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POTENTIAL OF COGON GRASS (IMPERATA CYLINDRICA) AS AN ALTERNATIVE FIBRE IN PAPER-BASED INDUSTRY

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ABSTRACT

Non-wood plants were examined as alternative fibre due to the limited origin resources in paper production. In Malaysia, *Imperata cylindrica* was used as renewable materials to obtain cellulosic pulps to produce paper and hence preventing the environmental problems. The chemical compositions, fibre dimension, pulp and mechanical properties of *I. cylindrica* were investigated for application in paper-based production. The surface morphology of hand sheet was also visualized. The chemical compositions involved in this study (holocellulose, cellulose, lignin, ash, hot water and 1% NaOH solubilities) were determined according to the chlorite method, Kurscher-Hoffner approach and TAPPI test method. Meanwhile, fibre dimension were measured following the Franklin method. The mechanical properties of the hand sheet (tensile, burst and tear indices) were measured according to the TAPPI test method. Scanning Electron Microscopy (SEM) was used to visualize the surface morphology of *I. cylindrica* hand sheet. The *I. cylindrica* has lower amount of lignin (5.67%), hot water (3.83%) and 1% sodium hydroxide solubilities (19.6%) than polished *C.tataria*, switch grass and Palmyra palm fruit. Although *I. cylindrica* contains high felting rate (139), the sheets produced showed higher tensile index (45.06 Nm/g), burst index (3.90 $kPam^2/g$) and tear index (2.17 mNm^2/g) compared to other published non-wood fibers. From SEM images, sheets of *I. cylindrica* contained abundant, straight and smooth fibre. In conclusion of the characteristic study, *I. cylindrica* is a good potential alternative fibre in the paper-based industry.

Keywords: cogon grass, chemical and fibre dimension properties, sustainable, mechanical properties.

INTRODUCTION

The net paper consumption in Malaysia is approximately 3 million metric ton in 2007 (Goyal, 2010), and was further increased in 2009 with the average paper consumption of about 151 kg/capita (Katri, 2010). Owing to the environmental concerns and resources depletion especially in wood, more attention is being paid to renewable materials as alternative fibre in the paper production. Therefore, non-wood plant materials including, annual plants and agriculture residues are potential substitute to replace the limited wood resources in paper-based industries (Rodríquez *et al*. 2008 and Ververis *et al*. 2004).

Imperata cylindrica is also known as japgrass, bladygrass, speargrass, alang-alang and lalang-lalang (Dozier *et al*. 1998). It is an aggressive and perennial grass that is distributed worldwide in the tropical and subtropical regions (Wilson, 2004). Today, cogon grass has been found in over 73 countries (MacDonald, 2004). In Malaysia, I. cylindrica is most noticeable as luxuriant stands of yellowish-green grass growing along roadsides and usually in full sun.

Due to the short growth cycle, abundance, yet unsuitable for grazing animal and lack of commercial applications of this grass, it can be proposed as an alternative fibre in the pulp and paper based industries to reduce or substitute the use of virgin pulp worldwide. The usage of I. cylindrica as an alternative fibre can increase the utilization of unused resources, and in the long run decreasing the demand for deforestation activities worldwide. The objectives of this study are to (a) investigate the chemical compositions and the fibre morphological properties, (b) determine the strength of hand sheet produced for paper-based application and (c) observe surface morphology of cogon grass sheets as a raw material for paper production by comparing their properties with those of successful non-wood plants from previous studies.

MATERIALS AND METHODS

Preparation of Material

I. cylindrica was collected from Parit Raja, Batu Pahat, Johor. Prior to air-dried, these samples were cut (2-5 cm) and thoroughly washed to eliminate sand and other contaminants. For chemical analysis, air-dried samples were ground (0.40 - 0.45 mm) and stored in an air tight container for further analyses.

Chemical Compositions

Chemical compositions of I. cylindrica were performed according to standard methods to determine cellulose, holocellulose, lignin hot water solubility, 1% NaOH solubility and ash contents. Prior to determination of chemical compositions, the I. cylindrica was submitted to soxhlet extraction for six hours according to method T 264 om-88. The evaluation of extractive substances was carried out in different liquids according to Technical Association of the Pulp and Paper Industry (TAPPI) standard methods: hot water solubility (T 207 om-08) and

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1% NaOH solubility (T 212 om-07). Ash content (T 211 om-07) was determined gravimetrically after total ignition at 525ºC for three hours in a muffle furnace. The lignin (klason lignin), holocellulose and cellulose were assessed by using the following respective standard methods: T 222 om-06, chlorite method (Han and Rowell, 1997) and Kurscher-Hoffner approach (Cordeiro *et al.* 2004).

Pulping and Pulp Properties

400 g oven-dried I. cylindrica was pulped using 15% active alkaline in a 7:1 liquid to sample ratio. This was carried out in Mk Twin Tub digester at a cooking temperature of 170 ºC for 90 min. Once reached the cooking temperature (170 ºC), the sample was isothermally cooked for another 120 min as shown in Figure-1. The cooked I. cylindrica was disintegrated in a hydro pulper for 15 minutes followed by thorough washing with tap water. Then, the pulp was screened on a fractionator vibratory flat screen with 0.25 mm slits. The pulp was concentrated by a centrifuge to about 20 min and homogenized using a Hobart mixer for 10 min. Rejected and screened pulp were dried to constant weight at 105 ºC for determination of dry weight and subsequently, yield of the pulp.

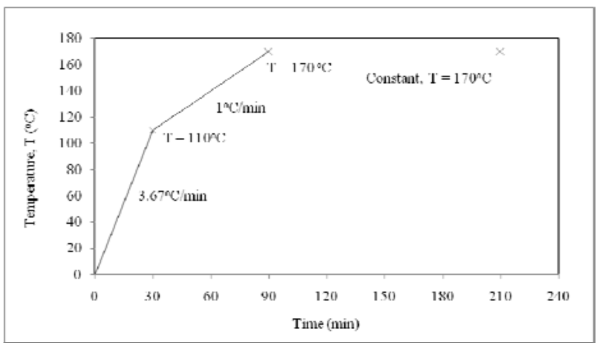

Figure-1. Condition of cooking time and temperature.

Morphological Characterization

To measure the fibre length of the cogon grass, Franklin method (Han *et al.* 1999) was applied. In this method, the grass pulp was immersed into glacial acetic acid and hydrogen peroxide for 24 h at 60 ºC in a water bath. The reaction was stopped by dispersing the pulp in distilled water. Next, the pulp was gently mixed in a magnetic stirrer container for 60 min to separate of the fibre bundles into individual fibre and three drops of safranine-O was added into the mixture and allowed to homogenously mix. Three drops of the mixture was transferred to microscope glass slides. The fibre length was then measured using a profile projector microscope (Nikon V-12, Japan) at 100x magnification. Ten individual fibers were selected and measured in this study.

Mechanical Property

The conventional papers with a basis weight of 60 g/m^2 were prepared according to T 205 sp-02. Prior to mechanical testing, the hand sheets were put at a condition of 25 ºC with 50% relative humidity for 24 hr. Eight papers were used to determine the tensile, tearing and bursting strengths according to standard method T 494 om-06, T 414 om-04 and T 403 om-08 respectively.

Surface Morphology

A small portion of the hand sheet was cut and the sample was coated with a thin layer of gold. Then the surface morphology of sample was observed using a scanning electron microscopy (SEM) (Quanta 200) at different magnifications (500x and 1000x).

Statistical Analysis of Data

The experimental data regarding the results of chemical compositions, fibre dimensions and physical properties of pulp and hand sheet of I. cylindrica were statistically analyzed by Kruskal-Wallis test. All the statistical analyses were conducted by using computer program of SPSS 19.0.

RESULTS AND DISCUSSIONS

Chemical Compositions

The papermaking potential of I. cylindrica was investigated in this study. Chemical analyses (three replicates) were performed for each property under specific methods and average values of I. cylindrical were summarized in Table-1. The quantified data characterized I. cylindrica with relatively low lignin (5.67%), ash (8.24%) and hot water solubility (3.83%), whereas acceptable holocellulose, cellulose and 1% NaOH solubility of 64.9%, 37.1% and 19.6% respectively.

Table-1 also presents the chemical compositions of several published non-wood plants, which have been successful as alternative fiber resources. Chemically, holocellulose and cellulose are important parameters in measuring the suitability of material for paper production (Sridach, 2010). I. cylindrical (64.9%) shows the lowest amount of holocellulose than Palmyra palm fruit (68.5%) and C.tatarial (70.5%). Generally, holocellulose is the total content of cellulose and hemicellulose in dried materials (Rowell *et al.* 2000) and usually should accounts for 65 to 75% of the plant dry weight in order to be potential alternative fiber (Han and Rowell, 1997). Therefore, the amount of holocellulose obtained in I. cylindrica is acceptable to be applied in paper production.

When comparing between Palmyra palm fruit and I. cylindrica, it appears that the cellulose content is relatively similar as seen in Table-1. Although, the lower amount of cellulose content in I. cylindrica than other non-wood materials indicated lower fibre availability, Shakhes *et al.* (2011) stated that plant materials with 34% and higher cellulose content were considered as promising candidate for pulp and paper production. This is because the strength properties of the paper highly depending on the cellulose content of the material.

Interestingly, I. cylindrica shows the lowest content of lignin than all non-wood plants (Table-1). Lignin is considered as an undesirable polymer and must

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be removed during the pulping process (Rodríquez *et al.* 2008). In addition, high amount of lignin could be disadvantages during the pulping process (increase volume of liquor concentration and temperature needed), bleaching process (more chemicals and energy needed) and ultimately rising hazard release to the environment if not fully treated (Dutt and Tyagi, 2011; Marques *et al.* 2010; Wathén, 2006). Moreover, high lignin can decrease the performance of paper product and can cause yellowing of the paper products.

Ash content analysis quantified minerals or inorganic component found in plants fibre (Shakhes *et al.* 2011). As seen in Table-1, I. cylindrical has the highest amount of ash content compared to C.tataria, switch and elephant grasses and Palmyra palm fruit. High amount of ash content obtained in I. cylindrica can cause problem during refining and recovery of the cooking liquor due to the deriving silica content of this material (Rodríquez *et al.* 2008). For this reason as well, the cogon grass is unsuitable for the grazing animals. Although ash content in cogon grass is the highest, the value is still at the low end of the range (0 – 20%) in non-wood characterization study by Rowell *et al.* (2000).

The hot water solubility of I. cylindrica is quite similar with switch grass, but lower than C.tataria, elephant grass and Palmyra palm fruit as seen in Table-1. High value of hot water solubility indicated that the material contains high content of tannins, gums, sugar, colouring matters and starch that could affect the quality of the pulp and paper produced (Akpakpan *et al.* 2011). 1% NaOH solubility is another parameter that is linked to the quality and performance of the pulp and paper product. The lowest amount of 1% NaOH solubility in I. cylindrica is preferred and indicates low amount of fibre will be disintegrated during the pulping process and hence resulting in high pulp yield compared to the rest non-wood.

Table-1. Comparison of chemical compositions of *I.* cylindrica with published non-woods.

Property (% w/w o.d)	Species				
	I. cylindrica (Kassim et al., 2015)	*C. tataria* (Tutus et al., 2010)	Switch grass (Madakazde et al., 2010)	Elephant grass (Madakazde et al., 2010)	Palmyra palm fruit (Sridach, 2010)
Holocellulose	64.9	70.5*	n.a.	n.a.	68.5
Cellulose	37.1	40.1	41.2	45.6*	37.0
Lignin	5.67*	24.5	23.9	17.7	18.5
Ash	8.24	7.83	4.83	4.23	0.64*
Hot water solubility	3.84	18.0	3.80*	10.9	21.3
1% NaOH solubility	19.6*	34.9	34.7	44.6	44.7

n.a. not available; *best values for paper-making parameters.

Fibre Dimensions

Table-2 shows the fibre length, diameter and felting rate of I. cylindrica and other published non-wood plants fibre. The fibre length and diameter of I. cylindrica were 1.04 mm and 7.49 µm respectively. The fibre length was higher than that C.tataria, switch and elephant grasses, but lower than tobacco fibre as seen in Table-2. Meanwhile, the fibre diameter of I. cylindrica is the smallest than other plants in Table-2.

The fibre length of any plant is vital since there is a strong relationship between the fibre length and the strength properties of the resultants pulp and paper product (Ververis *et al.* 2004; Akpakpan *et al.* 2011). The relationship between fibre length and diameter was explained based on the felting rate of the material. This criterion was used to determine suitability of a fibre in papermaking. Since the felting rate (slenderness) is positively correlated with the strength property of the material, I. cylindrica is the best among the four non-wood materials in Table-2. Based on this quantification, I. cylindrica is expected to consist of long and thin fibre which can be confirmed by surface morphology analysis.

Table-2. Comparison of fibre dimensions of the I. cylindrica with other non-wood fibre.

Material	Property			References
	Fibre length (L), mm	Fibre diameter (D), µm	Felting rate (L/D)	
C.tataria	0.62	17.4	35.5	Tutus et al., 2010
Switch grass	0.76	13.9	94.3	Madakadze et al., 2010
Elephant grass	0.75	15.1	87.9	Madakadze et al., 2010
Tobacco	1.23*	24.3	50.6	Shakhes et al., 2011
I. cylindrica	1.04	7.49	138*	Kassim et al., 2015

*best values for paper-making parameters.

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Pulping and Pulp Properties

The key parameters that indicate the performance of the pulping process are the pulp yield and fibre strength. Table-3 shows the yield, tensile index, tear index and burst index of cogon grass and other published non-wood pulp from previous study. It can be seen that I. cylindrica has the highest amount of pulp yield (38.2%) compared to vine shoot (32.1%) and rice straw (33.9%). The pulp yield is directly depending on the liquor concentration, cooking temperature, cooking time and types of pulping process (Sridach, 2010). High amount of pulp yield is due to the low degradation of cellulose polymer during the pulping process (Dutt and Tyagi, 2011) which is also contributed by the low amount of lignin in the material.

The mechanical properties of pulp sheets (tensile, tear and burst indices) are probably the most used parameters for the direct measurement of paper strength as reported in Table-3. Increase fibre length and decrease cell wall thickness had considerable effects on the physical properties of the paper (Tutus *et al.* 2011). The pulp sheet of I. cylindrica shows the highest tensile index (45.06 Nm/g) and burst index (3.90 kPa.m^2/g) compared to other non-wood plants. The high strength in tensile and burst indices are affected by the fibre length and fibre formation of the paper product (Tutus *et al.* 2011). I. cylindrica has longer fibre length than most non-wood species as depicted in Table-2. Fibre length ia also correlated with the tear strength of the material. Although tear index of I. cylindric (2.17 mN.m^2/g) is lower than canola straw (5.07 mN.m^2/g), it is much higher than vine shoot and rice straw. Low tear index could indicate a reduce of cell wall thickness (Tutus *et al.* 2011) and decrease in the inter-bonding of fibre (Ashori *et al.* 2004) that could be influenced by the degradation of carbohydrate during the pulping process (Nada *et al.* 2004).

Table-3. Comparison of pulp and mechanical properties of I. cylindrica hand sheets with other non-wood.

Material	Property				References
	Yield (% w/w oven dry)	Tensile index (Nm/g)	Burst index (kPa.m^2/g)	Tear index (mN.m^2/g)	
Canola straw	n.a.	24.0	1.22	5.07*	Enayati *et al.*, 2009
Vine shoot	32.1	6.45	1.01	0.90	Jiménez *et al.*, 2006
Rice straw	33.9	26.1	1.20	1.20	Rodríquez *et al.*, 2008
I. cylindrica	38.2*	45.1*	3.90*	2.17	This study

n.a: non-available; *best values for paper-making parameters.

Surface Morphology

Figure-2 displays the SEM images of the I. cylindrical hand sheets at different level of magnifications (500x and 1000x) show the major features of the fibre physical structure on the sheet produced. In Figure-2a, abundant long fibre of cellulose and hemicellulose are randomly distributed on the surface of I. cylindrica hand sheet. In addition, several parenchyma cells are also appear on the surface hand sheet made, which is expected of the characteristic feature in this species (Gominho *et al.* 2001; Abrantes *et al.* 2007).The sheet produced from cogon grass is an inter-bonded membrane (Figure-2b) due to the hydrogen bond between cellulose and hemicellulose fibre (Ang *et al.* 2010), which increase the strength properties of the sheet. The fibre cogon grass is uniform, straight, and intact with a smooth surface. Several broken fibre are also appear (Figure-2b) due to the pulping process and it could also reduce the quality and strength properties of hand sheet.

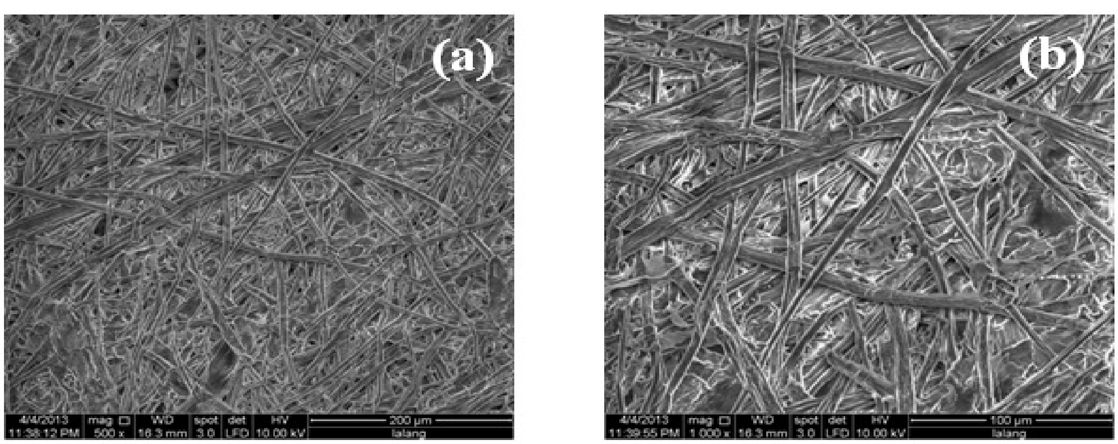

Figure-2. SEM images of I. cylindrica hand sheet at magnifications of: (a) 500x and (b) 1000x.

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CONCLUSIONS

A comparison of cogon grass's chemical properties with various non-wood plants reveals that this material is an effective alternative resource in producing pulp and paper sheets mainly due to its low lignin, hot water and 1% NaOH solubilities and acceptable content of hollocellulose. The morphological properties of I. cylindrica (fibre length and diameter) are in the range of the successful alternative fibre as in published non-woods and it is reasonably suitable to be applied in paper-based industries. The SEM images show that the I. cylindrica hand sheet is uniform, straight with abundant long and thin fibre.

The I. cylindrica was successfully converted into pulp indicated by the high pulp yield quantification after the pulping process. High strength in tensile (45.1 Nm/g), burst (3.90 kPa. m^2/g) and tear (2.17 mNm^2/g) indices further supported that I. cylindrica is a suitable alternative fibre to be used in paper-based production.

The results of this study provide an understanding that I. cylindrica fibre represents a highly potential alternative resource for pulp and paper-based manufacturing. It gives an insight of this underutilized non-wood resource (cogon grass), for various application possibilities in paper-based industries as well as in other sectors such as biofuel and agriculture.

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