

Potential of using Two Types of Reed for Pulp and Paper Industry

Selim O. Tupach¹, Sayed E. Kandeel¹, Ibrahim A. Kherallah¹, Houssni El-Saied² and

Ramadan A. Nasser¹

ABSTRACT

The objective of this study is to measure and evaluate the suitability of two types of reed, namely giant reed (*Arundo donax*) and common reed (*Phragmites australis*) as non-woody raw materials using soda-anthraquinone (AQ) pulping process for pulp and paper industry. Two fractions of reed were used to produce experimental papersheets. The two fractions are woody stem and whole plant including woody stem, leaves, and sheaths. The biometric characteristics, such as extractive solvents, chemical, morphological properties, and physical properties in addition to some strength properties of the papersheets made from these resources were measured. The results indicated that *P. australis* had the highest contents of cellulose, hemicellulose and ash were 53.5%, 33.9% and 3.9%, respectively while the lowest lignin content value was 13.6%. Fiber length of both types of fiber length were also determined as 1800µm and 1400µm. The derived Runkel ratio and flexibility coefficient for *P. australis* were also determined as 1.25, 61.4, respectively. Overall strength properties of pulp and papersheets made from the two reed types were significantly different from each other. Based on the results of this study, it appears that both types of reed, giant reed and common reed could have a potential to be used as an alternative raw material for pulp and paper production with accepted properties.

Keywords: Reed, pulp and paper, soda-antherquinone, non-wood, fiber length.

INTRODUCTION

The pulp and paper industry is one of the largest growing industries all over the world which mainly depends on, softwood and hardwood species (Dutt and Tyagi, 2011) as raw material. Paper consumption is continuously increasing in the world even in countries where wood resources are very limited such as Egypt. Globally, there is a significant increase in the demand for paper and paperboard as the consumption increased from 125.9 million tonnes in 1970 to 422 million tonnes in 2018 (FAO, 2021) and it is expected such increase will reach to more than 500 million tones by 2030

(Nasser *et al.*, 2015). Consequently, there has been a massive demand for raw material

to manufacture pulp and paper (Bajpai *et al.*, 2004). Currently, the material used for the production of cellulose pulp is obtained from hardwood and softwood species. With the lack of wood supplies from natural forests creates raw material problems and turning towards non-wood fiber resource to be used as pulp and paper production. Attempts have been made to introduce the other materials, which are available in different forms of biomass wastes, and as important fiber resources specifically in the areas where forest resources are very limited (Khristova *et al.*, 2005 and Nasser *et al.*, 2015). As a result of these researches, many biomass types such as grasses and hemp (Paavilainen, 1998) were used as popular resources to decrease the gap between demand and production in papermaking industry. Wood waste, non-woody materials, fast growing wood species, agricultural residues and other lignocellulosic materials are examples of biomass types used for paper industry. However only 5-10% of these materials are used for paper production while more than a total of 85% of paper is still manufactured from wood species (Azeez, 2018). Pulp is an aggregation of cellulosic fibers produced from wood or other lignocellulosic materials physically or chemically which can be dispersed in water and reformed into a web. Paper is a sheet of cellulose fibers with a number of added constituents to affect the quality of the sheet and its fitness for intended end use.

The current usage of non-woody plants fibers such as rice straws, corn stalks, cotton stalks, bagasse, grasses, banana pseudo-stems and reeds would play a main role to increase papermaking as alternative raw materials supply for paper production (Cordeiro *et al.*, 2004). The main drawbacks that are considered to limit the use of non-wood fibers in paper production are difficulties in collection, transportation, storage and handling (Saijonkari-Pahkala, 2001).

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¹Department of Forestry and Wood Technology,
Faculty of Agriculture, Alexandria University, Alexandria, Egypt,

²Chemical Industries Research Division,
National Research Centre, Cairo, Egypt.

Selim O. Tupach (Selimstupach1@gmail.com)

Sayed E. Kandeel (elasyed.kandeel@alexu.edu.eg)

Ibrahim A. Kherallah (Ibrahim.khairallah@alexu.edu.eg)

Houssni E. Ali (hel_saied@yahoo.com)

Ramadan A. Nasser (nasser67@alexu.edu.eg)

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Several studies have been carried out to test the suitability of some wood species and non-woody plants that are available for pulp and paper production (Ahmadi *et al.*, 2010). These studies determined the potentiality of the non-woody resources using different pulping processes and conditions and the most of these studies concluded that the non-wood resources are suitable for pulp and paper production. It is a fact that non-wood plants are important alternative source of fibers for the pulp and paper industry. The role of agro-fiber biomass is particularly prominent in countries with limited wood resources. In some areas of Asia, Africa and Latin America this is the only source of industrial papermaking fibers (Atchison, 1993).

Common reed (*Phragmites australis*) is an invasive large perennial grass producing tall and hollow stems. It is one of the most widely distributed vascular plants globally (Kask *et al.*, 2013). In suitable habitat, it is a vigorous and aggressive plant and usually form a totally dominant stand over the rest other plant species. Throughout temperate and tropical regions of the world, common reed is mostly found in wetlands. It grows efficiently on the shores of streams, lakes, ponds, shallow water, ditches and aquatic wastelands. In all regions of Egypt, common reed is widely distributed in aquatic habitats (Shaltout, 2017). Annually, a hectare of common reed produces between 4 to 12.6 tons of dry organic matter with an average of 7.4 t/ha-1 in nutrient-rich lands and in its natural habitat (Komulainen *et al.*, 2008). Szijarto *et al.*, 2009 reported that common reed has high cellulose and hemicelluloses contents and it is used as a fiber source for pulp and paper manufacturing. Giant reed (*Arundo donax*) is also widely distributed naturally growing perennial rhizomatous grass, which is a well-known fiber crop having a great potential in (Atchison, 1993).

Currently there is a very limited information on different properties of both reed species to be considered as a raw material for pulp and paper manufacture. Therefore the objective of this study was to measure the suitability of two types of reed widely available in Egypt as non-wood raw materials for pulp and paper industry by using soda-anthraquinone (AQ) pulping process. The study was focused on the effect of reed types and their parts as well as interaction between them on the properties of pulp and paper produced by soda-AQ pulping. The effect of refining level on the strength properties of paper produced from the two types of reed was also evaluated within the scope of this work.

EXPERIMENTAL

1. Raw materials used for the samples

Two types of reed, namely Giant reed (*Arundo donax*) and common reed (*Phragmites australis*) were

used for the experiments. The reeds were harvested above the ground level from different areas in Alexandria and samples were identified in the Department of Botany, Faculty of Sciences, at Alexandria University, Egypt. Reed cane stalks were cleaned from leaves, roots, and soils. After air-drying the stalks were separated manually and cut into pieces with a length of 3 to 5 cm they were stored in polyethylene bags to be used for chemical composition, physical properties, morphology characterization and pulping process. For biomass and biomass allocation, each type of samples was divided into four parts i.e. stem, leaves, sheathes and influences. Each part was initially weighed in green state and its moisture content was determined based on the oven-dry weight. Then, the biomass and biomass allocation were calculated based on oven-dry as a percentage. For chemical analysis, each part was cut to small pieces for grinding into wood meal using a laboratory Wiley mill and before the meals were screened. The chemical analysis of wood was carried out on the meal portion which was retained on a B.S-60-mesh after passing a B.S-40 mesh sieves and coded as (-40/+60). For pulping process, each type of reed was divided into two parts i.e. part one include stem only (S-only) and the other one include the stalk or whole plant (Stalk or AP) including other plant parts such as leaves, sheath, and inflorescence as received, so that there are four treatments two reed types and two reed parts (S-only and AP).

Physical properties of the samples including the moisture content based on green and dry bases and density were also determined. Portion of the materials from each reed types and parts were prepared for pulping quality as illustrated in Photo 1.

2. Chemical Analysis of the samples

The chemical analyses were carried out according to the appropriate conventional methods and standards. Each analysis was carried out at least three replicates taking the average results. The total extractive content of wood as a percentage of oven-dry basis were determined using air-dried particles (-40/+60 mesh) in Soxhlet apparatus based on ASTM D1037 (1989). The content of the main chemical components of wood including cellulose, hemicellulose and lignin were determined using free-extractive meal according to the standard methods (Nikitin, 1960, Rozmarin & Simionescu, 1973 and ASTM D1037, 1989). All data were expressed as percent oven-dry on oven-dry free-extracted meal. Ash content of the samples was also determined using un-extracted wood meal according to NREL (2005) in muffle at $525 \pm 25^\circ\text{C}$ for 6 h. Solubility of samples in cold and hot water as well as in 1% NaOH solution were determined in accordance with the methods outlined in ASTM D1037 (1989).



Photo.1. Reed stalks

3. Fiber analysis of the samples

Fiber length of both the two types of reed was determined according to the method outlined by Franklin (1945). Reed pieces were cut into chips and macerated in an oven at 60C for 48 h by using a solution (1:1 by volume) of glacial acetic acid and hydrogen peroxide. Fifty selected fibers were measured in length for each reed type by fibers image of SEM. The main fiber dimensions i.e., the diameter (D), lumen (d) and wall thickness (FWT) of the selected fibers were measured. From the data of fiber dimension, the fiber indices were calculated including Runkel ratio ($2FWT/d$), rigidity coefficient ($2FWT/D$), slenderness ratio (L/D), flexibility ratio ($d/D*100$) and shape factor (D^2-d^2/D^2+D^2).

4. Pulping process

Soda-AQ pulping process of the chips was conducted in 2.5 L Laboratory-scale batch cylinder stainless steel mini digester No#321 according to Khristova *et al.* (1990 and 2005). The cooking conditions are presented in Table 1. The concentration of active alkali as NaOH and anthraquinone (AQ) were 20% and 0.1% (w/w), respectively based on the oven-dry weight of the raw materials. The moisture content of chip was determined before white liquor preparation to justify the liquor-to-chip particles ratio constant as 1:5. After cooking, the content of the digester was discharged on 200 mesh screens and the pulp was washed until the filtrated water was colorless. The total screened and rejected pulp yields were also determined. The Kappa number, beating process at 15, 30 and 40° SR and the freeness test of the samples were determined based on TAPPI standard methods as displayed in Table

2. The lignin and ash contents of the pulp samples were also calculated according to kappa number and Tappi T211 om-02, respectively.

5. Papersheet and their properties

For each reed pulp (total 16; 2 species*2 part types*4 SR), ten papersheets were manufactured from the pulp of *Arundo donax* and *Phragmites australis* in accordance with Tappi T 205 sp-06 (2006). After preparation and conditioning the papersheets in a room with temperature and humidity controlled for two days according to Tappi T 402 om-93, the strength properties of papersheets were determined based on the TAPPI standard method, as showed in Table 4. Five free-defect papersheets from each reed pulp were obtained and tested. The strength properties of papersheets including tensile strength ($kN.m^{-1}$), burst strength (JPa), tear resistance (g) and breaking length (km). Tensile index ($N.m.g^{-1}$) and tear index ($mN.m^2.g^{-1}$) were calculated. The brightness of the papersheet paper was measured.

6. Statistical analysis

The samples from two types of reed were evaluated based on their suitability for pulp and paper production as well as for the quality of the paper produced from their pulps. All properties of the reed type feedstock, namely chemical constituents and morphological characteristics as well as the properties of the pulp and papersheets, including pulp yield, kappa number, lignin content, ash content and strength properties, and brightness were evaluated by using the analysis of variance (ANOVA) in a randomized complete design (CRD). The least significant difference test at a 5% level of probability ($LSD_{0.05}$) was calculated and used to detect the differences between the mean values of the tests.

Table 1. Cooking conditions of the two reeds raw materials by soda-AQ pulping process

Pulping conditions	Unit	Values
Weight of the oven-dried fibers	G	2000
Active alkali*	%	20
AQ charge*	%	0.1
Liquor-to-reed ratio	L/kg	5:1
Cooking temperature	°C	170
Time to maximum temperature	Min.	30
Time at maximum temperature	Min.	90

* Based on oven-dry weight of reed chips, w/w.

Table 2. Test methods used for pulp and papersheets evaluation produced from the two reed types

Property	Analytical method	Apparatus used
For pulp:		
Kappa number	TAPPI T236 cm-85	-
Beating process	TAPPI T200 om-89	Laboratory valley beater, model VB-20
Freeness test	TAPPI T227 om-92	Freeness tester "Schopper-riegler" manual SR-10
Ash content	TAPPI T211 om-02	Muffle furnace
For papersheets:		
Tensile strength	TAPPI T494 om-81	Multi-test computerized tensile tester model MTT-50
Breaking length	TAPPI T494 om-81	Multi-test computerized tensile tester model MTT-50
Burst strength	TAPPI T403 os-76	Auto burst tester
Tearing resistance	TAPPI T414 om-88	Tearing tester computerized Elmendorf model MTT-10
Brightness	TAPPI T452 om-92	Reflectance "Photovolt" model 577-A

RESULTS AND DISCUSSION

Table 3 displays biometric characteristics of the two type of samples. The differences between two types of reeds were found significant and can be attributed to the biological properties of the species and their cultivars. Weight proportion percent for different reed parts were also significant and the proportion of stem weight was the highest among the other parts of the reed plant based on oven-dry bases 60.8 and 62.1% for *A. donax* and *P. australis*, respectively. The proportion weight of leaves for both reed types was about 15% and the differences between the two reed species were not significant.

In the current study, the reed density number of stalks in 1 m² areas according to Ritterbusch (2007) in the location used to collect the two types of reed was 60 and 40 reed plants per 1 m² area for *A. donax* and *P. australis*, respectively. The yield of the two reed types used was 32.2 and 38.4 t/ha for *A. donax* and *P.*

australis, respectively (Fig. 1). These values are high compared to the values obtained by Komulainen *et al.* (2008), who reported that the yield (dry matter per hectare, t/ha) of Finlandian common reed is ranged from 4.6 to 7.4 t/ha with the average of 5.0 t/ha which may be increased to 30 t/ha in nutrient rich area. This result is in agreement with those determined by William and Biswas (2010) stating that the stem biomass yield of reed was ranged from 7.52 to 35.9 t.ha⁻¹year⁻¹. Comparing the yield of the two reed types to other raw materials, the dry matter of the two reed types were relatively higher than other plants according to Grigoriou and Ntalos (2001) and Nasser *et al.* (2012). The growth characteristics especially yield indicated a good potential to produce pulp with suitable yield in comparison with other non-woody species.

Table 3. Biometric characteristics* of the two reed types used for pulp and papermaking

Reed types	Stem length (cm)	Stem diameter (mm)	Weight proportion (%)**			
			Stem	Leaves	Sheaths	Inflorescences
<i>A. donax</i>	242.1 ^B	20.4 ^A	60.78 ^B	15.93 ^A	14.46 ^B	8.83 ^A
<i>P.australis</i>	375.5 ^A	10.0 ^B	62.14 ^A	15.04 ^A	16.21 ^A	6.66 ^B

* Each value is an average of 10 reed plants.

± is standard deviation.

Means followed by the same letter in the same column are not significantly different at 5% level of probability according to LSD test.

** Based on oven-dry basis.

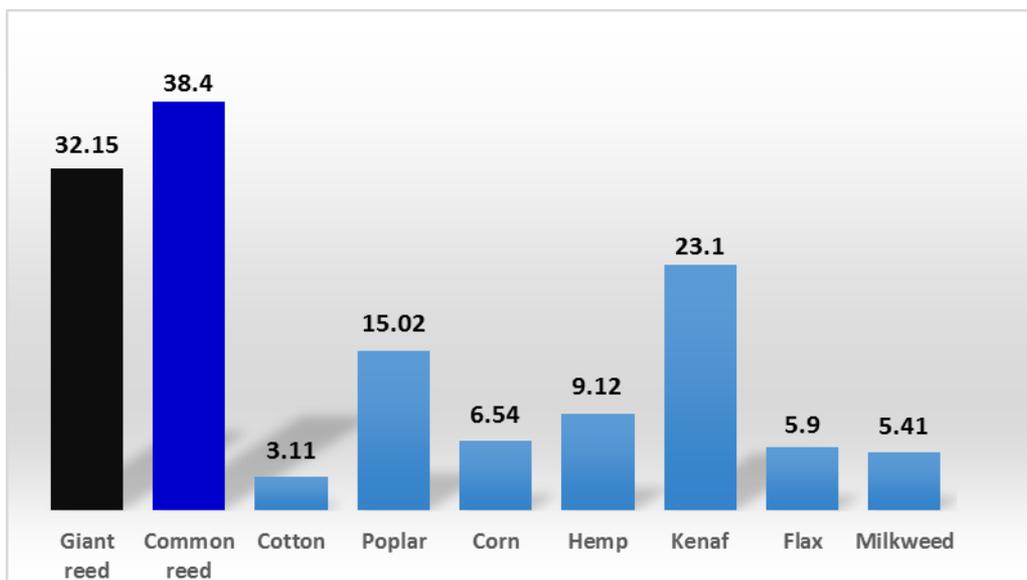


Fig.1. Yearly dry yield (t/ha) of the two reed types compared to other plants

Table 4 displays the results of solubility extractives for the two reed types *A. donax* showed the highest extractives content in stem, while *P. australis* had the lowest. Leaves of reed had the highest values of extractives content compared to other parts of the same plant, so it is expected an increase in chemicals needed in pulping and bleaching (Al-Mefarrej *et al.*, 2013). It seems that such results indicated that the paper produced from reed stalks only will be have high strength properties as compared to those made from whole reed plant.

The analysis of variance of the chemical composition of the raw materials showed significant differences between the two reed types in their main components, namely cellulose, hemicellulose, lignin and extractives content. No significant differences were found between the two reed types in ash content and 1% NaOH solubility. With exception of extractives and ash contents, as can be seen from Table 5 that the three main chemical components of the two reed plants were in the range of typical hardwood species. *P. australis* had the highest hemicellulose value of 33.9% and ash

content of 3.9%, while *A. donax* had the lowest lignin and extractives content values of 13.6 and 9.3%, respectively. In previous studies it was found that such raw materials could be cooked easier and delignify with low chemical required for pulping and bleaching (Sable *et al.*, 2012 and Al-Mefarrej *et al.*, 2013). Therefore and according to the chemical analysis, both reed types could have excellent potential as raw materials for pulp and paper manufacture.

Although no significant differences in the ash content between the two reed types were determined, the ash content of the reed appeared to be high as compared to that of softwood and hardwoods but close to cotton stalks (Jimenez *et al.*, 2007). This increase in ash content of reed may be inversely affected on the strength properties of the paper made from them (Al-Mefarrej *et al.*, 2013). The solubility of reed in 1% NaOH was about 60% compared to date palm residues (Nasser *et al.*, 2016) and cotton stalks 20.3% (Jimenez *et al.*, 2007) as well as white straw and bagasse 42.3% (Mohamed, 2004).

Table 4. Total extractives content (%)* of different parts of the two reed types

Reed types	Stalk (stem)	Leaves	Sheaths	Inflorescences
<i>A. donax</i>	12.32 ^A	30.45 ^B	10.15 ^A	3.45 ^A
<i>P. australis</i>	9.65 ^B	32.58 ^A	9.79 ^A	2.24 ^B

* Each value is an average of 3 samples based on oven-dry basis.

Means followed by the same letter in the same column are not significantly different at 5% level of probability according to LSD test.

Table 5. Chemical analysis* of the two types of reed used for pulp and paper compared to published data

Reed Species	Percentage content of					1% NaOH solubility
	Ash	Total extractives	Cellulose	Hemicelluloses	Lignin	
<i>A. donax</i>						
Stem only	3.71 ^C	12.32 ^C	47.26 ^B	32.55 ^C	19.62 ^A	59.19 ^C
Whole plant	4.12 ^B	22.63 ^A	48.03 ^B	34.28 ^A	18.98 ^A	58.53 ^D
<i>P. australis</i>						
Stem only	3.91 ^C	9.65 ^D	53.47 ^A	33.85 ^B	13.60 ^B	61.19 ^A
Whole plant	4.61 ^A	20.18 ^B	54.22 ^A	32.89 ^C	14.26 ^B	60.02 ^B
Hardwood ¹	0.2-0.5	2-6	45-50	15-35	23-30	-
Softwood ¹	0.2-0.5	2-8	45-50	20-32	25-34	-
Bagase ²	-	16.81	-	-	22.8	42.43
Date palm residues ³	1.3-15.2	7.8-32.9	32.8-47.5	12.6-31.3	25.6-39.9	1.8-15.2
Cotton stalks ⁴	2.17	1.42	58.48	14.38	21.45	20.34
White straw ⁵	6.81	17.50	47.14	35.37	17.48	43.58

* Each value is an average of 9 samples except for ash content 6 samples.

Means followed by the same letter in the same row are not significantly different at the 5% level of probability.

¹ According to Fengel and Wegener (1993).

² According to Mohamed (2004).

³ According to Nasser et al (2016).

⁴ According to Jimenez *et al.* (2007).

⁵ According to Nasser *et al.* (2015).

Table 6 displays the mean values fiber dimension as morphological characteristics of *A. donax* and *P. australis*, as compared to the data available in the literature including those of hardwood species. Fiber dimensions are important measurements for papermaking to evaluate the quality paper produced. Fiber length (L), fiber width (D), fiber wall thickness (w), and lumen diameter (d) of the samples were measured. The results showed that there are significant

differences between the two reed types in all fiber dimensions except fiber lumen diameter. The average value of fiber length of *A. donax* was higher than *P. australis*, however fiber width and fiber wall thickness were higher in *P. australis* as compared to that of *A. donax* and no significant differences were found in fiber lumen diameter of the samples. All fiber dimensions of both reed types were within the range of the previous studies carried out for different biomass.

Table 6. Morphological properties of the fibers, measured dimensions, from the two reed types used for pulp and papermaking in the current study

Reed types	Measured property			
	Fiber length, L (μm)	Fiber width, D (μm)	Fiber lumen diameter, d (μm)	Fiber wall thickness, w (μm)
<i>Arundo donax</i>	1794 ^A	12.97 ^B	8.50 ^A	4.40 ^B
<i>Phragmites australis</i>	1398 ^B	14.04 ^A	8.60 ^A	5.20 ^A
<i>Eucalyptus</i> sp ¹	670-2300	15-27	5-35	3-6
<i>Phenoix dactylifera</i> ²	1180	12.9	8.7	2.1
<i>Triticum sativium</i> ²	1020	11.0	8.6	1.2
<i>Pinus kesiya</i> ¹	2300	40.7	34.8	5.9
Saikia et al (1997)	600-2150	21.22	13.17	4.5

Each value is an average of twenty five fibers.

Means followed by the same letter in the same row are not significantly different at the 5% level of probability.

¹ According to Dutt and Tyagi (2011).

² According to Nasser *et al.* (2015).

According to Saikia *et al.* (1997).

The fiber length of *A. donax* was longer in length and narrower in diameter than the *P. australis* as can be seen in Table 6. It appears that giant reed fibers were expected to be more flexible resulting in better fiber-to-fiber bonding than that of common reed fibers which also influenced overall strength properties of papersheets, especially burst strength. Such results are in agreement with those determined by Sable *et al.* (2012) on two pine species. The fiber length of reed was close to hardwood fibers (Dutt & Tyagi, 2011 and Saikia *et al.*, 1997). It is predicted that the papersheets formed from the two reed types would give a smoother paper because short fibers will fill the voids in the paper sheet. Morphological characteristics of the fibers presented in this study were similar to those found in previous studies carried out for different lignocellulosic materials (Dutt and Tyagi, 2011).

Table 7 displays the derived mean values of fiber dimensions determined from the two reed types. These indices were calculated including Runkel's ratio, slenderness ratio, rigidity coefficient, flexibility coefficient and shape factor. All of these indices are of the most important factors affecting the strength properties of the paper and used to predict the suitability of any raw materials for pulp and paper production.

The value of Runkel's ratio in the current study was higher than 1 and varied from 1.05 to 1.25 for *A. donax* and *P. australis*, respectively. It is known from the previous studies that the raw materials with Runkel's ratio less than 1 are suitable for paper production. It was reported that high Runkel's ratio gave lower paper strength properties especially burst factor, tear index and tensile index (Sharma *et al.*, 2013 and Nasser *et al.*, 2015). With regard to Runkel ratio, it can be concluded

that both the two reed types used in this study are less suitable for paper production.

Flexibility ratio is another important parameter for the evaluation the strength properties of paper. Flexibility ratio determines the degree of fiber bonding in paper sheet. Flexibility ratios for the reed samples ranged from 61% to 65% for *P. australis* and *A. donax*, respectively and the difference between them was significant. The values were close to *Phenoix dactylifera* (Nasser *et al.*, 2015) and in the range of hardwood species (Dutt and Tyagi, 2011). These results revealed that fibers of the two reed types were flexible and suitable for paper production. Slenderness ratio is calculated from fiber length and its diameter measuring the tearing property of paper. The fibers with high slenderness ratio are long, thin and have high tearing resistance. In this study, slenderness ratios ranged from 100% for *P. australis* to 136% for *A. donax*, thus, the selected two reed types were suitable for pulp and paper production.

The analysis of variance (ANOVA) for pulp properties produced from the two reed types and from two parts of reed are presented in Table 8. The results indicated that total pulp yield, kappa number and ash content were significantly different between the two reed types while no significant difference was detected in their lignin content. The differences between the pulp made from the two reed parts in pulp yield and ash content were significant while kappa number and lignin content were not significant. The interaction between reed types and reed parts were significant for pulp yield and ash content.

Table7. Morphological properties of the fibers, derived indices, from the two reed types used for pulp and papermaking in the current study

Reed types	Measured property				
	Runkel ratio	Slenderness ratio	Rigidity coefficient	Flexibility coefficient	Sharpe factor
<i>Arundo donax</i>	1.04 ^B	138.6 ^A	0.340 ^A	65.69 ^A	0.397 ^A
<i>Phragmites australis</i>	1.21 ^A	99.9 ^B	0.372 ^A	61.77 ^B	0.451 ^A
<i>Eucalyptus</i> sp ¹	0.31-1.76	25.57	0.03-0.63	33-85	-
<i>Phenoix dactylifera</i> ²	0.49	93.5	0.33	67.5	0.38
<i>Triticum sativium</i> ²	0.28	96.4	0.22	78.2	0.25
<i>Pinus kesiya</i> ¹	0.34	56.51	0.03	85.0	0.16
Saikia <i>et al</i> (1997)	0.46-0.63	38.99	0.16	60.8	0.23-0.47

Each value is calculated from the data of Table 6.

Means followed by the same letter in the same row are not significantly different at the 5% level of probability.

¹ According to Dutt and Tyagi (2011).

² According to Nasser *et al.* (2015).

According to Saikia *et al.* (1997).

Table 8. Analysis of variance for the strength properties of hansheets made from soda-AQ pulps

SOV	d.f.	Mean square			
		Pulp Yield	Kappa Number	Lignin content	Ash content
Reed types (RT)	1	39.31**	1492.5**	0.395 ^{NS}	1.77**
Reed Part (RP)	1	128.71**	7.04 ^{NS}	0.001 ^{NS}	0.80**
RT*RP	1	2.29*	6.24 ^{NS}	0.005 ^{NS}	0.40*
Error	20	0.269	3.99	0.095	0.07
Total	23				

** And * are significant at the 1% and 5% level of probability, respectively, and NS is not significant. For pulp yield the d.f. of the mean square error is 8.

The average values of the pulp properties of pulp produced by using AQ-sod pulping process from the two reed types and the two reed parts are presented in Table 9. The table also shows the specific wood consumption, SWC which calculated according to Sable *et al.* (2012) in $m^3.t^{-1}$. As can be seen that *P. australis* resulted in higher values of the pulp yield and ash content compared to those of *A. donax* and the same trend was found between the two reed part types for each reed type where the whole reed showed the highest pulp yield and ash content. No significant differences were detected for kappa number ranging from 14.8 to 32.6 while lignin content of the samples ranged from 4.0 to 4.3%. However, both the kappa number and lignin content of *A. donax* were higher than those of *P. australis* samples.

According to SWC it appears from Table 9 that the giant reed gives a higher value of SWC compared to common reed due to the higher density stem of the

common reed than giant reed. This means that assuming the digester is filled by volume of each reed types, common reed will produce more pulp in weight which will be more economical for paper manufacture.

The statistical analysis of the strength properties of the papersheet samples made from reed is presented in Table 10. The ANOVA showed that the effect of reed types on burst index and tear index was significant which meaning that each reed type differed significantly from the other. No significant differences were obtained between the two reed types for other strength properties of papersheets. The results in Table 10 showed the differences between the two parts types of reed were highly significant overall the strength properties of the samples. The interaction between reed types and reed parts were significant for all the strength properties of papersheets except their burst index.

Table 9. Yield pulp and properties of the pulp produced from the two reed types by soda-AQ pulping process

Reed type	Reed part	Pulp yield (%)	Kappa number	SWC ($m^3.t^{-1}$)	% content of	
					Lignin	Ash
<i>A. donax</i>	Stem only	43.9 ^D	15.40±2.1	4.74	3.98±0.1	3.65 ^C
	Whole	49.1 ^B	14.84±2.0	-	4.00±0.2	3.75 ^{BC}
<i>P. australis</i>	Stem only	46.2 ^C	32.60±1.7	3.42	4.24±0.4	3.93 ^B
	Whole	53.8 ^A	31.60±2.1	-	4.26±0.5	4.55 ^A
Significant		*	NS		NS	*

According to LSD test, means with the same letters in the same column are not significant at 0.05 level of probability.

SWC is specific wood consumption in $m^3.t^{-1}$ according to Sable *et al.* (2012).

Stem density is 481 and 632 $kg.m^{-3}$ and for *A. donax* and *P. australis*, respectively.

Table 10. Analysis of variance for the strength properties of papersheets made from reed by AQ-soda process

SOV	d.f.	Mean square				
		Tensile strength	Tensile index	Burst index	Breaking length	Tear index
Reed types (RT)	1	0.74 ^{NS}	8.24 ^{NS}	0.51**	0.09 ^{NS}	36.23**
Reed Part (RP)	1	88.90**	3926.8**	2.53**	40.84**	0.63**
RT*RP	1	17.36**	838.9**	0.04 ^{NS}	8.72**	5.61**
Error	16	0.88	38.16	0.02	0.40	0.06
Total	19					

** And * are significant at the 1% and 5% level of probability, respectively, and NS is not significant.

Table 11 shows strength properties of the papersheets produced from *A. donax* and *P. australis* reeds plant. Burst index ($\text{kPm}^2.\text{g}^{-1}$), tear index ($\text{mNm}^2.\text{g}^{-1}$) and brightness (%) as strength properties of the specimens made from the two types of raw materials were found significant from each other. Other strength properties including tensile strength (kN.m^{-1}), tensile index (Nm.g^{-1}) and breaking length (km) were not significant. The values of tensile index were measured in this study ranged from 51 to 52.3 Nm.g^{-1} for *A. donax* and *P. australis*, respectively the differences between them were not significant. The tensile strength of the samples increased with increasing cellulose content of the raw materials. Molin (2002), and Al-Mefarrej *et al.* (2013) also found that increasing cellulose content of the raw material increased the strength of the paper. The tearing indexes of the specimens calculated from the two reed plants were significantly different and *P.*

australis gave the higher value compared to those of *A. donax*.

The pulp brightness ranged from 17.9% to 19.8% for giant reed and common reed, respectively. All results related to the strength properties of papersheets made by using AQ-soda process from the two reed types and from the two reed parts are in the range of published data by Nasser *et al.* (2015), Abdel-Aal (2013), Sable *et al.* (2012), Aripin (2014). Based on the findings of this study, the two types of reed and the parts of them could have a potential for pulp and papermaking with accepted strength properties. These results are in agreement with Khiari *et al.* (2011) on date palm rachis from Tunisia and Khristova *et al.* (2005) on date palm rachis and leaves from Sudan and Aripin (2014) on non-wood plants from Indonesia, Nasser *et al.* (2015) on wheat straw and date palm midrib from Saudi Arabia and Sable *et al.* (2012) on two pine wood species.

Table11. Strength properties of the papersheets made from the two reed types and reed part types by soda-AQ pulping process

Reed type	Tensile strength (kN.m^{-1})	Tensile index (Nm.g^{-1})	Burst index ($\text{kPm}^2.\text{g}^{-1}$)	Breaking length (km)	Tear index ($\text{mNm}^2.\text{g}^{-1}$)	Brightness (%)
<i>A. donax</i>	7.75±3.4	51.00±22	2.07 ^A ±0.4	5.20±2.3	5.92 ^B ±0.8	17.86 ^B ±1.2
<i>P. australis</i>	8.13±1.3	52.29±8	1.75 ^B ±0.4	5.33±0.9	8.61 ^A ±0.5	19.80 ^A ±4.9
Significant	NS	NS	**	NS	**	**

Each value is an average of 10 samples except brightness is 6 samples.

Means with the same letters in the same column are not significant at 0.05 level of probability according to LSD test.

NS is not significant at 0.05 level of probability according to LSD test.

± is standard divisions.

Unbleached pulp cooked by AQ-soda process and beaten at 30° SR.

Table 12. Strength properties of the papersheets made from the two reed types and reed part types by soda-AQ pulping process

Reed type	Reed part	Tensile strength (kN.m^{-1})	Tensile index (Nm.g^{-1})	Burst factor ($\text{kPm}^2.\text{g}^{-1}$)	Breaking length (km)	Tear index ($\text{mNm}^2.\text{g}^{-1}$)	Brightness (%)
<i>A. donax</i>	Stem	10.79 ^A ±1	71.49 ^A ±9	2.47±0.14	7.29 ^A ±1.2	5.22 ^C ±0.17	19.00 ^B ±0.2
	Whole	4.71 ^D ±0.3	30.52 ^D ±2	1.67±0.12	3.11 ^D ±0.2	6.63 ^B ±0.24	16.72 ^C ±0.3
<i>P. australis</i>	Stem	9.31 ^B ±0.6	59.82 ^B ±4	2.06±0.15	6.10 ^B ±0.4	8.97 ^A ±0.34	24.49 ^A ±0.3
	Whole	6.96 ^C ±0.3	44.75 ^C ±2	1.49±0.16	4.56 ^C ±0.2	8.26 ^A ±0.18	15.10 ^D ±0.7
Significant		**	**	NS	**	**	**

Each value is an average of 5 samples except brightness is 6 samples.

Means with the same letters in the same column are not significant at 0.05 level of probability according to LAS test.

NS is not significant at 0.05 level of probability according to LSD test.

± is standard divisions.

Unbleached pulp cooked by AQ-soda process and beaten at 30° SR.

Table 13. Rating of the four raw materials including two reed types (*A. donax* and *P. australis*) and the two reed parts (stem and whole) used for pulp and papermaking (1= best and 4= worst)

Property (X)	<i>A. donax</i>		<i>P. australis</i>	
	Stem only	Whole plant	Stem only	Whole plant
Yield pulp	4	2	3	1
Pulp ash content	1	1	2	3
Tensile strength	1	4	2	3
Tensile index	1	4	2	3
Burst index	1	1	1	1
Breaking length	1	4	2	3
Tear index	3	2	1	1
Brightness	2	3	1	4
Score rank ($\Sigma X/8$)	1.75	2.63	1.75	2.38
Final rank	1	3	1	2

Table 12 displays the results for strength properties of the two reed plants species and the two reed parts. Overall, the results showed that the stem part of the two reed types gave the highest values of the strength properties of the papersheets while using the whole plant for pulping had the lowest one. *A. donax* have the highest strength values compared with *P. australis* in all the strength properties of the papersheets and the differences between them are significant. For example and for stem part, the highest tensile strength of papersheets ranged from 9.3 kN.m⁻¹ for *P. australis* to 10.8 kN.m⁻¹ for *A. donax*. The lowest tensile strength properties were obtained for the papersheets produced from the whole part of both the two reed types. Therefore it appears that both reed types are suitable as good raw materials for pulp and paper production.

The hypothetical rating using the measured data of both chemical and anatomical properties of reed as well as the strength properties of the papersheets produced from the reed types and parts are presented in Table 13. Using this rating method regarding to the determined properties of feedstock and papersheets produced from them, the stem of both giant reed and common reed showed a preferable order (1.75) followed by the whole plant of common reed (2.38), while the whole plant of giant reed showed the poorest rating (2.63).

CONCLUSION

Characterizations of chemical and morphological properties of two types of reed were evaluated, as well as the derived indices were calculated to investigate the suitability of such material as an alternative source for pulp and paper production. Reeds were used as raw material for pulp and papermaking using the modified soda process known as soda-AQ pulping process. The results showed small differences but significant between the two reeds types but in general all chemical and morphological properties of the two reed types indicated

that they could be used as an alternative source for pulp and paper production. The high ash content of the two types of reed may cause some problems during pulp and paper production. Based on the results found in this study it appears that the pulp and paper produced from both reed types and their parts had accepted strength properties and they could have a potential for pulp and paper production with accepted properties.

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المُلخَص العَرَبِي

إمكانية استخدام نوعان من البوص في صناعة لب الورق والورق

سليم توفاج ، السيد قنديل ، إبراهيم خيرالله ، حسني علي ، رمضان ناصر

خواصها الميكانيكية. أظهرت النتائج ارتفاع محتوى البوص العادي من الهيميسليلوز والسليلوز والرماد وكانت القيم ٥٣,٥%، ٣٣,٩% و ٣,٩%، على التوالي، في حين أعطى البوص العملاق قيم منخفضة في اللجنين فكانت ١٣,٦%. سجل البوص العادي والعملاق طول الياق أكبر من الاخشاب الصلدة وأقل من الاخشاب اللينة فكانت ١٨٠٠ و ١٤٠٠ ميكرون على التوالي. وكان معامل رانكل والمرونة المحسوب من ابعاد الالياف هو ١,٢٥ و ٦١,٤ على التوالي للبوص العادي. أظهرت الخواص الميكانيكية للورق الناتج من نوعي البوص اختلافات معنوية بين النوعيين وبين جزئي النبات سواء الساق او كل النبات. بناءً على النتائج المتحصل عليها من هذه الدراسة يمكن القول ان كلا من البوص العملاق والبوص العادي مواد غير خشبية صالحة جداً لإنتاج لب الورق والورق بخواص جودة ورق مقبولة وجيدة.

الكلمات المفتاحية: البوص- لب الورق- الورق- طريقة الصودا المعدلة- طول الالياف- جودة الورق.

الهدف من الدراسة هو قياس وتقييم مدى صلاحية نوعان من البوص هما البوص العملاق (*Arundo donax*) والبوص العادي (*Phragmites australis*) كمواد غير خشبية باستخدام طريقة الصودا المعدلة soda-anthraquinone لإنتاج لب الورق والورق كمادة بديلة للخشب في هذه الصناعة. كما استخدم في هذه الدراسة جزعين من نبات البوص هما الساق فقط Stem only وكامل النبات Whole plant لمعرفة تأثير مكونات النبات على عملية إنتاج لب الورق من البوص. واشتمل كامل النبات على الساق، الأوراق، الأغصان والنوره. تم تقدير الخصائص الحيوية للبوص والتي شملت خواص فيزيقية، كيميائية وتشريحية. واجري تقدير للكتلة الحيوية وتوزيعها النسبي. تم تقدير المستخلصات الكلية، المحتوى من السليلوز، اللجنين والهيميسليلوز وكذلك محتوى الرماد والإذابية في الصودا الكاوية ١%. وتم تقدير ابعاد الألياف الخشبية من طول الليفة وقطرها وابعادها الاخرى وتم حساب دلائل منها للحكم على مدى الصلاحية. كانت ظروف الطبخ ١٦% من الصودا الكاوية، ١٧٥م درجة الحرارة القصوى لمدة ٩٠ دقيقة. وتم تصنيع اوراق معملية Papersheets تم تقدير