Utilization of Pandan Leaf Fibers (*Pandanus simplex merr.*) for the Production of Paper

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Abstract. One of the main consumers of natural resources and energy is the paper industry. Wood is the conventional raw material in the producing pulp and paper around the world. The dependence on timber material to produce paper has led to the severe deforestation and greatly affected the ecosystem’s flora and fauna. With the increasing demand for paper, efforts are being made to find non-timber materials for paper production. *Pandanus simplex merr.* is a *Pandanus* species that is endemic to the Philippines and the amount of agricultural waste materials from its leaves being used for weaving contributes to solid wastes. In this study, we investigate the production of paper sheets from *Pandanus simplex merr.* leaf fibers and determine the effect of the pulping concentration to the tensile properties of the paper sheet made. The paper sample made using a 5% w/v NaOH pulping solution had the highest tensile index of 2.234 Nm g⁻¹, tear index of 8.46 mN m² g⁻¹, and average pore size 29.094 μm. The paper sheets produced showed potential as a sorbent material and can be used as an alternative to wood source in producing pulp and paper.

1. Introduction

One of the most important inventions that has become a necessity in the modern world is paper. Traditionally, it is mainly produced from wood and is used for educational, packaging, and construction purposes among many others [1]. Recent studies have established the potential of paper as an inexpensive, biodegradable, sustainable polymer substrate [2]. With wood being used as the conventional raw components for the production of pulp and paper, the result to is the severe depletion of forest resources and this has consequently created negative impacts in our environment [3]. With the increasing demand for paper and the decreasing conventional supplies for pulp production, this has led to research for an alternative raw material for producing paper [4]. In the Philippines, burning agricultural crop residues is still a common practice. A survey conducted in 2007, indicated that only 5% of the rice crop residue is used for other activities while 95% is burnt in the field. With the average rice produced year of 14,239 kiloton, 10,146 kilotons of rice straw were estimated to be burnt in the field [5].

A strategy to reduce crop residue burning is utilizing agricultural residues as substitute resource in the pulp and paper industry. Also, the short growth cycles, and the material’s low lignin content improves the use of the chemicals and energy during the pulping process [3]. Pandan leaf fibers have similar if not greater cellulose content than conventional wood used in the pulp and paper industry [6]. The pandan leaves can be also processed into textile products such as ropes, mats, and other woven products. However, little study can be found on pandan leaves being used as an alternative material for paper production.
This study aims to produce a paper sheet from *Pandanus simplex merr.* leaves using the traditional soda pulping method, and to study the effects of the concentration of pulping solution to the tensile properties of the paper samples.

2. Methodology

2.1. Raw material preparation
Pandan leaves were dried at 60°C for 12 hours in a laboratory oven and cut into small pieces of about 2 cm long.

2.2. Handmade paper preparation and formation
The pandan leaves were pulped using the soda process using different NaOH solution (5%, 9%, and 15%). Wherein the prepared raw material was boiled with stirring in a NaOH solution at 105°C for 4 hours with a weight of oven-dried raw material to volume of NaOH solution ratio of 1:2. After pulping, the pulp was filtered and washed with distilled water. The pulp was then disintegrated using a laboratory blender and dried in an oven at 60°C. The dry mass of the pulp to be used for paper production was determined.

A 1% pulp slurry solution was prepared, transferred and dispersed evenly into a mold and deckle of 10 cm wide and 20 cm long in a plastic tub filled with distilled water. Water was allowed to drain completely, and the wet sheet was transferred onto a muslin cloth. The formed sheet was then covered with 5 pieces of muslin cloth and pressed using a rolling pin. The formed sheet was then transferred to a galvanized iron sheet and covered with 2 pieces of muslin cloth. The formed sheet was pressed using a rolling pin once more. The muslin cloth covering the formed sheet was then removed and the sheet was air dried on the iron sheet.

2.3. Thickness
Using a Shirley Thickness Tester, the thickness of the paper sheet produced was determined following T-411 om-97 Tappi standard. The samples were measured at ten different locations of the sample. The mean thickness of the paper sample was then determined and recorded.

2.4. Absorbency
Using a micropipette, 5 μL of distilled water was transferred on the paper sample. The time it takes for the water droplet to disperse through the sample was measured using a stopwatch. This was repeated fifteen times, dropping 5 μL of distilled water on different locations on the sample. Using PM-I01 ink, the same procedure was done to test the ink absorbency of the paper sample.

2.5. Tensile index
For each sample of paper sheet produced, a total of 5 test pieces that were 20 mm wide and 160 mm long were prepared. The tensile index of each sample was then determined using a Universal Testing Machine. The rate of elongation was set at 2 mm per minute.

2.6. Tearing resistance
The internal tearing resistance of the paper sample was determined using an Elmendorf-type tearing tester following the T-414 om-98 Tappi standard. The paper sample was clamped at the center of the clamps using the same pressure on both clamps. An initial knife cut was made, and the tearing force was measured and recorded.

2.7. Surface Morphological Analysis
A Scanning Electron Microscope was used to study its fiber morphological properties of handmade paper sheets made from *Pandanus simplex.* The samples were sputtered with gold coating. The pore sizes were measured using *ImageJ* software.

2.8. Contact Angle
The contact angle of the paper samples was measured following the T-558 om-97 Tappi standard. For each sample, measurements were repeated five times on different locations on the sample and the corresponding mean result was recorded.

3. Results and discussion
The leaves of P. simplex were collected in Cavinti, Laguna, Philippines in June 2019 and identified by Engr. Teresita F. Bueno from Laguna State Polytechnic University.

Table 1. Soda pulping pulp yield.

| Pulping Solution Concentration | Pulp Yield (%) |
|--------------------------------|----------------|
| 5% NaOH                        | 39.20          |
| 9% NaOH                        | 33.15          |
| 15% NaOH                       | 28.80          |

The pulp yield from either a certain species of wood or agricultural waste is greatly influenced by the pulping method used. In this study, the traditional soda pulping method was used to digest the pandan leaves to produce pulp for paper production. The concentration of the pulping solution was varied while keeping the cooking temperature and cooking time constant at 105°C for 4 hours. As shown in Table 1, the pulp yield using 5% w/v NaOH was the highest while the pulp yield using 15% w/v NaOH was the lowest.

3.1. Physical properties: grammage and thickness
As shown in Figure 1, the thickness of the paper increases as the grammage increases. An increase of grammage 145.39 g m⁻² to 162.08 g m⁻² resulted in an increase in the thickness of the paper sample from 617.5 μm to 775.5 μm. This is probably because there were more cellulosic fibers in the paper sample per unit area. The data shows that the thickness of the paper sample is a factor of the amount of the material that was used to produce the paper. Wherein, the more raw material used to produce a sheet of paper, the greater the grammage as well as the thickness of paper increases.

Figure 1. Relationship between Grammage and Thickness.

3.2. Absorbency
It was found that the absorbency time of the paper samples made using 15% w/v NaOH solution was the highest for both liquids while the paper sample made using 5% w/v NaOH solution was the lowest. For the paper sample made using 15% w/v NaOH solution, the absorbency time was 1.895s for ink
and 9.653s for distilled water. As for the paper sample made using 5% w/v NaOH solution, the absorbency time was 1.113s for ink and 5.119s for distilled water. As shown in Figure 2, The absorbency time increases as the concentration of the pulping solution increased. This might be because the paper sample made using a NaOH solution lower than 15% w/v had a higher cellulose or lignin content that may have resulted in a higher moisture uptake rate [7].

![Figure 2. Absorbency time of various paper samples.](image)

### 3.3. Tensile strength, tensile index, and tear index

The mean tensile properties of the paper samples were determined using a universal testometric machine. A total of 5 trials per each sample of paper was done and the results are shown in Table 2.

| Sample | Maximum Force (N) | Young’s Modulus (MPa) | Tensile Strength (kN · m⁻¹) | Elongation (%) | Tensile Index (Nm · g⁻¹) |
|--------|-------------------|-----------------------|-----------------------------|----------------|----------------------|
| Paper 5% NaOH | 5.721 ± 1.050 | 19.829 ± 4.861 | 0.286 ± 0.052 | 2.32 ± 0.22 | 1.894 ± 0.347 |
| Paper 9% NaOH | 3.933 ± 0.798 | 29.509 ± 8.220 | 0.204 ± 0.041 | 1.60 ± 0.37 | 1.353 ± 0.274 |
| Paper 15% NaOH | 4.301 ± 0.973 | 16.119 ± 2.723 | 0.200 ± 0.045 | 3.13 ± 0.26 | 1.327 ± 0.300 |

Table 2 shows the average tensile properties of the paper samples produced in this study. The results showed that the paper sheet made using a 9% w/v NaOH pulping solution had the highest Young’s modulus (29.509 MPa) while the paper sheet made using a 15% w/v NaOH had the lowest (16.119 MPa). The tensile properties of the paper sheet samples tested were inferior compared to paper available commercially. However, the pulping method used for commercially available paper is more efficient compared to the pulping method used in this study. Also, additives such as mineral fillers, binders, and retention agents are added to paper available commercially that significantly improves the properties of paper.

In Figure 3, the tensile index of the paper samples seems to decrease as the concentration of the pulping solution increase. The paper sample made using 5% w/v NaOH solution had a tensile index of 1.894 Nm g⁻¹ while the sample made using 15% w/v NaOH solution had a tensile index of 1.327 Nm g⁻¹. The tensile index obtained for the paper sample made with 5% w/v NaOH solution could be due to the presence of more cellulosic fibers in the sample [8].
Figure 3. Average Tensile index of the paper sample tested.

Figure 4. Average Tear index of the paper sample tested.

In Figure 4, the result of the tear index analysis showed that as the concentration of the pulping solution increased, a decrease in the tear index of the paper samples can also be observed. The paper sample made using 5% w/v NaOH solution had a tear index of 8.46 mN m\(^{-2}\) g\(^{-1}\) while the sample made using 15% w/v NaOH solution had a tear index of 4.01 mN m\(^{-2}\) g\(^{-1}\). The decrease in tear index may be caused by the increase in the cellulose/hemicellulose ratio [9]. Wherein as the pulping solution concentration increases, the more hemicellulose is degraded. Also, it must be noted that the consistency of the pulp, degree of pulp beating, impurities, and the uneven formation of the paper sample may affect the properties of the paper sheet. The tear index of the paper sheet made using 5% w/v NaOH solution is comparable to the tear index of paper samples such as Filter paper, Index card, Newsprint, and Pamphlet cover [10].

3.4. Surface morphological analysis

As shown in Figure 5, the results showed that bulk fiber bundles can be found in the paper sample. These bundles of fibers were technical fibers made up of finer elementary fibers. The results showed that as the concentration of the pulping solution increased, the more the delamination of elementary fibers from the bulk technical fibers as shown in Figure 5a, Figure c, and Figure e.
Figure 5. SEM images of paper samples made using (a) 5% NaOH at x100 magnification, (b) 5% NaOH at x1000 magnification, (c) 5% NaOH at x100 magnification, (d) 5% NaOH at x1000 magnification, (e) 9% NaOH at x100 magnification, and (f) 9% NaOH at x1000 magnification.

The average pore size of the paper samples was determined using the ImageJ software. From Table 3, the average pore size decreases as the pulping concentration used to produce the paper sample increased. This decrease may result from the presence of more elementary fibers to fill the gaps. The distribution of the fibers, grammage, and impurities are also factors may influence the average pore size of a paper sample.
| Sample  | Average Pore Size (μm) |
|---------|-----------------------|
| Paper 5% NaOH | 29.094 ± 17.507 |
| Paper 9% NaOH | 16.397 ± 6.4474 |
| Paper 15% NaOH | 11.598 ± 7.179 |

3.5. Contact Angle
Lastly, the contact angle of the paper samples was determined. Wherein, as shown in Figure 6, the contact angle of the paper sample increases as the pulping solution used to make the paper sheet increases. All paper samples had a surface contact angle less than 90° and were considered to be hydrophilic. The contact angles of the paper samples also decreased rapidly over time. This rapid decrease shows that the paper samples has potential as a sorbent material.

Figure 6. Average contact angle of paper samples tested.

4. Conclusions
In this study, paper sheets were made using Pandanus simplex merr. leaves using the traditional soda pulping method. Using a pulping solution concentration of 5% w/v NaOH, the highest pulp yield was obtained (39.20%). The paper sheet made using a 5% w/v NaOH pulping solution also demonstrated the highest value for Tensile index (2.234 Nm g⁻¹) and Tear index (8.46 mN m⁻² g⁻¹) while the paper sheet made using a 15% w/v NaOH pulping solution had the lowest for both tests (1.430 Nm g⁻¹ and 4.01 mN m⁻² g⁻¹). The most absorbent paper (1.113s for ink and 5.119 for distilled water) was found to be the paper sheet made using a 5% w/v NaOH pulping solution. Using the ImageJ software, the paper sheet made using a 15% w/v NaOH pulping solution had the lowest average pore size (11.598 μm) while the paper sheet using a 5% w/v NaOH pulping solution having the highest (29.094 μm). The surfaces of all paper sample were determined to be hydrophilic having a contact angle of less than 90°. The contact angles of the paper samples also decreased rapidly over time and shows potential as a sorbent material. The results obtained from this study shows the potential of the leaves of Pandanus simplex merr. as substitute material to wood source for the production of pulp and paper.

For future works that will use the same pulping method, it is recommended that the effect of the cooking time, temperature, and beating time to the tensile properties of the paper samples be studied. Different filler additives should also be investigated to determine the dynamics of filler additive that produces the highest quality of paper sheet made from Pandanus simplex merr. leaves. The use of a sheet former is also recommended to future researchers to produce a paper sheet that has uniform fiber distribution. Moreover, the capabilities of the paper sheet made from Pandanus simplex merr. leaves as a sorbent material is also recommended to be investigated in future studies. Lastly, the pulping
method in this study is considered to be a harsh pulping method where most of the hemicellulose is degraded as the pulping proceeds. It is then recommended to use a milder pulping method such as peracetic acid or sodium chlorite.

5. References
[1] Sibaly S, Jeetah P 2017 Production of paper from pineapple leaves Journal of Environmental Chemical Engineering 5 5978–5986
[2] Mazlana N, Talib R, Ibrahim R, Abdul R 2014 Suitability of Coir Fibers as Pulp and Paper Agriculture and Agricultural Science Procedia 2 304–311
[3] Aremu M, Rafiu M, Adeleke K 2015 Pulp and Paper Production from Nigerian Pineapple Leaves and Corn Straw as Substitute to Wood Source Int. Res. J. Eng. Technol.
[4] Sharma C, Kumar S 1999 Detection of chlorophenolics in effluents from bleaching processes of rice-straw pulp J. Environ. Monit. 1 569–572
[5] Gadde B, Bonnet S, Menke C, Garivait S 2009 Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines Environ. Pollut. 157 1554–1558
[6] Teli M, Jadhav A 2017 Mechanical Extraction and Physical Characterization of Pandanus Odorifer Lignocellulosic Fibre Int. J. Sci. Res. 6 1370–1374
[7] Dwan A 2006 Paper Complexity and the Interpretation of Conservation Research J. Am. Inst. Conserv. 26 1
[8] Suhr M, Klein G, Kourti I, Gonzalo M, Giner-Santonja, G, Roudier S, Sancho L 2015 Best Available Techniques (BAT) - Reference Document on Best Available Techniques in the Pulp and Paper Industry
[9] Molin U, Teder A 2017 Importance of cellulose/hemicellulose-ratio for pulp strength Nord. Pulp Pap. Res. J. 17 14-19a
[10] Biermann C 1996 Handbook of pulping and papermaking

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