The Potential of *Cymbopogon nardus* in the Production of Pulp for Paper Industry

Omar L. M. Kamoga, J. B. Kirabira, and J. K. Byaruhanga

Abstract*— *Cymbopogon nardus believed to contain cellulosic fibres has been proposed to be a potential source of pulp for paper industry with less environmental degradation threat. This study involved characterisation of *Cymbopogon nardus* as a new potential raw material, identifying the appropriate pulping techniques and conditions as well as characterisation and evaluation of the pulp and paper made. Norman and Jenkins's methods as well as the standard TAPPI methods were used to determine the chemical composition. Soda and Kraft pulping techniques were studied at varied temperature and chemical charges. It contained high hollocellulose, α-Cellulose; and moderately low extractives, ash content and lignin Content. The pulp yield of 42.82% at a kappa number of 24.4 was achieved with soda pulping at soda charge of 25%, at160°C and in one hour. A yield of 45.79% at a kappa number of 31.2 was achieved with Kraft pulping at 30 % sulphidity, 20% active alkalis, at the same time and temperature. The isolated pulp contained moderate fibre length (0.771mm), fibre width (14.4µm), slenderness ratio (51.67), a brightness (69.65%); and paper sheets with a tear index (6.44m Nm^2/g). Properties of *Cymbopogon nardus* as a raw material, pulp and paper were very closer to those of other non-wood materials. *Cymbopogon nardus* stands a potential source of pulp for paper industry.

***Keywords*—** *Cymbopogon nardus*, kappa number, pre-bleached, pulping and pulp yield.

I. INTRODUCTION

THE consumption of paper worldwide has escalated by 400 percent in the preceding 4 decades and around 4000 million trees are cut across the globe for pulp and paper mills on every continent.[1] This has caused global deforestation and forest degradation creating the ecological and climatic imbalance. [2] Realizing such severe consequences, major pulp and paper producing companies worldwide have considered not cutting down natural forests any longer[3] and hence one group of researchers in pulp and paper is working towards exploration of non-wood lignocellulosic materials and recyclable fibres for assessment and expansion in their pulp and papermaking capability[4]. Non-wood fibrous materials and recycled fibres offer a great opportunity to decrease or even replace the use of wood fibres[5]. In recent years, the attention has been focused on grasses [6] and the hope of many countries including Uganda with insufficient forest resources lies in grasses for production of any virgin pulp.

Among the alternative fibrous materials are grasses such as *Cymbopogon nardus* (L) (Rendle) of the poaceae family. *Cymbopogon nardus* is perennial plant commonly referred to as Citronella, known commercially worldwide for its essential oil. Citronella oil is traditionally known for its medicinal values and it used as fragrant in cosmetic industry as well as flavours of foods and alcohols. It grows on well drained soils, mainly in the hilly areas. Not only when it colonises area it forms a big bush which is unpalatable by most animals including cattle but also it slows the growth of pasture and it a menace to herdsmen[6]. A study of the extraction pulp for paper and paper boards will give the crop additional value.

There are various grasses such as reed canary grass (*Phalaris arundinacea*), tall fescue (*Festuca arundinacea*) [6], dogtooth grass (*Chenopodium album*), [7] switch grass (*Panicum virgatum*) [8], elephant grass (*Pennisetum* purpureum) [9] etc. have been researched upon for pulping and papermaking. However, to the best of our knowledge, the pulping and papermaking potentiality of *Cymbopogon nardus* from Uganda has not been investigated.

Evaluation of pulping and papermaking potential of a raw material basically involves determination of its proximate-chemical composition, identification of suitable pulping process and bleaching sequence, evaluation of bleached and unbleached pulp, morphological analysis of pulp fibre as well as testing for the physical properties of handmade paper sheets.

II. MATERIALS AND METHODS

A. Raw material

Cymbopogon nardus was collected from Eastern Uganda. The collected samples were chopped in sizes of about 2-3 cm, screened to get rid of the fines, cleaned with distilled, and dried in dried under shed. Some were converted into dust using the laboratory grinder and used to determine of it proximate chemical composition.

Kamoga Department of Mechanical Engineering, College of Engineering Design, Art and Technology, Makerere University, P.O. Box 7062 Kampala, Uganda.

Kirabira, Department of Mechanical Engineering, College of Engineering Design, Art and Technology, Makerere University, P.O. Box 7062 Kampala, Uganda

Byaruhanga, Department of Mechanical Engineering, College of Engineering Design, Art and Technology, Makerere University, P.O. Box 7062 Kampala.

http://dx.doi.org/10.15242/IIE.E0715025

B. *Hydrolysis of the Raw Material*

The oven dry materials were soaked in water at room temperature for 24 hours in a solid/liquor ratio of 1:10 to reduce on the extractives. The liquid part was decanted off and the plant materials were transferred to hot water in the autoclave in solid/liquor ratio of 1:8 and heated at 100°C for 1 hour [10].

C. *Pulping*

Two pulping methods were employed and these were soda-anthraquinone (AQ) and Kraft pulping. The soda –AQ pulping was done under certain varying conditions of soda concentration (10%-25%), temperature (100°C – 160°C) at constant time duration of 1hour and 0.1% anthraquinone concentration. The Kraft pulping was done under certain varying conditions of sulphidity (10%-25%), temperature (100°C – 160°C) at same duration of 1 hour. The cooked materials were fiberized in a wet pulper at 1200 rpm for 20 minutes and the screenings separated by sieving through a screen of 1mm mesh size.

The isolated pulps were pre-bleached with a two-step HPE sequence. The hypochlorite stage involved subjecting the isolated pulp to a hypochlorite charge of 3%, at 60°C for 1 hr. and at consistency of 6%. The alkalised hydrogen peroxide stage was carried out at hydrogen peroxide charge of 6% alkalized with 2.7% NaOH and 0.05% MgSO4 at a consistency of 6% at 80oC for 1hr.

D. *Taguchi Experimental design*

A series of experiments were conducted to evaluate the effect of cooking liquor charge and cooking temperature on the yield and Kappa number of pulp produced. Taguchi Optimization design which uses the signal to noise (S/N) ratio to identify of best conditions was employed. The S/N ratios were calculated using the equation (1) [11] [12];

$$S/_{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{1}$$

Greater the S/N ratio, the better is the performance. The range of the S/N ratios (dB) was also used find the significance a pulping condition towards Kappa number. The control variables (cooking temperature (T) and Liquor charge) had four levels. The four levels were 100°C, 120°C 140°C and 160°C for temperature; 10%, 15%, 20%and 25% for soda charge and 10%, 20%, 30% and 40% for sulphidity.

E. *Characterization of pulp and paper Made*

The yields of pulps were determined gravimetrically in replicates of three to four. The other properties of the isolated pulp analysed were kappa number (TAPPI T236 om-99), viscosity (TAPPI T230 om 08) and brightness (TAPPI T525 cm 92). The morphological characteristics of fibres were determined using Morphi Fibre Analyser and the Olympus BX61 auto-research microscope.

The Canadian Standard Freeness (CSF) of the unbeaten and beaten pulp samples was measured before paper sheet making (TAPPI T227 om-99). Some pulp was subjected to mechanical beating using the PFI mill (TAPPI T248 sp-00). The paper sheets of 60 GSM were made with a handmade sheet making machine (TAPPI T205 sp-95). The properties of the paper sheets such as tensile index (TAPPI T494om-96), burst index (TAPPI T403 om-97), tear index (TAPPI T414 om-98), apparent density (gravimetrically) and air resistance (TAPPI T460 om-96) were analysed.

III. RESULTS AND DISCUSSION

A. *Characterization of the Raw Materials*

The chemical composition (proximate) analysis is a major determinant of the pulping method and conditions as well as their yield. First the chemical composition *Cymbopogon nardus* was analysed and results are presented in Table.1. Findings show that the chemical constituents of *Cymbopogon nardus* are similar to those of wood although differing in magnitude. It contained hollocellulose, lignin, ethanol-benzene extractives, ash content, α-cellulose, cold water extractives and hot water extractives. *Cymbopogon nardus* contained the high value of hollocellulose (68.51%). The hollocellulose was close to those of Anatolian black pine (72.34%) and Silver Birch (73.4%) commonly use in paper industry[13] and was in the same range as those of bamboo (67.1%)[10] and Corn stalk (61.6%) [14], are already recommended for the paper production.

Cymbopogon nardus had high α-cellulose content (35.0%). These α-Cellulose values were in the same range to those of most non-wood materials such as Arundo-donax reed (32.6%) [15], wheat stalk (29%- 35%) [16], those of some softwood such hybrid poplar (29.7%) [17] and spruce (39.5%) [13]. According to the rating system designated by Nieschlag et al 1960 described that plant materials with 34% and over of α-cellulose content being characterized as promising for pulp and paper manufacture[18][15]. According to this categorization Cymbopogon nardus was found to be promising among the selected grasses.

Cymbopogon nardus had the slightly high lignin content (27.38%) but was within the satisfactory level (<30%). In practice this means that it needs in general milder conditions (i.e. lower temperatures and chemical charges) than those of softwood and hardwood in order to reach a satisfactory kappa number[15].

Cymbopogon nardus had low ash content (3.66%). The values were within range for most non-wood fibre raw materials and less than that rice straw of (16.6%).[19] High ash content is undesirable during refining and recovery of cooking liquor [20].

Cymbopogon nardus had the least alcohol- benzene extractives (5.14%). These extractive values were within limits of many non-wood materials for example sofia grass 5.86%, arundo-donax 7.30%.[22] Alcohol- benzene extractives of *Cymbopogon nardus* were higher than those of most wood e.g. Anatolian black pine with 3.45%.

Results show that Cymbopogon nardus had the lowest NaOH extractives (25.99%) The NaOH extractives were within the range of values identified by most non-wood materials for example H Cannabinus (25.8%), *Chenopodium album* (30.00%)[7], lemon grass (30.64%) [22], but higher than those of wood for example eucalyptus grandis (17.9%)[23] and *pinus nigra arnold ssp* (13.0%)[24].

TABLE I
PROXIMATE COMPOSITION OF THE CYMBOPOGON NARDUS IN COMPARISON WITH OTHER RAW MATERIALS

Raw materials	HC	LC	AB	AS	αC	CW	HW	NS	Reference
Cymbopogon nardus	**68.51**	**27.38**	**5.14**	**3.66**	**35.00**	**15.00**	**20.0**	**25.99****	**Present work**
Tobacco stalks	67.69	18.90	7.10	6.86	39.20	16.85	20.02	42.00**	[23]
Rice straw	70.85	17.3	3.52	16.60	48.19	-	16.24	10.65**	[19]
lemon grass	72.13	17.39	*4.33*	7.05	44.16	10.95	12.08	*30.64***	[23]
sunflower	66.90	29.30	*4.07*	7.90	37.60	-	21.10	*50.40***	[38]
pinus nigra arnold ssp (soft wood)	72.34	26.40	*3.45*	0.18	43.55	2.02	3.45	*13.00***	[24]
Dog tooth grass	70.20	21.50	2.14	2.89	39.70	4.87	9.69	30.00**	[7]
E. grandis (hard wood)	72.80	27.10	2.89	0.72	44.30	2.19	4.59	17.90*	[32]
E. tereticomis (hard wood)	71.60	28.80	3.02	0.45	42.10	1.87	4.87	18.80*	[23]
Anatolian black pine (soft wood)	72.34	26.4	3.45	0.18	43.55	2.02	3.17	13.00**	[24]
Silver Birch (soft wood)	73.40	22.0	-	-	-	-	-	-	[13]
spruce (soft wood)	74.46	25.20	3.40	0.32	44.31	1.47	2.81	10.26	[13]
Bamboo	67.1	23.10	23.12	1.78	23.10	4.45	6.75	26.91	[10]

HC: holocellulose (%); LG: lignin (%); AB: alcohol benzene solubility (%); AS: ash (%); αC: α-Cellulose (%); CW: cold water solubility (%); HW: hot water solubility (%); NS: NaOH solubility (%); **0.1 N NaOH solubility;* ***1% NaOH solubility*

B. Identification of the Appropriate Pulping Techniques and Optimization of the Pulping Conditions

The pulping technique and conditions are key determinants of the quality and the quantity of pulp and hence the quality of paper obtained from different fibrous materials.

1) Evaluation of the Soda-Anthraquinone pulping technique and conditions

The variation of unscreened pulp yield, pre-bleached yield, rejects and Kappa numbers with cooking soda charges and cooking temperatures are shown in Fig 1. Findings reveal that all the four measured properties decreased when both the cooking soda charge and cooking temperature were increased. The decrease in all four parameters implies increased level of lignin removal during pulping process. The kappa number was used to evaluate pulping efficiency for the given pulping conditions.

There was a reduction in the change of kappa number as the soda charge increases from 15% to 20%. This implies that the greater amount of lignin is removed at a soda charge of 15%. The lowest kappa number of 24.4 for Cymbopogon nardus soda pulp was achieved at pre-bleached yield of 42.74 %, soda charge of 25% and cooking temperature of 160°C. Rejects from soda pulping of Cymbopogon nardus decreased to 0.17% at a cooking temperature of 160oc and cooking soda charge of 25%.

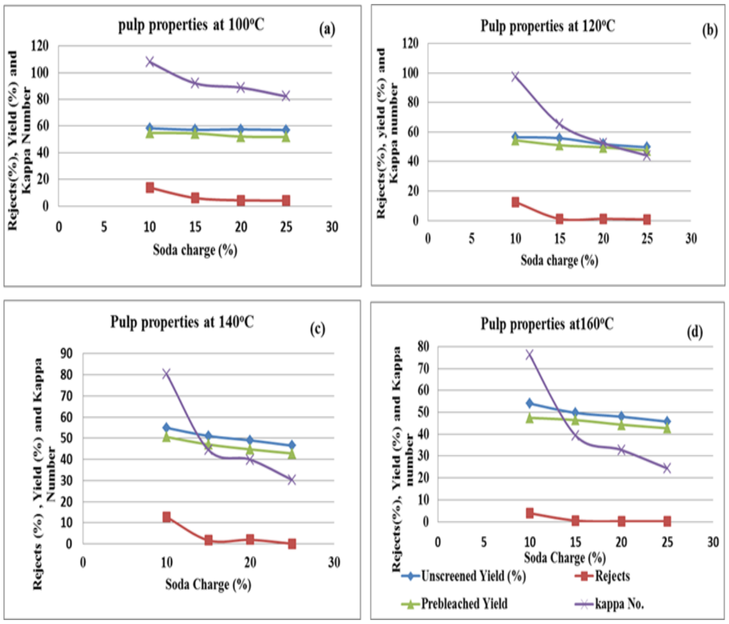


Fig. 1 Variation of Cymbopogon nardus Soda pulp properties with soda charge at different temperatures

Evaluation the Kraft pulping Technique and conditions

The variations of unscreened pulp yield, rejects, pre-bleached yield and kappa number with sulphidity for Kraft pulping are shown in Fig 2. Research findings reveal that unscreened pulp yield, rejects and pre-bleached yield all slightly increased as the sulphidity of the cooking liquor was increased but decreased with the increased cooking temperature. The increase in all the three parameters with increased sulphidity of the pulping process was attributed to the protective action of hydrogen sulphide ions on cellulose fibre against depolymerisation during Kraft pulping process. The hydrogen sulphide ions that replace the hydroxyl ions have no effect on carbohydrates and other hemicellulose hence increase in the unscreened yield, pre-bleached yield, and rejects. This lignin selectivity has a significant influence on the level of delignification and hence on the unscreened yield, pre-bleached yield, rejects and, kappa number. This is also in agreement with the earlier report that the pulp yield increases with increase in sulphidity until a yield plateau (constant value) is reached[25] [26]. The yields of both unscreened and pre-bleached pulp from the four fibrous materials remained almost constant beyond the sulphidity of 30%, this showed that at higher values, sulphidity do not influence the yield [27].

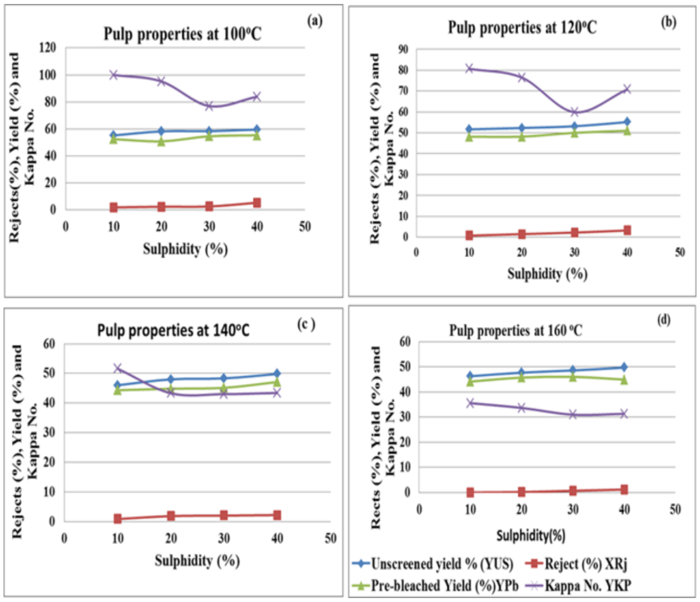


Fig. 2 Variation of Cymbopogon nardus Kraft pulp properties with sulphidity at different temperatures

The kappa numbers of *Cymbopogon nardus* decreased as the sulphidity was increased from 10 to 30%, this decrease was attributed to the high selectivity nature of hydrogen sulphide ions on the removal of lignin.

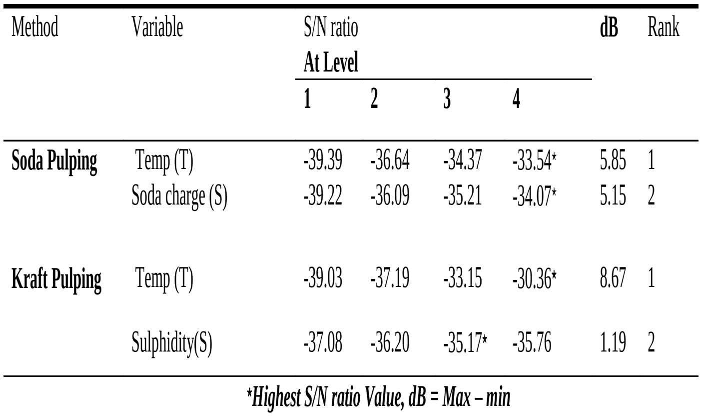
The lowest the kappa number of 31.00 was achieved at Sulphidity percentage of 30 % and at a cooking temperature of 160°C with a pre –bleached yield of 45.13 %.

2) *Analysis of the S/N Ratios for optimisation pulping conditions*

From the S/N ratios in Table 2 it is observed that optimal pulping conditions for the two variables were at their level 4 (T_4 = 160°C and S_4 = 25%) for soda AQ pulping. The cooking temperature had the higher value of dB which shows it significantly influencing the kappa number value and hence on the pulping effectiveness. This is in close agreement with Shakhes et al (2011) who observed that bleachable grades of Tobacco pulp were only produced using 25% alkali charge, 0.2 % AQ charge and cooking temperature of 165°C[23].

The highest S/N ratios for sulphidity for *Cymbopogon nardus* were observed at level 3 (S_3 = 30%). The Delta terms dB for the cooking temperature was higher than that of sulphidity charge, therefore cooking temperature was ranked to be more significant to the lowering of kappa number. Therefore high cooking temperature is more important on the pulping effectiveness.

TABLE II
THE RESPONSE S/N RATIOS FOR KAPPA NUMBER FOR OPTIMISATION THE PULPING CONDITIONS



Method	Variable	S/N ratio At Level				dB	Rank
		1	2	3	4		
Soda Pulping	Temp (T)	-39.39	-36.64	-34.37	-33.54*	5.85	1
	Soda charge (S)	-39.22	-36.09	-35.21	-34.07*	5.15	2
Kraft Pulping	Temp (T)	-39.03	-37.19	-33.15	-30.36*	8.67	1
	Sulphidity(S)	-37.08	-36.20	-35.17*	-35.76	1.19	2

**Highest S/N ratio Value, dB = Max – min*

3) *Regression Analysis of Soda pulping conditions*

The mathematical regression models were developed for the Kappa number and pre-bleached yield in terms of the cooking temperature and soda concentration as the control variables. The multivariable regression analysis of Stata (standard statistical software) was used to derive model equations of the kappa numbers and those of the pre-bleached yield.

The multivariable model equation for Kappa numbers of soda pulp extracted any pulping conditions is numbered (2). The model equation is presented along with the coefficient of determination R^2 which shows the confidence levels to which model equation fits the experimental data.

$$Y_{KP} = 62.4 - 24.71X_T - 21.4X_S \text{ at } R^2 = 0.87,\ F>42.86,\ p<0.0000 \quad (2)$$

X_T, X_S the normalized values of the cooking temperature and soda concentration respectively.

The model equation shows that the kappa numbers of soda pulp decreased as the cooking temperature (X_T) and cooking soda charge (X_S) were increased.

The yields of pre-bleached soda pulp of *Cymbopogon nardus* was developed into the multivariable model equation (3).

$$Y_{Pb} = 48.88 - 4.28X_T - 2.84X_S \text{ at } R^2 = 0.94\ F> 97.01,\ p<0.0001 \quad (3)$$

All mode equations reveal that pre-bleached soda pulp yields decrease with increased cooking temperature and soda concentration charge. The regression model equations are used to estimate the quality and quantity of pulp at the optimised pulping conditions. This can optimise cost of chemical and energy require in pulping.

http://dx.doi.org/10.15242/IIE.E0715025

4) Regression Analysis of Kraft pulping conditions

The kappa numbers (Y_{KP}) of Kraft pulp for *Cymbopogon nardus*, at any pulping conditions were found to be described by the model equation (4),

$$Y_{KP} = 60.13 - 29.83X_T - 5.19X_S \text{ , at } R^2 = 0.95, F>122.47, p<0.00001 \quad (4)$$

The Pre-beached yield (Y_{Pb}) of Kraft pulp was described by the model equation (5).

$$Y_{Pb} = 48.31 - 4.26X_T + 1.54\, X_s \text{, at } R^2 = 0.91, F> 69, P<0.00001 \quad (5)$$

The multivariable regression model equations showed that the pre-bleached yield decreased with increase in temperature and increased with sulphidity. The change in temperature (X_T) was found more significantly affecting the pre-bleached yield of pulp than sulphidity (X_S). According Rama *et.al*, (2012), multiple linear regression analyses with coefficients of determination R^2 greater than 0.90, indicate that models satisfactorily fit the experiment data[28]

5) Confirmation Test of model equations

The developed model equations for kappa number value were tested in comparison with experimental results at a pulping condition of 20% of the cooking liquor charge /sulphidity and cooking temperature of 160°C.and results are as shown in Table3. The error percentages between the experimental values of Kappa numbers and those estimated from model equations for soda AQ and Kraft pulping were 6.93% and 0.19% respectively. The error percentages were lower than 10%, showing that the predicted values from model equations were in agreement with experimental data.

6) Characterization and Evaluation of Pulp and Paper

Fibre morphology and physical properties of pulp and paper sheets were analysed and reported for the pulps extracted by the two pulping methods.

Results of properties of pulp isolated from the *Cymbopogon nardus* grass materials are summarised in Table 3. The kappa numbers of pulp extracted using soda-AQ pulping were generally lower than those of Kraft pulping. This implies Cymbopogon nardus grass responds very well to soda AQ pulping. Soda pulping gave slightly lower yields than Kraft pulping suggests possible fibre peeling or dissolution of hemicellulose.

Remarkably high brightness for both soda and Kraft pulp was achieved with a simple preliminary bleaching sequence. This implies the easy of bleachability of its pulp implying less chemical charges required in bleaching. Brightness reciprocates the kappa number which is in turn is a measure of the level of delignification. Soda pulps were brighter than the corresponding Kraft pulp.

Generally the viscosity of soda pulp was observed to be lower than that of Kraft pulp. This is attributed to the loss of the short chain carbohydrate during the soda pulping. The presence of more carbohydrates also increases the viscosity of pulp. The magnitude of viscosity is a precursor for fibre length and degree of polymerisation. From the observed viscosity, it implies Cymbopogon nardus pulps contain longer and coarse fibres.

TABLE III
PROPERTIES OF BOTH SODA AQ PULP AND KRAFT PULP

Property of pulp	Soda AQ Pulp	Kraft Pulp
Kappa Number	24.4	31.0
Pre-bleached Yield (%)	42.74	44.20
Intrinsic Viscosity /cm^3/g	782.51	915.00
Brightness	69.65	57.71
Arithmetic avg. length, mm	0.512	0.520
Weighted avg. length, mm	0.744	0.771
Avg. width/ µm	14.4	13.7
Coarseness, mg/m	0.0646	0.0635
Kinked fibre, %	18.6	22.5
Curl, %	6.1	6.6
Broken ends, %	13.13	13.44
Fine elements, %	31.7	29.18
Slenderness ratio	51.67	56.28

7) Fibre Morphological analysis

Photomicrographs of pulp fibres from soda AQ pulping and Kraft pulping were taken using a microscope Olympus BX61 at different magnifications as shown in Fig 3. Pulps from *Cymbopogon nardus* like those of other non-wood materials in addition to cellulose fibres contained other non- fibre cellular materials such as parenchyma cellular tissue, vessel element and epidermal tissues which don't have any paper making properties. Their presences in large numbers are undesirable and impair drainage which is a problem during paper pressing[22] [29]. The non-fibrous materials also results into the formation of fines in pulp during pulping and beating which reduce freeness and increases water retention by pulp. The photomicrographs show that the fibre morphologies of pulp were similar irrespective of the pulping methods

Data for the different morphological properties of fibres as determined with Morphi Fibre Analyser (MFA) are shown in Table 3. Results reveal that both soda and Kraft pulps contained fibres with intermediate fibre length very close to those of hardwood e.g. aspen (0.73mm) [30] and close to those of other grasses already investigated e.g. *Chenopodium album* (0.60mm) [7], alfalfa and switch grass (0.78) but higher than those of two years old poplar and willow with 0.38 and 0.34mm respectively [31]. The fibre length of pulp obtained from the two pulping techniques did not differ significantly although the fibre lengths of Kraft pulp were slightly higher than that of soda pulp.

The fibre lengths distribution study showed that the largest proportions of fibres for all pulps were short (0.2mm - 0.5mm) Fig.4. The fibres of all pulp samples with intermediate lengths (0.5- 0.75mm and 0.75-1.25mm) were evenly distributed. Few fibres from pulp samples were in the range of 1.25mm to 1.5mm.

The fibres widths of all pulp from the four grasses varied between 13.7 and 14.4 µm. The fibre widths of all pulp samples were close those of *Eucalyptus tereticornis* and *Eucalyptus grandis* of 14.6 μm and 19.2 μm respectively [32] as well as those of other grasses such as switch grass (13.90 μm) and elephant grass (15.14 μm) [33]. The fibre width distributions for all pulp samples obtained from both methods were skewed to the left, having the majority of the fibres (66.1% - 86.6%) being thin (5-17 μm). Cymbopogon nardus had the least kinked and curled fibres an indicator of stiffer fibres.

Generally soda pulp fibres had less broken ends than the Kraft pulp fibres. The fine element percentages for all samples were high and did not significantly differ among the two methods. The slenderness of all pulp samples are closer to those other non-wood materials already recommended for paper production e.g. lemon grass (66.9) and Sofia grass (59.2) [22]

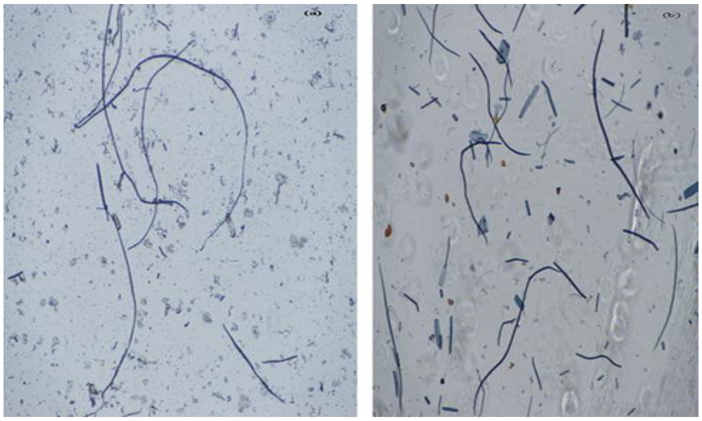


Fig. 3 Photomicrographs of Cymbopogon nardus soda pulp (a) and Kraft pulp (b) at 40X

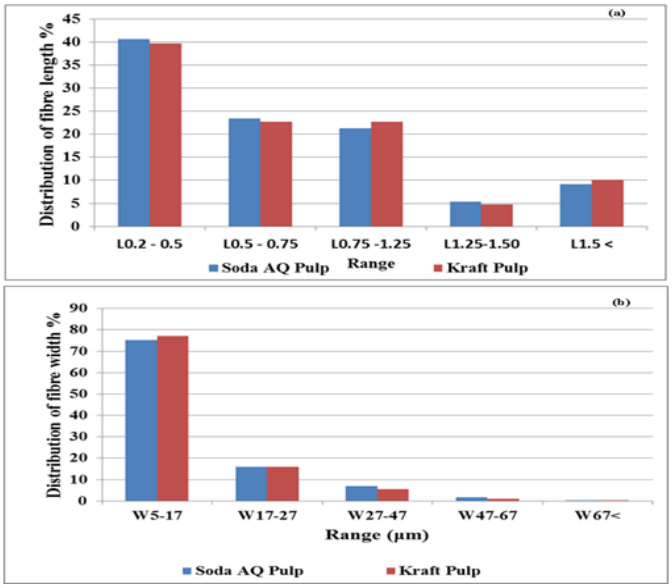


Fig. 4 Distributions Fibre Length for (a) Fibre Width (b) for Soda- AQ and Kraft Pulp

8) *Characteristic physical properties of paper sheets*

The physical properties of paper were measured from handmade paper sheets from the pulp extracted using the two pulping methods and results are shown in Table 4. The Canadian Standard Freeness (CSF) values of pulps were measured for both the unbeaten and the beaten pulp isolated before making the handmade paper sheets. The findings demonstrate that the CSF values of the unbeaten pulp were generally low compared with those normally identified with wood pulp. This reveals high interactions of pulp fibres with water molecules. With beating, the CSF decreased tremendously further due to the fact that beating opens more fibrils thereby increasing the surface area from a number of broken and short fibres for water adsorption. All pulp samples had attained recommended CSF values of about 200ml at the PFI beating of 500 revolutions. PFI mill beating of pulp samples caused substantially improvement in the strength properties with minimal energy requirements. Unlike wood pulp whose beating goes up to 5000 to 6000 PFI revolutions to acquire the CSF value of about 200ml, beating of *Cymbopogon nardus* pulp the energy required for 500 PFI revolutions is very low, implies saving energy and cost of production. The CSF values of Kraft pulps are generally higher than those of soda pulps of the corresponding fibrous materials this is attributed to presence of less open fibrils in the Kraft pulp which can retain more water.

The apparent densities of the two types of isolated pulps were of medium values, but slightly higher than that of switch grass (0.35-0.57g/cm3) [30], cotton stalks (0.37-0.63g/cm3) [34] and they were of the same magnitude as that of the dogs' tooth grass (0.62-0.73g/cm3) [7]. The apparent density of the paper samples increased with the increased beating level which increased proportions of short fibres that increases the fibre packing efficiency. The apparent density of soda AQ pulps were generally greater than Kraft pulps, this is attributed to highly polished flexible fibres obtained by the soda AQ pulping.

Burst indices for paper sheets at PFI beating of 500 to 1000 PFI revolutions were in normal ranges for most paper uses. Both the apparent density and burst indices for all paper samples were ideal for writing paper and they could be increased with addition of additives during the production processes. The burst indices of all samples when beaten to 1000 revolutions were very close to those of spruce wood pulp (3.09 – 3.64 k pa m2/g) [19], that of tobacco stalks pulp of 3.98-4.36 kN/g [23] and higher than that of banana tree residue of 0.64-2.79 kN/g [35].

The tensile indices of all the paper sheets from both types of pulp were generally slightly lower than those of hardwood e.g. *Eucalyptus globulus* an average of 110.21Nm/g [36] and the some other non-wood materials e.g. *Chenopodium album* (56.70Nm/g) [7]. As expected the tensile indices of the Kraft paper sheets were higher than the corresponding Soda paper sheets.

The tear indices of all paper sheets were moderately high compared that of *Chenopodium album* of 4.9mNm2/g [7] but lower than that of *Eucalyptus globulus* an average of 8.6mNm2/g[36]. The unbeaten soda pulp had greater tear indices than the respective Kraft pulp. But with beating the Kraft pulp gained more tear strength.

TABLE IV
PHYSICAL PROPERTIES OF PAPER HAND SHEETS

Property	PFI Rev	Soda AQ Pulp	Kraft Pulp
Freeness CSF	0	345.00	360.00
	500	205.00	255.00
	1000	165.00	175.00
Apparent Density(g/cm^3)	0	0.56	0.49
	500	0.65	0.61
	1000	0.68	0.62
Burst Index (Nm/g)	0	2.01	1.27
	500	2.90	2.78
	1000	3.07	2.98
Tensile Index (k Nm/g}	0	28.95	16.78
	500	32.70	36.00
	1000	34.50	40.40
Tear Index (mNm^2/g)	0	5.23	4.12
	500	5.09	6.44
	1000	5.01	5.54
Porosity(Air resistance) ml/min	0	1880.00	2495.00
	500	757.50	780.00
	1000	299.80	447.00

This is attributed to the opening up of the fibrils on beating of the Kraft pulp which increases the number of bonded sites.

The unbeaten pulp samples had high porosity and decreased with pulp beating.. High porosity of *Cymbopogon nardus* is attributed to the high portions of longer fibres. The network of longer fibres leaves many open structures through which air can percolate.

From a morphological point of view, pulp beating produces recognisable changes in the fibre structures which in turn increase fibre bonding. The beating process causes the outer primary wall and the first secondary (S1) layers to loosen and separate. The exposed area of fibrils forms potential bonding sites during sheet formation [37], [36]. These changes are manifested in the increase of some physical properties of pulp and paper such as apparent density, burst index, tensile index while CSF, porosity and tear index

IV. CONCLUSIONS

The hollocellulose and α-cellulose of *Cymbopogon nardus* are slightly lower than those of the most wood and very closed to those of other non-wood materials already used in paper industry. The effectiveness of both soda AQ and Kraft pulping improve with increase in cooking temperature and cooking liquor charge. In case soda AQ pulping, most delignification occurs at a soda charge of 15% although the Taguchi optimisation design indicated that a soda concentration charge of 25% at $160^{o}C$ for cooking time of 1 hour and AQ charge concentration of 0.1% as the optimum conditions. The optimal Kraft pulping conditions were 20% active alkali, 30% sulphidity at a cooking temperature of $160^{o}C$. *Cymbopogon nard*us responds very well to both soda AQ and Kraft pulping. Generally *Cymbopogon nard*us grass contains short fibres close to those of hard wood and some non-wood materials. There are no significant differences in the fibre morphology between Soda-AQ and Kraft pulps. The physical properties of the handmade sheets from pulps from *Cymbopogon nard*us grass are lower than those of hardwood which implies that pulp from *Cymbopogon nard*us can replace hard wood pulp to low or moderate extend in writing, news, toilet papers etc. The pulp beating up to 500 PFI revolutions significantly improves paper properties and gives the optimal properties hence pulping *Cymbopogon nardus* requires less energy in comparison to wood pulp.

The choice of the pulping methods for paper production will depend on the end uses of paper. Depending on the technical evaluation of the production processes, *Cymbopogon nardus* grass is recommended for pulp and paper production.

ACKNOWLEDGMENTS

The authors would like to extend their sincere thanks and acknowledgement to the Swedish International Development Agency (Sida) for financing this research work. Omar would like to express his gratitude to the Government of the Republic of India through the Department of Science and Technology for the Visiting CV Raman Research Fellowship awarded to accomplish the research study. Authors convey special thanks to Makerere University, Uganda; Busitema University, Uganda and Central Pulp and Paper Research Institute, India for hosting the research and the research facilities offered.

REFERENCES

[1] S. Martin, 2011, Paper Chase; http://www.ecology.com/2011/09/10/paper-chase/ (Accessed 18/9/2014)

[2] P. Covington, 2013, Deforestation and the role of paper products, http://www.triplepundit.com/2013/09/deforestation-role-paper-products/ (Accessed 18-09-2014).

[3] N. Sizer, R. Nogueron, J.Anderson, 2013, Asia Pulp & Paper's Anti-Deforestation Pledge: Sign of a Changing Industry? http://www.wri.org/blog/2013/02/asia-pulp-papers-anti-deforestation-pledge-sign-changing-industry (Accessed 18-09-2014)

[4] A.K. Sharma, K. Anupam, V. Swaroop, Lal P.S., V. Bist, 2014, Pilot scale soda-anthraquinone pulping of palm oil empty fruit bunches and elemental chlorine free bleaching of resulting pulp. J. Clean. Prod. http://dx.doi.org/10.1016/j.jclepro.2014.03.095.

[5] J. Shakhes, C.P Rezayati, F. Zeinaly, 2010, Evaluation of harvesting time effects and cultivars of Kenaf on papermaking, BioResources, 5(2), 1268-1280.

[6] K.A. Pahkala, L. Paavilainen, T. Mela, 1997, Grass species as raw material for pulp and paper In: Proceedings XVIII IGC (International Grassland Congress) 1997 Winnipeg, Manitoba: 55-60.

[7] D. Dutt, A.K. Sharma, S. Agnihotri, A. Gautam, 2012, Characterization of dogs tooth grass and its delignification by soda pulping process, J. Sci. Technol. 1 (8), 434-447.

[8] I.C. Madakadze, T.Radiotis, J. Li, K. Goel, D.L.Smith, 1999. Kraft pulping characteristics and pulp properties of warm season grasses. Bioresoure. Technol. 69 (1), 75–85. http://dx.doi.org/10.1016/S0960-8524(98)00131-X

[9] I. C. Madakadze, T. M. Masamvu, T. Radiotis, J. Li, D. L. Smith, 2010., Evaluation of pulp and paper making characteristics of elephant grass (Pennisetum purpureum Schum) and switchgrass (Panicum virgatum L.) Afr. J Environ. Sci. Technol. 4 (7), 465-470.

[10] X. J. Ma, L. L. Huang, Y. X. Chen, Cao, S. L., L. H. Chen, 2011, Preparation of bamboo dissolving pulp for textile production. Part 1, Study on pre-hydrolysis of green bamboo for producing pulp for dissolving pulp, BioResources 6 (2), 1428-1439

[11] Taguchi G., (1990) Introduction to quality engineering, Asian productivity Organisation Tokyo

[12] Neseli S., Asilturk I. and Celik L., (2012), “Determining the optimum process parameters for grinding operations using robust process Journal

of Mechanical science and technology 26(11) pp. 3587 -3595 Springer publishers.

[13] Sjöström E.,(1993), Wood chemistry, Fundamentals and Applications, Second edition ed. Inc., San Diego, Academic press,.

[14] Jirleska Flandez, M. Angels Pelach, Julio Tijero, FabiolaVilaseca, MiquelLiop, Pere mutje (2010), "Aptitude of cellulosic Fibres from whole corn stalks" XXI Tecniclpa Conference and Exhibition/ VI CIADICYP 2010 – 15 October 2010, Lisbon, Portugal.

[15] Ververis C., Georghiou K., Christodoulakis N. Santas P. Santas R., (2004), "Fibre dimensions, lignin and cellulose content of various plant materials and their suitability for paper production" International Journal on Industrial Crops and Products Vol.19 245-254. http://dx.doi.org/10.1016/j.indcrop.2003.10.006

[16] Katri S. P., (2001), Non-wood Plant as raw materials for pulp and paper, PhD Academic Dissertation Faculty of Agriculture and forestry, University of Helsinki 2001 Finland

[17] Goel, K. Eisner. R., Sheron G. Radiotis.T. and Li J., (1998), Switch grass: A potential pulp fibre source, in Proceedings of the 84th Annual Meeting of the Technical section of the Canadian Pulp and Paper Association. January 1998. 1998: Montreal. Pp. 109-114.

[18] Nieschlag H. J., Nelson G. H., and Wolff I. A. (1960) "A search for new fibre crops" Tappi J. Vol. 44 ser 7 pp. 515-516

[19] A. Tutus, S. Ates, I. Deniz, 2010, Pulp and paper production from Spruce wood with kraft and modified kraft methods, Afr. J. Biotechnol 9(11), 1648-1654.

[20] Rodriguez A., Serrano L., Moral A. and Jimenez L. (2008), "Pulping of rice straw with high- boiling organo solvents" Biochem. Eng. J. Vol.42 No.l, pp.243-247 http://dx.doi.org/10.1016/j.bej.2008.07.001

[21] Dutt D., Upadhyay J. S., Singh B., and Tyagi C. H. (2009), "Studies on Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: An optimisation of Kraft delignification process" Industrial Crops and products Vol.29, pp. 16-26. http://dx.doi.org/10.1016/j.indcrop.2008.03.005

[22] Harjeet. Kaur, D. Dutt, 2013, Anatomical morphological characterization of lignocellulosic by-products of lemon and Sofia grasses obtained after recuperation of essential oils by steam distillation. Cellulose Chem. Technol. 47 (1-2), 83-94.

[23] J. Shakes, Marandi, F. Zeinaly, A. Saraian, T. Saghafi, 2011, Tobacco residuals as promising lignocellulosic materials for pulp and paper industry. BioResources 6 (4), 4481-4493.

[24] Ates S, Kirci H., (2007), "Influence of pulping conditions on the properties of Anatolian black pine (pinus nigra Arnold ssp. Pallassiana) Kraft pulps" Biotechnol & Biotechnol Eq. 21/2007/1

[25] Macleod M., (2007), "The top ten factors in Kraft pulp yield" Paperi ja puu- Paper and Timber Vol.89 No.4 pp. 1-7.

[26] Kleppe, P.J., (1970), Kraft Pulping, Tappi J 53(1) pp. 35

[27] Gustafson, C., (2012), "Reducing Variation in Mill Control Variables by Evaluation of Differences in Pulp- and Paper Properties of Two Pine Species," Dissertation Master of Science in Engineering Technology, Chemical Engineering Design, Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering.

[28] Rama R.S. and Padmanabhan, G., (2012) "Application of Taguchi method and ANOVA in optimization of process of parameters for metal removal rate in electrochemical machining of Al/5% SiC composites" International Journal of engineering Research and Application Vol.2 Issue 3 pp.192-197.

[29] Lalit K. Dharm D. and Amit B., (2013) "Delignification of Phragmites Karka a wetland Grass by soda process", BioResource Vol8 (3), pp. 3426-3437

[30] K. Law, B. V, Kokta, C. B. Mao, 2001. Fibre morphology and soda-sulphite of switch grass.Biores. Technol. 77 (1), 1-7. http://dx.doi.org/10.1016/S0960-8524(00)00140-1

[31] J. Ai, U. Tschirner, 2010, Fibre length and pulping characteristics of switchgrass, alfalfa stems, hybrid poplar and willow biomasses, Biores, Technol. 101 (1), 215-221. http://dx.doi.org/10.1016/j.biortech.2009.07.090

[32] A.K. Sharma, D. Dutt, J.S. Upadhyaya, T. K. Roy, 2011, Anatomical, morphological and chemical characterization of Bambusa tulda, Dendrocalamus hamiltonii, Bambusa balcooa, Malocana baccifera, Bambusa arundinacea and Eucalyptus tereticornis, BioResources 6 (4), 5062-5073

[33] Madakadze I. C, Masamvu T.M, Radiotis T, Li J and Smith D.L (2010) 'Evaluation of pulp and paper making characteristics of elephant grass (pennistetum purpureum schum) and Switch grass (panicum virgatum L) African Journal of Environmental science and Technology, Vol.4 (7) pp. 465-470

[34] M. Ali, M. Byrd, H. Jameel 2001, Soda-AQ pulping of cotton stalks, Proceedings of Tappi pulping Conference, Seattle, USA.

[35] A. Rosal, A. Rodriguez, Z. Gonzalez, L. Jimenez, 2012, Use of banana tree residues as pulp for paper and combustible, Int. J. Phys. Sci. 7 (15), 2406-2413. http://dx.doi.org/10.5897/IJPS11.1661

[36] R. Wimmer, Downes, G.M., Evans, R., Rasmussen G., French J., 2002, Direct effects of wood characteristics on pulp and hand sheet properties of Eucalyptus globulus, Holzforschung. 56 (3), 244-252. http://dx.doi.org/10.1515/HF.2002.040

[37] W.J. Smith, 1981, Fibre properties affecting pulpwood processing and paper properties, In: Proceedings of the 20th Forest products research conference. 16-20. November 1981 CSIRO, Vol. 2, T4

[38] D.F. Caulfield, D.E. Gunderson, 1988. Paper testing and strength characteristics, In: TAPPI Proceedings: 1988 Paper Preservation Symposium 19–21 October, Washington D.C., 31–40.

[39] Lopez F., Eugenio M. E., Diaz M. J., Nacimiento J. A., Garcia M. M., and Jimenez, (2005) "Soda pulping of sunflower stalks. Influence of process variables on the resulting pulp" Journal of Industrial and Engineering Chemistry, Vol. 11 (3) pp. 387 – 394

Kamoga Omar Lwako M. was born on 03rd June 1971 in Mukono District Uganda, He completed MSc (Chem.) in 2000, PGDE in 1998 and BSc (Ind.Chem.) in 1996, all from Makerere University.

Currently he is PhD Student at Makerere University, Department of Mechanical Engineering and a Lecturer at Busitema University. He has interest in materials science technology more especially in paper technology. He is currently researching on extraction pulp from non-wood materials for paper industry.