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Pulp and Paper Evaluation of Solid Wastes from Agricultural Produce

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Abstract

The pulp and paper potentials of solid-waste of *Ananas comosus* (pine-apple leaves), *Cocos nucifera* (coir i.e. fiber from coconut husk), *Tithionia diversifolia* (sunflower) and *Sansevieria liberica* (mother-in-law's tongue) were investigated. Pulp was produced by soda pulping process at liquor to solid ratio 7:1 and bleached with hydrogen peroxide in basic medium. The pulp yield of pineapple leaves, coir, sunflower, and *Sansevieria liberica* were 80%, 75%, 79% and 82.5% respectively.

The fiber morphology were determined after maceration with 1:1 acetic acid–hydrogen peroxide ratio. The fiber length of the pine apple leaves, *Tithonia diversifolia,* coir and *Sansevieria liberica* were 0.935mm, 0.758mm, 0.894mm and 2.291mm respectively. The Runkel Ratio were 0.639, 0.540, 1.057 and 0.923mm respectively. The experimental design adopts the use of complete randomized block design on morphological examination of the solid-waste. In this configuration, we construct and solve as optimal network flow, the problem of minimizing the cost of disposing wastes from sources of generation to dumpsites by establishing processing mills in rural areas.

The surface response results indicated optimum conditions for the production of good quality pulp and paper from the studied solid-wastes is when the fiber length is 0.61mm, fiber diameter is 17.16µm, lumen width is 12.40µm, cell wall thickness is 1.31µm, and Runkel Ratio is 0.2073. The average fiber length of 0.61mm coupled with low Runkel ratio 0.2073 would result in highly flexible fibers that can easily collapse to produce pulp and paper of good optical and strength properties.

Keywords: solid waste, ananas comosus, cocos nucifera, tithionia diversifolia, sansevieria liberica, pulping

1. Introduction

In the field of paper industry, World paper consumption was about 300 million tons in 1996/1997 and is expected to rise above 400million tons in the nearest future. Pulp and paper industries are economically important in developing and developed countries alike because their products are consumed nearly in all facets of human endeavors. The consumption of paper per capital does not only correlate with the gross domestic products but also with the standard of welfare and education. The greatest value of the forest resources and the increasing demand for paper and paper board call for an overall plan for the utilization of these resources and for development of plantations of specific most suitable for the various sectors of forest industry.

Wood has been the major source of fibrous materials for paper industries all over the world. However, increasing cost of pulp-wood and its scarcity in many countries have directed attention towards the use of non-wood like solid - waste plants fibers for the production of different grades of pulps. Environmental benefit are being considered in using agro-wastes that are in abundance in production of new materials for pulp and paper industry. In addition, growing environmental awareness, new rules and regulations throughout the World for creation of bio-based economy are challenging researchers in institutions and industries. In the last decade, a lot of research has been on non-wood like abaca (Jinenez et al., 2005), *Musa paradisiaca*, (Ogunsile et al., 2006), rice straw (Rodriguez et al., 2008), *Hibiscus* species ((Dutt et al., 2009) and canola stalks (Enayat et al., 2009).

In Nigeria, one of the problems of pulp and paper industries is lack of adequate supply of long fiber pulpwood for paper production (Raw Material Research and Development Council of Nigeria, 1996). The great value of the paper board in Nigeria call for an overall plan for the utilization of the plantation of species most suitable for the various sectors of the forest industries. Apart from raphia palms fibers, there is the possibility to produce long fiber pulp (even at small- scale basis) from certain annuals.

Oluwadamilare (1998) suggested the use of bast fibers like kenaf (*Hibiscus cannabinus*), roselle (*Hibiscus sabdariffa*) and plantain (*Musa paradisiaca*) as a way of alleviating the present long fiber shortage. Although the suitability of *Musa paradisiaca* for pulp and paper production have been reported in the literature (Ogunsile et al., 2006) much has not been done on the pulp and paper potential of other solid-wastes like pine apple leave, coir, sun flower (*Tithonia diversifolia*) and S*ansevieria liberica*.

Villar et al. (2001) studied the effect of different species of kenaf on the quality of Kraft pulp and they found that good quality pulp could be obtained from a reasonable number of the species they investigated depending on their growing conditions. The fiber dimension of kenaf bast was also studied by Shakhes et al. (2011). Their results were comparable to those reported for sugarcane bagasse (Sadegh et al., 2011).

Other agricultural non-woody materials like cotton stalks, abaca and sugarcane bagasse were also studied as sources of raw materials for pulp and paper industries (Jimenez,et al., 2005; Sadegh, et al., 2011; Hemmasi, et al., 2011). They all reported that these non-woody sources were promising raw materials for paper production.

In the present study, the mechanical and physiological properties as well as the soda pulping characteristics of some solid-wastes of agricultural produce were investigated. This is to provide basic information on the prospect of using these solid-wastes as a source of long fibers which are important raw materials for pulp and paper production in Nigeria as well as getting rid of the environment of these solid wastes.

2. Materials and Method

2.1 Collection of Sample

Pineapple leaves, coir (coconut husk), sun flower and *Sansevieria liberica* were collected at dump sites in Oshodi fruits market within Lagos metropolis. The samples were washed, sorted and cut into chips of about 2-4cm, sun dried and sorted in polyethylene bags.

2.2 Pulping Procedure

The soda pulping were carried out at the pulp and paper technology laboratory of the Federal Institute of Industrial Research Oshodi, Lagos. Samples were digested in a 50liter electrical stainless steel digester. The solid-waste was charged into the digester with the required amount of chemical solution at liquor to solid ratio (L: S) of 7:1. The digester was heated to the operating temperature of 170^{o}C which was maintained throughout the experiment for the different cooks for 45 minutes. At the end of each cooking scheme, the pulp was washed several times and allowed to dry to a constant weight to determine the yield.

2.3 Measurement of fiber Dimensions

The fibers were obtained by reducing the samples into splints of about 24 – 40mm. The splints were placed in a round bottomed flask for maceration using a mixture of equal volume (1:1) of glacial acetic acid and 50% hydrogen peroxide. The macerated splints were disintegrated to release the fibers. The fiber dimensions were taken at the wood anatomy laboratory at the Forestry Research Institute of Nigeria, Ibadan. The released fibers were mounted on Photomicrograph microscope with attached camera. Magnification of x10mm and x4mm was adopted for the measurement of fiber length (FL), fiber diameter (FD), lumen width (LW) and cell-wall thickness (CWT) of the samples. The derived quantities determined from these measurements include:

$$\text{Runkel Ratio} = (2 \times CWT)/LW$$

$$\text{Flexibility coefficients } (\%) = (LW/FD) \times 100$$

$$\text{Slenderness Ratio} = \text{Length of fiber/diameter of the fiber}$$

FL= fiber length

FD = fiber diameter

LW = lumen width

CWT= cell wall thickness

2.4 Determination of Specific Gravity

The specific gravity of the fiber was determined using representative samples from each batch in accordance with the ASTM standard procedure designated D2395 - 89 method.

2.5 Mechanical Properties

The morphological indices of the paper formed during the tensile strength test were equally determined. The tensile strength determination was carried out on the Testometric M500-25KN Rochdale England equipmentwith the test speed of 5mm/min and standard length of 120mm.

2.6 Treatment of Data

Statistical products and services solution (SPSS) was used to evaluate the fiber statistical data generated using Duncan post hoc Test on one way Analysis of variance. Surface response methodology was used to corroborate the results.

3. Result and Discussion

The pulp yield are 80%, 75%, 79% and 82.5% for pine apple leave, coir, *Tithonia diversifolia* and *Sanseviera liberica* respectively. The percentage pulp yield recorded in the literature for wheat straw is about 50% (Wong, 1997) and between 47.32 and 49.37% for kenaf (Shakhes et al., 2011) which are low compared to those studied. All the samples are high yield raw materials for pulp and paper industries. This is also supported by moderate fiber lumen obtained for all the samples.

The tensile strength obtained for the paper formed from the fibers of the samples were 78.4Nm/g, 73.2Nm/g, 70.5Nm/g and 65.7Nm/g for *Sanseviera liberica, Ananas comosus, Tithonia diversifolia* and *Cocos nucifera* respectively. Shakhes et al. (2011) recorded highest tensile strength of 83.90Nm/g for kenaf which is comparable to those of this study. Tensile strength is a function of the strength of the fiber and the bond between the fibers. The highest value for *Sansevieria liberica* might be due to fact that its fibers collapsed easily and the bonding between them is high thereby delayed the failure of the paper formed from it. The paper formed from *Cocos nucifera* might have failed at a low stress as a result of weak bonds between its fibers.

The fibers of *Cocos nucifera* husk has the highest specific gravity (1.10) while those of pineapple leaves, *Sansevieria liberica* and *Tithonia diversifolia* were 0.80, 0.75 and 0.70 respectively. These values are higher slightly than those obtained for kenaf fibers (0.65 – 0.76) (Shakhes et al., 2011) but they are in correlation with the tensile strength obtained for the fibers. Smaller specific gravity gives rise to higher tensile strength of the paper formed since the fibers would collapse easily and bonds between the fibers would be strong. The specific density of the fiber can be used to predict the bonded area in the paper formed. As the specific density increases, the bonded area in the paper increases. *Tithonia diversifiola* hull is very light, voluminous and therefore very expensive to transport to dump site. Hence, it is useful for pulp and paper production and thereby saves cost of disposal if small processing mills are sited in rural areas where the wastes are generated.

Mean value of fiber characteristics for the solid-wastes shown in Table 1 depicts the fact that the solid waste samples examined fall between medium and long fiber length. *Sanseviera liberica* has the highest fiber length of 2.291mm which is comparable to 2.77mm obtained for bast of kenaf (Shakhes et al., 2011). *Ananas comosus* fiber length is 0.935mm which is almost the same as the value obtained for cotton (0.926mm) by Sadegh et al., 2011. *Tithonia diversifolia* and *Cocos nucifera* have fiber length 0.7575mm and 0.8939mm respectively which are in the same range as those of rice and wheat straw (Tutus et al., 2004; Deniz et al., 2004). An increase in fiber length affects resistance properties of paper positively but causes malformation of paper. On the basis of the fiber length, *Sanseviera liberica* is expected to form high resistant paper.

Table 1. Mean Value of Fiber Characteristics for the solid-wastes

Sample	Fiber Length (mm)	Fiber Diameter (μ m)	Lumen Width (μ m)	Cell Wall thickness (μ m)	Runkel Ratio	Coefficient of Flexibility	Slenderness Ratio	Felting Power
Ananas comosus	0.935	30.63	19.10	5.766	0.6390	62.348	30.527	2.6559
Tithonia diversifolia	0.758	25.20	16.00	4.416	0.5395	64.956	30.063	2.8536
Cocos nucifera	0.894	16.49	8.10	4.194	1.6574	51.848	54.202	2.2435
Sansevieria liberica	2.291	23.19	12.15	5.518	0.9226	52.349	98.780	2.1142

The fiber diameter range is between 16.49 and 30.63μm (Table 1). This is comparable with 13.2μm obtained for wheat straw by Deniz et al. in 2004, 14.8μm for rice straw (Tutus et al., 2004), 20.96μm for bagasse (Hemmasi et al., 2011) and 29.89μm for kenaf core (Shakhes et al., 2011). *Ananas comosus* has the highest fiber diameter and lumen width out of the four solid-waste samples studied (Figure1). It is therefore expected to form better pulp than the others.

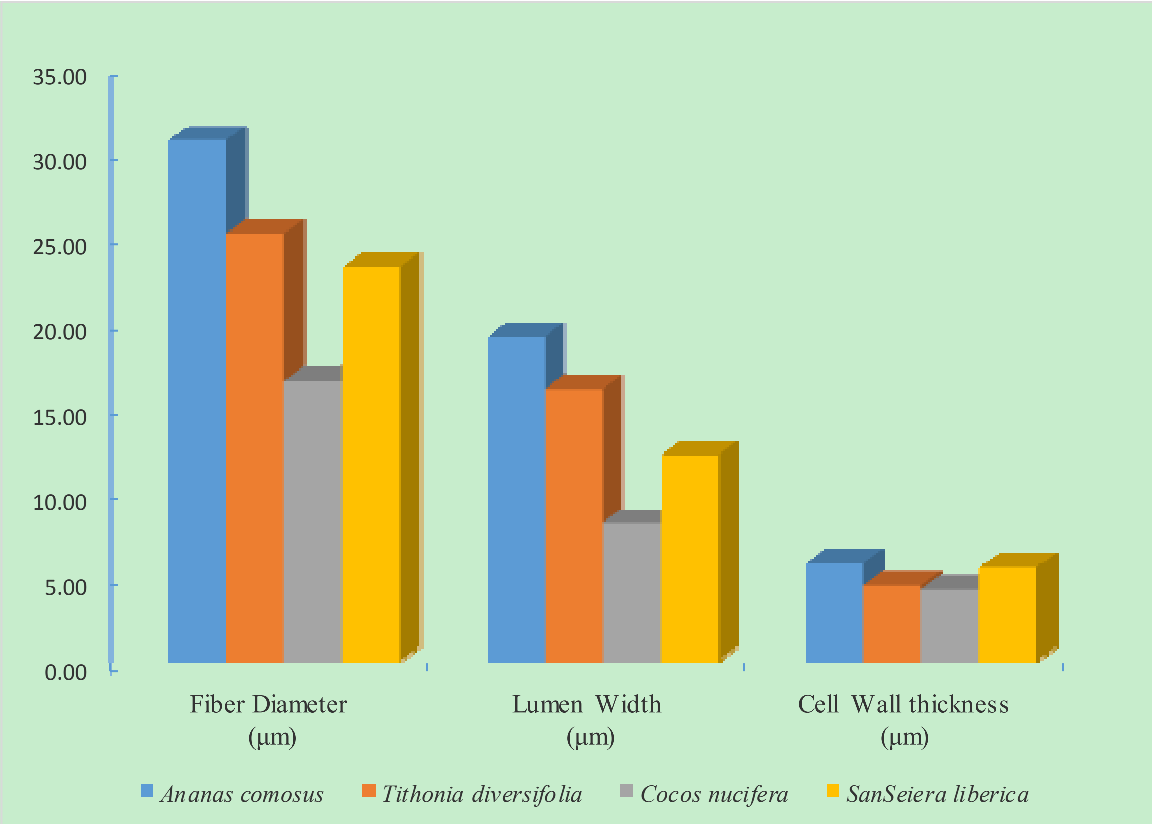

Figure 1. Comparison of the diameter, lumen width and cell wall thickness of the fibers

Lumen width affects the beating of the pulp. The larger the lumen width, the better the beating of the pulp because of the penetration of liquids into empty spaces of the fibers. The lumen width range is between 8.10 and 19.10µm for the fibers with *Ananas comosus* having the highest value. These values are comparable with 5.37µm to 16.40µm obtained for bast, core and whole stalk of kenaf (Shakhes et al., 2011).

The values of the cell-wall thickness are almost the same for all the samples (4.194 – 5.766µm) which is comparable with that reported by Shakhes et al., 2011 for kenaf bast. These are low and will therefore allow easy collapse of the fibers resulting in good surface contact and inter fiber bonding during paper forming. This implies that the four samples studied have potential for paper making based on their cell wall thickness. Thick cell-walled fibers form bulky paper sheets of low tensile, burst and folding endurance but with high tearing strength. These fiber dimensions contribute to the strength, optical and surface properties of the paper (Esa Tiikaja et al., 1980).

According to Yusuf (2007), fiber for pulp and paper can be classified into two groups using Runkel Ratio. Fibers with Runkel Ratio > 1 have very poor paper potential while those with Runkel Ratio ≤ 1 have good paper potential. Apart from *Cocos nucifera* that has a high Runkel Ratio greater than one, other solid-wastes studied have Runkel Ratio of less than one. The values of the Runkel ratio are still comparable with those of bast, core and whole stalk of kenaf that are between 0.518 and 2.36 (Shakhes et al., 2011).

The fibers coefficient of flexibility 51.848 to 64.956 and slenderness ratio 30.527 – 98.780 are in close agreement with coefficient of flexibility and slenderness ratio obtained for bast, core and whole stalk kenaf that range from 29.00 – 710 and 24.12 – 154.21 respectively (Shakhes et al., 2011). Coefficient of flexibility and slenderness ratio of fibers are indices that measure pulp quality or its suitability for paper making. The coefficient of slenderness shows the bonding ability of individual fiber. Generally, all the solid-waste samples studied have relatively high slenderness ratio. The higher the slenderness ratio, the better the ease for the fibers to collapse resulting in good surface contact and inter fiber bonding during formation of paper.

In statistics, analysis of variance (ANOVA) is a collection of statistical models and their associated procedures in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal. The statistical results in Tables 2 and 3 show that there is no significance difference in the means of the various sources of variance of the solid-waste samples.

Table 2. Analysis of variance for fiber morphology

SOURCE OF VARIANCE		Degree of Freedom	Sum of Squares	Mean Square	F – Cal	Significant
Fiber Length	Block	3	16.758	5.586		0
	Size	36	0.891	0.025	225.593	
	Total					
	Error	39	17.649			
Fiber Diameter	Block	3	1013.71	337.903		0
	Size	36	644.911	17.912	18.862	
	Total					
	Error	39	1658.621			
Lumen Width	Block	3	638.269	212.756	15.121	0
	Size	36	506.513	14.070		
	Total					
	Error	39	1144.782			
Cell-Wall Thickness	Block	3	25.784	8.595	8.499	1
	Size	36	36.403	1.011		
	Total					
	Error	39	62.186			
Runkel Ratio	Block	3	1.097			
	Size	36	1.916	0.365		1
	Total					
	Error	39	3.013	0.053	6.869	
Coefficient of Flexibility	Block	3	1186.403	395.468		2
	Size	36	2285.91	63.497	6.228	
	Total					
	Error	39	3472.313			
Relative Fiber Length	Block	3	34,735.09			0
	Size	36	6561.639	11578.364	63.524	
	Total					
	Error	39	41296.752	182.268		

Table 4 shows the Duncan post hoc analysis of variance of the solid-waste fibers at $p \leq 0$. The mean with the same alphabet in each column are not significantly different. This also confirms the suitability of the solid-waste fibers for pulp and paper production.

The data in Table 5 was generated from the experimental data using analysis of variance (ANOVA) in randomized complete block design (RCBD) to determine the fiber characteristics while the variable were run on surface response methodology of the variance. Statistical model for randomized complete block design is:

$$Y_{Ij} = \mu + B_i + T_j + E_{Ij}$$

Y_{Ij} = Individual observation

μ = General mean

B_i = Effect of block

T_j = Effect of treatment

E_{Ij} = Experimental Error

Table 3. Descriptive analysis of variance

		N	Mean	Std. dev.	Std. Error	Minimum	Maximum
Fiber length	Pine apple leaf	10	0.94	0.05	0.02	0.83	1.00
	Coconut husk	10	0.76	0.85	0.26	0.67	0.92
	Tithonia diversifolia	10	0.88	0.17	0.05	0.61	1.13
	Sanseveria liberica	10	2.34	0.24	0.08	1.97	2.83
	Total	40	1.23	0.67	0.11	0.61	2.83
Fiber diameter	Pine apple leaf	10	30.56	6.16	1.95	24.08	37.2
	Coconut husk	10	25.2	2.39	0.76	21.08	28.8
	Tithonia diversifolia	10	16.49	4.34	1.37	12.4	24.8
	Sanseveria liberica	10	23.19	3.04	0.96	17.36	27.28
	Total	40	32.86	6.52	1.03	12.4	37.2
Lumen width	Pine apple leaf	10	19.15	5.67	1.79	12.4	27.8
	Coconut husk	10	16.37	3.55	1.12	11.16	22.32
	Tithonia diversifolia	10	8.68	2.74	0.87	6.20	13.64
	Sanseveria liberica	10	0.63	2.01	0.63	8.68	16.12
	Total	40		5.42			
Cell wall thickness	Pine apple leaf	10	5.77	1.13	0.36	0.34	7.44
	Coconut husk	10	4.22	0.92	0.29	3.10	5.58
	Tithonia diversifolia	10	3.90	1.13	0.36	2.48	5.58
	Sanseveria liberica	10	5.51	0.8	0.25	3.72	6.20
	Total	40	4.85	1.26	0.2	2.48	7.44
Runkel Ratio	Pine apple leaf	10	0.65	0.23	0.07	0.36	1.00
	Coconut husk	10	0.56	0.23	0.07	0.28	0.89
	Tithonia diversifolia	10	0.94	0.28	0.89	0.57	1.40
	Sanseveria liberica	10	0.92	0.16	0.53	0.69	1.29
	Total	40	0.77	0.28	0.43	0.28	1.40
Coefficient of Flexibility	Pine apple leaf	10	61.77	8.45	2.67	50.00	74.72
	Coconut husk	10	64.58	10.34	3.27	51.67	78.76
	Tithonia diversifolia	10	52.58	7.54	2.38	41.67	63.64
	Sanseveria liberica	10	52.35	4.34	1.37	43.75	59.00
	Total	40	57,82	9.44	1.49	41.67	78.26
Relative Fiber length (mm)	Pine apple leaf	10	31.64	6.11	1.93	25	41.71
	Coconut husk	10	30.5	6.00	1.9	24.35	43.53
	Tithonia diversifolia	10	55.97	14.91	4.71	27.22	75.83
	Sanseveria liberica	10	103.24	20.82	6.58	79.41	143.57
	Total	40	55.34	32.54	5.14	24.35	145.57

Table 4. Duncan Post Hoc Tests: Mean of groups in homogeneous subset

SAMPLES	FIBER CHARACTERISTICS					
	Fiber Length (mm)	Fiber Diameter (μm)	Lumen Width (μm)	Cell Wall thickness (μm)	Runkel Ratio	Coefficient of Flexibility
Ananas Comosus	0.9350b	30.5560c	19.1510c	5.7660b	0.6543a	61.7717b
Cocos Nucifera	0.7576a	25.2000b	16.3680c	4.2160b	0.5682b	64.5850c
Tithonia Diversifolia	0.8792ab	16.4920a	8.8600a	3.91a	0.9378b	52.5863a
Sanseveria Liberica	2.3447a	23.1880b	12.1520b	5.5150b	0.9226b	52.3493a

The cell wall thickness and the fiber lumen width were kept constant at 1.05μm and 9.3μm respectively. The independent variables are the fiber length and its diameter while the dependent variables are Runkel ratio, coefficient of flexibility and felting power.

Table 5. Data generated for Surface Response Mechanism

FL	FD	LW	CWT	RR	CF	FP
2.52	24.8	9.3	2.00	0.430108	465.00	6.2
1.56	24.8	6.2	2.00	0.645161	310.00	6.2
1.56	12.4	12.4	1.05	0.170161	1175.36	5.87678
1.56	12.4	9.3	2.00	0.430108	465.00	3.1
2.52	24.8	9.3	0.11	0.023656	8454.55	112.727
1.56	37.2	12.4	1.05	0.170161	1175.36	17.6303
2.52	37.2	9.3	1.05	0.226882	881.52	17.6303
1.56	24.8	9.3	1.05	0.226882	881.52	11.7536
0.61	24.8	12.4	1.05	0.170161	1175.36	11.7536
0.61	24.8	9.3	0.11	0.023656	8454.55	112.727
1.56	37.2	9.3	2.00	0.430108	465.00	9.300
1.56	24.8	12.4	2.00	0.322581	620.00	6.200
1.56	12.4	6.2	1.05	0.340323	587.68	5.877
2.52	24.8	6.2	1.05	0.340323	587.68	11.754
1.56	24.8	12.4	0.11	0.017742	11272.70	112.727
1.56	24.8	9.3	1.05	0.226882	881.52	11.754
0.61	24.8	9.3	2.00	0.430108	465.00	6.200
0.61	37.2	9.3	1.05	0.226882	881.52	17.630
0.61	12.4	9.3	1.05	0.22688	881.52	5.877
1.56	24.8	9.3	1.05	0.226882	881.52	11.754
2.52	24.8	12.4	1.05	0.170161	1175.36	11.754
2.52	12.4	9.3	1.05	0.226882	881.52	5.877
1.56	24.8	9.3	1.05	0.226882	881.52	11.754
1.56	37.2	9.3	0.11	0.023656	8454.55	169.091
1.56	24.8	6.2	0.11	0.035484	5636.36	112.727
0.61	24.8	6.2	1.05	0.340323	587.68	11.754
1.56	24.8	9.3	1.05	0.226882	881.52	11.754
1.56	12.4	9.3	0.11	0.023656	8454.55	56.364

It can be deduced from Figures 2 to 4 that the optimum condition for production of good quality pulp and paper using the studied solid-wastes is achievable with fiber length of 0.61mm, fiber diameter of 17.16, lumen width of 12.40µm, cell wall of 1.31µm, and Runkel Ratio of 0.20730. The average fiber length of 0.61mm coupled with low Runkel ratio 0.207301 would result in highly flexible fibers that can produce pulp and paper of good strength properties.

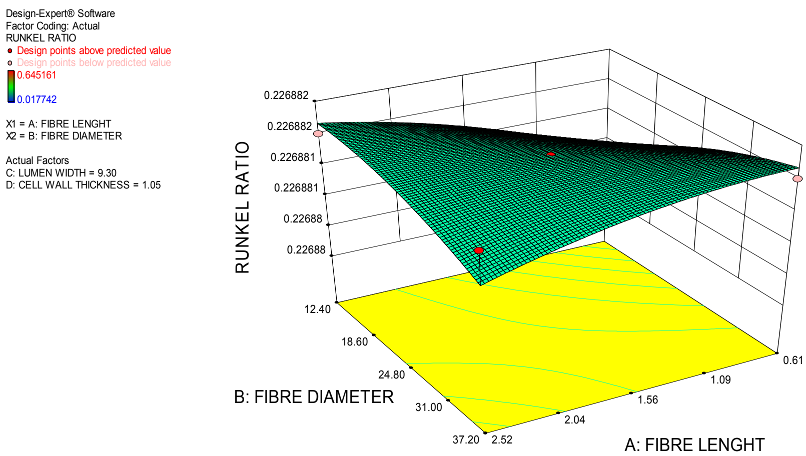

Figure 2. Surface response methodology of Runkel Ratio

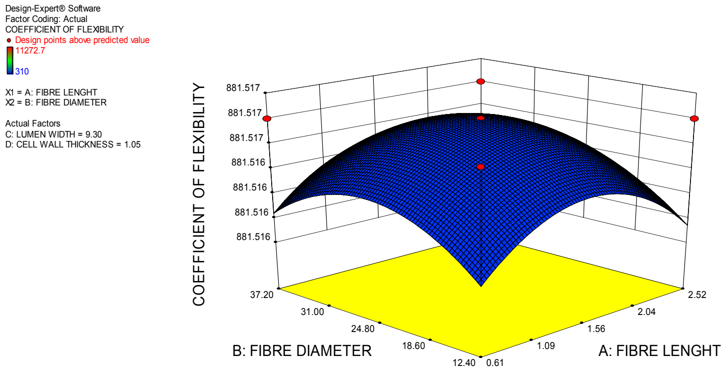

Figure 3. Surface response methodology of the coefficient of flexibility

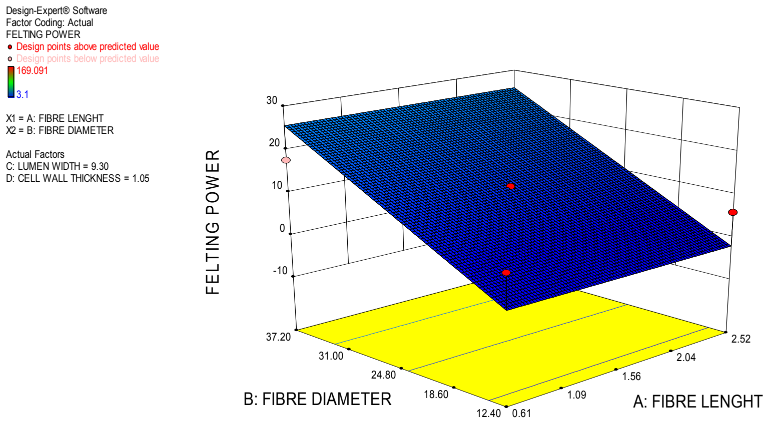

Figure 4. Surface response methodology of the felting power

4. Conclusion

Long fibers needed to produce good quality pulp and paper can be generated from the four agro-wastes studied and can compete favorably with other highly rated pulp and paper making materials. They are available and renewable. As a way of converting waste to wealth, the research is expected to put value on the solid wastes. Farmers will obtain more revenue and also play a prominent role in getting rid of the environment from the huge solid wastes generated by the poor disposal of these agro-wastes in Nigeria. It is also expected to provide raw materials for would-be-investors and employment opportunity for people since it will allow cash-poor start-up industries to save capital and encourage establishment of processing mills in rural areas.

References

American Society of Testing Materials, (1989). ASTM D2395–83.

Dinwoodie, J. M. (1985). The relationship between fiber morphology and paper properties. A review of literature. *TAPPI*, *48*, 440 – 447.

Dutt, M. J., Garcia, M. M., Eugenio, M. E., Tapias, R., Fernandez, M., & Lopez, F. (2008). Studies on *Hibiscus cannabinas* and *Hibiscus sabdariffa* as an alternative pulp blend for softwood: An optimization of Kraft delignification process. *Industrial crops and products*, *29*(1), 16–26. http://dx.doi.org/10.1016/j.indcrop.2008.03.005

Enayati, A. A., Hamzeh, Y., Mirshokraie, S. M., & Molaii, M. (2009). Paper making potential of canola stalk. *BioResource*, *4*(1), 245 – 256.

Esa, T. (1998). Fiber dimension characteristics effect on paper quality. *Finish pulp and paper resources J., 5*, 21-52.

Hemmasi, A. H., Samariha, A., Tabei, A., Nemati, M., & Khakifirooz, A. (2011). Study of morphological and chemical composition of fibers from Iranian Sugarcane Bagasse. *American-Eurasian J. Agric. and Environ. Sci., 11*(4), 478-481.

Jimenez, L., Ramos, A., Rodriguez, A., De La Torrre, M. J., & Ferrer, J. L. (2005). Optimization of pulping conditions of abaca, an alternative raw material for producing cellulose pulp. *Bioresource Technol., 96*, 977-983. http://dx.doi.org/10.1016/j.biortech.2004.09.016

Ogunsile, B. O., Omotoso, M. A., & Onilude, M. A. (2006). Comparative soda pulps from the mid-rib, pseudo stem and stalk of *Musa paradisiacal*. *Journal of Biological Sciences, 6*(6), 1047–1052. http://dx.doi.org/10.3923/jbs.2006.1047.1052

Oluwadamilare, A. O. (1998). Evaluation of the fiber and chemical properties of some selected Nigerian wood and non-wood species for pulp production. *J. Trop. Forest Res., 14*, 110–119.

Raw Materials Research and Development Council, Nigeria (1998).Techno-Economic Survey of Multi-disciplinary task Force on pulp and paper products, printing and publishing sector. 12–28.

Rodriguez, A., Moral, A., Serrano, L., Labidi, J., & Jinenez, L. (2008). Rice straw pulp obtained by using various methods. *Bioresource Technology*, *99*, 2881–2886. http://dx.doi.org/10.1016/j.biortech.2007.06.003

Rodriguez, A., Serrano, L., Moral, A., Perez, A., & Jinenez, L. (2008). Pulping of rice straw with high boiling point organosolvents. *Biochemical Engineering Journal, 42*(3), 243–247. http://dx.doi.org/10.1016/j.bej.2008.07.001

Sadegh, A. N., Rakhshani, H., Samariha, A., Nemati M., & Khosravi, E. (2011). The effect of processing variables on the soda and soda – Anthraquinone pulping of Kenaf bast fiber. *BioResource, 6*(4), 4626-4639.

Smook, G. A. (1997). Handbook for pulp and paper technology, 2nd Edition, Angus Wide Publication Inc., Vancover.

Tutus, A., Comlekcio, N., Karaman, S., & Alma, M. H. (2010). Chemical composition and fiber properties of *Crambe* oriental and *Crambe* tatar. *International Journal of Agriculture and Biology*, *12*, 286–290.

Villar, J. C., Poveda, P., & Tagle, J. L. (2001). Comparative study of Kenaf varieties and growing conditions and their effect on Kraft pulp quality. *Wood Science and Technology, 34*(6), 543-552. http://dx.doi.org/10.1007/s002260000072

Wong, A., (1997). Agricultural fiber supply for pulp production, "Presented at the Fiber Future Conference," Monterey, CA.

Yusuf, S. O. (2007) Evaluation of the fiber characteristics of kenaf (*Hibiscus sabdariffa* and *Hibiscus canebianus*, and yellow bush (*Duranta ripens. ripens*). *Nigeria Journal of Forestry, 20*, 23-26.