Evaluation of Sudanese Sorghum and Bagasse as a Pulp and Paper Feedstock

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The suitability of specific Sudanese agrowastes, sorghum straw, bagasse, and their 50% blend, were investigated for pulp and papermaking initiatives. A chemical analysis of sorghum straw and bagasse revealed levels of cellulose, lignin, hemicellulose, and ash for sorghum straw and bagasse that signalled a suitable relation to traditional wood feedstocks for pulping and papermaking applications. Moreover, the pulp yield and viscosity of sorghum straw were lower and higher, respectively, compared with the bagasse and the blend. More specifically, the papers obtained from bagasse showed better physical properties (tensile strength, tearing index, bursting index, and folding) compared to those of sorghum straw and the blend. The surface morphologies of the papers were analysed using scanning electron microscopy (SEM), which showed that the fibres had a long, swollen, compact, and closely packed arrangement and were more homogeneous and well-blended for the bagasse compared with the pure sorghum straw and the 50% blend.

Keywords: Agricultural residues; Sudan; Bagasse; Sorghum; Fibres; Pulp; Papermaking

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INTRODUCTION

An enormous amount of agricultural residue cellulosic materials, such as cotton linters, sorghum, sunflower, millet, sesame stalks, and sugarcane bagasse, are burned annually in Sudan because of the lack of suitable and available processing facilities. However, the utilisation of these materials for pulp and papermaking are attractive (Khider *et al*. 2012). In recent years, there has been an increasing trend towards the application of agro-industrial residues as raw materials for pulp and paper production (Sánchez *et al*. 2016).

Sorghum (*Sorghum bicolour* (L.) Moench) is an important crop in Sudan, and the country ranked eighth in the world in sorghum grain production (3.5 million tonnes) in 2014 (Hamed *et al*. 2015). Jiménez *et al.* (1993) studied the application of sorghum stalks in pulp and papermaking and determined they had better properties than other agricultural residues, such as olive tree fellings, wheat straw, sunflower stalks, vine shoots, and cotton plant stalks. Gençer and Şahin (2015) identified conditions for producing pulp and paper from sorghum. Indeed, the length of sorghum stalks is sufficient to make them a viable alternative for pulp and paper production.

Albert *et al.* (2011) studied the fibre properties of Indian *Sorghum halepense* for paper production. Not surprisingly, the obtained results showed that *S. halepense* is a promising raw material that can be used in mixtures with other raw materials for pulp and paper production.

Bagasse is a by-product of the stem of sugarcane after crushing and juice extraction. There are six sugar plants in Sudan (Kenana, Asalaia, Elgneed, Khashm el-Girba, West Sennar, and White Nile). The quantity of sugar cane pressed yearly in Sudan is more than 6 million tonnes, and the dry remnants yield up to 27 thousand tonnes of pulp. It is well known that bagasse is a promising raw material for pulping and papermaking. Local pulp and paper industries have been importing significant quantities of pulp and paperboard to meet trade balances, thus ignoring local raw materials. Bagasse consists of 43.8% cellulose, 28.6% hemicellulose, 23.5% lignin, 1.3% ash, and 2.8% other components (Pereira *et al.* 2011). Samariha and Khakifirooz (2011) studied sugarcane bagasse in pulp and papermaking and found the freeness levels of 345 to 433 mL CSF and better strength properties in all indices in comparison with hardwoods.

The advantages of agricultural residue include abundance, low expense, ready availability, and a very short life cycle. Considering their lower lignin content compared with wood, these agricultural residues can be pulped in one-third of the time needed for softwoods and hardwoods. They also demand roughly 30% less chemical charge, which reduces power consumption in pulp refining (Ververis *et al.* 2004). Recently, various research groups have initiated research to improve non-wood pulping (Al-Mefarrej *et al.* 2013). The current effort investigated the utilisation of Sudanese agricultural residue (sorghum stalks and bagasse) for pulping and papermaking. The experimental route is shown in Fig. 1.

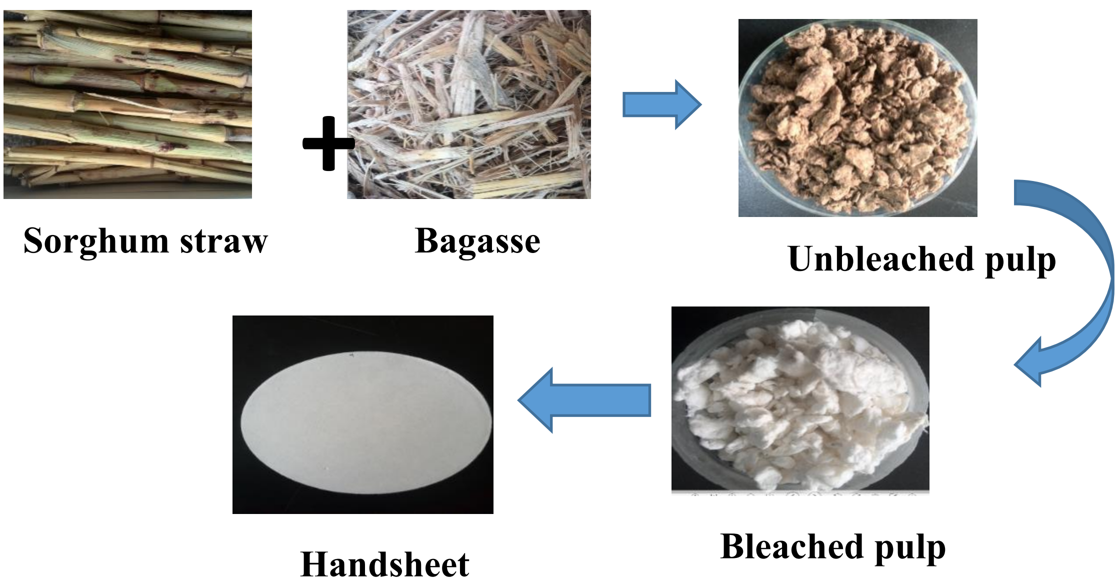

Fig. 1. Experimental design used in the present work

EXPERIMENTAL

Materials

Sorghum straw and bagasse were collected from Gezira scheme and Elgenid sugar plant (Gezira state, Sudan). Samples were washed with water to remove any impurities. They were then dried at ambient temperature for 4 days.

Samples were further dried in an oven at 110 °C for 24 h to make sure there was no water left inside. Next, the air-dried samples were ground to mesh size 0.40 to 0.45 mm according to the Technical Association of Pulp and Paper Industry (TAPPI) standard method. The samples were collected in plastic bags and placed in air-tight containers until further use. Hydrogen peroxide (H_2O_2), sodium hydroxide (NaOH), and anthraquinone were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

Chemical Composition

The chemical compositions of sorghum straw and bagasse were determined as follows: holocellulose contents were determined according to Wise method (Wise 1946); ash and lignin contents were determined according to TAPPI T211-om-93 (1993) and TAPPI T222-om-98 (1998).

The extractive substances were determined as follows: Hot and cold water TAPPI T207 cm-08 (2008), 1% sodium hydroxide solution TAPPI T212 om-07 (2007) and the amount of alcohol-benzene extractives was determined based on TAPPI T204 cm-07 (2007).

Pulping Process and Testing

Pulping of sorghum straw, bagasse, and their 50% blend was carried out in a laboratory digester according to Khiari *et al.* (2010). A total of 100 g of each material and the 50% blend were cooked at 160 °C for 1 h, with a liquid to material ratio of 5:1 and a holding time at maximum temperature of 2 h. A solution of 20 g of sodium hydroxide was used in the cooking, with 0.1% anthraquinone.

After cooking, the materials were immediately washed with flowing water, disintegrated in a hydropulper for 20 min, and screened through a vibratory flat screen with 0.25-mm slots.

The pulp yield was calculated and the kappa number, freeness, and viscosity of the pulp were determined according to TAPPI T236 om-99 (1999), TAPPI T227 om-99 (1999), and TAPPI T230 om-08 (2008), respectively. Pulp bleaching was carried out in two stages at 10% pulp concentration using H_2O_2 and 4% NaOH at 80 °C for 2 h.

Handsheet Making and Testing

Laboratory handsheets of 60 g/m^2 were prepared according to TAPPI T221 cm-99 (1999) on a PTI laboratory equipment (Vorchdorf, Austria) sheet former, pressed, and air-dried under atmospheric conditions. All of the handsheets tests were based on the following standards: thickness, TAPPI T411 om-97 (1997); bulk, TAPPI T500 cm-98 (1998); tensile index, TAPPI T494 om-96 (1996); burst index, TAPPI T403 om-97 (1997); tear index, TAPPI T496 sp-99 (1999); opacity TAPPI T1214 sp-98 (1998); and brightness TAPPI T1216 sp-98 (1998).

The reported results represent the average values of 5 tested hand-sheets. Fibre dimensions were measured by a Fibre Quality analyser (LDA02128, OpTest Equipment Inc., Ontario, Canada). An OCTANE 9.88/1114658 (AMETEK®, Mahwah, USA) was used to determine fibre morphological properties in the hand sheet as well as the elemental analysis (C, O, N, Si, Ca, Mg, and Al atoms).

RESULTS AND DISCUSSION

Chemical Composition

A complete wood chemical analysis was performed to determine differences in chemical composition. The main substances are listed in Table 1. The (α) cellulose contents of sorghum straw and bagasse were found to be 35.4% and 43.0%, respectively. The cellulose content of sorghum is similar to that found in a previous study (35.9%) (Cardoso *et al.* 2013). Higher amounts of cellulose lead to better quality of paper produced (Syed *et al*. 2016). The hemicellulose contents of sorghum straw and bagasse were 19.4% and 21.1%, respectively. Hemicellulose increases the strength of paper, especially the tensile strength, burst, fold, and pulp yield (Al-Mefarrej *et al*. 2013). The chemical analysis showed low lignin contents of 10.3% and 15.2% in sorghum straw and bagasse, respectively. A low lignin content is preferable and economically advantageous for pulp and paper production, as low-lignin content substrates need smaller levels of chemicals for pulping (Ververis *et al*. 2004; Wang *et al.* 2011). As shown in Table 1, sorghum straw and bagasse had relatively high ash contents of 5.3% and 5.0%, respectively. Paper's mechanical strength decreases as ash content increases. In spite of the high content of ash, the ash contents were in the typical range for non-wood materials and were not expected to have any significant impact on the papers' mechanical properties (Ververis *et al*. 2004). The solubility in hot water was about 11.3% and 13.2% for bagasse and sorghum straw, respectively. On the other hand, the solubility in cold water was found to be 10.6% for bagasse, while it was little higher (11.6%) for sorghum straw. Besides, the extractive contents in 1% NaOH were 16.2% and 15.5% of sorghum straw and bagasse, respectively. However, the amounts of the extractives were higher than those of temperate hard wood, but within the normal limits for soft wood species. This will be reflected as higher chemical consumptions both in pulping and bleaching processes.

Table 1. Chemical Composition of Sorghum Straw and Bagasse

Chemical composition (%)	Sorghum Straw	Bagasse
Holocellulose	54.8	64.1
Cellulose	35.4	43.0
Hemicellulose	19.4	21.1
Klason Lignin	10.3	15.2
Acid Insoluble Lignin	0.05	0.03
Ash	5.3	5.0
Soluble in hot water	13.2	11.3
Soluble in cold water	11.6	10.6
Soluble in 1% NaOH	16.2	15.5

Elemental Analysis

The results of elemental analysis are shown in Table 2. Sorghum straw exhibited the following levels: carbon (C) 43.54%, oxygen (O) 51.14%, sodium (N) 2.02%, magnesium (Mg) 0.53%, aluminium (Al) 0.23%, silica (Si) 0.57%, and calcium (Ca) 0.75% which were relatively higher than that of bagasse. However, high silicon-containing lignocelluloses are generally not preferred for pulp and paper manufacturing because they may causes several damages for cooking, bleaching, and washing devices. On the other hand, bagasse had the following levels of the elemental contents: carbon (C)

42.96%, oxygen (O) 54.29%, aluminium (Al) 0.09%, silica (Si) 0.23 %, and calcium (Ca) 0.85%. Gündüz *et al.* (2016) reported that *Rhododendron ponticum* L. and *Laurus nobilis* showed higher carbon content 53% and 51%, and less oxygen content 33% and 35%, respectively compared to sorgum straw and bagasse. However, Sorghum straw and bagasse contained very little silica, so they should not cause silica problems in the chemical recovery after pulping.

Table 2. Elemental Analysis

Material	C (%)	O (%)	N (%)	Mg (%)	Al (%)	Si (%)	Ca (%)
Sorghum Straw	43.54	51.14	2.02	0.53	0.23	0.57	0.75
Bagasse	42.96	54.29	1.34	-	0.09	0.23	0.85

Pulp Yield, Kappa Number, and Canadian freeness standard (CFS)

The characteristics of sorghum straw, bagasse, and the 50% blend in terms of the pulp yield, kappa number, and freeness are listed in Table 3 and shown in Fig. 2. Sorghum straw showed comparatively low pulp yield (33.15%) with a kappa number of 15.1 and a viscosity of 744 mL/g compared to the pulp yields (42.3%, 35.6%), kappa number (17.60, 9.20), and viscosity (636, 690) mL/g for bagasse and the 50% blend, respectively. However, sorghum straw showed relatively low pulp yield, which was probably related to its extremely high content of extractives in all solvents.

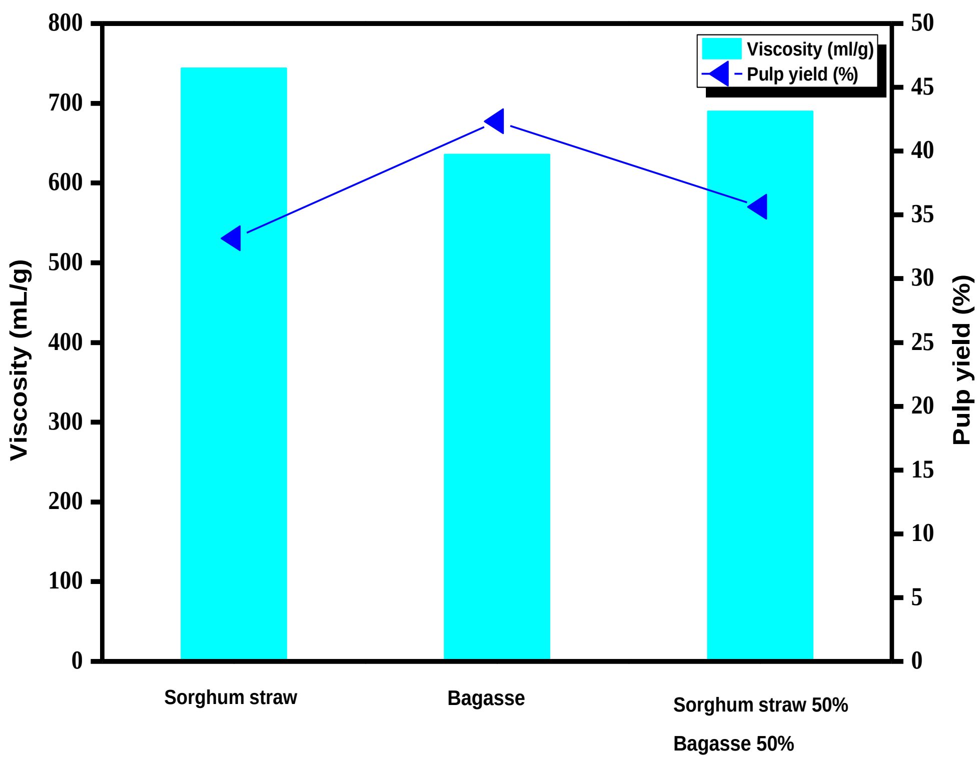

Fig. 2. Pulp yields and viscosities of sorghum straw and bagasse and their 50% blend

The kappa number of sorghum straw was lower than that content of bagasse (Kamoga *et al*. 2016), as shown in Table 3. Bagasse and the 50% blend pulp showed lower viscosities than that of sorghum straw (Fig. 1 and Table 3). Bagasse had a higher Canadian freeness standard (CFS) value compared with those of sorghum straw and the 50% blend.

Table 3. Pulp Properties

Material	Pulp Yield (%)	Pulp Viscosity (mL/g)	Kappa Number	(CSF) (mL)
Sorghum Straw	33.15	744	15.12	430
Bagasse	42.33	636	17.60	640
Sorghum Straw (50%) + Bagasse (50%)	35.64	690	9.20	610

Fibre Properties

Fibre dimensions are important for determining the appropriateness of cellulosic material for paper production (Syed *et al*. 2016). Fibre length generally influences the mechanical properties of paper (Agnihotri *et al*. 2010). The average fibre dimensions for sorghum straw and bagasse are given in Table 4. In general, longer fibres lead to higher tear resistance of paper (Syed *et al*. 2016). The mean kink index of sorghum straw was observed to be higher than that of bagasse. Problems such as micro-compressions and misaligned zones can occur if there is a sudden change in the curvature of a fibre (Agnihotri *et al*. 2010).

Table 4. Fibre Properties

Material	Sorghum Straw	Bagasse
Average Fibre Length (mm)	0.52	0.91
Average Fibre Diameter (μm)	26.80	25.20
Mean Kink Index (mm)	1.73	1.51
Mean Curl Index (mm)	0.11	0.12

Paper Properties

The mechanical and strength analysis of paper are a function of the physical and optical properties, morphology, and structure of each fibre, as well as the structure of the paper surface. The tear, tensile, and burst indices of sorghum straw, bagasse, and 50% blend handsheets are presented in Table 5 and Fig. 3. From this study, bagasse handsheets showed high tensile strengths (56.70 Nm/g compared to that 50.70 Nm/g and 40.47 Nm/g) of sorghum straw and the 50% blend, respectively. This may be due to the higher fibre length of bagasse, because long fibres generally produced paper with higher mechanical properties than paper from short fibre as well as high coarseness of the fibres and hence low flexibility, which does not allow good formation of a bonded network. However, the dimensions and strength of the individual fibers, their arrangement, and the extent to which they are bonded to each other are all important factors that affect the tensile strength of the produced papers.

In addition, bagasse had a tear index of 3.48 mNm^2/g while it was 2.61 mNm^2/g and 4.85 mNm^2/g for sorghum straw and the 50% blend, respectively. The tear index is influenced by many factors, including the average fibre length, hydrogen bonding area, and the natural fibre strength (Tajik *et al*. 2016). However, in the case of the blend, the higher tearing index may be due to the compatibility of the fibres, their structure, arrangement, and the extent to which they are bonded to each other are all important parameters which can affect tearing index of the produced paper.

Sorghum straw showed a higher bursting index (2.55 KPa m^2/g) compared to that 2.23 KPa m^2/g and 2.10 KPa m^2/g for the bagasse and the 50% blend, respectively. The folding endurance reaches the maximum fold to become a tissue paper with a low density (Daud *et al*. 2015).

Sorghum straw showed a folding endurance of 15 times compared to 10 times and 11 times of bagasse and the 50% blend, respectively. The optical properties of papers depend on end usages.

Opacity properties are useful for printing and writing papers, while for tracing paper, lampshades, and some packing papers, brightness is very important (Tajik *et al*. 2016). Paper produced from the 50% blend had a better opacity 86.3% compared to 82.6% and 82.9% for sorghum straw and bagasse, respectively. Due to the fibres compatibility of the two materials, that may led to more fibre-to-fibre bonding, thus less voids between the fibres then reduces the light scattering at fibre-air and pigment-air interfaces. On the other hand, sorghum straw showed a higher brightness of 71.2% compared to 66.6% and 65.8% for bagasse and the 50% blend, respectively. However, the papermaking processes will greatly limit the final optical properties of the produced papers. Moreover, these properties can easily be affected by various bleaching process.

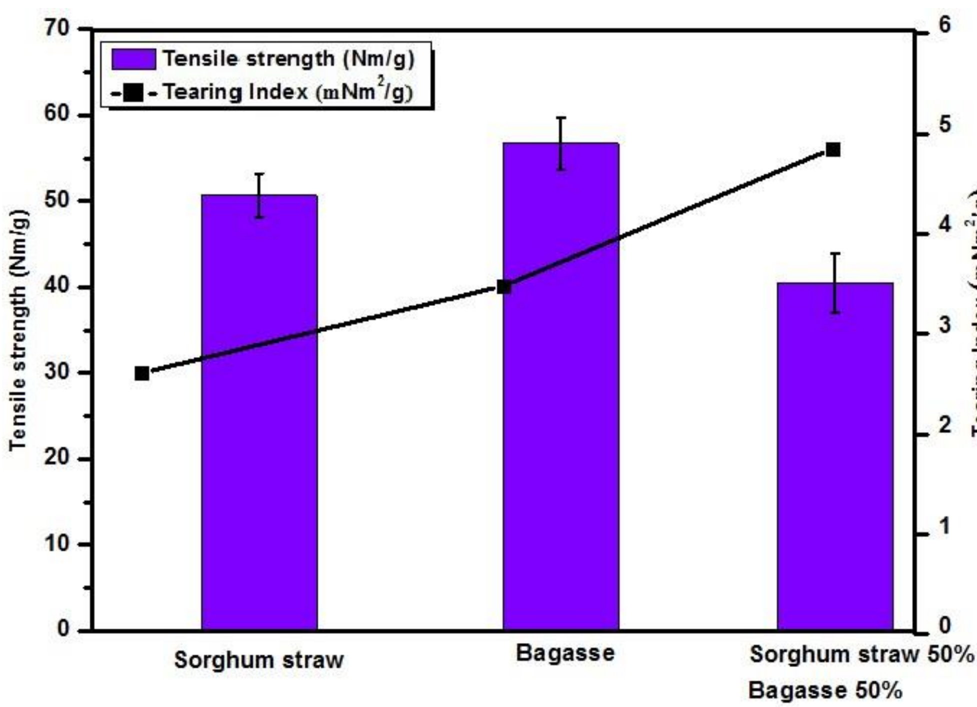

Fig. 3. Tensile strength and tearing index

Table 5. Paper Properties

Material	Sorghum Straw	Bagasse	Sorghum stalk (50%) + Bagasse (50%)
Thickness (μm)	150.00	150.00	140.50
Tensile Strength (N m/g)	50.70	56.70	40.47
Tearing Index (mNm^2/g)	2.61	3.48	4.85
Brightness (%)	71.15	66.58	65.78
Bursting Index (kPa m^2/g)	2.55	2.23	2.10
Folding Endurance ($\log_{10}n$)	15	10	10
Opacity (%)	82.60	82.90	86.30
Density (cm^3/g)	2.50	2.50	2.30

Paper Morphology

The paper structure was qualitatively studied using scanning electron microscopy (SEM), as shown in Fig. 4. The sorghum straw, bagasse, and 50% blend handsheets were magnified at 500x.

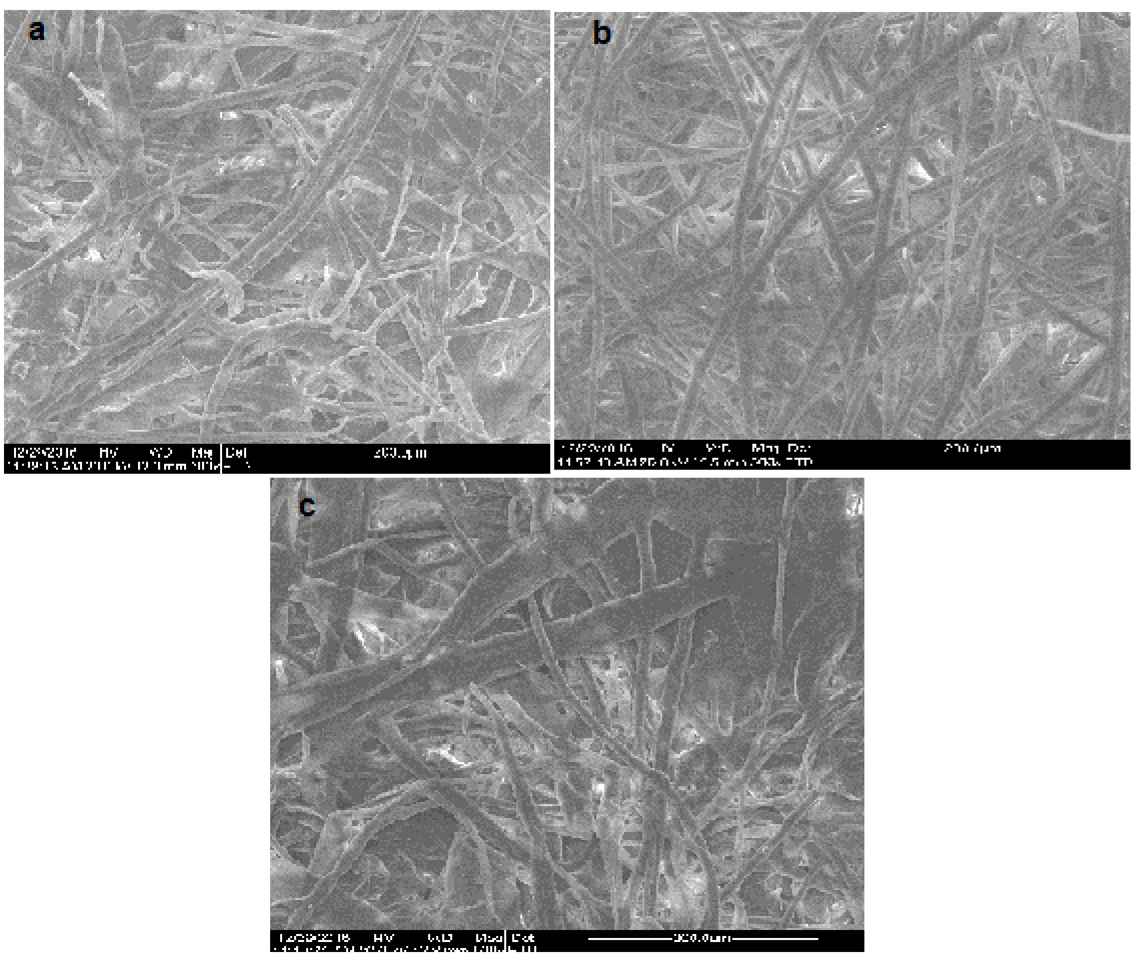

Fig. 4. Scanning electron microscopy of (a) sorghum straw, (b) bagasse, and (c) 50% blend

The results indicated that bagasse fibres (Fig. 4b) were long, swollen, compact, in a closely packed arrangement, homogeneous, and better blended than that of sorghum straw (Fig. 4a) and the 50% blend (Fig. 4c). Well-arranged and compact fibres will lead to higher mechanical properties for the produced handsheets (Pereira *et al*. 2011).

CONCLUSIONS

1. The chemical compositions of sorghum straw and bagasse revealed high polysaccharide and moderate lignin contents, which supports their suitability as cellulosic material candidates for pulp and paper manufacturing.
2. Bagasse pulp showed a higher yield and a higher kappa number than that of sorghum straw and their blend.
3. The handsheets produced from bagasse showed better mechanical properties. The SEM results indicated that fibres of bagasse and the 50% blend were long, swollen, compacted, closely packed, homogeneous, and better blended than those of pure sorghum straw.
4. Papers made from these materials had good mechanical strength and thus were suitable for producing writing and printing papers as well as for wrapping and packaging paperboard production.

ACKNOWLEDGMENTS

The authors are grateful for the financial support received from the National Science Foundation of China (Grant Nos. 31470602, 31600472, and 31570566,), the Foundation for Outstanding Young Scientist in Shandong Province (BS2015SW011), the Project of Shandong Province Higher Education Science and Technology Program (No. J13LD03), and the Foundation of Key Laboratory of Pulp and Paper Science and Technology of Ministry of Education (Shandong Province) of China.

REFERENCES CITED

Agnihotri, S., Dutt, D., and Tyagi, C. (2010). "Complete characterization of bagasse of early species of *Saccharum officinerum*-Co 89003 for pulp and paper making," *BioResources* 5(2), 1197-1214. DOI: 10.15376/biores.5.2.1197-1214

Al-Mefarrej, H., Abdel-Aal, M., and Nasser, R. (2013). "Chemical evaluation of some lignocellulosic residues for pulp and paper production," *Am.-Eurasia J. Agric. Environ. Sci.* 13(4), 498-504. DOI: 10.5829/idosi.aejaes.2013.13.04.1959

Albert, S., Padhiar, A., and Gandhi, D. (2011). "Fiber properties of *Sorghum halepense* and its suitability for paper production," *Journal of Natural Fibers* 8(4), 263-271. DOI: 10.1080/15440478.2011.626236

Cardoso, W. S., Tardin, F. D., Tavares, G. P., Queiroz, P. V., Mota, S. S., Kasuya, M. C. M., and Queiroz, J. H. D. (2013). "Use of sorghum straw (*Sorghum bicolor*) for second generation ethanol production: Pretreatment and enzymatic hydrolysis," *Química Nova* 36(5), 623-627. DOI: 10.1590/S0100-40422013000500002

Daud, Z., Hatta, M. Z. M., and Awang, H. (2015). "Oil palm leaf and corn stalk–Mechanical properties and surface characterization," *Procedia-Social and Behavioral Sciences* 195, 2047-2050. DOI: 10.1016/j.sbspro.2015.06.226

Gençer, A., and Şahin, M. (2015). "Identifying the conditions required for the NaOH method for producing pulp and paper from sorghum grown in Turkey," *BioResources* 10(2), 2850-2858. DOI: 10.15376/biores.10.2.2850-2858

Gündüz, G., Saraçoğlu, N., and Aydemir, D. (2016). "Characterization and elemental analysis of wood pellets obtained from low-valued types of wood," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 38(15), 2211-2216. DOI: 10.1080/15567036.2015.1040900

Hamed, A. H., Abbas, S. O., Ali, K. A., and Elimam, M. E. (2015). "Stover yield and chemical composition in some sorghum varieties in Gadarif State, Sudan," *Animal Review* 2(3), 68-75. DOI: 10.18488/journal.ar/2015.2.3/101.3.68.75

Jiménez, L., López, F., and Martínez, C. (1993). "Paper from sorghum stalks," *Holzforschung* 47(6), 529-533. DOI: 10.1515/hfsg.1993.47.6.529

Kamoga, O. L., Kirabira, J., Byaruhanga, J., Godiyal, R., and Anupam, K. (2016). "Characterisation and evaluation of pulp and paper from selected Ugandan grasses for paper industry," *Cellul. Chem. Technol* 50(2), 275-284.

Khiari, R., Mhenni, M., Belgacem, M., and Mauret, E. (2010). "Chemical composition and pulping of date palm rachis and *Posidonia oceanica* –A comparison with other wood and non-wood fibre sources," *Bioresource Technology* 101(2), 775-780. DOI: org/10.1016/j.biortech.2009.08.079

Khider, T. O., Omer, S., Taha, O., and Shomeina, S. K. (2012). "Suitability of Sudanese cotton stalks for alkaline pulping with additives," *Iranica Journal of Energy & Environment* 3(2), 167-172. DOI:

Pereira, P. H. F., Voorwald, H. C. J., Cioffi, M. O. H., Mullinari, D. R., Da Luz, S. M., and Da Silva, M. L. C. P. (2011). "Sugarcane bagasse pulping and bleaching: Thermal and chemical characterization," *BioResources* 6(3), 2471-2482. DOI: 10.15376/biores.6.3.2471-2482

Samariha, A., and Khakifirooz, A. (2011). "Application of NSSC pulping to sugarcane bagasse," *BioResources* 6(3), 3313-3323. DOI: 10.15376/biores.6.3.3313-3323

Sánchez, J. H., Fajardo, M. E., and Quintana, G. C. (2016). "Viscoelastic properties of pulp suspensions of bleached sugarcane bagasse: Effects of consistency and temperature," *BioResources* 11(4), 8355-8363. DOI: 10.15376/biores.11.4.8355-8363

Syed, N. F. N., Zakaria, M. H., and Bujang, J. S. (2016). "Fiber characteristics and papermaking of seagrass using hand-beaten and blended pulp," *BioResources* 11(2), 5358-5380. DOI: 10.15376/biores.11.2.5358-5380

Tajik, M., Resalati, H., Hamzeh, Y., Torshizi, H. J., Kermanian, H., and Kord, B. (2016). "Improving the properties of soda bagasse pulp by using cellulose nanofibers in the presence of cationic polyacrylamide," *BioResources* 11(4), 9126-9141. DOI: 10.15376/biores.11.4.9126-9141

TAPPI T205 sp-95 (1995). "Forming handsheets for physical tests of pulp," TAPPI Press, Atlanta, GA, USA.

TAPPI T211 om-93 (1993). "Ash in wood, pulp, paper and paperboard: Combustion at 525 °C," TAPPI Press, Atlanta, GA, USA.

TAPPI T222 om-06 (1996). “Acid-insoluble lignin in wood and pulp,” TAPPI Press, Atlanta, GA, USA.
TAPPI T222 om-06 (1996). “Water solubility of wood and pulp,” TAPPI Press, Atlanta, GA, USA.
TAPPI T212 om-07 (2007). “One percent sodium hydroxide solubility of wood and pulp,” TAPPI Press, Atlanta, GA, USA.
TAPPI T204 om-07 (2007). “Solvent extractives of wood and pulp,” TAPPI Press, Atlanta, GA, USA.
TAPPI T227 om-99 (1999). “Freeness of pulp (Canadian standard method),” TAPPI Press, Atlanta, GA, USA.
TAPPI T230 om-08 (2008). “Viscosity of pulp (capillary viscometer method),” TAPPI Press, Atlanta, GA, USA.
TAPPI T236 om-13 (2013). “Kappa number of pulp,” TAPPI Press, Atlanta, GA, USA.
TAPPI T403 om-97 (1997). “Bursting strength of paper,” TAPPI PRESS, Atlanta, GA, USA.
TAPPI T411 om-97 (1997). “Thickness (caliper) of paper, paperboard, and combined board,” TAPPI Press, Atlanta, GA, USA.
TAPPI T414 om-99 (1999). “Internal tearing resistance of paper (Elmendorf-type method),” TAPPI PRESS, Atlanta, GA, USA.
TAPPI T425 om-98 (1998). “Diffuse opacity of paper (d/0 paper backing),” TAPPI PRESS, Atlanta, GA, USA.
TAPPI T494 om-96 (1996). “Tensile properties of paper and paperboard (using constant rate of elongation apparatus),” TAPPI Press, Atlanta, GA, USA.
TAPPI T500 cm-98 (1998). “Book bulk and bulking number of paper,” TAPPI Press, Atlanta, GA, USA.
TAPPI T1216 sp-98 (1998). “Indices for whiteness, yellowness, brightness, and luminous reflectance factor,” TAPPI Press, Atlanta, GA, USA.
Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., and Santas, R. (2004). "Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production," *Industrial Crops and Products* 19(3), 245-254. DOI: org/10.1016/j.indcrop.2003.10.006
Wang, Q., Chen, K., Li, J., Yang, G., Liu, S., and Xu, J. (2011). "The solubility of lignin from bagasse in a 1, 4-butanediol/water system," *BioResources* 6(3), 3034-3043. DOI: 10.15376/biores.6.3.3034-3043
Wise, L. E. (1946). "Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses," *Paper Trade Journal* 122(2), 35-43.

Article submitted: March 20, 2017; Peer review completed: May 26, 2017; Revised version received and accepted: May 27, 2017; Published: June 6, 2017.
DOI: 10.15376/biores.12.3.5212-5222