

Exploring of Agro Waste (Pineapple Leaf, Corn Stalk, and Napier Grass) by Chemical Composition and Morphological Study

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Malaysia is a country that is a rich source of agricultural waste material. Three different crops were studied here, including pineapple (*Ananas comosus*) leaf, corn (*Zea mays*) stalk, and Napier grass (*Pennisetum purpureum*). These crops are characterized as agricultural waste materials in Malaysia and have a high potential to be used as alternative fibers for the paper making industry. The objective of this work was to analyze the chemical composition of pineapple leaf, corn stalk, and Napier grass and to investigate the fiber morphology of these crops. The chemical components analyzed include the following: cellulose (Kurshner-Hoffner method), holocellulose (chlorination method), hemicellulose (chlorination method), ash content (TAPPI method T211-om-93), lignin content (TAPPI method T222-om-98), and soluble sodium hydroxide (TAPPI method T203-om-98). All handsheets morphologies were observed using scanning electron microscopy (SEM). Results indicated each crop has the potential for use as a fiber in paper making. SEM images indicated a condensed composition of the fiber structure. The observed chemical composition and morphology of these three crops indicate their suitability for use as fiber sources for the paper industry.

Keywords: Fiber; Napier grass; Pineapple leaf; Corn stalk; Composition; Green technology; Pulp and paper making

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INTRODUCTION

Wood makes up about 90% of the conventional raw material used for pulp and paper production in the world (Madakadze *et al.* 1999). However, depleting forests to obtain the wood has made an impact on the environment (Mohanty *et al.* 2005). As this issue becomes a crucial one, alternative fibers from non-wood sources will provide a good solution to limiting the destruction of the environment. Many paper industries have applied the kraft process as their main pulping process.

Figure 1 depicts the process of paper production in the pulp and paper industry. Previous studies have compared non-wood and wood materials for the suitability of their fibers in paper making (Tran 2006). Stenius (2000) reported that the composition of wood and non-wood material can be quite similar. Such findings suggest that nonwood species can provide a good solution to the need for alternative fiber.

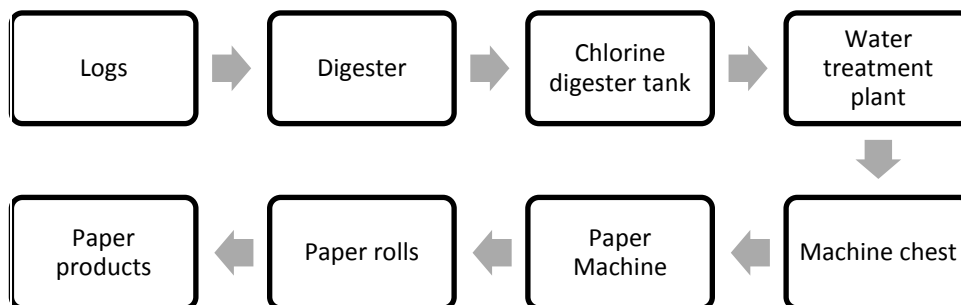


Fig. 1. Overview of the paper making process (Aziz and Zhu 2006)

Pineapple is a common tropical plant that consists of coalesced berries (Banik *et al.* 2011). This plant is the lead member of the Bromeliaceae family and comes from the genus *Ananas*. A fiber bundle from pineapple leaves can be separated from the cortex, and the pineapple leaf fiber has been shown to be multi-cellular and lignocellulosic (Arib *et al.* 2006).

The crucial paper properties depend on the chemical compositions of the pineapple leaf fiber, which consists of cellulose, hemicellulose, and lignin (Madakadze *et al.* 1999). The pineapple leaf has a ribbon-like structure and is cemented together by lignin and pentosan-like materials, which bind together with a cellulosic composition (Banik *et al.* 2010). Apart from the lignin, both cellulose and hemicelluloses will lead to the high strength of the fiber produced. As shown by Tran (2005), pineapple leaf fiber from Japan shows a greater cellulose content than that from wood fiber. This result confirmed the cellulose content of pineapple leaf fiber and showed how the composition could affect the properties for paper production.

The corn plant is from the Poaceae family and the *Zea* genus (*Zea mays*). This plant has a distinct growth form, wherein the leaves are generally 50 to 100 centimetres long and the stems can be up to 2 to 3 metres in height (Reddy and Yang 2005). Flandez *et al.* (2010) reported that corn stalk could be a good source of lignocellulosic fibers for the production of pulp for papermaking. Corn stalk has a reported fiber length of 1.32 mm, fiber width of 24.3 mm, lumen width of 24.3 mm, and cell wall thickness of 6.8 mm (Akhgul *et al.* 2010). Lignocellulose from cornstalk is composed of single cells of cellulose that are only about 0.5 to 3.0 mm in length (Pang *et al.* 2012). Cornstalks are a cheap and annually renewable resource suitable for producing natural cellulose fibers.

Napier grass is in the Poaceae family and the *Pennisetum* genus. This grass has high yielding fodder, giving dry matter yields that surpass most other tropical grasses (Ansah *et al.* 2010). Natural detergent fibers are based on hemicelluloses and cellulose, but not pectin, and these are the most common chemical components in the structural elements of plant cells (Ansah *et al.* 2010).

Therefore, the purpose of this study is to analyse the chemical compositions and to give a comprehensive overview by analysing the fiber morphology of handsheets produced from pineapple leaves, corn stalks, and napier grass.

EXPERIMENTAL

Preparation of Samples

The sample of pineapple leaf was collected from Ayer Hitam, Johor. Corn stalks were collected at Pontian, Johor. Napier grass was collected at Parit Sulong, Johor. These raw materials were used as alternatives to wood fibers in the paper production carried out this study. All samples were washed with water to remove any impurities from the non-wood material. The samples were air-dried at ambient temperature for 72 h. Samples were then further dried in an oven at 110 °C for 24 h to make sure there were no water particles inside the sample. Next, the sample was cut into smaller pieces, ground with a grinder, and sieved to about 2 mm. After that, the samples were collected in plastic bags and placed in air-tight containers.

The prepared samples underwent TAPPI test method T 264 om-97 for the chemical composition analysis.

Analysis of Chemical Compositions

The chemical attributes under investigation were cellulose, lignin, hemicellulose, holocellulose, 1% sodium hydroxide solubility, hot water solubility, and ash content. These were determined according to the following TAPPI standard methods:

1. T 211 om-07 (ash content)
2. T 212 om-98 (1% sodium hydroxide solubility)
3. T 222 om-98 (lignin content)
4. Kurshner-Hoffener method (cellulose and hemicelluloses content)
5. Chlorination method (holocellulose).

The Kurshner-Hoffener method makes use of alcoholic nitric acid with four cycles of treatment to determine the hemicelluloses content. The chlorination method is used to test for both hemicelluloses and cellulose. Results from tests of hemicelluloses content were then used to determine cellulose content for the three sample.

Analysis of Surface Morphology

To study the non-wood fiber morphological properties, the produced handsheets were observed under a scanning electron microscope (SEM). Images were taken under several magnifications to observe the content, arrangement, and compactness.

RESULTS AND DISCUSSION

Analysis of Chemical Compositions

The chemical compositions of pineapple (*Ananas comosus*) leaf, corn (*Zea mays*) stalk, and napier grass (*Pennisetum purpureum*) are listed in Table 1. Results indicate that these raw materials have a high potential for use as alternative fibers for pulp and paper making.

Overall, pineapple leaf fibers were found to have a lower ash content (4.5%) than corn stalk (24.9%) and napier grass (14.6%). The function of ash content is to show the absence or presence of other materials such as various organic and inorganic matter. The low ash content indicates high pulp yield from pulping process (Lopez *et al.* 2004). Pineapple leaf has very high moisture content (81.6%) compared to that of corn stalk

(7.3%) and napier grass (11.7%). This high moisture content will affect the mechanical and surface properties of the paper, as less dimensional stability of the paper will be obtained. The adsorption of water on the vast internal surfaces in the cell wall will change the external dimensions of the stability of that paper. A quality paper product needs a good dimensional stability, because the structure and the strength of the sheet are dependent on it (Cauldfield 1988). Cellulose fibers will swell up to 15 to 20% from dry conditions to saturation, which can cause the changes in dimensions when the humidity changes. Such changes in dimension will make the dimensional stability decrease and lead to undesirable cockling and curling in the dimensional stability of the paper (Sridach 2010). These results show that corn stalk has a higher stability compared to the pineapple leaf and napier grass. This stability will cause the paper produced from it to be of higher quality (Khampan *et al.* 2010).

Table 1. Chemical Composition of Pineapple Leaf, Corn Stalk, and Napier Grass

Constituents/ Composition (w/w %)	Pineapple leaf	Corn Stalk	Napier Grass
Ash Content	4.50*	24.9	14.6
Cellulose Content	66.2*	39.0	12.4
Holocellulose Content	85.7*	82.1	80.4
Hemicellulose Content	19.5	42.0	68.2*
1% NaOH Solubility	39.8*	69.6	52.0
Lignin Content	4.28*	7.30	10.8
Moisture Content	81.6	7.32*	11.7

(Note: * = favourable value)

From Table 1, it can be seen that pineapple leaf contains a high holocellulose content (85.7%), followed by corn stalk (82.1%) and napier grass (80.4%). Holocellulose is a combination of cellulose and hemicellulose content. The greater the holocellulose inside the material is, the better will be the quality of the paper produced. In this study, pineapple leaves have the highest cellulose content (66.2%), followed by corn stalk (39.0%) and napier grass (12.4%). Cellulose is the component that makes the fiber of the non-wood materials stronger (Enayati *et al.* 2009). Higher content of cellulose can provide stronger fibers, hence increasing the quality of the paper produced (Khalil *et al.* 2006). However, for hemicellulose, napier grass has the highest content (68.2%), followed by corn stalk (42.0%) and pineapple leaf (19.5%). As mentioned earlier, these are the important parameters in determining the suitability of a raw material for pulp and papermaking. Therefore, the quality of the fiber produced from a non-wood material depends on the contents of cellulose, hemicellulose, and holocellulose. This result suggests that pineapple leaves have an acceptable chemical composition of their fibers when compared to wood material (Aziz and Zhu 2006) and therefore have the potential to be an alternative fiber source for use in the paper making industry.

Lower lignin content is normally found in non-wood fibers. Lignin functions as an adhesive to bind the cellulose together in the fiber. Lower lignin content makes the fiber strength greater and harder to break (Tran 2006). Pineapple leaf fiber has a low lignin content of 4.28% compared to corn stalk (7.3%) and napier grass (10.8%). Lower lignin content means that lignin removal is easier during the pulp process, and the paper that will be produced is of greater quality (Enayati *et al.* 2009). Pineapple leaves have a

lower 1% sodium hydroxide solubility (39.8%) than that of corn stalk (69.6 %) and napier grass (52.0%). The solubility in 1% sodium hydroxide indicates the extent of fiber degradation during the pulping process. Among all three, corn stalk has the highest 1% sodium hydroxide solubility, and therefore the production of chemical pulp will be low (Onggo and Astuti 2005). Furthermore, a high 1% sodium hydroxide solubility helps to explain the screen yield of chemical pulp; a low screen pulp yield was reported in earlier work (Kargarfard *et al.* 2011). This indicates that pulp production from the cooking process of pineapple leaf is higher than corn stalk and napier grass.

Analysis of Surface Morphology

Scanning electron microscopy (SEM) analyses of the handsheets produced from pineapple leaf, corn stalk, and napier grass fibers are shown in Figs. 2 and 3.

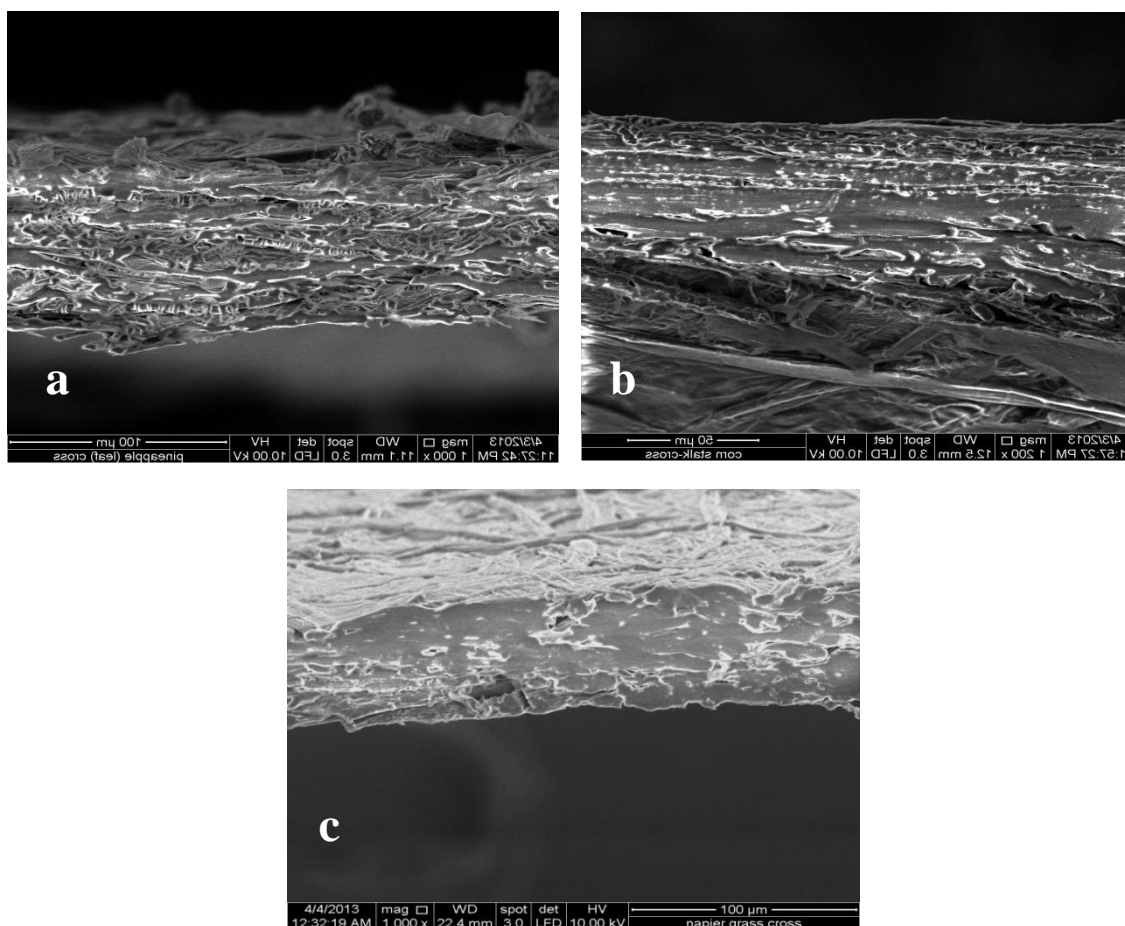


Fig. 2. SEM cross-section images of (a) pineapple leaf, (b) corn stalk, and (c) napier grass fibers

The SEM micrographs of the cross-sections (Figs. 2a, 2b, and 2c) show fibrillation on the surfaces of all three non-wood materials. From these cross-sections, the fibrillation of the non-wood material can be seen. This fibrillation can be attributed to the removal of lignin and other structural effects (Mohanty *et al.* 2005). The pineapple leaf cross-section has a rougher structure than that of corn stalk and napier grass. The surface from the cross-section of napier grass (Fig. 2c) is smooth, and there is a space between the outer layers of adjacent fibers. This morphology reveals the presence of lumen surrounding the cell wall of this material (Merlini *et al.* 2011).

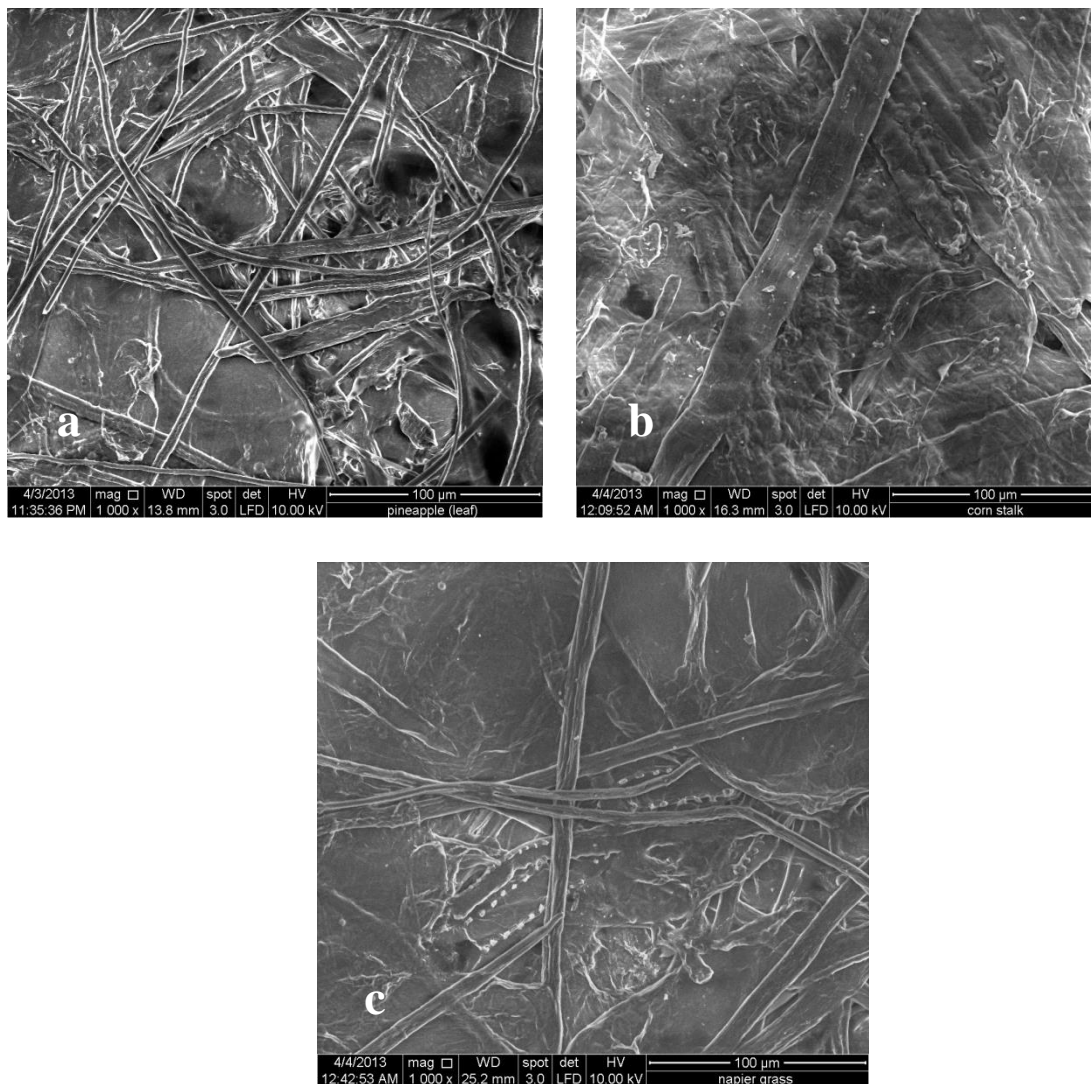


Fig. 3. SEM micrographs of the surface morphologies of (a) pineapple leaf, (b) corn stalk, and (c) napier grass fibers

This analysis reveals the structure and shape of the fiber bundles inside the three materials. Using SEM, the strength of the fiber can be understood based on the arrangement and packing of the fiber matrix. From the figures, pineapple leaf fibers have many fiber matrices and have a more compact surface rather than corn stalk or napier grass. This is due to the higher fiber content in pineapple leaf compared to the other two. In Fig. 3 (a) we can see that the structure of the pineapple leaf fiber is more closely compacted and formed many more bundles of fiber matrix than do corn stalk or napier grass fibers. This fiber structure could increase the fiber strength and the quality of the paper produced (Han and Rowell 1999). Nevertheless, corn stalk fibers also show a closely packed arrangement, but not as packed as the pineapple leaf fibers. The thicker fiber could yield a stronger fiber bundle and hence give a higher strength of paper produced (Khalil *et al.* 2006). On the other hand, napier grass fiber seemed to be loosely packed, and the fiber arrangement was not as compact as that found in pineapple leaf and corn stalk fibers. Inevitably, the less dense arrangement and loose packing could make

the paper produced become low in the strength and quality. The compactness and arrangement of fibers could contributed for the factor to the quality structure of the produced paper beside the other factors such as cellulose content in the non-wood materials (Ververis *et al.* 2004).

CONCLUSIONS

1. Pineapple leaf fiber is more favourable as a potential substitute for wood fiber in paper production in comparison to fiber from corn stalk and napier grass.
2. The high cellulose content and low lignin content could lead to high-quality pulp and paper produced from pineapple leaf fiber. Corn stalk and napier grass fibers can also be alternatives for pulp and paper making.
3. Furthermore, scanning electron microscopy (SEM) analysis shows the condensed arrangement of fiber, which forms a stronger structure in pineapple leaf than in corn stalk and napier grass.
4. This study therefore confirms the suitability of pineapple leaf waste as an alternative pulp that can be further processed in preparation for its use in papermaking.

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