DEVELOPMENT OF PULP AND PAPER FROM PANDANUS LEAVES, NIPA PALM FRUIT HUSK, AND BANANA PSEUDOSTEMS

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Abstract

In Thailand, there are a great number of non-wood plant residues derived from the beverage and food industries. Pandanus leaves, Nipa palm fruit husk, and banana pseudostems are used as raw materials, and the residues of these plants have not been used. Therefore, this study aimed to study the chemical properties of the fibres for developing pulp paper and food containers. Banana pseudostems exhibited the highest cellulose content (41.35%), followed by Nipa palm fruit husk (38.62%) and pandanus leaves (33.99%). Nipa palm fruit husk had the highest lignin content (29.42%), followed by pandanus leaves (13.16%) and banana pseudostems (10.25%). The pulp and paper were made using a soda-anthraquinone cooking process with 16% NaOH and 0.2% anthraquinone of dried weight. The paper made from banana pseudostems exhibited the highest properties, with a tensile strength at 2,400 N/m and tearing strength of 615 mN. Paper made from Nipa palm fruit husk exhibited the lowest tensile strength (370 N/m) and tearing strength (353 mN). The fibre was mixed at a rate of 1:1, and the papers mixed with banana pseudostem showed better paper properties. The mixed pandanus leaves and banana pseudostem fibres exhibited the highest tearing and tensile strengths (711 mN and 2,650 N/m, respectively). However, blending banana pseudostem fibre with pandanus leaf fibre or Nipa palm fruit husk fibre could improve paper strength. The food containers made from the fibres that were mixed with banana pseudostem exhibited better quality compared to the unblended fibres. The results suggest that blending plant residues could be an alternative method for pulp and paper making.

Keywords: **Banana; Development; Nipa palm; Pandanus; Paper**

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Introduction

Thailand is one of the leading countries producing paper from a non-wood plant with 34% production of pulping paper making in the world (Abd El-Sayed *et al.*, 2020). Thailand possesses an abundance of agricultural residues derived from food industries, such as oil palm fronds, bagasse, and rice straw, that need to be recycled to add value to the waste (Abd El-Sayed *et al*., 2020; Jarupan *et al.*, 2021). Nipa palm (*Nipa fruticans*) is a mangrove plant that can be found ubiquitously along the coastal area of Thailand, and its plant parts are utilised in food and products (Cheablam and Chanklap, 2020). However, fibres from several parts of the Nipa palm, including leaves, bunches, stalks of empty bunches, stalks, and trunks, have been utilised as textile fibre sources (Pigunthong and Soodsang, 2023). However, the Nipa palm fruit husk is still underutilised.

Pandanus (*Pandanus amaryllifolius*) is widely used in Southeast Asia. Its leaves have a specific aroma and flavour and are widely used as a source of pandan odour for food production industries (Diyana *et al*., 2021).

These non-woody plants have good fibre qualities that make them appropriate for paper making, and the paper qualities are good enough to substitute the paper made from hardwood and softwood (Ferdous *et al*., 2021). However, several agricultural residues have high potential for paper making but have not been used for this purpose. In Thailand, the drinking industries use several agricultural raw materials, resulting in a high amount of waste. Beverage entrepreneurs generate about 100 kg of boiling pandanus leaves every week or 5 tonnes annually. Nonetheless, the precise quantity of abandoned banana pseudostems and Nipa palm fruits are unknown. They are discarded in barren areas and remain unused.

Leftover materials from the beverage industry, such as pandanus leaves and Nipa palm fruit husk, require a suitable recycling procedure to add value and reduce waste from food processing. Therefore, this agricultural waste should be recycled to decrease waste.

However, the fibre characteristics from pandanus leaves and banana pseudostems have been studied. Mariatti *et al*. (2008) reported that extracted pandanus leaf fibre had a tensile strength inferior to that of banana fibre, with a tensile strength of 135 MPa, while that of banana fibre had a value of 355 MPa. Similarly, Nipa palm fruit husk fibre has been reported to have the highest chemical composition of cellulose (36.5%), followed by lignin (27.3%) and hemicellulose (21.8%). Nipa palm fruit husks have a rather high ash content (8.1%) (Tamunaidu and Saka, 2011). Several studies have shown that pandanus leaves, Nipa palm fruit husks, and banana pseudostems have good potential for pulp and paper development (Onukwuli *et al*, 2018). Although several studies have reported on the fibres from pandanus leaves, bananas, and Nipa palm fruit, data on the use of these fibres as the raw material for pulp and paper making in Thailand have not yet been reported. Samut Songkhram province is a famous tourist town. It has various tourist activities, including exploring local people’s lives, unique markets, seafood, and historic tourist attractions. Food and goods are produced and processed using various raw materials derived from agricultural products supplied by local people. The high amount of food and agricultural waste is ubiquitous and lacks suitable management methods. Thus, it is important to determine a suitable method for eliminating this waste to decrease the amount of agricultural waste residues.

In this study, pulp was made by mixing fibres from Nipa palm, pandanus leaves, and banana pseudostems to improve paper quality. Moreover, the paper made from these fibres can be used to make food containers to add value to the paper. Therefore, this study aimed to investigate the fibre properties of pandanus leaves, Nipa palm fruit husk, and banana pseudostems and to develop pulp and paper from the selected fibres.

Material and Methods

Non-Wood Plants

All non-wood plants were collected from waste from the soft drink industry and agricultural activities. Boiled pandanus leaves were collected from a beverage factory located in Banpeaw district, Samut Sakorn Province, Thailand, as shown in Figure 1. Boiled pandanus leaves were used in *Aloe vera*-pandanus beverage production to confer the pandanus flavour. The boiled pandanus leaves were discarded after beverage processing. The discarded Nipa fruit was collected from small entrepreneurs located in the Bang Kaew sub-district, Mueang district, Samut Songkhram, Thailand. Nipa palm fruits were used to make Nipa palm Thai sweet, which is called Nipa palm endosperm in syrup. After the endosperm of Nipa palm fruit was removed from the shell, the Nipa palm fruits were discarded as organic waste, as shown in Figure 2. The banana pseudostems were cut and discarded

Figure 1. The Pandanus leaves and the cut leaves

Figure 2. Nipa palm fruit and cut fibres

in the planted area, and then, we collected them from the banana planting area located in Samut Songkhram Province, Thailand, as shown in Figure 3.

Fiber Preparation

All plant raw materials were weighed and then dried in the sun for 1 week. Pandanus leaves and Nipa palm fruit husk were cut using a universal cutting machine (Pulverisette 25, FRITCH, Idar-Oberstein, Germany), and the length of the cut fibre was set to 4 mm. For the banana peduncle, the fibres were prepared by drying, and the peduncles were separated into long strips and cut into small pieces at a length of 4 mm.

Chemical Substances

Sodium hydroxide (NaOH) and anthraquinone were purchased from Sigma-Aldrich (St. Louis, MO, USA).

Non-Wood Plant Fibre Morphological and Chemical Property Analyses

The following chemical properties of all studied fibres were determined based on the TAPPI standard method: ash (TAPPI 211-07), acid-soluble lignin (TPPI UM 250), holocellulose (Wise *et al.*, 1946), and α-cellulose (Mod, TAPPI T203 cm-09) conent. The fibre lengths of all non-wood fibres were determined using the LM method according to Zoccola *et al.* (2023). To determine the fibre length, the fibres were separated by maceration with 50% nitric acid at 75°C for 10 min. The morphological properties, including the length and width of 100 fibres, were measured using a microscopic photograph.

The fibre morphology index was calculated according to Mousavi *et al.* (2013), as follows in Equation 1:

$$\text{Slenderness ratio} = \text{Fiber length}/\text{Fiber width} \quad (1)$$

Figure 3. Banana pseudostems and cut fibres

Pulping and Paper Sheet Making

Pulping was carried out following the method described by Mousavi *et al.* (2013). The soda-anthraquinone pulping method was applied according to Mousavi *et al.* (2013). This method is suitable for non-wood pulping, and the use of anthraquinone can reduce the environmental impact of pulping emissions. The soda-anthraquinone method is also suitable for small-scale pulping, which was performed in this study.

The soda-anthraquinone pulping method was carried out by mixing 16% NaOH, which was the lowest amount that could result in a good pulp yield. Following Mousavi *et al*. (2013), 0.2% of anthraquinone by dried weight was applied. The cooking time was 2-3 h, and the cooking temperature was 175-182℃. After the cooking time ended, the cooked fibres were washed in tap water 3-4 times to remove soda-anthraquinone. All of the dried fibres were weighed before being sent to make the paper.

The paper sheets were prepared using 150 g of fibre per sheet, and the following 6 types were prepared: pandanus fibre, Nipa palm husk fibre, banana fibre, pandanus mixed with Nipa palm fruit fibre, pandanus mixed with banana fibre, and Nipa palm fruit fibre mixed with banana fibre. All mixed paper sheets were prepared in a 1:1 ratio.

The cleaned fibres were used to make handmade paper sheets using a paper frame with a size of 21×34×3 cm. The cleaned fibres were soaked in a large vat. The paper frame was dipped in the vat, and the fibres were transferred to the frame. The paper sheets were compressed to remove the water and sun-dried for 2 days. The paper was brought to dry by the oven, and the data were used to assess pulp yield. The thickness of the paper sheets was set to 5 mm.

The tensile strength and tearing resistance of the paper sheets were tested to evaluate the paper quality. Tensile strength was tested by universal testing (Instron model 68TM-30 machine) based on the TAPPI T 220 method. Tearing strength was tested using an Elmendorf tearing tester based on the TAPPI-T414 method.

Paper Container Making

The obtained paper sheets of each type were sent to make food containers using a Bamboo I machine. The applied heat ranged from 130-150℃, and the paper was compressed for 1 min. The moulds used were rectangular (4×6 inches) and circular (6 inches in diameter).

Results

Chemical Fibre Properties

The chemical compositions of the studied fibres are shown in Table 1. The chemical compositions of the studied fibres exhibited different properties. The Nipa palm fruit husk fibre showed the highest lignin and holocellulose contents compared to pandanus leaf fibre and banana pseudostem fibre. The pandanus leaf fibre exhibited the highest ash percentage compared to the other fibres. Banana pseudostems showed the highest α-cellulose content and longest fibre length. The cellulose content of pandanus leaves in this study was lower than that reported by Diyana *et al*. (2021), who found a content of 48.79%. This may be due to the chemical treatment of fibres (Diyana *et al*., 2021).

The highest fibre slenderness was determined in the banana pseudostem (113.67). Nipa palm fruit fibre exhibited the lowest slenderness (73.00). When comparing the results of the fibre properties of this study to several non-wood fibres, including rice straw, rape seed, and plant fruit, as shown in Table 1, it was found that fibre from Nipa palm fruit exhibited the highest lignin component and that pandanus leaves had the lowest α-cellulose content. The slenderness ratio of pandanus leaf fibre and banana pseudostem fibre was higher than that of fibre from Nipa palm fruit, rice straw, and rape seed.

Pulping and Paper Properties

The pulping procedure resulted in a pulp yield of 31.16-41.80%. The Nipa palm fruit husk showed the highest yield. In this study, paper made from banana pseudostems exhibited the highest tearing and tensile strength, which were 615 mN and 2,400 N/m, respectively. Paper made from Nipa palm fruit husk fibre exhibited the lowest tearing and tensile strengths. Mixing fibres from pandanus leaves and banana pseudostems improved the paper sheet quality. The tearing strength of paper made from pandanus leaves alone was 510 mN, and tensile strength was 1,320 N/m. Paper formed by mixing fibres from pandanus leaves and banana pseudostems had better tearing and tensile strengths (711 mN and 2,650 N/m, respectively). Paper made from Nipa palm fruit husk fibre exhibited the lowest paper quality, indicating that Nipa palm fruit fibres were not suitable for making pulp or paper using the soda-anthraquinone method.

Table 1. Chemical composition of fibres from nipa palm fruit, pandanus leaves, and banana pseudostem

Fibers	Ash component (%)	Lignin (%)	Holocellulose (%)	Hemicellulose (%)	α cellulose (%)	Fibre length (μm)	Fibre width (μm)	Slenderness	Reference
Nipa palm fruit husk	6.71	29.42	68.84	-	38.62	1,034.44	14.17	73.00	This study
Pandanus leaves	8.21	13.16	57.82	-	33.99	1,807.13	16.28	111.00	This study
Banana pseudo stems	1.81	10.25	58.72	-	41.35	2ม512.30	15.10	113.67	This study
Rice straw	9.20	21.90	60.70	-	41.20	780.00*	11.60*	83.87*	Rodríguez *et al.* (2008)
Rape seed	3.46	16.0	78.90	-	41.66	1030	28.0	36.80	Mousavi *et al.* (2013)
Plant fruit	-	18.54	-	31.51	37.01	-	-	-	Mulyantara *et al.* (2017)

Note : * Data from Ferdous *et al* (2021)

Figure 4. Paper containers made from Nipa palm fruit, pandanus leaves, banana pseudo stem, and the mixed paper sheet

Paper Container

When using the paper to make a container, a pumping machine was used. The containers made from Nipa palm fruit and pandanus leaf paper exhibited low-quality food containers, and tears were observed in these containers, as shown in Figure 4. The containers obtained from the Nipa palm fruit husk were soft and thick. The containers from Nipa palm easily tore and had an unstable shape. However, the paper of mixed Nipa palm fruit husk fibre with pandanus fibres showed better tearing and tensile strength compared to the container made from Nipa palm fruit husk paper.

In contrast, the paper containers made from banana pseudostems exhibited better quality, as shown in Figure 4. The paper containers made from Nipa palm fruit mixed with banana pseudostems and from pandanus leaves mixed with banana pseudostems exhibited better quality compared to the paper containers made from unmixed fibres.

Figure 4 Paper containers made from Nipa palm fruit, pandanus leaves, banana pseudo stem, and the mixed paper sheet.

Discussion

This study revealed that fibres from agricultural residues, including Nipa palm fruit husk, pandanus leaves, and banana pseudostems, can be applied as sources for making pulp and paper. Non-wood fibres have been reported to be alternative sources for pulping industries to substitute hardwood or softwood fibre (Abd El-Sayed *et al*., 2020; Ferdous *et al*., 2021). In this study, the highest tearing and tensile strengths were observed in paper made from pandanus leaf fibre mixed with banana pseudostem fibre. The tensile and tearing strengths of the papers are associated with the level of lignin, cellulose, and morphological properties of the fibre (Ferdous *et al*., 2021). A high cellulose content and high slenderness ratio results in good-quality paper (Ferdous *et al*., 2021). The fibres from banana pseudostems possess a greater cellulose content and a longer fibre length (Subagyo and Chafidz, 2020; Badanayaka *et al*., 2023) compared to those from Nipa palm fruit husk and pandanus leaf. Therefore, paper made from banana fibres showed better strength. When we mixed the banana fibre with pandanus or Nipa palm fruit husk, the paper's qualities improved, resulting in higher tensile and tearing strengths. The banana fibres may support the bonding reaction of the paper. The formation of paper sheets made from non-wood fibre is strongly influenced by the network and bond formation of pulp fibres and the morphological characteristics of fibres. The long fibre length and narrow characteristic are good properties for paper strength (Ververis *et al*., 2004; Ferdous *et al*., 2021). The high cellulose content and longer fibre length of the banana pseudostem may result in better network bonding for the pulp, improving the tensile and tearing strengths of mixed paper.

The pulp and paper made from Nipa palm was thick but easily torn, which might be due to the high lignin content. Tampubolon *et al*. (2022) reported that Nipa fruit skin fibre possessed high moisture and high hygroscopicity due to its high lignocellulose content. The high lignin content found in the Nipa fruit husk in this study might be associated with the low tearing strength and low quality of the paper containers. In this study, anthraquinone was applied for pulping to stabilise polysaccharides and accelerate lignin dissolution (Sridach, 2010). Nonetheless, Nipa palm fruit fibre had the highest pulp yield compared to banana fibre and pandanus leaves. Nipa palm fruit husk fibre contains a high holocellulose content, which can result in a high pulp yield (Yahya *et al*., 2019).

However, the lignin content in Nipa palm fruit husks still affected the paper properties despite using the soda-anthraquinone cooking method. For better pulp and paper made from Nipa fruit husks, a cooking process should be developed, and the amount of chemicals necessary to adjust the lignin content in Nipa palm fruit husks should be studied further.

The components of lignin and cellulose in the fibre influence the paper quality index, such as tensile and tearing strengths (Ferdous *et al*., 2021). Fibres that contain over 34% cellulose are promising raw materials for good-quality pulp and paper (Ververis *et al*., 2004). In this study, fibres of Nipa palm fruit husks and banana pseudostems exhibited a cellulose content greater than 34%, which seemed to produce good-quality pulp and paper. However, paper derived from banana pseudostem and pandanus leaves exhibited high tensile and tearing strengths compared to Nipa palm fruit husks. This could be associated with the lignin content in Nipa pal fruit husk fibres, which was 29.42%. Lignin in fibre influences the pulping procedure, particularly the delignification and digestion time of pulping (Mousavi *et al*., 2013). Good fibres for pulp and paper making should have a lignin content of less than 30% (Ververis *et al*., 2004). Fibres that have a high lignin content require strong pulping conditions. Therefore, the pulping method used in this study may not be suitable for Nipa palm fruit husk fibres, and the fibres require stronger chemicals and longer cooking times. The paper made from Nipa palm fruit husk alone and Nipa palm husk fibre mixed with pandanus fibre, as they demonstrated a relatively poor paper quality with low tensile and tearing strengths. Nipa palm fruit husk fibres had higher lignin and ash contents than pandanus leaves and banana pseudostems. High lignin and high ash contents cause low tensile and low tearing strength of paper made from Nipa palm fruit husks. Regarding tearing strength, the food containers made from the obtained paper sheet of each type was relevant. The food container made from Nipa palm fibre alone exhibited low quality, and tears were observed in the container. The tearing and tensile strengths of Nipa palm fruit paper exhibited the lowest values compared to the other fibres. The paper sheet from pandanus leaf fibres was not good enough to contribute to the food container, as tears were observed in the bottom of the container. When the paper fibre was mixed with banana pseudostem, food container quality improved, as they increased the tearing and tensile strengths of the mixed fibre paper. The paper sheet that contained the banana pseudostem could be an alternative source for making food containers because the mixed paper sheet could tolerate the compression force and heat of the machine. However, this study did not examine food container quality traits, such as thermal stability, porosity, shelf life, purity, and potential reactions with food, or any health effects. Since we initially used fibres obtained from the experiment to make food containers, we considered the possibility of further development in the future. Further evaluation of the food containers should be addressed.

Due to the high lignin and ash components in Nipa palm fruit husks, further study of the appropriate method for pulping fibre of Nipa palm fruit husks should be addressed. The paper made from a combination of pandanus leaf and banana pseudostem fibres should be used to make food packaging to add value to the fibres.

Conclusions

The fibre of plant residues from food industries, including pandanus leaves, Nipa palm fruit husks, and banana pseudostems, possess diverse chemical compositions. Among the studied fibre, banana pseudostems exhibited better properties for producing pulp and paper with a highest cellulose content and fibre length and the lowest lignin component. Nipa palm fruit husk fibre had the lowest fibre length and the highest lignin content, indicating that this fibre was unsuitable for paper making. The pandanus leaves had a high ash content and low cellulose content compared to banana pseudostems and Nipa palm fruit husk. The paper made from banana pseudostems showed better tearing and tensile strength compared to the paper made from pandanus leaves and Nipa palm fruit husk. However, blending banana pseudostem fibre with pandanus leaf fibre or Nipa palm fruit husk fibre could improve the paper strength compared to the unblended paper. This study revealed that blending plant residues could be an alternative method for producing pulp and paper from non-wood plants.

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