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Fibre Characteristics and Strength Properties of Nigerian Pineapple Leaf (*Ananas cosmosus)*, Banana Peduncle and Banana Leaf (*Musa sapientum)* – Potential Green Resources for Pulp and Paper Production

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Authors' contributions

This work is a product of the conscientious efforts of all authors. Author TKF designed the study, performed the experiments and wrote the first draft of the manuscript. Authors ODF and FB managed the literature searches and contributed immensely to the experimental process. Authors EM and CCI supervised the running of the project. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study investigated the suitability of three agricultural wastes commonly found in Nigeria namely Pineapple leaf (*Ananas cosmosus),* banana peduncle and banana leaf (*Musa sapientum*) for their pulp and paper-making potentials.
Study Design: Fresh *Musa sapientum* waste and pineapple leaves were obtained from banana plantation and local pineapple processing firms around the vicinity of the Institute. The samples were processed, characterized for fibre properties, pulped and converted to handsheets. The properties of the fibre and paper were compared to the properties of non-wood and woody biomass found in Nigeria.

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Place and Duration of Study: The study was carried out in the pulp and paper laboratory of the Federal Institute of Industrial research Oshodi, Lagos between January 2015 and December 2015. Paper testing was carried out in the pulp and paper laboratory of the Centre for Wood Science, University of Hamburg, Germany during the same period.
Methodology: Pulp samples were produced from the selected materials in a thermostatically controlled autoclave using the soda pulping method with 7% Sodium hydroxide at 120℃. Partially delignified pulp samples were macerated in equal volume of 10% glacial acetic acid and 30% hydrogen peroxide and thereafter studied under a Visopam microscope at × 10 mm x 8 mm magnification for fibre morphological properties such as fibre length, fibre diameter, lumen width, cell wall thickness and derived morphological indices. Handmade paper sheets were produced from the pulp samples and tested for strength properties. Data obtained was analyzed using Analysis of Variance (ANOVA).
Results: Results show that banana peduncle and banana leaf, with average fibre lengths of 1.27 mm and 0.88 mm respectively, are short-fiber resources while pineapple leaf has a longer fibre length of 2.92 mm. The average fibre diameter and lumen width of pineapple leaf, banana peduncle and banana leaf were 12.08/7.84 µm, 15.81/11.56 µm and 9.79/3.84 µm respectively. All studied samples possessed thin cell wall (2.13 – 3.46 µm). The Runkel Ratios for the three sample agricultural waste raw materials, namely; pineapple leaf, banana peduncle and banana leaf were 0.88, 0.37 and 1.69 respectively. Banana peduncle and pineapple leaf were found to be good sources of elastic fibres. Handmade paper sheets produced displayed impressive strength properties.
Conclusion: The three studied agricultural wastes have impressive fibre characteristics which compare very well with other non-wood and woody biomass found in Nigeria. Hand sheets produced from the unbeaten pulp of these agricultural wastes display good properties which make them useful in applications such as in food wrapping, newsprint and handmade crafts. Beating and refining of the pulp from these materials can impact significantly on the quality of handsheets produced.

Keywords: Pineapple; banana; non-wood; pulp; paper.

1. INTRODUCTION

Driven by increasing global environmental awareness and the increasing demand for paper, the past decades have witnessed lots of inquest into alternative resources that could serve as viable and sustainable alternatives to wood in the pulp and paper industry, resulting in major development of pulping technologies and processes that are considered to be environmentally benign [1,2,3,4,5].

Paper Industry in Nigeria is currently bedeviled with myriad of problems. One of which include the unavailability of good forest woods and fibrous materials suitable for pulp and paper production. This has resulted in inadequate capacity utilization in the primary pulp and paper mill and massive loss of jobs and capital investment in the sector [6]. In order to get out of this conundrum, it has become expedient to intensify research study on materials, particularly, non-wood biomass that have been found to possess tremendous variations in chemical and physical properties compared to wood [7,8,9,10,11].

Pineapple (*Anannus comosus*) is the second harvest of importance after bananas, contributing to over 20 % of the world production of tropical fruits [12]. *Anannus comosus,* the most economically important plant in the family *Bromeliaceae* is a tropical, herbaceous, perennial monocot, approximately 1-2 metres tall and wide, with leaves arranged spirally. It bears flowers on a terminal inflorescence, which form a large, edible fruit characterized by a tuft of leaves at its apex. Alongside Thailand, Costa Rica, Philippines, Brazil, China and India, Nigeria is the 7th world's largest producer of pineapples [13]. In Nigeria, the growing market for pineapple has made its cultivation a thriving and veritable business especially for young entrepreneurs. The demand for the fruit by the public and the juice processing firms has increased greatly. Many aspects of its production have also been mechanized, and commercial cultural practices are continuously being refined. Pineapple is cultivated predominantly for its fruit that is consumed fresh or canned. It is used as an ingredient in a variety of foods including pizzas, condiments, sweets, savouries, cakes, pastries, yoghurt, fruit Cocktails, punches, ice creams etc.

Pineapple products have also been marketed as a 'digestive aid' in health food stores.

In the same vein, production of bananas has grown rapidly in Africa over the past 15 years, now accounting for around 4% of the world banana trade. With an average consumption level of 190 kg/person/year, Nigeria produces more than 100 million tonnes of banana (*Musa sapientum*) and plantain (*Musa paradisiaca*) annually and ranked as one of the 20 most important banana and plantain producing countries worldwide [14]. Plantain is widely used to describe the edible fruit that has more starch, thicker skin and typically larger than the common banana. Banana and plantains play an important role in the diet of people in Central and West Africa [15]. They contribute significantly to food security and provide more than 10% of the daily intake of carbohydrates and calories, respectively, for more than 70 million people in Sub-Saharan Africa [16].

Enhanced by mechanisation and technology, global rapid increase in agricultural production and productivity comes with a massive progression of environmental challenges [17] not least the huge mass of residue left over during and after harvest and processing of agricultural produce. The post-harvest processing of pineapple fruits yields skins (outer peels), crowns, bud ends, cores, waste from fresh trimmings and the pomace of the fruit from which the juice has been extracted. These by-products account for approximately 30-35% of the fresh fruit weight [18]. Most of the edible bananas are also cultivated mainly for their fruits, thus banana farms could generate several tons of underused by-products and wastes such as banana peel, banana stalk or peduncle, banana leaf etc. These wastes, mostly dumped indiscriminately [19], constitute an environmental menace in developing countries like Nigeria due to non-availability of acceptable and safe solid-waste disposal technique, as well as sustainable technology for their commercial utilization. Banana waste, for instance, causes pollution, pests, and interfere with soil cultivation [20]. It also produces toxic gases including CO_2 and give growth to harmful fungi which attacks remaining banana trees thereby creating a great environmental imbalance [21]. Agricultural waste is therefore one of the most important problems that must be resolved for the conservation of global environment [22].

Growing usefulness of agro-wastes in wide variety of applications has been reported [23]. About 11% of world pulp production is made from non-wood fibrous raw materials, some of which are agricultural raw materials [24]. Over 70% of the raw material used by the pulp industries in

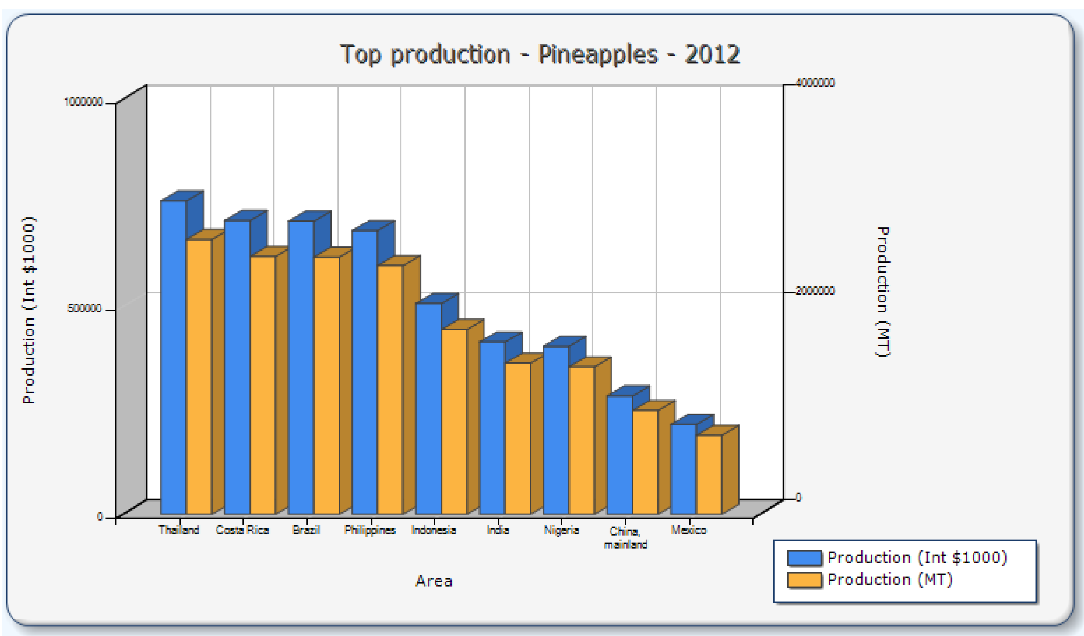

Fig. 1. World pineapple production
Source: (FAO 2012)

China and India comes from non woody plants which are mostly agricultural residues that consists mostly of straw and bagasse. Rice husk, jute, stalk, baggase, groundnut shell and coconut fiber, etc. are also produced in large quantities. Pineapple leaf has been found to possess tremendous mechanical properties which make it suitable for the production of reinforced polymer composites [25]. There has also been wide utilization of whole banana plant in food, feed, pharmaceutical, packaging and many industrial applications such as waste water treatment, biogas, wine/ethanol production, food wrapping etc. [26,27,28]. Pineapple and banana wastes are very good source of cellulose and therefore represent potential natural fibres sources for the pulp and paper industry. Pineapple leaves in Malaysia is composed of over 60% Cellulose and 85% holocellulose, which is higher than that obtained for most wood fiber [29]. The condensed arrangement of fibre is also an important factor in pulp and paper production from pineapple leaves [30]. Biodegradability, flexibility, availability, easy pulping capability, sustainability, low cost of processing and acquisition are few of the factors that make these materials veritable resources. Although, it is generally believed these natural non-wood materials are still very much underutilized, the quantification of the current use can only be done by making rough estimates [31].

With users' increasingly demanding papers that are produced via clean technologies or made from recycled or non-wood fiber – 'Tree Free' papers [32] -, utilization of fibers from raw materials such as pineapple and banana wastes would not only be beneficial to plant farmers as per extra income but can also be an effective way to alleviate the environmental impact of pineapple and banana processing. Their utilization can reduce pressure on forest, help keep ecological balance in nature and ultimately lead to the expansion of the bio-based economy. It can also help to reduce wood and cellulose fiber imports in countries, like Nigeria, with a shortage of wood raw materials.

The objective of the study, therefore, was to explore the suitability of pineapple leaf (*Ananas cosmosus*) and banana (*Musa sapientum*) wastes such as banana leaf and banana peduncle in the production of pulp and paper and compare them with pulp and paper from some Nigerian wood and non-wood biomass.

2. MATERIALS AND METHODS

2.1 Material Collection and Preparation

Fresh *Musa Sapientum* waste was procured from a banana plantation inside the Blind centre behind the Federal Institute of Industrial Research, Oshodi, Lagos. The unwanted portions of the plant were discarded and only the needed portion; peduncle and leaves were used in the study. Pineapple leaves were obtained from the bunch of freshly harvested pineapple fruits collected from local pineapple processing firms around the vicinity of the Institute. Samples were washed with water to remove all debris and unwanted particles. They were then air-dried for 72 hours. Size reduction of the air-dried samples was done manually and samples stored for further study.

2.2 Pulping Study

Pulping experiment was performed in a 5 L electrically-heated static autoclave using soda pulping process. The cooking parameters are highlighted in Table 1. The de-lignified pulp was thoroughly washed with distilled water to remove residual cooking liquor and fiberized in a laboratory disintegrator at 1200 rpm for 10 minutes. Fiberized materials were passed through a screen in order to remove the rejects. The screened pulp was washed again with distilled water, pressed, drained and allowed to dry to a moisture content of 10% at 105±3℃ for 24 hours. Pulp yield was calculated as percentage of the oven-dry weight of the raw samples. Bleaching of pulp samples was achieved by treating with 30% hydrogen peroxide at a temperature of 60℃. Bleached pulp was thereafter washed with distilled water. Kappa numbers of bleached pulp samples were determined according to TAPPI T236 om-299 standard procedure [33].

Table 1. Cooking condition for soda pulping

Cooking temperature (℃)	120
Cooking Pressure (atm)	4.08
Concentration (%)	7
Liquor: Sample (ratio)	4:1
Cooking time (min)	45

2.3 Determination of Fibre Characteristics

Fibre length (FL), fibre diameter (FD), lumen width (LW) and cell wall thickness (CWT) were determined using partially de-lignified pulp fibre. The pulp fibre was introduced into test tubes for maceration in equal volume of 10% glacial acetic acid and 30% hydrogen peroxide. The solution was put in the oven for 2 hours at temperature of about 100℃ for maceration. The mixture was thereafter decanted and macerated fibres washed in cold water and further disintegrated to release individual fibres. Twenty (20) fibres were selected from each representative sample, mounted on slides and examined under a Rheichert Visopam microscope at × 10 mm x 8 mm magnification. Four (4) derived fibre indices were determined as follows:

$$Runkel\ Ratio\ = (2\ x\ CWT)/LW$$

$$Felting\ power\ (Slenderness)\ = FL/FD$$

$$Rigidity\ Coefficient\ = \frac{CWT}{FD}\ x\ 100$$

$$Flexibility\ Coefficient\ = \frac{LW}{FD}\ x\ 100$$

2.4 Paper Formation and Testing

Laboratory hand sheets were made from the unbeaten bleached pulp in accordance with the standard method of the Technical Association of the Pulp and Paper Industry (TAPPI) (T221 cm -99). Resultant paper sheets were sampled and conditioned at 25℃ for about 24 hrs before testing. Paper properties were measured according to standard test methods [34]. Tensile index, burst index and tear index of paper sheets were determined with T 494om-01, T 403om-97 and T 414om-98 respectively.

2.5 Surface Characterization

The paper sheets were observed under a Digital Microscope (KEYENCE VHX-d500F) to study the fibre arrangement and distribution.

2.6 Statistical Analysis

Data obtained were subjected to one way analysis of variance (ANOVA) followed by post hoc Duncan's multiple range test (DMRT) (P = 0.05) using Statistical Package for Social Scientists (SPSS) program.

3. RESULTS AND DISCUSSION

3.1 Fibre Length

The average fibre dimensions and morphological indices of pineapple leaf, banana peduncle and banana leaf are presented in Fig. 2. Fibre length is one of the most important features of any potential material for pulp and paper making. Of the 3 examined materials, pineapple leaf has the highest average fibre length of 2.92 mm followed by banana peduncle with 1.27 mm and banana leaf, 0.88 mm. The fibre length of the studied banana wastes fall within the range of values reported for other agricultural wastes such as coconut fibre [35], Rice straw [36], corn husk [7], and banana stem (*Musa sapientum*) [37]. The fibre length of pineapple leaf compares favourably with the fibre length of Kenaf bast (*Hibiscus cannabinus*) [38] and Pinus Caribea [39]. Fibres with length ≥ 2 mm are classified as long fibre and are preferred in pulp and paper production. However, it has since been found that both long fibres and short fibres are essential for paper making. Long fibres from softwoods or from non-woody species form a strong matrix in the paper sheet leading to sheets of high tensile strength, while shorter hardwood fibres or grass fibres contribute to the properties of pulp blends, especially opacity, printability and stiffness [40]. Hence, fibres from the studied materials have usefulness in pulp and paper industry.

3.2 Fibre Diameter and Lumen Width

Fibre diameter and lumen width are vital to paper strength especially during beating operations [41]. From the result obtained, the average fibre diameters of banana peduncle, banana leaf and pineapple leaf are 15.81 µm, 9.79 µm and 12.08 µm respectively. These fall within the range of value reported for wheat straw, *Moringa olifera* stem and *Leucaena lencocephala* [42,43,44]. A small fibre diameter indicates less fibre flexibility [45]. Coupled with its fibre diameter, banana peduncle has the highest lumen width, 11.56 µm, out of the three agricultural wastes studied. This value is higher than the range (2.47 – 4.49 µm) reported for some indigenous hardwood species in the tropical rainforest ecosystem [46]; close to 14.8 µm for *Gerdenia ternifolia* [47]; lower than 17.55 µm for *Rhizohpara harrisoni* [48] and 16.9 µm for *Bambusa vulgaris* [49]. Lumen width of pineapple leaf is comparable to range (5.37 – 16.40 µm) reported for bast, core and whole stalk of *Hibiscus Cannabinus* [50].

3.3 Cell Wall Thickness

Results show that studied agricultural wastes have impressively thin cell walls, with values ranging between 2.13 µm for banana peduncle and 3.46 µm for pineapple leaf. These thin cells walls allow easier delignification during pulping and also enhance flexibility, collapsibility of fibres during pulp refining [51]. Thick-walled fibre tends to produce paper with high bulkiness and porosity [52].

3.4 Derived Morphological Indices

Runkel ratio is an important parameter for the measurement of biomass suitability for pulp and paper making [53]. The Runkel ratio of pineapple leaf (0.88) and banana peduncle (0.37) in Table 2 is typical of most temperate species like Populus and Caribbean pine which produce good quality paper [44]. Fibre with runkel ratio ≤ 1 is highly pulpable. Fibre with higher runkel ratio is stiff, less flexible and form bulkier paper of low bounded area than the lower ratio fibre [54].

High slenderness/felting power is imperative for paper resistance to tear, and burst. The slenderness ratio of banana peduncle, pineapple leaf and banana fibre are 84.94, 258 and 91.26 respectively. These values are greater than the bench mark of ≥ 33 considered being good for pulp and paper production [55]. Papers from these samples are expected to have sufficient tear strength suitable for packaging purposes.

Flexibility coefficient is a function of lumen diameter and fiber diameter. It determines the degree of fiber bonding in paper sheet. Results show that banana peduncle and pineapple leaf with flexibility coefficients of 73.77 and 66.52 respectively are elastic fibres and this is an indicative of acceptable burst and tensile strength [56]. High rate of rigidity affects tensile, tear, burst and double fold resistance of paper negatively. The low rigidity coefficient of studied agricultural wastes make then suitable for pulp and paper making.

The statistical result in Tables 3 and 4 shows that there is no significant difference in the means of the various sources of variance of the agricultural wastes at P ≤ 0.

3.5 Physical Strength Properties of Hand Sheets

The results of the physical strength properties of hand sheets obtained from unbeaten pulp of studied agricultural wastes are shown in Table 5. Hand sheets produced had good formation with basis weight ranging between 44.16 g/m^2 and 73 g/m^2. Banana peduncle has the highest tensile index (69.21 Nm/g) and breaking length (7.06 km). Lowest tensile index (34.01 Nm/g) and breaking length (3.47 km) was found in paper sheet from banana leaf. This can be attributed to the varying fibre length of the materials because long fibres generally produced paper with higher tensile strength properties than paper from short fiber. As opined by [57], the dimensions and strength of the individual fibers, their arrangement, and the extent to which they are bonded to each other are all important factors which can contribute to tensile strength. The results of the breaking length compare well with the range (5.5 – 7.5 km) reported for non-wood raw materials such as jute, cotton stalks, corn stalks, bagasse, rice straw and wheat straw [36]. In addition, these values compare well with the tensile strength and breaking length of different types of paper such as offset, rag bond and newsprint. Stretch of hand sheet from banana peduncle 2.35% and pineapple leaf is closely similar to that reported for hand sheets made from plantain pseudo stem and screw pine leaves [58].

Hand sheet from banana peduncle also had the highest density of 307 kg/m^3, compared to hand sheet from pineapple leaf and banana leaf with densities 207 $kg/m^3$and 288 kg/m^3 respectively. These values are lower than the densities of hand sheets from unbeaten pulp of *Gmelina arborea* (670 kg/m^3) and *Bambusa vulgaris* (462 kg/m^3) reported by [49]. Burst index of pineapple leaf hand sheet (4.29 $Kpa.m^2/g$) was found to be higher than that other studied materials. Tear index vary between 6.69 – 8.55 $mN.m^2/g$. The bleachability of pineapple leaf pulp is evident in its brightness value of 55.36% which is comparable to the brightness of unbeaten bleached kraft pulp of kenaf bast [38]. Banana peduncle, with brightness of 35.13%, displayed low affinity for the bleaching chemical used in this study.

Generally, the results of the strength test show that the studied agricultural wastes have good paper properties. Significant variation in the sheet properties can be obtained with variation in pulp kappa number, pulp consistency, degree of pulp beating, and relative humidity of the environment. Improved strength properties are also anticipated from the pulp blend of these agricultural wastes with other non-wood fibers. These paper sheets can find application in variety of areas such as for decorative purposes, greeting cards, souvenir boxes tissue paper, food

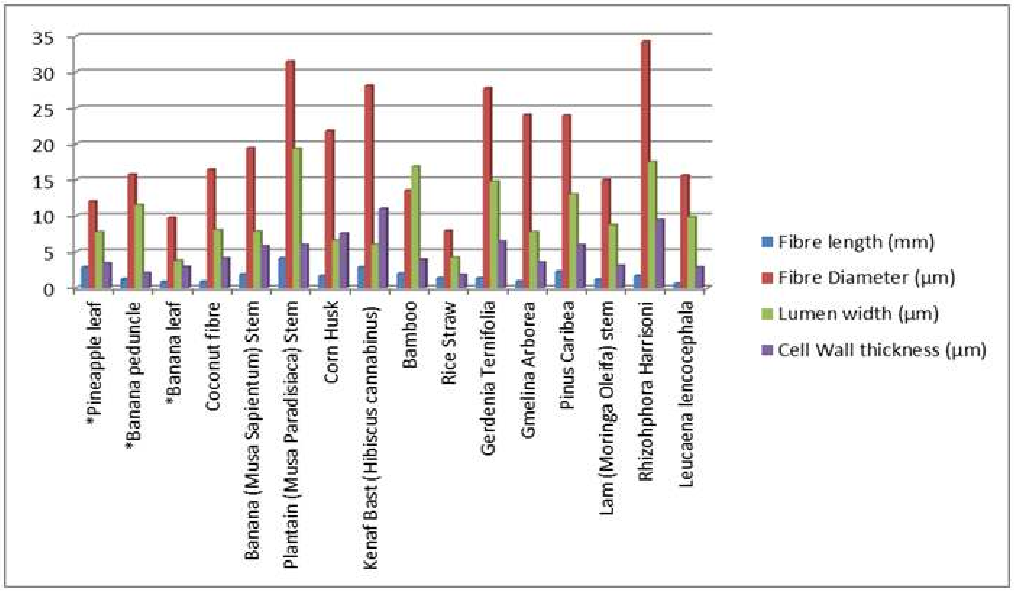

Fig. 2. Comparison of average fibre properties of selected agricultural wastes with various Nigerian wood and non-wood materials

Table 2. Derived morphological indices

Sample name	Runkel ratio	Slenderness ratio	Rigidity coefficient	Flexibility coefficient
Pineapple leaf	0.88	257.57	29.95	66.52
Banana peduncle	0.37	84.94	13.11	73.77
Banana leaf	1.69	91.26	30.46	39.08

wrapping, and can also be commercialized as value added materials for handmade crafts.

3.6 Surface Properties

Digital microscopic analysis of paper sheets is shown in Figs. 3, 4 and 5. The figures show that materials studied have many fibres in packed and scattered form. Pulp beating is expected to produce a better structured arrangement of fibres.

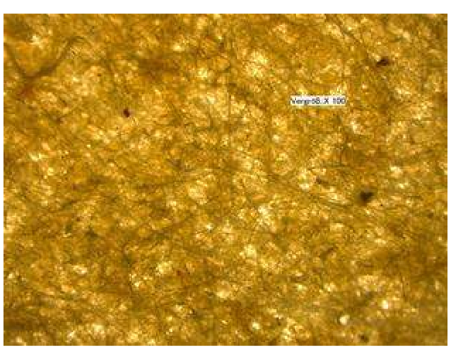

Fig. 3. Surface area of banana leaf

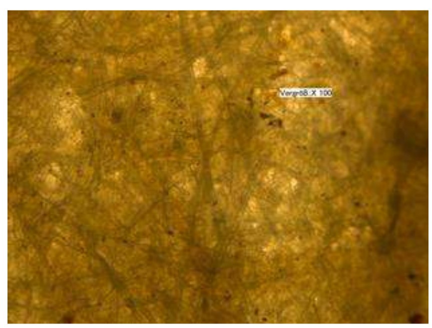

Fig. 4. Surface area of banana peduncle

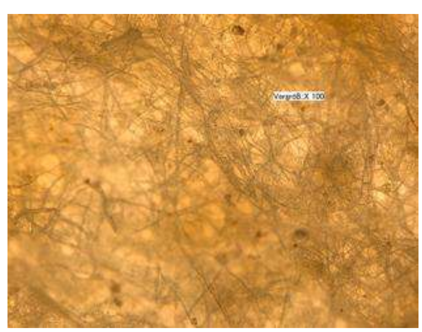

Fig. 5. Surface area of pineapple leaf

Table 3. Analysis of variance for fibre characteristics

Source of variance		Degree of freedom	Sum of squares	Mean square	F-Cal	Significant
Fibre length	Between groups	2	47.094	23.547	38.560	0
	Within groups	57	34.808	0.611		
	Total	59	81			
Fibre diameter	Between groups	2	368.804	184.402	11.338	0
	Within groups	57	927.085	16.265		
	Total	59	1295.889			
Lumen width	Between groups	2	596.955	298.477	15.132	0
	Within groups	57	1124.318	19.725		
	Total	59	1721.272			
Cell-wall thickness	Between groups	2	18.192	9.096	9.546	0
	Within groups	57	54.313	0.953		
	Total	59	72.505			
Runkel ratio	Between groups	2	18.367	9.183	31.488	0
	Within groups	57	16.624	0.292		
	Total	59	34.991			
Slenderness ratio	Between groups	2	383391.932	191695.966	33.805	0
	Within groups	57	323229.753	5670.697		
	Total	59	706621.685			
Rigidity coefficient	Between groups	2	3896.121	1948.061	65.898	0
	Within groups	57	1685.008	29.562		
	Total	59	5581.129			
Flexibility coefficient	Between groups	2	13392.801	6696.400	5.150	0.009
	Within groups	57	74109.688	1300.170		
	Total	59	87502.488			

Table 4. Descriptive analysis of variance

		N	Mean	Std. deviation	Std. error	Minimum	Maximum
Fibre length	Banana peduncle	20	1.27	0.47	0.11	0.38	2.00
	Pineapple leaf	20	2.92	1.23	0.27	0.84	5.34
	Banana leaf	20	0.88	0.33	0.07	0.52	1.92
	Total	60	1.69	1.18	0.15	0.38	5.34
Fibre diameter	Banana peduncle	20	15.81	4.94	1.10	3.75	25.00
	Pineapple leaf	20	12.08	4.81	1.07	7.68	25.60
	Banana leaf	20	9.80	1.14	0.25	6.06	11.11
	Total	60	12.56	4.69	0.61	3.75	25.60
Lumen width	Banana peduncle	20	11.56	3.44	0.77	2.50	20.00
	Pineapple leaf	20	7.84	6.81	1.52	2.84	23.08
	Banana leaf	20	3.84	1.02	0.23	2.02	5.05
	Total	60	7.75	5.40	0.70	2.02	23.08
Cell wall thickness	Banana peduncle	20	2.13	1.22	0.27	0.63	4.38
	Pineapple leaf	20	3.46	1.03	0.23	1.79	5.76
	Banana leaf	20	2.98	0.54	0.12	2.02	3.54
	Total	60	2.85	1.11	0.14	0.63	5.76
Runkel ratio	Banana peduncle	20	0.38	0.19	0.04	0.10	0.78
	Pineapple leaf	20	0.88	0.70	0.16	0.22	2.46
	Banana leaf	20	1.68	0.60	0.13	1.00	2.33
	Total	60	1.14	0.77	0.10	0.10	2.46
Slenderness ratio	Banana peduncle	20	84.94	33.42	7.47	44.74	160.00
	Pineapple leaf	20	257.58	120.56	26.96	81.88	472.86
	Banana leaf	20	91.26	36.90	8.25	51.00	190.00
	Total	60	144.60	109.44	14.13	44.74	472.86
Rigidity coefficient	Banana peduncle	20	13.11	4.96	1.11	4.55	21.88
	Pineapple leaf	20	29.95	6.69	1.50	10.00	38.89
	Banana leaf	20	30.46	4.39	0.98	25.00	35.00
	Total	60	24.51	9.73	1.26	4.55	38.89
Flexibility coefficient	Banana peduncle	20	73.77	9.93	2.22	56.25	90.91
	Pineapple leaf	20	66.52	61.03	13.65	27.73	257.57
	Banana leaf	20	39.08	8.78	1.96	30.00	50.00
	Total	60	59.79	38.51	4.97	27.73	257.57

Table 5. Pulp characteristics and physical strength properties of paper sheets

Properties	Banana peduncle *(Musa sapientum)*	Pineapple leaf *(Ananas cosmosus)*	Banana leaf *(Musa sapientum)*
Unbleached pulp yield (%)	58.50	44.30	65
Bleached pulp yield (%)	35.17	25.11	41.28
Kappa Number	16.22	17.10	17.19
Basis weight (g/m^2)	72.56	52.37	44.16
Thickness (µm)	236.4	252.4	153.3
Density (Kg/m^3)	307	207	288
Burst index (Kpa.m^2/g)	2.06	4.29	1.69
Tensile Index (Nm/g)	69.21	43.8	34.01
Breaking Length (km)	7.06	4.47	3.47
Stretch (%)	2.35	1.89	1.25
Tear Index (mN.m^2/g)	6.69	8.55	3.78
Brightness (%) ISO	35.13	55.36	43.99

4. CONCLUSION

This study evaluated the pulp and paper –making potential of three agricultural wastes such as pineapple leaf, banana peduncle and banana leaf; and concludes that:

1 Pineapple leaf is a potential source of medium to long fibre pulp while banana peduncle and banana leaf are sources of short fibre pulp.
2 The three agricultural wastes have impressive fibre characteristics which compare very well with other non-wood and woody biomass found in Nigeria.
3 Hand sheets produced from the unbeaten pulp of these agricultural wastes display acceptable burst factor, tear index, stretch and tensile properties which make them useful in applications such as in food wrapping, newsprint and handmade crafts.
4 Beating and refining of the pulp from the agricultural wastes can impact significantly on the quality of handsheets produced.
5 Blending of the pulp of the agricultural wastes with other non-wood and wood pulp can also produce hand sheets of varying qualities thereby broadening their applications.

Agricultural wastes are feasible sources of virgin fiber if appropriate process conditions are selected. Utilization of fibres from these materials for pulp and paper production can help to bridge the gap created by wood supply deficit in the country. It will provide low-cost raw materials for cottage industries thereby creating job opportunities for the youth and would-be entrepreneurs. It will also assist in the extension of the value chain of food crops, increase the income of farmers and serve as an efficient waste management process.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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