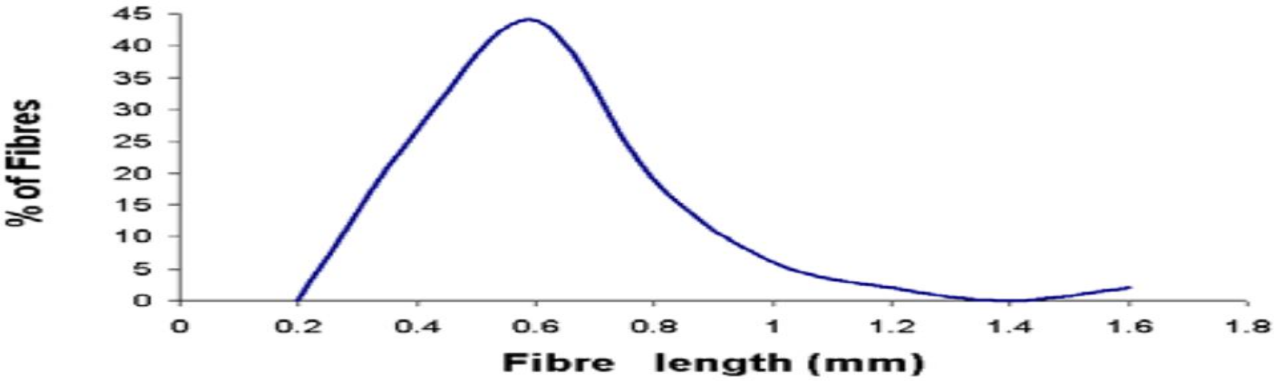


Figure 14: Distribution of EFB fibre length

The results of ANOVA indicate that the effects of the plant materials on the cell wall thickness were significant, so that the highest and lowest cell-wall thickness were found in rice and bagasse. The mean lumen widths of the plant materials investigated are shown in Table 3.3. Differences among the agricultural residues were tested at the level of p ≤0.01 and significant distinctions were marked with letters a, b, c, and d. The results of ANOVA indicate that the effects of agriculture residues on the lumen width were significant, so that the highest and lowest lumen width were found in rice and African Bamboo (Bambusa arudinacea).

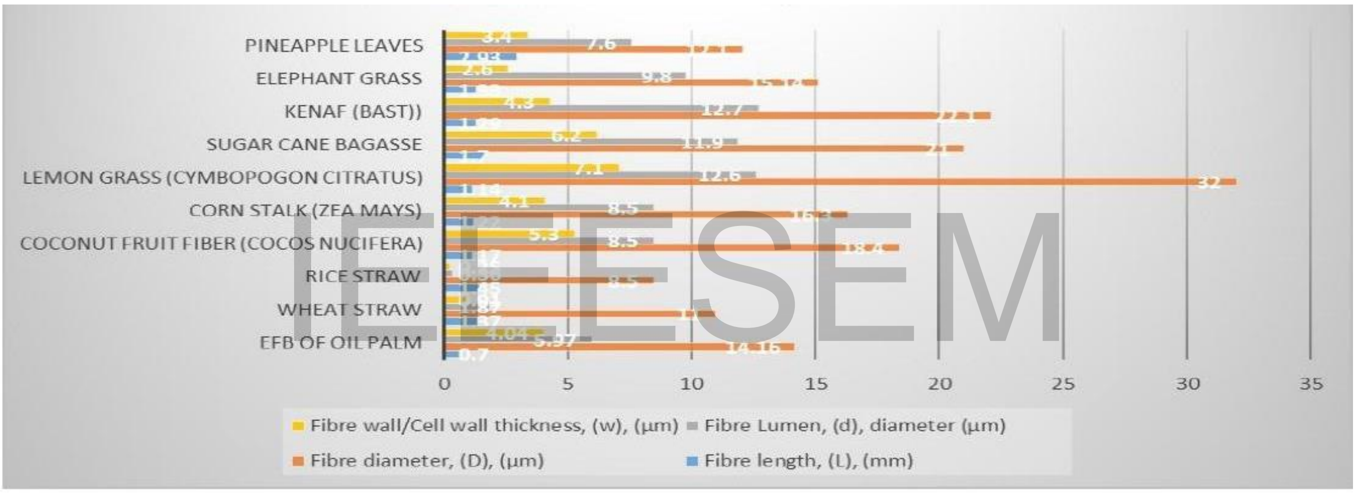


Figure 14: Summary of the Effect of Plant Materials on the Morphological Properties of Ten (10) Nigerian Cultivated Agro –based Fiber

The Fiber lumen width amongst all of agricultural residues investigated followed the order given as: (Highest) Rice (0.36 µm)>wheat (1.87 µm)>EFB (5.97 µm) >Pineapple leaves (7.6µm) > corn (8.5 µm) > Coconut (8.5µm)>Elephant grass (9.8 µm) > Bagasse (11.9µm) >kenaf (12.7 µm) > Lemon grass (12.6 µm) > (lowest). The Fiber cell wall thickness amongst all of agricultural residues investigated also followed the order given as: (Highest) Rice (0.25 µm)>wheat (0.91 µm)>Elephant grass (2.6 µm) >Pineapple leaves (3.4µm) >EFB (4.04µm) > corn (4.1 µm) >kenaf (4.3 µm) > Coconut (5.3µm)> Bagasse (6.2µm) > Lemon grass (7.1 µm) (lowest). Influence of morphological properties on Biometry (Slenderness, Flexibility, Runkel and Rigidity coefficient) of the various agro-base fibers investigated are shown in Tables 5. The Slenderness ratio of the plant materials investigated followed the order given as: (Highest) Pineapple leaves (215.70)>Rice (170.59)>Wheat (124.55)>Elephantgrass (87.85>Sugarcane Bagasse (80.95)>Corn (74.85)>Coconut (63.59)>kenaf (58.37)>EFB (55.79)>Lemon grass (35.63) (lowest). Slenderness ratio for rice residues was 170.59, which rate was greater than wheat fibers and EFB. The Flexibility coefficient of the plant materials investigated followed the order given as: (Highest) Elephant grass (64.73)>Pineapple leaves (62.81)>kenaf (57.47)>Sugarcane Bagasse (56.67)>Corn (52.15)>Coconut (46.20) > EFB (41.29)> Lemon grass (39.38) >Wheat (17.00) >Rice (12.24)> (lowest). Generally, there are four different types of fibers which are classified under flexibility ratio (Istas et al., 1954; Bektas et al., 1999): (1) High elastic fibers having elasticity coefficient greater than 75.Generally, there are four different types of fibers which are classified under flexibility ratio (Istas et al., 1954; Bektas et al., 1999): (1). High elastic fibers having elasticity coefficient greater than 75.

Table 4: Biometry/Morphological Indices of Fiber Dimensions

Plant materials	Derived Values			
	Slenderness ratio, L/D	Flexibility coefficient, (d/D)×100	Runkel ratio, 2w/d	Rigidity coefficient, 2w/D
EFB of Oil Palm	55.79	41.29	1.35	0.57
Wheat straw	124.55	17.00	0.97	0.17
Rice Straw	170.59	4.24	1.39	0.06
Coconut fruit fiber (cocos nucifera)	63.59	46.20	1.25	0.58

Corn stalk (zea mays)	74.85	52.15	0.94	0.50
Lemon grass (Cymbopogon citratus)	35.63	39.38	1.13	0.44
Sugar Cane Bagasse	80.95	56.67	1.04	0.59
Kenaf (whole)	58.37	57.47	0.68	0.39
Elephant grass	87.85	64.73	0.53	0.34
Pineapple leaves	215.70	62.81	0.89	0.56

Elastic fibers having elasticity ratio between50 to 75. Rigid fibers having elasticity ratio between 30 to 50.High rigid fibers having elasticity ratio less than 30.According to this classification, flexibility coefficient of lemon grass, coconut, and EFB residues fibers were 39.38, 46.20 and 41.29, respectively, which fall under rigid fibers group and it was found that corn stalk, sugarcane bagasse, kenaf, elephant grass and pineapple leaves residues are in uniformity with other hardwoods in terms of elasticity coefficient. The average slenderness ratios in pineapple leave, wheat and rice were more than other plant materials investigated, but the flexibility ratio in elephant grass, pineapple leaves, kenaf, Sugar Cane Bagasse and corn recorded the highest among other plant materials.

The mean fiber length in Bagasse residues was 1.70 mm, similar to species such as wheat straw, coconut fruit fiber, corn stalk, EFB, kenaf and rice straw with 1.14 to 1.45 mm. Also the mean thickness of the fiber walls was 4.04 µm for EFB, which was more than rice and wheat straw (0.25µm-0.91µm) and was less than corn stalk, coconut fruit fiber, kenaf, and sugarcane bagasse with values represented as 4.1µm, 5.3µm, 4.3µm, and 6.2µm respectively. By dividing cell wall thickness by lumen diameter, Runkel classification value was obtained. The Runkel ratio of the plant materials investigated followed the order given as: (Highest) Rice (1.39)> EFB(1.35)> Coconut(1.25) >Lemon grass (1.13) > Bagasse(1.04)> Wheat(0.97) > Corn(0.94)> Pineapple leaves(0.89) > kenaf (0.68)>Elephant grass (0.53) (lowest)

When Runkel proportion is greater than 1, it indicates that a fiber has thick wall and cellulose obtained from this type of fiber is less suitable for paper production; when it is equal to 1, it specifies that a cell wall has medium thickness and cellulose obtained from this type of fiber is suitable for paper production. When the rate is less than 1, it points out that a cell wall is thin and cellulose obtained from this fiber is the most suitable for production of paper (Eroglu et al., 1980; Xu et al., 2006).

Runkel value of EFB, Coconut fruit fiber, lemon grass and Rice were 1.39, 1.35, 1.25 and 1.13 and according to the Runkel classification, they fall under thick wall fibers group, indicating that cellulose from this materials are less suitable for paper production compared to bagasse with Runkel value approximately equal to 1, specifying that the cell wall of bagasse has medium thickness with cellulose suitable for paper production.

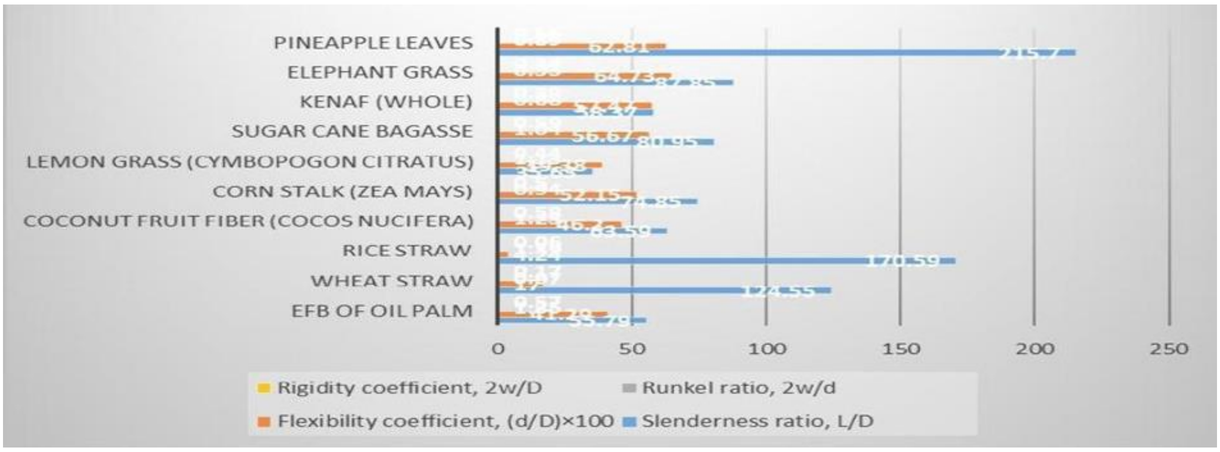


Figure 15: Effect of Plant Materials on the Biometry of Ten (10) Nigerian Cultivated Agro -based Fiber

As for corn, wheat straw, pineapple leaves, Elephant grass and kenaf their Runkel values were 0.94, 0.97, 0.89, 0.53, and 0.68, respectively, which make them fall under thin cell wall fibers group. It was recorded that pineapple leaves, coconut fruit fibre and EFB residues contained high percentage of lignin (17.90, 17.9 and 18.29%), but the lignin content was still lower than that of bagasse (19.50%). The high content of lignin in bagasse and EFB residues made the fibers appear tougher and stiffer compared to other fibers. This is probably because lignin provides compressive strength to plant tissue and individual fibers and stiffens the cell walls, to protect carbohydrates from chemical and physical damages. The Rigidity coefficient of the plant materials investigated followed the order given as: (Highest) Bagasse (0.59)>Coconut (0.58)>EFB(0.57)> Pineapple leaves(0.56) > Corn(0.50)> Lemon grass (0.44)>kenaf(0.39) >Elephant grass (0.34) > Wheat(0.17)>Rice(0.06)>(lowest).

Conclusion and Recommendation

Paper strength depends on the cellulose content of a raw plant material. Cellulose content was at a satisfactory level (above 40%) for each type of fiber utilized for the present study. Overall, the kenaf fibers appear to be the most suitable for producing paper products compared to the other agricultural residues due to lower lignin and extractive components as well as higher in cellulose content.

Literature studies about softwoods revealed that elasticity coefficient was found within the range 50-70. Examining this information given, and comparing it with data generated in this research study, it seems that EFB, coconut fruit fiber, sugarcane bagasse and kenaf fiber residues were similar to other softwood fibers. Depending on all of these, it is possible to conclude that EFB, coconut fruit fiber, sugarcane bagasse and kenaf fiber residues are more preferable than wheat, corn and rice fiber residues for paper production.

Analyses of data generated in this research work in comparison with literature studies, wheat, corn and rice fiber residues fall within the range of rigid fiber which means that they do not have efficient elasticity; hence they are more suitable to be used for the production of fiber plate, rigid cardboard and cardboard.

Agricultural wastes, annual plants and non-wood materials have attained such importance in the world cellulose economy, that to ignore their relevance in the pulp and paper industry would result in a complete lack of balance. In a world where virgin pulp sources are scarce, and environmental concerns require reduction in cutting down green forest, agricultural residues could become a good source of fiber in the tropical regions of the world where they are grown.

References

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Sampling and Preparing Wood for analysis (TAPPI Standard Test Method T222 om-02), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Ash in wood, pulp, paper and paperboard: combustion at 525°C (TAPPI Standard Test Method T211 om-02), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: One percent sodium hydroxide solubility of wood and pulp (TAPPI Standard Test Method T212 om-02), Atlanta, USA.

Anonymous, 1999. Technical Association of the Pulp and Paper Industry: Water solubility of wood and pulp (TAPPI Standard Test Method T207 cm-99), Atlanta, USA.

Anonymous, 2007. Technical Association of the Pulp and Paper Industry: Solvent extractives of wood and pulp (TAPPI Standard Test Method T204 cm-97), Atlanta, USA.

Anonymous, 1999. Technical Association of the Pulp and Paper Industry: Alpha-, beta- and gamma-cellulose in pulp (TAPPI Standard Test Method T203 cm-99), Atlanta, USA.

Anonymous, 2002. Technical Association of the Pulp and Paper Industry: Determination of Acid-insoluble lignin in wood and pulp (TAPPI Standard Test Method T210), Atlanta, USA.

Anonymous, 2004. Technical Association of the Pulp and Paper Industry: Determination of Holocellulose in wood and pulp (TAPPI Standard Test Method T210), Atlanta, USA.

Chibudike H.O., "Catalytic Enhancement of Monoethanolamine Pulping Process", PhD Thesis, International University, Bamenda (IUB), Cameroon, 2019 p. 72-92.

Chibudike H.O., Mgbachiuzo E., Adeyoju O.A., Kayode O.F., Arowolo A.B., Orekoya E.O., Tojola O.B. and Ojo B.I. (2011) "Studies of Fiber Characteristics and Paper -making Potentials of Agricultural Wastes", Nigerian Journal of Engineering Management (NJEM) , Vol. 12, No.1, pp 8 -11.

Chibudike H.O. and Udohitinah J.S. (2009) "Local Sourcing of Non-wood Pulp Plants for Paper-making", Journal of. Chem. Soc. of Nigeria (JCSN), Vol. 34, No.1, pp 169-172.

Panel Angela, Claudia Rodrigues, Marcela Boroski, Natalia Sueme, Shimada Juliana, Carla Garcia, Jorge Nozaki and Noboru Hioka, 2007. "Treatment of paper pulp and paper mill wastewater by coagulation–flocculation followed by heterogeneous photocatalysis", Departamento de Química, Universidade Estadual de Maringá, Av. Colombo, 5790, CEP 87020-900 Maringá, PR, Brazil.