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Fiber Characteristics and Quality of Paper Produced from Kenaf and Bagasse

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Abstract. In the present study, morphological characteristics and chemical composition of the two raw materials (kenaf and bagasse) were investigated. The optimum conditions for their cooking were also determined. Bagasse had the highest cellulose content (51%) with low lignin (17%) compared to cellulose and lignin contents for kenaf core (42.0) and (25.0), respectively. With regards to anatomical characteristics, the lumen diameter and cell wall thickness for bagasse were 10.91 µm and 7.37µm and for kenafbast were 7.75 µm and 2.33 µm, respectively. Runkle ratio for kenafbast was 0.31 which was lower than bagasse (0.62). Cell coefficient of rigidity was0.62 for bagasse and (0.77 for kenafbast). Longer fibers with lower cell wall thickness showed significant advantages in strength properties of the produced paper like the case of paper produced from kenafbast. Pulp yields for the studied materials were 49 and 49.5% for Kenafbast and, 43%-44% for kenaf core with 16% and 17% active alkali respectively. The increase in alkali charges lowered the screened yield from 49.9% to 45% and kappa number from 21 to 18forbagasse using active alkali charge of12% and 13% respectively. Bagasse also gave acceptable yield and kappa number. As for paper properties.the burst index for paper produced from bagasse cooked at 12% active alkali increased from 0.80 to 2.6 kpa m/g with beating time. The tensile index on the other hand, increased from 31.0 to 75.7 Nm/g with increased beating time, while bulk density increased from 5.88 to 9.31 g/cm³. When bagasse was cooked with 13% active alkali the burst index increased from 0.70 to 2.9 kpa m/g with beating time, while tensile index increased from 51.4 to 78.0 Nm/g. The bulk density also increased with beating time from 5.88 to 9.97 g/cm. The brightness was 37%. This indicated that all properties were significantly improved by increasing beating time and using higher active alkali percentage. When kenaf bast was cooked with 17% active alkali, the tensile index of the paper produced decreased from 105 to 79 Nm/g with beating time, while burst index increased first from 4.8 to 5.7 and then decreased to5.1 kpa*m/g with beating time. The decrease in these properties with beating time is due to the breaking of the long fibers of kenaf bast with beating. Kenaf core was cooked with 16% and 17% active alkali. The tensile index of paper in case of 16% active alkali increased from 23.5 to 45.7 Nm/g with increased beating time, while burst index increased from 0,50 to 1.5 kpa*m/g.

Keywords: Soda pulping, bagasse, kenaf, fiber characteristics, papermaking

Introduction

World demand for paper has increased at an average annual rate of 4.7% over the past 40 years. With future growth the existing wood resources may be inadequate to meet this growing demand for paper especially in the Asia-Pacific region and Eastern Europe. In addition, logging is coming under increasing pressure from environmentalists concerned about habitat destruction and other longer-term impacts of forest harvesting. It is, therefore, necessary to consider alternative fiber sources to meet the possible shortfall of wood fiber for papermaking. Suitable nonwood fibers are abundantly available in many countries and are the major source of fiber for papermaking in some developing nations (Ashori, 2006).

The use of nonwood plants for papermaking purposes has for some time been a subject of debate. Reasons such as the scarcity of raw materials have not permitted developed countries, where paper recycling is increasing at a sustained rate to expand on using virgin fiber. Countries such as China or India, however, have used nonwood plants such as bamboo and agricultural residues (e.g. sugar cane bagasse, cereal straw) for papermaking with good results (Haroon and yuliu,2017).

As compared to wood, nonwood raw materials are similar in cellulose content, lower in lignin and higher in pentosans (hemicelluloses) and silica content (Villar, *et al*, 2009). The advantages of nonwood fibers are that they are mostly by-products (agricultural residues); often cheaper than wood; large annual crops; need little refining; and make excellent filler and good printing and smoothness (Judt, 1993). Furthermore, the potential availability and economics of using agricultural residues is more interesting despite of their limitations (Biermann, 1996). For instance, this can provide added income to farmers without compromising the production of main food and even non-food crops (Reddy and Yang, 2005). The problems associated with the utilization of these nonwood fiber resources include: collection and transportation; storage and handling; washing; bleaching; papermaking; and chemical recovery (UNEP, 2009).

Kenaf (*Hibiscus cannabinus*) is aherbaceous annual plant grown in many parts of the tropics and in some subtropics and warm temperate areas for its bast fibers to substitute jute in cordage and sacking. In many studies kenaf was found to respond well to different chemical and semichemical pulping processes to produce acceptable yield of pulp with faily good paper properties. Bagasse is commonly used as a substitute for wood in many tropical and subtropical countries for the production of pulp, paper and board, such as India, China, Colombia, Iran, Thailand and Argentina. It produces pulp with physical properties that are well suited for generic printing and writing papers as well as tissue products but. It is also widely used for boxes and newspaper production.As the forest cover of the Sudan is estimated to be >10% of the area of the country, these alternative fibrous raw materials represent the right choice to suggest for the establishment of pulp and paper production in Sudan. Kenaf and bagasse are available on seasonal bases and hence they may compensate for each other to insure continuous raw material supply (Hammett, *et. al*, 2001).

METHODOLOGY

Tow non-wood fiberous materials were used in this investigation. These included kenaf and bagasse. Kenaf (*Hibiscus cannabinus*) studied was grown in Shambbat farm –Khartoum North-Sudan. Bagasse a by-product of the stem of sugarcane (*Saccharumofficinarum*), after crushing and juice extraction, was collected from Algineid Sugar Factory, Gezira State, Sudan. The studied samples were air dry and depithed.

Fiber Morphology

Kenaf stalks were air-dried, bast fiber was removed from the stalk manually, and the core stalks were chopped to pieces of about 1 inch long. Maceration process was carried out to liberate the fibers to determine their morphology or physical dimension. The fibers were cut into matchstick size of 25 to 30 mm in length. This was followed by the addition of 5ml hydrogen peroxide, and 5ml acetic acid into three (3) different test tubes. The mixture was boiled in water bath until fibers were completely white. Subsequently, the fibers were washed gently using distilled water, placed in separate test tubes and shakened in a distilled water to get the individual fibers. One drop of safranin-O was added to the fiber and left for 1 hour. A few of the individual fibers from different test tube were mounted on to a glass slide. The fiber length (FL), fiber diameter (FD), lumen diameter (LD),double cell-wall thickness (DCWT) were then measured using the Quant meter Image Analyzer equipped with a microscope. Morphological indices of kenaf and bagasse fibers were calculated from the above measurements as follows:

A) Slenderness Ratio (Felting coefficient) (SR)

SR = Fiber length/Fiber diameter

B) Runkle Ratio (RR)

RR = 2 X Cell wall thickness/Lumen diameter

C) Fiber Flexibility Ratio (Elasticity coefficient)(FF)

FF = Fiber lumen diameter/ Fiber diameter

Chemical analysis:

Proximate chemical analyses of the fibrous raw materials were carried out according to the following standards. Ash content according to (TAPPI T 211) cold water and hot water extract according to (TAPPI T 211) cellulose content according to (TAPPI T 17) lignin content according to (TAPPI T 222-om-96) 1%NaOH extract according to(TAPPI T 212).

Pulping and pulp evaluation

The soda pulping method of oven dried kenafcore, kenafbast and bagasse was carried out in a laboratory, cylindrical digester. This digester included an electrical heater, a motor actuator, and instruments required for measurement and control temperature and pressure. The raw material was 500g oven dried of bagasse, kenaf core and kenaf bast. Pulping conditions of soda processes to obtain pulp are shown in table (1).

Table.1 Pulping conditions for bagasse and kenaf

Control condition	Bagasse	Kenaf
Oven dry weight (g)	500	500
Active alkali as Na_2O %	12-13	16-17
Liquor/fiber ratio	5:1	6:1
Max temp. ^oC	160	170
Time to max temp, min	40-45	1h
Time at max temp ,min	1h	1h

At the end of cooking the pulp was washed by water and mechanical standard terpopulper. Fibers were then disintegrated using a disintegrator according to (TAPPI 205). The cooked pulp was then screened with a screen plate..The yield of pulp and reject were determined by measurement in the laboratory. The screened yield was also determined from duplicate samples. The kappa number was determined according to (TAPPI 1236-0m-99).

Beating and handsheets formation

Before forming the handsheets the different pulps were beaten to different beating times according

to(TAPPI 200-sp-01). The handsheets were formed according to (TAPPI 22-SP-01).The handsheets prepared were conditioned according to (TAPPI-402-SP-9). The different pulps were beaten to different beating times in accordance to (TAPPI 200-sp-01) bagasse had three beating times 0, 4 and 5 min..Kenafbast, also had three beating times 0, 1 and 2min. While kenaf core had tow beating times 0 and 5min. Canadian standard freeness resulting from the different beating times were measured according to (TAAPI227-1199).

Evaluation of paper properties

Evaluation of paper quality produced from this investigation was based on five properties, namely: bulk density, tensile index according to (TAPPI404OM-92), burst index in accordance to (TAPPI 403-0m-97) in addition to brightness according to (TAPPI 425-om-81).

Results and Discussion

Chemical Composition

Table (2) shows the proximate chemical composition and some solubility values in kenaf core and bagasse. Bagasse had shown the highest cellulose content 51% with low lignin content 17%, while cellulose and lignin contents in kenaf core were 42.0% and lignin 25.0 % respectively. Lower cellulose and lignin contents were reported for Sudanese bagasse (Kassim, *et. al*, 2015). In pulp and paper, high cellulose content is preferable because it leads to high yield pulp as well as better paper quality. Moreover, low lignin content is desirable in the pulp and paper because less chemicals and energy are required during the pulping process. Furthermore, low lignin will also produce paper with good optical properties and therefore requires less bleaching and ultimately reducing both the energy needed for processing and the hazardous chemical wastes released to the environment (Jiang, *et. al*, 2019).

The highest ash was observed in bagasse (3%), while kenaf core had showed the lowest 2.9%. Lower ash content is desirable as it expected to decrease chemicals required during pulping and bleaching. The high ash content could lead to bad softness and whiteness of the paper, resulting in reducing of physical properties of the paper (Fagbemi1, *et. al*, 2014). Solubility in water is the measure of the extractive compositions of the lignocellulosic material. High extractives values indicate high presence of tannins, alkaloids and starch. However, core shown the highest amount of extractives in hot and cold water (10.6, 30%) compared to bagasse (3.5, 6%) respectively. These values are very high compared with that found in hardwood.

Table2. Results ofproximate chemical analysis of kenaf core and bagasse.

Chemical composition%	Kenaf core	Kenaf core*	Bagasse	Bagasse**
Cellulose(K.H)	42.0	45.7	51.0	43.0
Ethanol Extraction	1.83	-	5.49	-
n-Hexane Extraction	1.38	-	4.23	-
Lignin	25.0	19.6	17.0	15.2
Cold Water Solubility	30.0	-	3.5	10.6
Hot Water Solubility	10.0	4.4	6.0	11.3
NaOH (1%) Solubility	26.0	29.3	16.7	15.5
Ash	2.90	2.9	3.0	5.0

* Khristova, *et al,* 2002

** Haroon, 2017

Fiber Morphology

Table 3 shows the fiber measurements for the three raw materials (bagasse, kenaf core and kenafbast). An important feature of non-wood fibers is the wide variability among the lengths of the fibers. In addition to fiber length, analysis of fiber characteristics such as fiber diameter, lumen width, cell-wall thickness and their derived morphological factors have become important in estimating pulp quality of fibers. Kenafbast fibers resemble softwood fiber with a length of 2.48mm (Table4.2), has drawn quite good research interest for paper pulp and new composites industries. Meanwhile, bagasse fibers however with (0.80mm) fiber length could be compared to that of hardwoods. The kenaf core fibers.were found to be the shortest (0.64mm) and the widest (26.92µm) among the studies materials.Short fibers do not produce adequate surface contact and fiber-to-fiber bonding. Pulps of kenaf core and bagasse are lower in paper strength because of their shorter fibers than those of with kenafbast longer fibers (Maria*, et. al*, 2014).

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. Bagasse having the highest value in lumen diameter compare with kenafbast. While the bast fibers are expected to produce pulp with good strength properties, the latter pulp will have poor strength. Double Cell wall thickness for bagasse (7.37) and kenafbast (2.33), this is low value than bagasse. The decrease of lumen diameter and increase in the secondary cell wall thickness increase the fiber strength (Brindha and Alarmlumangai, 2014).

Table 3 Fiber dimensions for the three raw materials

	FL mm	**FD un**	**LD un**	**DCWT un**
Bagasse	0.8	17.68A	10.91A	6.77A
KenafCore	0.64	26.92	23.85	3.08
KenafBast	2.48	10.12B	7.75B	2.37B
Value significant	-	0.0002	0.0296	0.0001

Analysis of variance showed significant difference in FD between the two species (p=0.0002) with bagasse having the higher value (17.68um) than kenaf (10.12um). The lumen diameter and cell wall thickness were (10.19, 7.37um) for bagasse and (7.75, 2.33um) forkenafbast respectively.

Morphological indices (ratios) of bagasse and kenaf fibers are given in Table (4). Kenafbast fibers were by far higher in slenderness ratio (245.06) compared to kenaf core (23.78) and bagasse (45.25). Runkle ratio for kenafbast was found to be (0.31) quite lowers than bagasse (0.62). Rankle ratio is the most important parameter in influencing the fiber papermaking properties. Lowerrunkle ratio gives high paper strength, the ratio for kenafbast(0.31) than bagasse (0.75), low runkleratio gives high paper strength. Thecell coefficient of rigidity was (0.91) for bagasse and (0.11), for kenafbast. High fiber rigidity isunaccepted for pulp and paper (Majid.K, 2014).

The fiber flexibility for bagasse (0.61) andkenafbast (0.78).This ratio withlength of fiber and wall thickness determine the flexibility of paper (folding properties).Therefore,kenafbast is expected to be good for paper making (Ekhuemelo and Udo, 2016). Flexibility ratio is another important criterion for evaluating fiber quality. The Flexibility ratio of the bagasse fiber was about 0.61 while that of kenaf core and bast were 0.88 and 0.76 respectively. If the flexibility ratio was between 0.50 and 0.70, this kind of fiber can easily be flattenedto give good contact and paper with high strength properties.

Table4. Morphological indices (ratios) of bagasse and kenaf fibers.

	Slenderness	Runkel's Ratio	Flexibility Coefficient	cell coefficient ofrigidity
Bagasse	45.25A	0.62A	0.61	0.91A
Kenaf Core	23.78	0.13	0.88	0.11 B
Kenafbast	245.06B	0.31B	0.76	-
Value significant	-	0.0033	0.0138	0.0009

Pulp properties

Table 5 shows pulp properties for the different raw materials The properties of the pulps obtained from the kenaf core and kenafbast showed acceptable yields and kappa numbers. The results revealed that there were some differences in pulp properties of the investigated kenaf core and kenafbast produced by the same pulping conditions. Pulp yields for the studied materials were as follows: kenafbast (49-49.5%), kenaf core (43%-44%) in the same order with alkali charge (16%-17%) respectively. It could be noticed that increasing the alkali charges has negligible effect on those parameters. Bagasse yielded (41% and 45%) with 21 and 18 kappa number at 12% and 13% active alkali respectively. These yields are within the acceptable ranges. This indicates that increasing the active alkali can shortene the cooking time by more than 10%. As indicated by (Bhardwaj, *et. al*, 2019). A Mixture (50:50 and 70:30) of kenaf core and bast were cooked with 16% active alkali charge, both mixtures ratios produced the same yield (42%). It was observed that kenafbast gave the highest pulp yield regardless the alkali charge; this could be attributed to the high cellulose content in kenafbast. The increase alkali charge did not change yield or kappa number significantly. Low kappa number, as the case of all of the studies materials, indicates low consumption of bleaching chemicals, which directly led to decreasing the effluent [31].

Table 5 show pulp properties for the different raw materials and mixtures:

Propertes	Bagasse		Kenaf core		Kenafbast		KB/KC/Mixture 50:50	70:30
	AA 12%	AA 13%	AA 16%	AA1 7%	AA 16%	AA 17%	16%	16%
Screen yield %	49.9	45	44	43	49.5	49	42	42
Reject%	1.1	0.45	0.90	1	0.17	0.12	2	1.5
Kappa number	21	18	21	22	19	18	22	22

AA=active alkali, KC kenaf core, KB kenafbast

Properties of Paper Made from Bagasse:

Handsheets were formed for all of the obtained pulps and also for pulp blends at different ratios. The freeness (drainability or beating time) was determined for the different beating intervals (Table 3.4). It could be noticed from the table that bagasse required minimum beating time.Refining of pulps is one of the most important stages in the paper production process and influences strongly the sheet formation and its physical properties. Beating time, as reflected in freeness of pulp, is generally used as an index in the pulp and paper industry to reflect water filtration speed. The rate of drainage of 1 L of pulp is related to the work done on the fiber during beating and refining. A greater beating degree causes a lower water filtration speed [32].

Table 6 shows the effect of active alkali percentage and beating time on bulk density and brightness of paper made from bagasse, Bagasse cooked at relatively low alkali charge (12-13%) produced pulp of acceptable brightness (37) and bulk density between 5.88 g/cm³ for ubeaten pulp to 9.97g/cm^3 pulp beaten for 5 minutes..

Table 6 Effect of active alkali and beating time on bulk density and brightness of bagasse paper:

Properties	Bagasse with AA12%		Bagasse with AA13			
Beating time (min)	Freeness (^{0}SR)	Bulk density (g/cm^3)	Beating time (min)	Freeness (^{0}SR)	Bulk density (g/cm^3)	Brightness %
Zero	27	5.88	zero	23	5.88	37
4	55	9.05	6	40	9.11	
5	57	9.31	8	50	9.97	

AA=active alkali

The Burst index for bagasse paper as shown in table (7) was found to increase from 0.7 to 2.9 kpa*m^2/g with beating time with 13% AA When cooked with 12% AA. The burst index increased from 0.8 to 2.5 kpa*m/g with beating time.

Table 7 effect of Active alkali and beating time on burst index for bagasse paper:

Bagasse with 12%AA			Bagasse with 13%AA		
Beating time(min)	Freeness (^{0}SR)	Burst index kpa*m^2/g	Beating time(min)	Freeness (^{0}SR)	Burst index Kpa*m^2/g
Zero	27	0.8	Zero	23	0.7
4	55	2.2	6	40	2.6
5	57	2.5	8	50	2.9

AA active alkali

Table 8 shows the effect of AA% and beating time on tensile index of bagasse paper. The tensile index increased from 31to 75.7 Nm/g for with beating time when 12% active alkali was used. With 13% active alkali the tensile index increased from 51.4 78.0 Nm/g. [29] who studied Nigerian bagasse pulp reported somewhat different results; tensile index was 58.50 Nm//g and burst index 6.5 kpa*m/g. It could be noticed that lowering the active alkali charge from 13 to 12% did not only increase the screened yield, but also resulted in sheets with lower strength properties.

Table 8 effect of AA and beating time on tensile index for bagasse paper l:

Bagasse with 12%AA			Bagasse with 13%AA		
Beating time (min)	Freeness (^{0}SR)	Tensile index Nm/g	Beating time (min)	Freeness (^{0}SR)	Tensile index Nm/g
Zero	27	31	zero	23	51.4
4	55	66.5	4	40	62.5
5	57	75.7	5	50	78

Table 9 shows the effect of beating time on properties of paper made from kenafbast cookedwith 17% AA. The highest tensile index was for paper made from unbeaten pulp and decreased with beating time. . This decrease in tensile strength with beating time is due to the fact that the long fibers of kenafbast are cut down to shorter segments during beating, The burst index increased first with beating time and then decreased with further increase in beating time,The other properties did not show any trends.

The handsheets produced from kenafbast and kenafcore cooked at different condition (16-17% AA) has shown good initial brightness (26% and 24% respectively). The highestbulk density for kenaf core (11.58g/cm^3) was obtained at 40^{o}SR freeness while that of kenafbast was 10.30g/cm^3 obtained at 46^{o}SR

Table 9 Effect of beating time on properties of paper made from kenafbast:

Kenafbast with 17%Active alkali

BT(min)	Freeness (^{0}SR)	Tensile index Nm/g	Burst index Kpa*m^2/g	Bulk density g/cm^3	Brightness %
Zero	36	105	4.8	10.24	30
1	43	85	5.7	9.38	-
2	46	79	5.1	10.30	-

*BT= beating time

Kenafbast fiber recorded the highest tensile index (105Nm/g) for unbeaten pulp and decreased with beating time (table 4.8). Unfortunately, beating has negatively affected the tensile index, indicating shortening of the long bast fiber during the beating process. The burst index of kenafbastwas 4.8 (36^{o}SR) 5.7 (43^{o}SR) and 5.18kpa*m2/g (46^{o}SR), showing that the beating should be kept at the minimum degrees.

Table 10 showed that the tensile index of kenaf core cooked with 16% AA increased from 23.87Nm/g to 45.7Nm/g with increased beaten time. The Burst index also increased with beating time from 0.7to 1.68 kpa*m2/g The paper from kenaf core cooked with 17% AA showed similar trends..

Table 10 effect of Active alkali and beating time on tensile index and burst index of paper made from kenaf core:

Kenaf core 16%AA				Kenaf core 17%AA			
BT (min)	Freeness (^{0}SR)	Tensile index (Nm /g)	Burst index kpa* m^2/g	BT (min)	Freeness (^{0}SR)	Tensile index (Nm /g)	Burst index kpa* m^2/g
Zero	27	23.5	0.5	Zero	27	23.6	0.7
5	40	45.7	1.5	5	40	40.5	1.6

BT-beating time

The presence of fines and parenchyma cell with higher surface area in kenaf core was reflected in its lowest freeness and highest drainage time compared to kenafbast fibers pulp [30].

Table 11 shows that bulk density of paper made from kenaf core cooked with 16% AA increased slightly from 10.37 to 11.58 g/cm³ with beating time. However, the increase was more significant (from 5.75 to 9.44 g/cm³) when the AA was increased to 17%., but the bulk density decreased when The AA was increased to 17%.

Table 11 Effect of Active alkali and beating time on bulk density and brightness of paper made of kenaf core:

Kenaf core withAA16%				Kenaf core with AA17%			
BT (min)	Freeness (^{0}SR)	Bulk density g/cm^3	Brightness %	BT(min)	Freeness (^{0}SR)	Bulk density g/cm^3	Brightness %
zero	27	10.37	30	zero	27	5.75	30
5	40	11.58		5	40	9.44	

*BT= beating time

Conclusions and recommendations

Conclusions

The following conclusion could be drawn from the present study:

1.Kenafbast has long fibers and thinner cell wall thickness and thereby greater interfiber contactsleading to paper with higher strength than kenaf core and bagasse in case of unbeaten pulp

2.Paper made from kenafbast, however, decreased with increased beating due to the breaking of fibers during beating..

3. Tensile index,burst index and bulk density of paper made from bagasse increased with increased active alkali and increased beating time

4. Tensile index of paper made from kenaf core decreased with increased active alkali but increased with increasing beating time,whereas burst index increased with increased active alkali and beating time

Recommendation

The future scopes in this area will continue in exploring optimum cooking conditions for as many non-woodfiberous raw materials as possible for more economic and sustainable paper production. They will also look into grouping together different fiberous raw materials adapted to similar cooking conditions, so that they can be cooked together when the need arises.

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