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Evaluating the Potential and Synergetic Effect of Palmyra, Banana and Coconut Fibers for Handmade Paper Production- A Sustainable Alternative to Hardwood Pulp

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Abstract: This study explored the development of two handmade paper sheets made from three different fiber sources: 100% palmyra fibers and a blend of palmyra, banana, and coconut fibers (composite). The both papers were prepared by the kraft pulping process. The resulting sheets were analyzed for their physical, chemical, and morphological properties. The physical parameters were assessed and showed the average thickness, grammage, moisture content, opacity, brightness, and apparent density values for 100% Palmyra paper and composite paper were 0.13 and 0.22 µm, 22.8 and 18.9 g/m², 8% and 6%, 63% and 60 %, 50% and 53% and 0.22 and 0.18 g/cm³ respectively. The water absorption capacity was evaluated by measuring Cobb value which was found to be 80 g/m². The chemical analysis provided the information on the composition of the fiber in both papers by determining the amount of ash, cellulose, hemicellulose, and lignin. The FTIR confirmed the presence of cellulose, while SEM provided detailed surface morphology of the fibers and their arrangement. This thorough characterization offers valuable information on the potential of these unconventional fibers for paper production, emphasizing the possibility of creating unique handmade papers with distinct properties.

Keywords: *Palmyra, Banana, Coconut Fibers, Composite, Handmade Paper.*

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I. INTRODUCTION

Paper remains an essential product worldwide, providing significant benefits in areas such as education, security, communication and even sanitation (Martin & Haggith, 2018; Ezeudu et al., 2019). However, its production raises important environmental concerns. The Food and Agriculture Organization (FAO) estimates that by 2025, the world's paper consumption will exceed 500 million tonnes, growing at an annual pace of 1.6%. Currently, almost 35% of the world's trees are used for paper (Beckline et al., 2024; Wennberg, 2014). Despite its clear advantages, the environmental impact of paper production is substantial, as about 50% of global logging is dedicated to paper and paperboard manufacturing, making it a significant consumer of natural resources (Gavrilescu et al., 2012; Phimmachanh et al., 2015).

The major component of paper is cellulose which is significantly obtaining from natural resources. The main supply of cellulosic fiber for the pulp and paper industry comes from hardwood. However, the growing demand for hardwood has resulted in significant deforestation, endangering the environment and accelerating climate change and ecological upsets (Coe et al., 2013). As wood resources deplete, coupled with rising consumption and

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limited raw materials for the paper industry, there has been a growing interest in exploring alternative, low-cost, and readily available options. To address these challenges, current research is actively investigating the potential of agro-based raw materials, especially natural fibers, as eco-friendly alternatives. (Khan et al., 2020). Natural fibers provide numerous benefits, such as being environmentally friendly, abundant, and biodegradable (Sanjay et al. 2019; Bichang'a et al. 2022a, 2022b).

Hence, plants and agricultural wastes can serve as alternative sources of natural fibers, replacing traditional woody fibers (Jorge et al., 2000). This shift offers significant economic benefits by lowering production costs, reducing environmental impacts, and safeguarding ecosystems (Omotoso et al., 2015). Consequently, research into pulp production from non-wood materials has grown substantially. Many of these studies have concentrated on various non-wood biomasses and agricultural byproducts, including grass, corn straw, bamboo, bagasse and other agricultural wastes, for the manufacturing of paper. These materials are used in applications ranging from lightweight specialty papers to multiwall alternatives, based on the characteristics of the fiber source (Jorge et al., 2000; Azeez, 2018). The interest in these materials stems from their unique properties, which make them suitable for a variety of fiber applications, such as reinforcement in composites, textiles, activated or conductive carbon, cellulose nanomaterials and biomaterials (Palanisamy et al., 2024). These fibers are valued for qualities such as low density, affordability, availability, non-toxicity, high strength, excellent thermal stability, recyclability and biodegradability (Sgriccia et al., 2008).

Given these factors, the present study was carried out to evaluate the properties of paper produced from a blend of fibers derived from coconut husk, palmyra husk, and banana stem. There is limited data on the specific impact of palmyra fibers on the physical, chemical and mechanical characteristics of paper. To fill this gap, the study will take a comprehensive approach, evaluating paper made from both palmyra fibers and a blend of coconut and banana pseudostem fibers. The evaluation will include measurements of physical and mechanical properties, along with characterization techniques include FTIR (Fourier Transform Infrared Spectroscopy) and SEM (Scanning Electron Microscopy). By examining these properties in detail, the research aims to establish a foundation for future investigation into the potential of palmyra fibers as a sustainable alternative to hardwood pulp in various paper applications.

Therefore, the purpose of this study is to examine the viability of employing non-wood plant materials as pulp for the production of paper, such as banana stems, coconut husks, and palmyra palm fruit fibers.

II. MATERIAL AND METHODS

➢ *Materials:*

All of the chemicals used in the study were purchased from Sisco Research Laboratory Pvt. Ltd. without any additional purification. The water used to make all of the reagents was double-distilled.

➢ *Preparation of Chemicals:*

- *Preparation of 14% Sodium Hydroxide (NaOH):*

14 g of NaOH was dissolved in 100 mL of distilled water.

- *Preparation of 4% Sodium Sulfide (NaS):*

4 g of NaS was dissolved with 100 mL water.

- *Starch Solution:*

0.8 g of starch was dissolved in 10 mL of distilled water. The mixture was then boiled until the starch was completely dissolved.

- *30% of Hydrogen Peroxide (H_2O_2):*

30% of H_2O_2 was used for the study.

➢ *Collection and Preparation of Samples:*

Samples of coconut and palmyra husk were collected from Mugavai, in the Gulf of Mannar, and banana pseudo stems from Viruthupatti, in Tamil Nadu. After collection, the samples were cleaned to remove dirt and soil. Banana fiber was extracted from the pseudostem using a manual peeling method, specifically the hand stripping technique. The coconut and palmyra fibers were obtained using a husk peeler. The obtained fibers were rinsed with water to eliminate any remaining flour. All samples were sun-dried for several days to lower the moisture content. The fibers were cut into 2 to 3 cm lengths using a sharp knife and placed in an industrial oven at 60 ℃ for 72 hr to ensure complete removal of moisture. After that, the fibers were stored in airtight containers for further analysis (Fig.1).

a. Banana Pseudo Stem (*Musa x paradisiaca*)

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b. **Coconut fibre (*Coccus nucifera)***

c. Palmyra *(Borassus flabellifer)*

Fig 1 Dried Fibres of a. Banana Pseudo Stem; b. Coconut Fibre c. Palmyra Fibre

➢ *Processing of Sample:*

The oven-dried and chopped fibers were boiled in water for 60 minutes at 160℃. After an hr, the samples were sun-dried to eliminate any residual moisture.

➢ *Pulping (Kraft Pulping):*

The dry samples underwent kraft pulping to separate the cellulose fibers. The white liquor was prepared by mixing 14% NaOH and 4% NaS in a 3:1 ratio. The mixture was then heated to a boil in a container, maintaining a ratio of 1 part solid sample (palmyra) to 30 parts white liquor (1:30). The concentration of NaOH in the white liquor varied depending on the plant material being pulped. For paper 1, only 100% palmyra fibers were used, without the inclusion of coconut and banana fibers. For the composite paper (paper 2) preparation, a blend of coconut, palmyra, and banana stem fibers was used. Banana stems were pulped with a 12% NaOH solution, while palmyra and coconut husks were pulped with a 14% NaOH solution. In all cases, 4% NaS was added to the white liquor. For each pulping process, 20 g of fiber were measured and combined with 1080 mL of the prepared white liquor solution.

- Paper 1- 100% palmyra fibers (without coconut and banana fibres)
- Paper 2- 20% of palmyra fibers; 20% of banana fibers; 20% of coconut fibers

➢ *Cooking*

The prepared sample mixture was boiled in a container with the white liquor solution for about 2 hr, maintaining a temperature of 95 ℃, with a tolerance of ±2.5℃. During the pulping process, the solid to liquid ratio was kept constant at 1:30 for all samples. After the cooking, the samples were allowed to cool. The black liquid (sodium lignin) was then separated from the pulp using a mesh screen. Finally, the pulp was extracted, and the black liquid was discarded.

➢ *Conditioning of Pulp*

The partially delignified pulps were rinsed with water to neutralize the reaction. They were then mechanically broken down and screened on a flat screen with 0.25 mm slits to eliminate any unprocessed particles. To eliminate moisture, the pulp was dried in an oven at 60℃ for a period ranging from 2 hr to 1 day. The pulp's weight was recorded on a dry weight basis.

➢ *Production and Testing of Handmade Paper Sheets*

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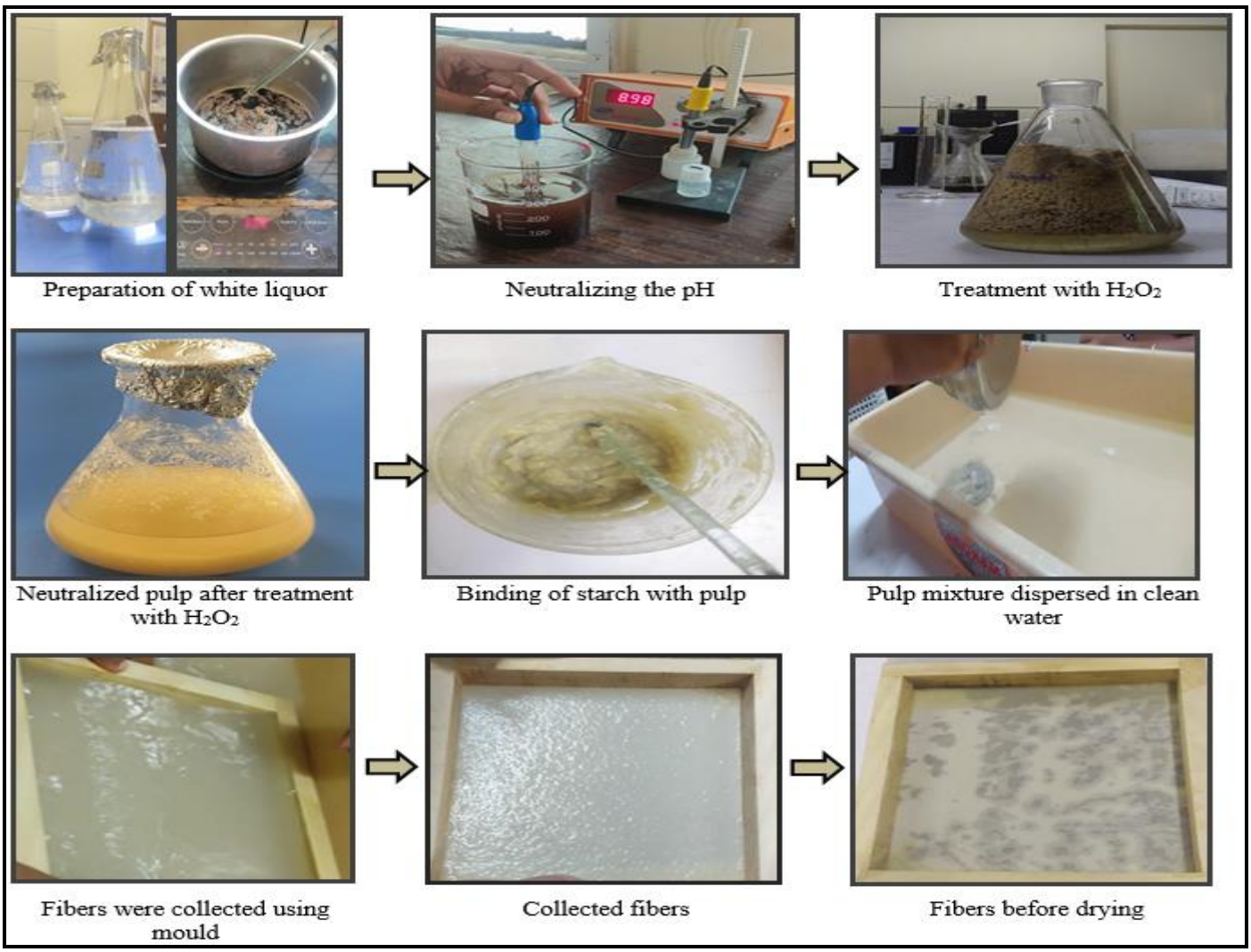

Fig 2 Production and Processing of Handmade Paper

The dried pulps of each sample were weighed and placed in a beaker with a mixture of water and 30% H_2O_2 in a 4:1 ratio. The mixture was heated on a heating mantle until the pulp turned white. After bleaching, the pulps were thoroughly rinsed with clean water until the p^H reached neutral (p^H 7). The pulps were then defibered for 6 minutes using a laboratory blender (acting as a wet disintegrator). During this process, a starch solution was added to bind with the fibers for the final paper products. The starch slurry was made by boiling 16 g of starch in 200 mL of distilled water for the palmyra fibers, and by boiling 40 g of starch in 500 mL of distilled water for the 20% blends of palmyra, banana, and coconut fibers. The fiber mixture was then poured into clean water and collected using a mold. The molded fibers were left to dry in the sun for 12 to 24 hr. Prior to additional testing, the paper samples were conditioned at 23℃ in polythene bags after being dried and pressed to increase smoothness (Fig.2).

➢ *Measurement of Physical Properties*

- *Thickness*

The TAPPI T411 method was used to measure the thickness of a paper sheet using a digital thickness micrometer (Hans Schmidt, D2000C). Six separate measurements were taken at various points on the paper sheet.

- *Grammagae*

Grammage refers to the weight of paper per unit area, essentially indicating its density. It is an important property in the paper industry, typically measured in grams per square meter (g/m²), also known as gsm. This measurement was conducted following the TAPPI-410 standard, with the process being carried out under controlled conditions of 23℃ temperature and 50% relative humidity (RH).

To calculate the grammage, a paper sheet measuring 500 cm² was cut using a circular cutter, and its weight was measured (± 0.001 g). The grammage (g/m²) was determined by dividing the weight (g) by the area (m²). This process was repeated for six different measurements for each sample. Thicker paper (higher grammage) is more durable and ideal for applications such as covers, brochures, and cards, while thinner paper (lower grammage) is lighter, more cost-effective, and suitable for everyday printing and writing.

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- *Moisture Content*

To measure the moisture content under ambient conditions, a 2 g paper sample, conditioned at 23℃ and 50% RH, was placed in an oven set to 105 ± 2℃ for 24 hr. Following drying, the sample was weighed after being cooled in a non-hygroscopic desiccator. The moisture content was calculated by the gravimetric method, based on the weight difference before and after drying. Three separate measurements were taken for each sample to ensure accuracy.

- *COBB 60*

The Cobb 60 value is measured using a standard Cobb sizing tester, in accordance with the TAPPI-T441 method, which is specifically designed for paper that doesn't readily absorb water (non-bibulous paper). After measuring, presence of any remaining water is removed from the paper sample.

- *Opacity and Brightness*

A standard brightness-opacity tester (UEC1018, India) was used to measure the paper's opacity and brightness (ISO brightness). To ascertain the optical characteristics, two paper specimens measuring 10 mm by 10 mm were cut and placed in the tester.

➢ *Determination of Chemical Composition*

The amounts of cellulose, hemicellulose, lignin, and ash present in the paper and fiber samples were quantified using a gravimetric method following established testing standards (Boopathi et al., 2012; Kandel et al., 2012; Das et al., 2014; Ayeni et al., 2015).

- *Determination of Cellulose Content*

1 g of the oven-dried sample (dried at 105 ℃ for 4 hr and cooled in a non-hygroscopic desiccator) was treated with a 5% NaOH solution (w/v) for 5 hr in order to measure the amount of cellulose in the sample. 10% H_2SO_4 was used to neutralize the mixture when it had cooled. After neutralizing the remaining biomass with multiple washes, it was treated for 5 hr at room temperature with a 2% H_2O_2 solution made in a p^H 9 $NaHCO_3$–Na_2CO_3 buffer system. The biomass was cleaned properly to get rid of any contaminants. After that, it was dried in an oven at 105 ℃ until its weight remained constant, ensuring all moisture was removed for accurate measurements. The amount of non-cellulose material eliminated during the process was shown by the weight difference between the initial sample and the dried sample. This weight difference was utilized to determine the amount of cellulose in the initial biomass sample because it is the main component that remains after other chemicals have been removed. This process was carried out three times for every sample in order to ensure reliability.

- *Determination of Lignin*

1g of the extractive-free paper sample was treated with 72 % H_2SO_4 (sample to acid ratio of 1:12.5 w/v) and gently shaken for 2 hr in order to measure the amount of lignin present in the sample. After several dilutions and washings, the top liquid was removed. After filtering, the leftover residue was dried at 105℃ until its weight remained constant. The lignin content was then determined using the weight difference. Each sample was measured three times separately.

- *Determination of Hemicellulose*

The amount of hemicellulose in the sample was measured by precisely weighing 1 g of the extractive-free sample, which was then boiled for 4 hr in a 0.5 M NaOH solution to dissolve the hemicellulose. Following boiling, the sample was repeatedly washed with distilled water to eliminate the NaOH solution and neutralize it. After washing, the sample was dried at 105℃ in an oven until its weight remained constant, confirming that all moisture had been eliminated for accurate measurement. The amount of hemicellulose dissolved throughout the process was shown by the weight difference between the dried sample and the original sample. This procedure was repeated three times for each sample to ensure accuracy.

- *Ash Content*

1 g of the moisture-free paper sample was burned at 550 ± 10℃ in an electric muffle furnace to measure the amount of ash present. The percentage of ash content was determined using the weight difference. For every sample, three measurements were taken in consecutively.

III. RESULTS AND DISCUSSION

➢ *Collection of Raw Materials*

Natural fibers of palmyra and coconut were collected from Mugavai, and banana pseudo stems were obtained from Viruthupatti, Tamil Nadu, India. The collected fibers were manually cleaned and sun-dried to remove moisture. The total yield of dried fibers was 76 g of banana pseudo stem fibers, 60 g of coconut fibers, and 40 g of palmyra fibers.

The fibers were pulped using the kraft process, which involves several chemical treatments. Two types of paper were produced using this method: one was made entirely from palmyra fibers (100% palmyra), and the other was a composite paper made from a blend of 20% each of palmyra, banana, and coconut fibers. Each type of paper was individually characterized to assess the physical and chemical properties of both the palmyra paper and the composite sheet (Fig. 3).

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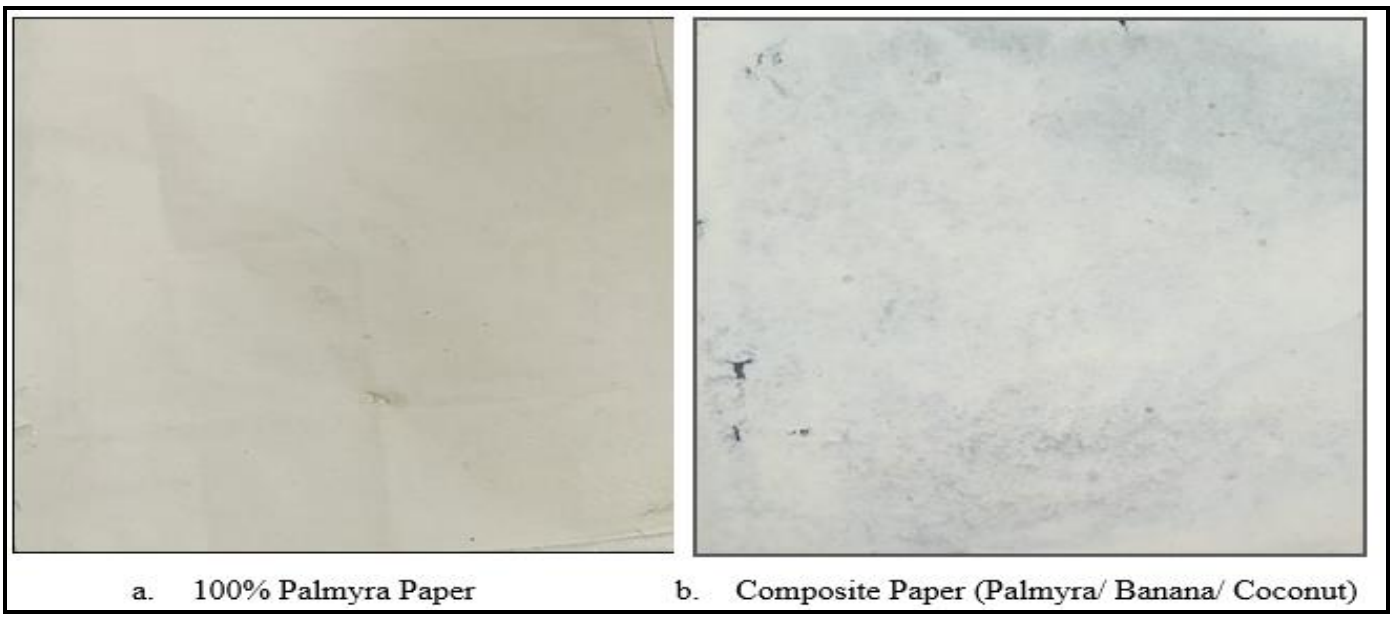

Fig 3 Handmade Paper Sheets Produced from the Pulps of a. Palmyra b. (Palmyra/Banana/Coconut)

➢ *Physical Properties of Paper*

The basic physical properties of the palmyra and composite papers are presented in Table 1. The paper sheets show good formation, with a basic weight of 2.280 g. The palmyra paper samples' average thickness was determined to be 0.13 µm. The grammage was calculated by converting the area from cm^2 to square meters (m^2) by dividing by 10,000 (since 1 m^2 = 10,000 cm^2). As a result, the grammage of the palmyra sheet is approximately 22.8 g/m^2.

The apparent density (g/cm^3) of the palmyra paper samples was determined by accounting for the ratio of grammage (g/m^2) to thickness (µm). It is ranged from 0.22 g/cm^3. The average thickness of the composite paper made from coconut, banana, and palmyra pulp was measured to be 0.22 µm. The composite paper's grammage was found to be 18.9 grams per square meter (g/m^2). Similarly, the grammage of handmade paper made from raw lokta fiber ranged from 20 g/m^2 to 150 g/m^2. The analysis showed a strong positive correlation (r = 3), likely due to the broad range of grammage (weight) observed in the papers, indicating they were designed for various applications.

Papers of grammage of 50 g/m^2 or less are generally used for printing, whereas higher grammage papers are better suited for creating items with additional value, like gift boxes and photo albums (Aryal et al., 2022). The sample's caliper was 180–254 µm in length. Handmade paper is usually produced through a process that combines chemicals and mechanical action to break down plant fibers, which results in long fibers (over 1 millimeter in length). However, these long fibers can easily clump together during papermaking, leading to uneven thickness in the final product (Beghello et al., 1998; Lundell et al., 2011).

Table 1 Physical Properties of Paper

Physical Composition	Paper 1 (Palmyra)	Paper 2 (Composite Palmyra/Coconut / Banana Fibre)
Thickness	0.13µm	0.22µm
Grammage	22.8 (g/m^2)	18.9 (g/m^2)
Moisture content	8 %	6 %
Apparent density	0.22 (g/cm^3)	0.18 (g/cm^3)
Brightness	50%	53%
Opacity	63%	60%

The apparent density (g/cm^3) of the composite paper samples was determined by accounting for the ratio of grammage (g/m^2) to thickness (µm). It was found to be 0.18 g/cm^3. The volume that is occupied by air or free space within paper is included in its apparent density. Because of this, the apparent density of the solid paper fibers is always less than their true density. Machine-made paper commercially sold typically has a higher apparent density (around 0.5 to 0.8 g/cm^3) compared to Lokta paper, a type of handmade paper. The lower apparent density of Lokta paper suggests it is lighter and contains more air pockets than commercially produced paper (Bajpai et al., 2018). In papermaking, the long fibers, insufficient refining, and absence of fillers in handmade paper result in lower apparent density (higher porosity). Handmade paper typically has an apparent density ranging from 0.2 to 0.5 g/cm^3 (Mejouyo et al., 2020).

The moisture content of the palmyra and composite paper samples was estimated around 8 % and 6 % respectively. This is similar and comparable to other cellulose-based paper, as Bajpai et al. (2018) also found moisture content of 4.4% in their study.

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The Cobb 60 test is a widely used method to assess a paper's tendency to absorb water. It involves applying water to a paper sample for 60 seconds and measuring how much water is absorbed per square meter. The higher the Cobb 60 value indicates the greater the water absorption. This value is affected by numerous factors, including the type of fibers, fiber arrangement, chemical composition, thickness, morphology, and organization. Different fibers have varying chemical compositions and structures, which can impact their water absorption capacity. Thicker paper generally absorbs more water. In tests, the Cobb 60 values were found approximately 80 grams per square meter (g/m²). According to Aryal et al. (2022), who also reported a range of Cobb values beginning from 50 g/m^2, the observed variation in Cobb 60 values is probably caused by variations in the chemical composition of the paper samples.

Brightness and opacity are two important factors that influence how light interacts with paper. When paper with a yellowish tint is exposed to blue light, it absorbs more of that light and reflects less, which is why brighter paper appears less yellow. Simply put, higher brightness means the paper reflects more light, making it look whiter and less yellowish. A paper sample's brightness depends on a number of variables, including surface smoothness and the degree of bleaching (Bajpai, 2018). Commercial printing papers that are bleached and calendared (smoothed) can achieve very high ISO brightness ratings, even reaching up to 100%. The brightness of the paper samples varied from 53% for the composite paper to 50% for palmyra paper.

The brightness of paper and pulp samples is influenced by factors such as lignin content, microscopic surface characteristics, and impurity levels. The lignin content in both the palmyra and composite paper was found to be relatively high, which is consistent with findings from a previous study by Aryal et al. (2022), where the brightness of samples varied from 56% to 67%. Sheets manufactured from A. comosus leaves had the maximum bleachability and brightness (77.70%), whereas sheets created from P. caribaea had the lowest brightness (Saeed et al., 2017).

Opacity measures a paper's ability to block light from passing through, which is especially important for double-sided printing to prevent text from being visible on the opposite side (strike-through). In our study, the opacity of the paper samples varied from 63% for palmyra to 60% for the composite paper. Papers with lower apparent density (less compact fibers) can sometimes have moderate opacity, as they may contain more air spaces (porosity) that scatter light, making the paper appear less transparent. Interestingly, a moderate positive connection between perceived density and opacity was observed, suggesting that, while not the only reason, denser sheets tended to be more opaque. This conclusion is in line with Aryal et al.'s (2022) findings, which showed that paper opacity varied between 83% and 98%.

➢ *Chemical Analysis*

The ash, cellulose, hemicellulose, and lignin content of the two paper samples measured and compared. The mean values (n=3) for ash, cellulose, hemicellulose, and lignin content varied from 59% to 67%. Our analysis revealed clear differences in the composition of the two papers (Fig. 4). Paper 1 had a lower ash content (3.2 ± 0.12%) compared to Paper 2 (4.52 ± 0.08%). In contrast, Paper 2 contained significantly more lignin (8.25 ± 0.01%) than Paper 1 (4.11 ± 0.18%). Regarding carbohydrate content, Paper 1 showed higher cellulose content (59.14 ± 0.11%) and slightly lower hemicellulose content (18.22 ± 0.12%) than Paper 2 (cellulose: 67.00 ± 0.13%, hemicellulose: 21.78 ± 0.18%). These compositional differences can impact the properties of the final paper product (Table 2).

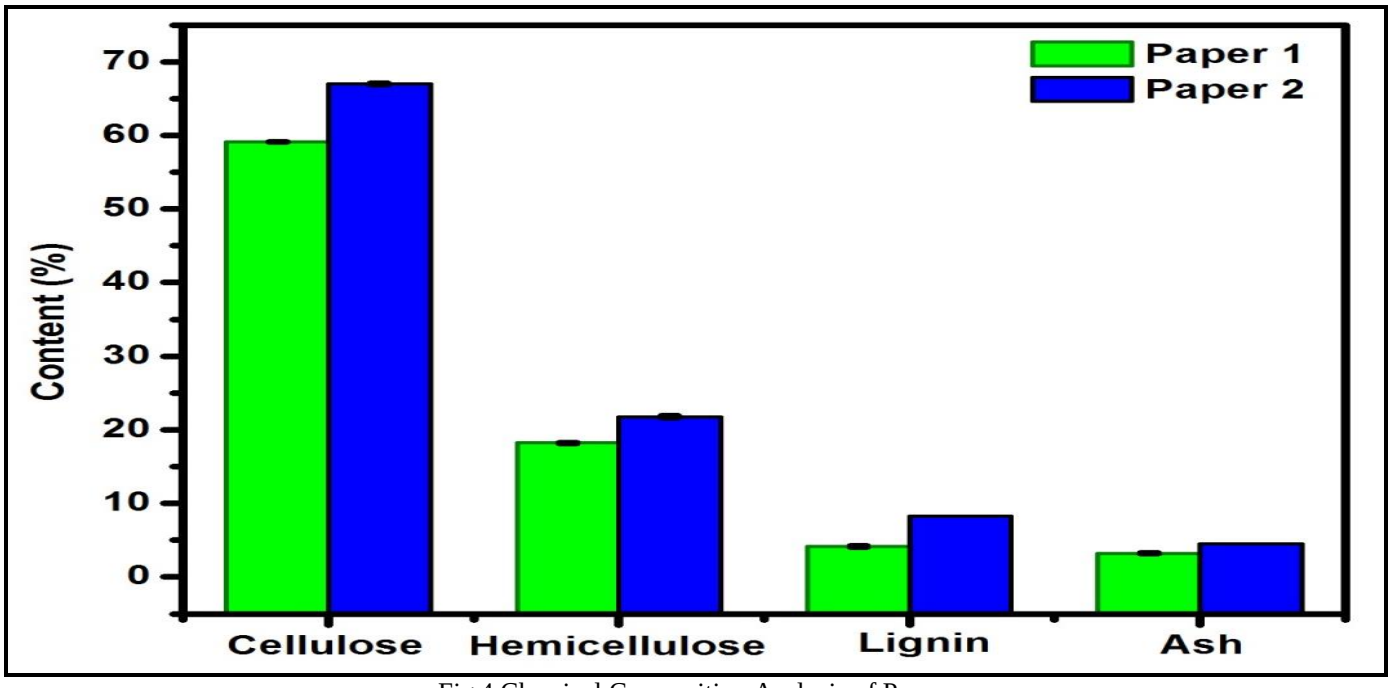

Fig 4 Chemical Composition Analysis of Papers

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Table 2 Chemical Composition of Papers

Chemical Composition	% Based on Dry Weight of Paper 1 (Palmyra)	% Based on Dry Weight of Paper 2 (Composite Palmyra/ Coconut/ Banana Fibre)
Ash	3.2 ± 0.12	4.52 ± 0.08 %
Cellulose	59.14 ± 0.11	67.00 ± 0.13
Hemicellulose	18.22 ± 0.12	21.78 ± 0.18
Lignin	4.11 ± 0.18	8.25 ± 0.01

The quality of paper made from non-wood materials is influenced by the levels of holocellulose, which is the combined content of cellulose and hemicellulose (Daud et al., 2014). In studies, the cellulose and hemicellulose content in the samples followed the order: *P. purpureum* < *H. crepitans* < *T. grandis* < *A. comosus* < *P. caribaea for cellulose, and P. caribaea* < *H. crepitans* < *P. purpureum* < *T. grandis* < *A. comosus* for hemicellulose. According to these patterns, P. caribaea might offer the strongest fibers with a chemical composition similar to that of wood. The high holocellulose content (89.70 ± 0.23%) of *A. comosus* leaves further indicates its potential to produce higher-quality paper (Khalil et al., 2006; Enayati et al., 2019; Aziz et al., 2006). Different fiber types and processing methods may be the cause of the differences in chemical composition among the paper samples.

➢ *FTIR Analysis*

Natural plant fibers are typically lignocellulosic materials with a heterogeneous structure, exhibiting spectral patterns with sharp absorption bands. In this study, FTIR spectroscopy was helpful to analyze the obtained fibers, identifying the absorption peaks corresponding to their constituent materials (Mayandi et al., 2015). The FTIR spectra for the handmade paper obtained from the different non-wood pulps are shown in Fig. 5 and 6, and Tables 3 and 4. For the composite paper, peaks appeared around 3351 cm^{-1}, similar to those found in other natural fibers (Gopinath et al., 2021). This observation was also reported by Bemerw et al. (2021) in their study of Papyrus fibers. The peak at 3351 cm^{-1} corresponds to O-H stretching, indicating the presence of cellulose. Peaks at 2912, 2914, and 2847 cm^{-1} represent C-H stretching, which results from the vibration of cellulose and hemicellulose (Santhanam et al., 2016). These peaks were present in both the 100% palmyra paper and the composite paper (palmyra/banana/coconut). Additional bands at 1637, 1462, and 1370 cm^{-1} were ascribed to the stretching of the benzene ring, CH_2 deformation, and CH_3 bending, respectively, reflecting the vibration of C-H and C-O groups in the aromatic ring of hemicellulose and lignin. The 1462 cm^{-1} peak was observed in both spectra, while the 1370 cm−1 band corresponds to C-O stretching vibration in acetyl groups of lignin, which was present in the palmyra paper. The intensity of this peak was weaker in the composite paper, suggesting that fiber processing during papermaking led to the removal of hemicellulose. The absorption peaks at 722 and 718 cm^{-1} were ascribed to O-H out-of-plane bending in crystalline cellulose, while those at 549, 520, and 511 cm^{-1} corresponded to O-H out-of-plane bending in amorphous cellulose.

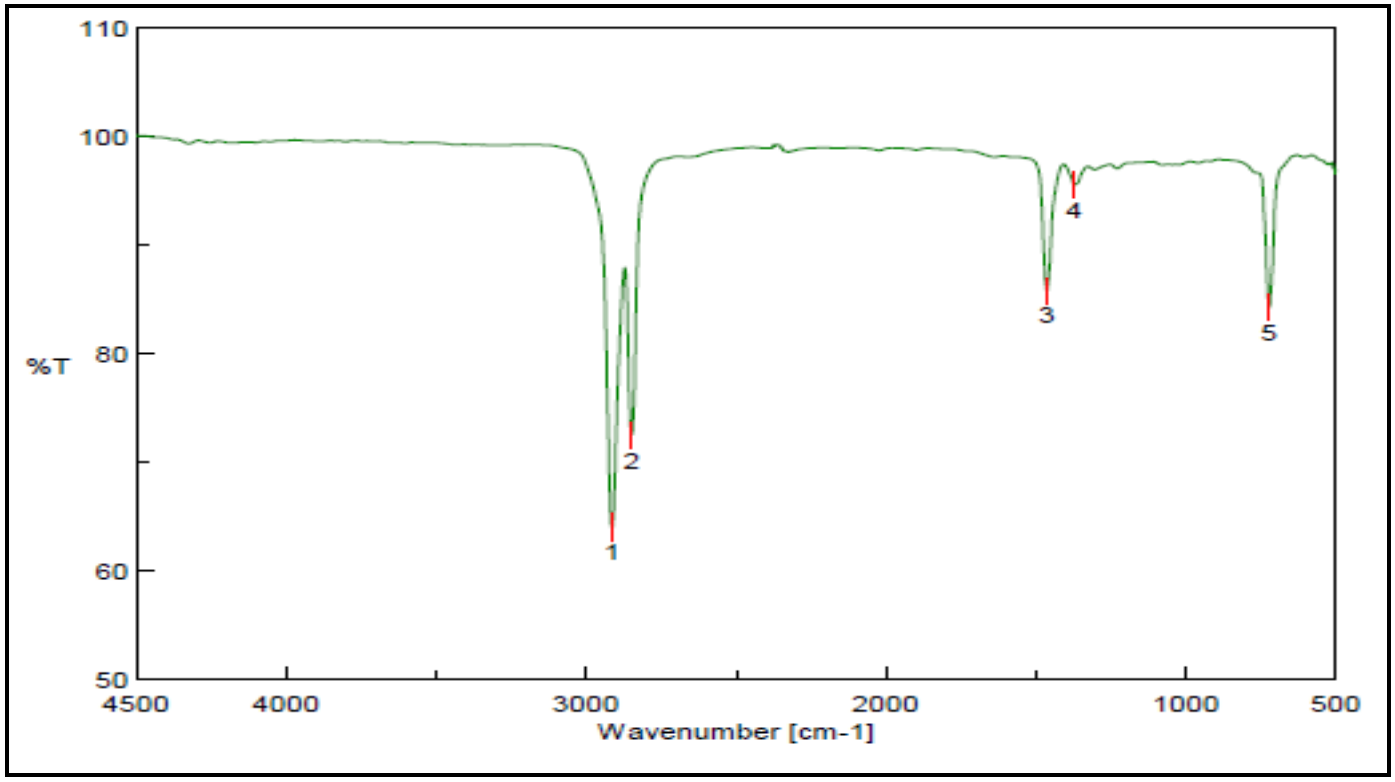

Fig 5 FTIR Spectrum of 100% Palmyra (*Borassus flabellifer*) Paper

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Table 3 IR Peaks and Relative Intensity of Palmyra

No.	Wavenumber (cm^{-1})	Intensity (%)	Vibrations
1	2912.95	64.0411	C-H stretching
2	2847.38	72.5326	C-H stretching
3	1462.74	85.7922	CH_2 deformation
4	1370.18	95.5277	CH_3 bending
5	722.211	84.2616	O-H out-of-plane bending

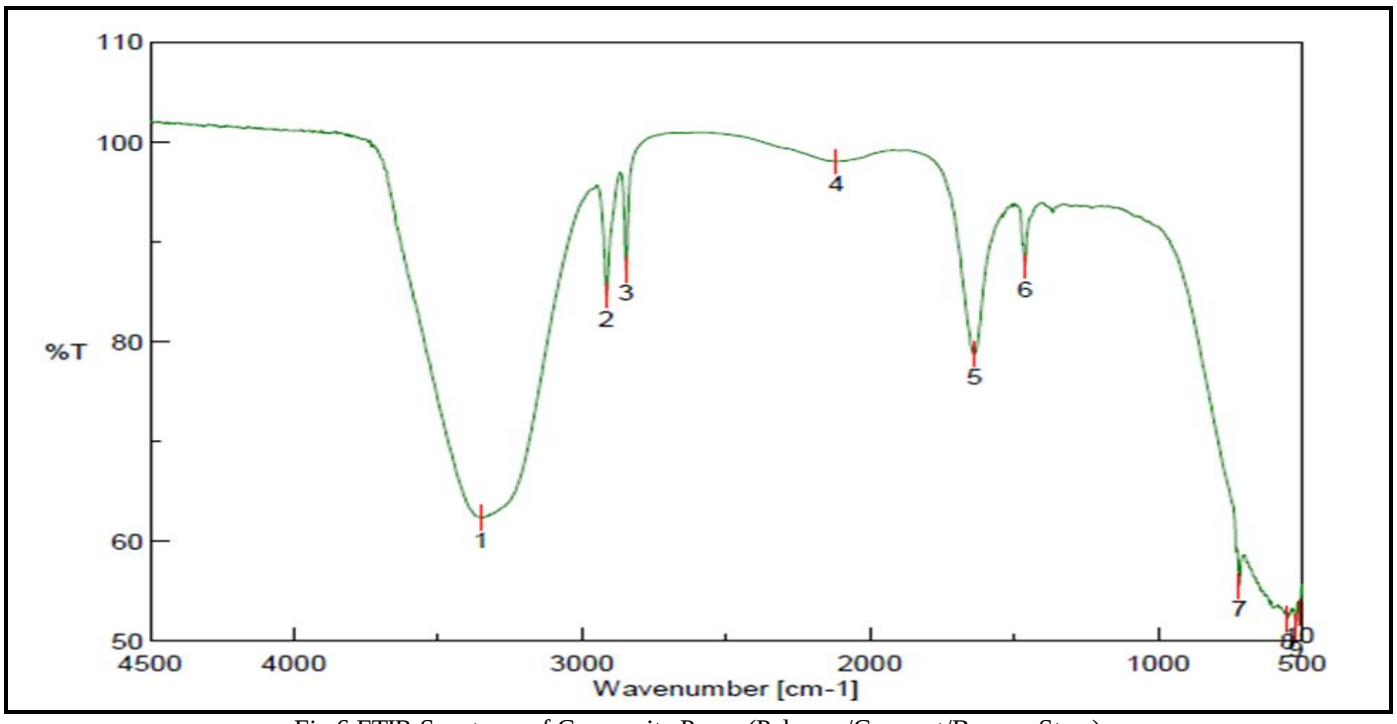

Fig 6 FTIR Spectrum of Composite Paper (Palmyra/Coconut/Banana Stem)

Table 4 IR Peaks and Relative Intensity of Composite Paper

No.	Position (cm^{-1})	Intensity (%)	vibrations
1	3351.68	62.371	O-H stretching
2	2914.88	84.5798	C-H stretching
3	2847.38	87.1602	C-H stretching
4	2116.49	98.0253	C-H stretching
5	1637.27	78.733	Stretching of the benzene ring
6	1462.74	87.5475	CH_2 deformation
7	718.354	55.5124	O-H out-of-plane bending in crystalline cellulose
8	549.613	52.2781	O-H out-of-plane bending in amorphous cellulose.
9	520.686	51.4982	
10	511.044	52.8727	

➢ *SEM Imaging of the Paper Samples*

The surface morphology of handmade papers made from natural fibers was examined using SEM images at different magnification. The images revealed long fibers with some serration along their length. The study highlighted significant differences in how the fibers were organized and bundled within the paper sheets made from these non-wood fibers (Daud et al., 2014). These variations are attributed to the type, strength and quality of the original plant fibers. As noted in a previous report by Daud et al. (2014), the pattern in which fibers are arranged can impact the final strength of the paper. Interestingly, the surface of the paper fibers from both types of papers appeared relatively smooth. The overall quality of the paper and the mechanical qualities of the fibers may be improved by these fiber arrangements. The ultimate quality of the paper also depends on the fibers' compactness and arrangement, as well as elements like the amount of cellulose in the non-wood materials (Daud et al., 2014; Saeed et al., 2017) (Fig. 7).

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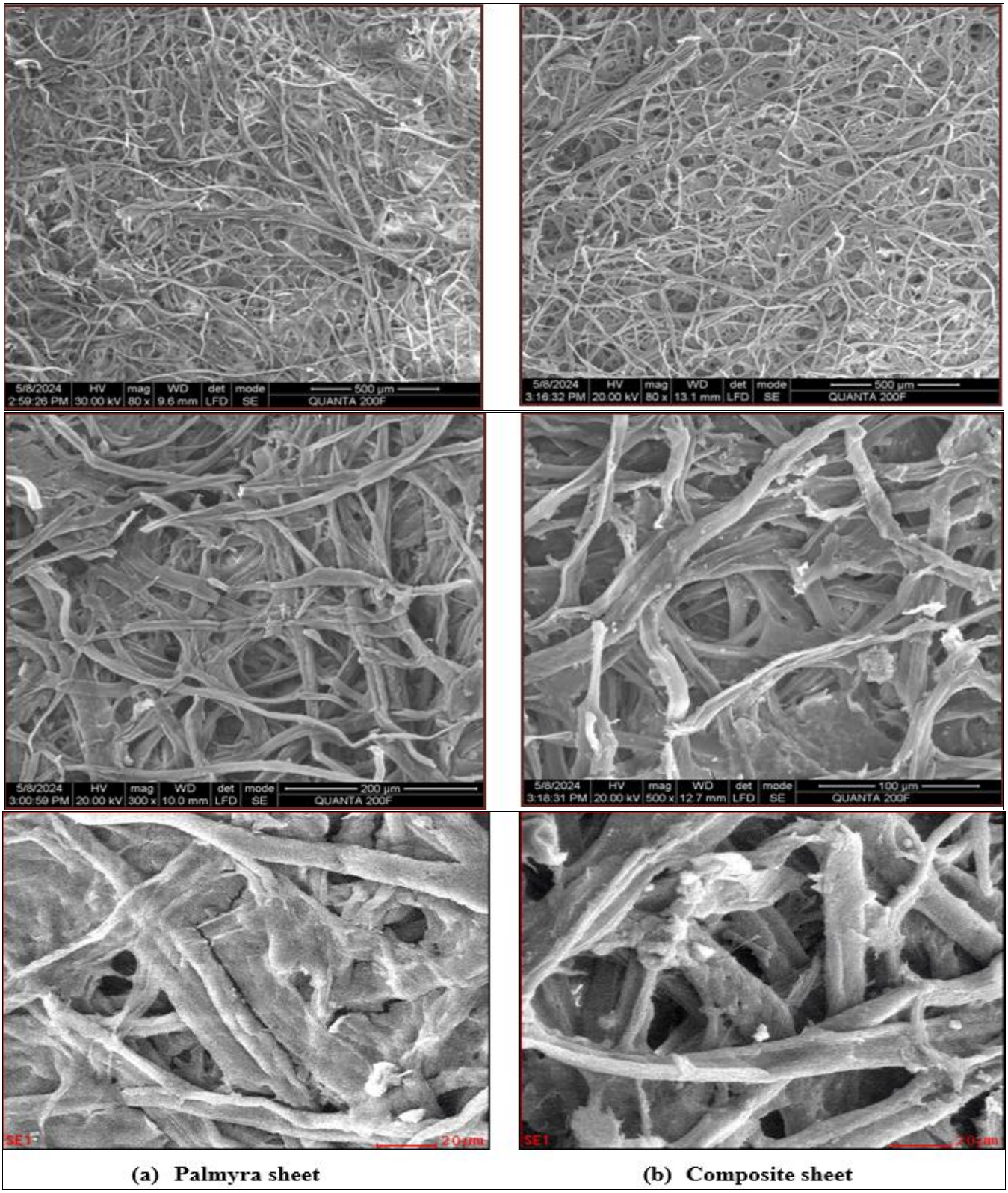

Fig 7 SEM Images of Handmade Paper Sheets from the Pulps of the Non-Woody Fibres a. Palmyra b. Composite Paper

➢ *Elemental Analysis of Handmade Paper*

Energy Dispersive X-ray Spectroscopy (EDX) was used to analyse the composition of both natural papers, as shown in Fig. 8. The cellulose is the major component of paper which has two main elements in the chemical structure such as carbon and oxygen, have noticeable peaks in the EDX spectrum. The photoelectron peaks for carbon and oxygen are detected at 0.25 keV and 0.46 keV, respectively. These peaks align with those identified in the FTIR analysis, further supporting the classification of the paper as a biomaterial. In addition to carbon and oxygen, Palmyra paper contains trace amounts of calcium, barium, lanthanum, and terbium, which are macronutrients absorbed

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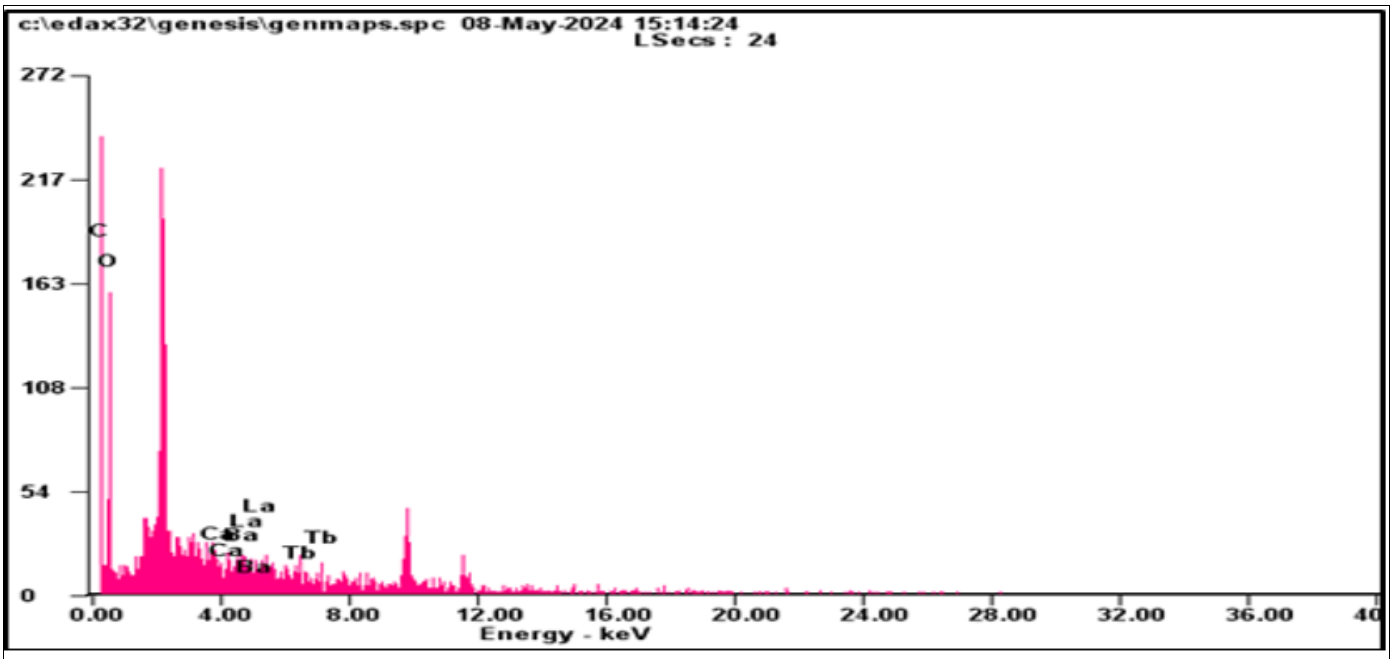
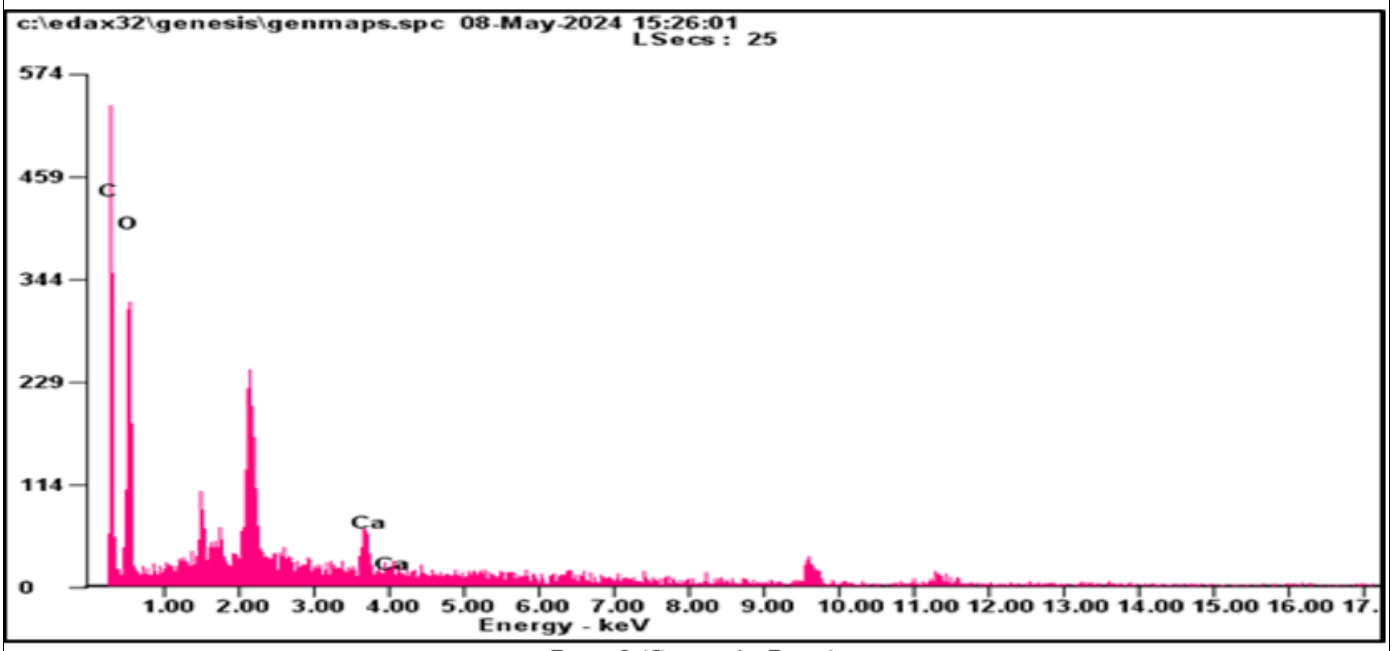
by plants from the soil. The composite paper contains trace elements of calcium and aluminum.

The elemental analysis shows that composite paper and Palmyra paper have relatively higher carbon content (53.47% and 55.04%) compared to oxygen content (45.41% and 40.22%) respectively. This implies that both composite and Palmyra paper have fewer amorphous or non-cellulosic elements on their surfaces. Both papers' carbon/oxygen (C/O) ratios show that the fibers' surface is hydrophilic. Greater hydrophobicity is generally indicated by a higher C/O ratio, which is a desired characteristic for creating natural fiber-reinforced composites with better qualities.



Paper 1 (Palmyra Paper)



Paper 2 (Composite Paper)

Element	Wt%	At%
CK	53.47	60.83
OK	45.41	38.79
CaK	01.12	00.38
Matrix	Correction	ZAF

Fig 8 Elemental Analysis Handmade Paper

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IV. CONCLUSION

In summary, various physical and chemical properties of paper made from natural fibers such as palmyra, banana stem, and coconut. It was prepared by kraft pulping method. The physical and chemical properties of obtained papers were evaluated. The paper samples had average thickness, grammage, moisture content, opacity, brightness, and apparent density values for 100% Palmyra paper and composite paper were 0.13 and 0.22 μm, 22.8 and 18.9 g/m², 8% and 6%, 63% and 60 %, 50% and 53% and 0.22 and 0.18 g/cm³, respectively. These findings show that the handmade palmyra and composite sheets have intermediate levels of yellowness, moderate to high tensile strength, and are lightweight. The presence of cellulose was detected in the samples by FTIR analysis. SEM images further revealed an interconnected network of long cellulose fibers within the paper sheets. These characteristics are helpful to explain the mechanical properties in the paper samples. EDX analysis reveals the existence of carbon and oxygen content present in the sample. The obtained results highlight the possibilities of producing handmade papers with distinctive qualities and provide insightful information on the potential use of coconut husk, palmyra husk, and banana stem for paper production.

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- *Conflicts of Interest statement:*

Authors declare no conflicts of interest.

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