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Full Length Research Paper

Evaluation of pulp and paper making characteristics of elephant grass (*Pennisetum purpureum* Schum) and switchgrass (*Panicum virgatum* L.)

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Shortage of conventional raw material for the pulp and paper products together with the increasing world demand for paper has renewed interest in non-wood fibres. Non-wood pulping capacity has been increasing steadily over the last decade. A lot of crops grown for biomass, like switchgrass (*Panicum virgatum* L.), are good examples of plants with potential for pulp production. Raw material chemical composition, kraft pulp yield and properties, and fibre characteristics of elephant grass or hybrid pennisetum (*Pennisetum purpureum* Schum. cv. SDPN3) and switchgrass (cv. Cave-in-Rock) were determined in an effort to evaluate them as raw materials for pulp and paper production. Elephant grass had α-cellulose and Klasson lignin contents of 45.6 and 17.7%, respectively. The respective values for switchgrass were 41.2 and 23.89 %. Pulp yields, following a mild kraft process, were 48 and 50% for switchgrass and elephant grass, respectively. The corresponding kappa numbers were 15.5 and 9.2. The weight-weighted fibre length averaged 1.32 mm. Pulp freeness was higher for switchgrass (330 mL) than for elephant grass (139 mL). Elephant grass had a burst index above 5.85 kP.m^2 g^{-1}. These characteristics demonstrate the suitability of both elephant grass and switchgrass for pulp production.

Key words: Grass pulp, kraft pulping, non-wood fibre, elephant grass, switchgrass.

INTRODUCTION

Although nonwoods were originally used for paper making since the late 1700s wood has been largely the conventional raw material for pulp and paper production (Smook, 1992). In 2004, 70% of global wood fiber was from roundwood and chips, the remaining 30% being from manufacturing and /or forest residues (SCA and WRI, 2007). This is on the backdrop of a projected global papermaking fibre consumption of 425 million tonnes by the year 2010 (Hurter, 1998). An estimated 2.5 million tons of new pulp production capacity are needed annually (Lammi, 2006). Until recently non-wood fibre was mainly produced in the developing world (FAO, 1994) and nonwood pulping capacity has been growing at a faster rate than wood pulping capacity (Hurter, 1998). Non- wood pulp capacity was estimated at 5% of total paper making capacity in 2004 (SCA and WRI, 2007). A convergence of environmental concerns and wood fibre shortage constraints has led to an increase in non-wood fibre production even in seemingly forest rich regions like Canada and USA (Kissinger et al., 2006).

A number of strategies have been suggested towards meeting the increased demand for fibre. Changes in consumption patterns can help reduce waste while improved recovery rates will ensure a significant contribution from recycling. Increasing the range of raw materials is a central component of current efforts to increase fibre supply (Markets Initiative, 2007). The renewed interest in non-wood fibre sources is not in vain because they offer several advantages in the pulp and paper industry. These

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include annual production in agricultural systems (renewable resource) compared to the long growth cycles for wood. Because of the lower lignin contents chemical processes for non-wood pulping are generally more benign than with the pulping of wood sources (Paavilainen, 1994; Madakadze et al., 1999). Nonwood fibres can be used in every grade of paper and board, fibreboard (Hurter, 1998; Ververis et al., 2004) and composite materials (Sain and Panthapulakkal, 2006). However, compared to wood, non-wood fibres sources present challenges with their seasonal (and not year-round) availability; handling, given their high-volume-low-density; and the large volumes of silica that have to be removed during processing (Pande, 1998). In the Southern African context, several grass species are evaluated annually for yield and nutritive quality for animal production and environmental conservation. While several of these grasses are adopted in pasture-forage systems, an even greater number is discarded on the grounds of poor quality or one of several unpalatability factors. An example is the recent evaluation by the SADC ICRISAT Sorghum and Millet Improvement Program (SMIP) of elephant grass, king grass or napier (*Pennisetum purpureum* Schum.) and its interspecific hybrids with pearl millet (*Pennisetum americanum* (L.) K. Schum) (Gupta and Mhere, 1997). A lot of these materials were found not suitable for animal production but produce a lot of ligno-cellulosic biomass (average of 28 ton DM ha^{-1}) of potential industrial usage. Biomass produced from such sources can be used for energy, industrial chemical and/or pulp and paper production. The objective of this study was to evaluate kraft pulping characteristics and pulp properties of elephant grass and compare them to those of the relatively better studied switchgrass.

MATERIALS AND METHODS

Pulping procedure

The two grass species used, elephant grass (cv SDPN3) and switchgrass (cv. Cave-in-Rock), are cultivated in Southern Africa both experimentally and for animal production, and are being considered as energy production crops. Material used in this study was harvested from ongoing biomass production trials at the end of the growing season. Air dried samples of the grasses were cut into about 2 cm long pieces and washed with water to remove adhering soil particles, air dried, and stored with less than 15% moisture content. Subsamples of the grasses, 200 g (air dry weight), were pulped using a 14% active alkali (AA) and 20% sulphidity using a 5:1 liquid to grass ratio, excluding moisture, following Madakadze et al. (1999) procedure. This was done in 2-L rotating bomb digesters at a cooking temperature of 160°C, being allowed 60 min to reach cooking temperature and another 60 min at that temperature. The cooked grasses were disintegrated in a Cowles mixer (Louis Allis Co., Milwaukee, Wisconsin, USA) for two minutes followed by thorough washing with tap water. After soaking in tap water overnight the pulp was screened on a vibrating flat screen with 0.2 mm wide slots. The screened pulp was captured on a 450 mesh screen, small enough to retain fines. The pulp was concentrated by a centrifuge to about 30% solids and weighed. Rejects and a subsample of the pulp were dried to constant weight at 105°C for determination of dry weight, and subsequently, yields of screened pulp and rejects. The results reported below represent an average of three different digestions and subsequent pulp processing.

Chemical analyses and pulp physical testing

Subsamples of the raw materials were analysed for ash, nitrogen (N), lignin, pentosans and extractives using Standard Tests Methods of the Canadian Pulp and Paper Association (CPPA, 1997). The lignin was analysed as acid-insoluble lignin (Klason lignin). A sample of the cook liquor (black liquor) was analysed for residual effective alkali (EA) and sulphides by titrating with 1M hydrochloric acid (TAPPI, 1992). The permanganate (Kappa) number, viscosity of the screened pulp, pulp freeness (rate at which a dilute suspension, 3 g pulp in 1 L of water, is drained), bulk and density were all determined using standard CPPA procedures. Fibres from the screened pulp were characterised using the Kajaani FS 200 Optic Fibre analyser and the Bauer-McNett classifier. Pulp hand sheets were prepared for determination of strength properties (for example burst, tear, breaking length and elastic modulus). All results were subjected to analysis of variance with variation being partitioned for grass type and cook, followed by a separation of means (t-test, $p<0.05$) using SAS procedures (SAS, 2007).

RESULTS AND DISCUSSION

Chemical composition

Table 1 presents the chemical composition of the raw materials used. The low N contents of these grasses are typical of material harvested at the end of the growing season. Plant material composition/quality changes during the course of the season. With α- and γ-cellulose fractions (cellulose and hemicellulose, respectively) of 40% $^{+}$ and 30%, respectively, these two species would be satisfactory/promising raw materials for pulp and paper using the guide suggested by Nieschlag et al. (1960). The lignin contents of elephant grass (17.70%) and switchgrass (23.89%) were low indicating that both these grasses should be easier to pulp than wood with a lignin content of 26 - 30% (Moore, 1996). Both cold and hot water extractives were higher for the elephant grass than the switchgrass. Alkali solubility was distinct between switchgrass (34.70%) and elephant grass (44.60%) indicating compositional dissimilarities between the two species. On a comparative basis elephant grass would need less severe pulping conditions than switchgrass. Although the ash content average of 5% is typical of non-wood materials it still is high enough to pose detrimental effects during industrial processing of these grasses.

While the lignin contents of the two grasses are comparable to those of *Miscanthus* spp and various switchgrasses (Madakadze et al., 1999; Ververis et al., 2004) they are, however, higher than reported in kenaf (*Hibiscus* spp., 14.7%; Mittal, 1990; 15%; Ververis et al., 2004), and lower than for wood based materials (26 - 30%; Moore, 1996). While the proportions of higher

Table 1. Chemical composition of elephant grass and switchgrass

Chemical component (%)	Switchgrass	Elephant grass	SED[#]
Nitrogen	0.69b	0.84a[‡]	0.03963
Ash	4.83a	4.23b	0.1945
Acid insoluble ash	1.74a	0.83b	0.04683
Klason lignin	23.89a	17.70b	0.5548
Cellulose[†]			
α	41.20b	45.60a	0.9005
β	2.20a	1.50b	0.1261
γ	30.50	29.70	0.9366
Pentosans	22.90	21.50	0.6124
Extractives			
cold water	1.91b	9.90a	0.7925
hot water	3.80b	10.90a	0.5764
1% NaOH	34.70b	44.60a	1.585
acetone	1.19b	2.70a	0.1513

[#]Standard error of difference.
[†] presented as proportion of total cellulose corrected for lignin and ash.
[‡]means within a row followed by different letters differ significantly at $p<0.05$.

Table 2. Pulping characteristics of elephant grass and switchgrass.

Parameter	Switch grass	Elephant grass	SED[#]
Total yield (%)	47.98b (47.65)[¶]	50.01a[‡] (50.63)	0.4251
Rejects (%)	1.18	0.60	0.2269
Kappa number	15.47a	9.17b	0.3566
Viscosity (mPa·s)	30.00b	35.00a	1.2392
Residual chemicals (g L^{-1} as Na_2O)			
EA[†]	3.32b	4.16a	0.0727
Sulphides	0.34	0.00	0.2269

[#] Standard error of difference.
[†] Effective alkali.
[‡] Means within a row followed by different letters differ significantly at $p<0.05$.
[¶]Values in parenthesis are calculated total yields at a kappa number of 13.28 (average for several grass pulps) and assuming that 0.15 is the conversion factor for kappa number to total yield.

molecular weight cellulose and hemicellulose, respect-tively are higher, pentosan contents are comparable to those of hardwoods (19 - 25%, TAPPI standards (1992) and kenaf (20.2%, Mittal, 1990).

Pulping

The small amounts of rejects and the low kappa numbers as presented in Table 2 indicated that the mild kraft pulping provided adequate defibering. Elephant grass produced better quality pulp as indicated by a lower kappa number which indicates extent of delignification and hence completeness of pulping. Differences in rejects, kappa numbers and residual alkali may be due to differences in pulping kinetics of the individual grasses. Sulphide consumption was very high for both species, and for elephant grass it was interesting to note that there were no sulphides detected in the black liquor of each of the three different cooks.

For both grasses the uncooked fragments were largely from nodal tissue which was identifiable by its dark brown to black colour after cooking. It is conceivable that the higher pulp yield (50.01%) in elephant grass is attributable to its low lignin content and high alkali solubility.

Table 3. Fibre characteristics and pulp physical properties of elephant grass and switchgrass.

Parameter	Switch grass	Elephant grass	SED#
	Fibre length† (mm)		
Arithmetic mean	0.32	0.30	0.0108
Length weighted mean	0.76	0.75	0.018
Weight weighted mean	1.31	1.33	0.018
Diameter (µm)	13.89b	15.14a	0.3674
Coarseness (mg m^{-1})	0.086a	0.080b	0.0014
P<0.2mm‡ (%)	50.36	54.97	1.758
	Physical properties		
CSF (mL)¶	335.00a	139.00b	24.86
Grammage (g m^{-2})	61.60	60.20	0.7565
Specific volume (cm^3 g^{-1})	2.03a	1.47b	0.0403
Apparent density (g cm^{-3})	0.49b	0.68a	0.01
Caliper (mm)	126.6a	88.60b	2.4712

Standard error of difference.
† As measured by the Kajaani FS 200 optic fibre analyser.
‡ Proportion of fibers less than 0.2 mm.
¶ Canadian Standard Freeness.

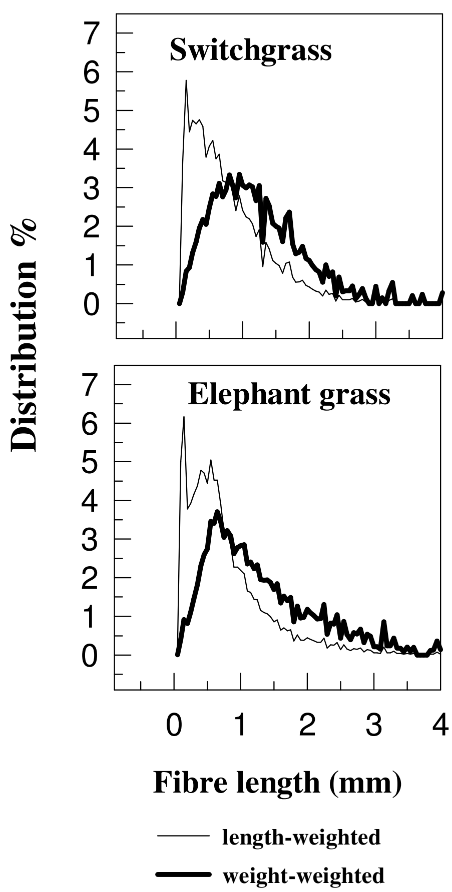

Figure 1. The length- and weight-weighted fibre distributions of banagrass and switchgrass using the Kajaani FS-200 optic fibre analyser.

Fibre characteristics

The pulp fibre characteristics are presented in Table 3. There were no significant differences in fibre lengths between the two species. The fibre length distribution curves for the pulps (Figure 1) indicate a considerable proportion of short fibres for both species. The distribution curves for elephant grass were narrower indicating a relatively higher degree of fibre uniformity. The Kajaani proportions of fines (P<0.2 mm) were above 50% for both grasses. These proportions of fines were greater than those from the Bauer-McNett classification (Figure 2). For elephant grass, but not for Cave-in-Rock (which had a high 48/100 and low 100/200 proportions), the combined Bauer-McNett 100/200 and 200 fractions approximated the Kajaani proportion of fines. Fiber diameters and lengths were generally in the range expected of grasses (Madakadze et al., 1999; Ververis et al., 2004). The high slenderness ratios (fiber length/fiber diameter) of 94.31 and 87.85 for switchgrass and elephant grass, respectively, make these pulps suitable for printing, writing and/or even packaging paper(Law et al., 2001; Ververis et al., 2004).

Physical and strength properties

The pulp physical properties are also summarised in Table 4. Elephant grass pulp had lower freeness, which at a CSF value of 139 mL was also lower than for various grasses reported by Madakadze et al. (1999). This is most likely attributable to its higher proportions of short fibers and high apparent density. Freeness values for the Cave-in-Rock switchgrass being reported are lower than

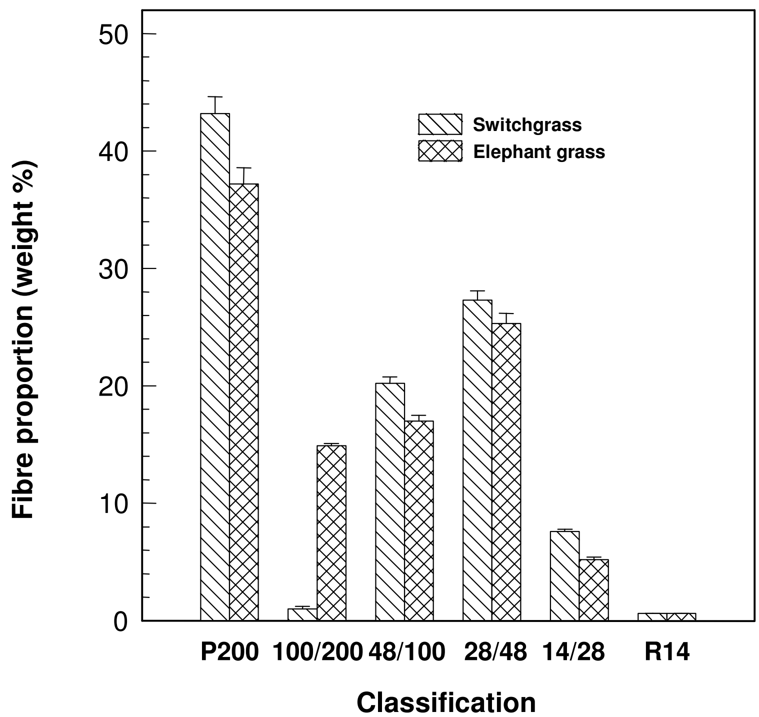

Figure 2. The Bauer-McNett fibre classification for elephant grass and switchgrass after kraft pulping.

Table 4. Strength properties of standard handsheets of elephant grass and switchgrass

Parameter	Switchgrass	Elephant grass	SED#
Burst Index ($kPm^2\ g^{-1}$)	4.06b	5.85a	0.1585
Tear index ($mN.m^2\ g^{-1}$)	5.64a	4.40b	0.1153
Breaking length (km)	7.75b	9.51a	0.1081
Elastic modulus (km)	811.4a†	776.00b	8.9553
Z-span breaking length (km)	15.11	14.83	0.2954
Breaking energy (Scott bond, $J\ m^{-2}$)	385	..... ‡	
Tensile Index ($N.m\ g^{-1}$)	75.98b	93.25a	1.0447
Stretch (%)	1.96b	2.86a	0.0504
TEA index ($mJ\ g^{-1}$)	985.53b	1812.91a	42.3271
Air resistance (Gurley, s $100mL^{-1}$)	22.34b	1019.02a	48.4114

Standard Error of Difference.
† Means within a row followed by different letters differ significantly at p<0.05.
‡ Sample too strong (value beyond the range of the testing instrument).

those of the switchgrasses reported in the study by Madakadze et al. (1999). Elephant grass also displayed the lower bulk (specific volume) and thickness of hand sheets produced than Cave-in-Rock. The strength properties presented in Table 4 show that elephant grass pulp is characterised by a high burst index, breaking length, tensile strength and TEA index (energy required to rapture sheets). The tear and burst indices were comparable to those reported for wheat straw of 5.2 and 5.9, respectively (Lavoie et al., 1996) and for various grasses (Madakadze et al., 1999) and higher than for corn stalk which had values of 4.0 $mN.m^2\ g^{-1}$ and 3.8 $kP.m^2\ g^{-1}$, respectively (Lavoie et al., 1996). However, the high burst and tensile indices recorded for elephant grass are in the lower end of the ranges (burst, 5.9-7.15 $kP.m^2\ g^{-1}$ and tensile, 94 - 108 $Nm\ g^{-1}$) reported for coniferous kraft pulps (Akhtaruzzaman and Shafi, 1995).

Brightness of the unbleached pulp (Table 5) averaged 27%, and in general these pulps should be very easy to bleach. The low light scattering coefficients of both pulps

Table 5. Optical properties of pulp from elephant grass and switchgrass.

Parameter	Switch grass	Elephant grass	SED[#]
Brightness (%)	27.59a[¶]	26.15b	0.3134
Opacity (%)			
ISO[†]	98.21a	96.76b	0.1225
TAPPI[‡]	94.73a	91.06b	0.3386
Light scattering coefficient ($m^2 kg^{-1}$)	27.32a	25.04b	0.3999
Light absorption coefficient ($m^2 kg^{-1}$)	14.33a	11.92b	0.1009

[#] Standard Error of Difference
[†] International Standards Organization
[‡] Technical Association of Pulp and Paper Industries
[¶] means within a row followed by different letters differ significantly at p<0.05

is consistent with the high hemicellulose content of the grasses. The pulp brightness reported for jute (*Corchorus* spp.) kraft pulp (18.3 - 27.6%; Akhtaruzzman and Shafi (1995) are comparable to those we are reporting for elephant grass and switchgrass. In the event that the pulps are used as reinforcement components in news-print, Law et al. (2001) suggested an inclusion rate of less than 50% to ensure acceptable brightness and light scattering coefficients. Opacity values were lower for elephant grass, the difference being larger in the TAPPI than the ISO scale. We should however mention that, firstly, the paper making processes will greatly determine the final optical properties; and secondly, that these pro-perties can easily be manipulated by various bleaching treatments and/or varying rates of inclusion in a mixture.

Conclusion

Chemical analysis of the two grasses showed Klasson lignin values in the typical range for non-wood materials. The grasses could be pulped easily with the conventional kraft pulping process. Pulping yields averaged 49%, and kappa numbers averaged 12.3%, using 14% AA and 1 h cooking at 160°C. The pulp from these grasses was characterised by short fibres and high proportions of fines. If substituted for hardwoods or recycled paper these pulps could impart good printability properties to paper. However, there might be need to improve the drainage rates of the pulps to make them more acceptable to the paper industry. The low tear strength values might impact negatively on print room runnability of paper sheets from the two tested species.

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