**Evaluation of Percentage Solubles, Fibre Dimensions and Morphological Indices of Different Parts of *Raphia hookies* as raw materialsfor Pulp and Paper production**

**Abstracts**

**Fibre characteristics and solubility contents** of the raw materials are **critical indicators** for predicting their suitability for pulp and paper production. This research work evaluates the percentage solubles and fibre characteristics of different parts of *Raphia hookies* (Tietie, Piassava, Petiole and Frond). The samples were ground into powder and solubility in cold and hot water, 1% NaOH and ethanol/benzene were determined using TAPPI standard methods. Ethanoic acid/ hydrogen peroxide macerated samples fibres were used for the determination of fibre characteristics. Results revealed that the soluble contents were within the range of other non woods pulping raw materials, average fibre length for Tietie, Piassava, Petiole and Frond were 1.21, 1.85, 1.59 and 2.46 mm respectively. Frond with long fibre length will give stronger, more durable paper. Fibre diameters varied slightly across samples (14.65 –15.50 µm), while lumen width (7.33 –7.55 µm) and cell wall thickness (3.660 – 3.975 µm) values remained consistent, indicating similar structural properties. These results revealed that the samples have short-long fibres. The results of the morphological indices indicate that the Runkel ratio ranged from 0.998 to 1.053, with Frond exhibiting the most favorable value (0.998), Slenderness ratios were highest in Petiole (164.44) and Piassava (123.66), suggesting excellent fibre flexibility and high tensile potential. Flexibility coefficients for all samples were about 50 %, indicating good potential for fibre collapse and inter-fibre bonding. Rigidity coefficients ranged between 20.00 % and 25.65 %, all below the critical 30 % threshold. These results showed that the tested samples exhibited varying fibre dimensions and morphological characteristics and are suitable for the production of various grades of papers. The solubility characteristics of different parts of Raphia hookeri will offer essential insights into their potential use as raw materials for pulp and paper production.

**Keywords:** Fibre, solubility, fibre dimension, morphological indices, *Raphia hookies*

**Introduction**

The need for pulp and paper has risen significantly due to exponential population growth, industrialization, and urbanization. Most paper manufacturing industries use wood fibers to meet pulp and paper requirements. The shortage of fibrous wood resources and increased deforestation are linked to the excessive dependence on wood for pulp and paper production (Worku et al., 2023). The increasing demand for sustainable and renewable raw materials in the pulp and paper industry has intensified the exploration of non-wood plant fibres. These Agro-based residues and non-wood plants materials are gaining prominence due to their abundance, renewability, and relatively low environmental impact (Akpabio and Akpakpan, 2012). Pulp and paper mills are an essential part of the global economy and provide a wide variety of products for various uses. Because of their rapid industrial development and urbanization (Osung and Akpakpan, 20120), the consumption of paper has constantly increased over the past decades in high-income countries. The use of forest resources to make pulp has increased in recent years, having a variety of industries, such as furniture manufacturing, construction, and others, using wood as a raw material. The pulp and paper industry relies primarily on the uses of fibrous wood. This overreliance on fibrous wood is linked to significant environmental problems, including deforestation, greenhouse gas emissions, and global warming (Laftah *et al*., 2016; Mashanova *et al*., 2024). In recent years, traditional pulping materials have faced various restrictions, and environmental protection requirements have made the supply of wood raw materials insufficient since deforestation has drastic effect on the environment. Therefore, finding new alternatives has emerged as a future development trend (Danielewicz, 2019). Non-wood fibres are predominantly used in countries with limited wood supply. Recently, the use of non-wood fibre materials for pulping is increasing (Yusuf *et al*., 2018). Therefore, non-wood fibres have the potential to replace wood as raw materials for pulp and paper making.

Presently, the main non-woody plants being used as raw materials for pulping include corn stalks, wheat straw, bagasse, rice straw, bamboo, reeds, hemp, sorghum stalks, kenaf and other materials (Abd *et al*, 2020; Hurter, 1988; Singh *et al*. 2011). Also, physicochemical properties and pulping potentials of other non-wood plants such as plantain pseudosterm and screw pine leaves (Akpabio and Akpakpan 2012, Ogunsile, 2006, Omotoso and Ogunsile, 2009), Nypa palm fronds and petioles (Akpakpan *et al*., 2012a), pineapple leaf (Fagbemigun *et al*. 2016), *Cocos nucifera* fibres (NagarajaGanesh, 2023) have been reported. Although these non-woods raw materials have not been commercial utilized for paper making. The pulp from these raw non-woods materials can also be utilized for the preparation of cellulose derivatives (Akpabio *et al*., 2012).

Raphia hookeri which is a native palm species of West and Central Africa may stand out as a promising candidate, replacing wood as a raw material for paper. This is due to its abundant fibrous biomass, rapid growth rate, and renewable nature. After wine tapping, the plant is left unutilized for any industrial purposes. The plant produces large fronds, leaf stalks, piassava, tietie and trunk which are often discarded as agricultural waste despite their potential to serve as eco-friendly raw materials in pulp and paper production. However, a comprehensive evaluation of their physicochemical properties and fibre morphological characteristics is necessary to assess their suitability for such industrial usage (Osung and Akpakpan, 2012).

Fibre dimensions, such as fibre length, diameter, lumen width, cell wall thickness always influence the paper strength properties and paper processing processes. Understanding these properties of different anatomical parts of *Raphia hookeri* is critical to enhancing their usage in pulp and paper making.Therefore, this study aims to bridge this knowledge gap by systematically analyzing the solubility and fibre characteristics of distinct parts of Raphia hookeri which include the frond, petioles, piassava and tietie. The findings are expected to contribute to the development of sustainable alternatives to wood-based pulp, promote waste utilization, and support the growth of green industries in tropical regions (Osung and Akpakpan, 2012).

**2.0 Materials and methods**

**2.1 Sample collection and preparations**

 The samples used in this research which are Raphia hookeri frond, petioles, piassava and tietie (Figure 1), were collected from Ikot Obio Inyang in Etinan L.G.A., Akwa Ibom State, Nigeria, after the wine has been tapped. The samples were cut into chips and carried to Chemistry laboratory for further processing and analysis. At the laboratory, different parts of Raphia hookeri were ground into powder and kept in an air-tight bottle pending further analysis.



Figure 1: Pictures of different part of Raphia hookeri

**2.2 Determination of percentage solubles in different solvents**

Solubility of different parts of Raphia hookeri were determined as follows:

1. ***Determination of Solubility in Hot and Cold Water***

The percentage soluble content of each sample in cold and Hot-water was determined using TAPPI standard method designated T207. Hot and cold-water solubility is used to determine the percentage content of tannins, gums, sugars and colouring matter in the samples (TAPPI, 1999).

For cold water solubility, the sample (2 g) was put into a 400 mL beaker; 300 mL of distilled water was added and kept at room temperature with sequential stirring for 48 h, it was later filtered, washed with distilled water, and then dried in the oven at 105 oC to a constant weight. For hot water solubility, 2 g of the sample was put into a 250 mL Erlenmeyer flask and 100 mL of hot distilled water was added. This was placed in a heating mantle at 100 oC and refluxed for 3 h. After this time, the content in the flask was filtered and dried at 105 oC in the oven to a constant weight.

Hot and cold-water solubility were calculated using Equation 1

Hot or cold-water solubility (%) = $\frac{w\_{1}-w\_{2}}{w\_{1}}$ X 100 % …………………………. (1)

$w\_{1}$= initial weight of the sample, g

$w\_{2}$ = weight of the sample after extraction, g

1. ***Determination of Solubility in 1 % NaOH (TAPPI, 2002)***

The solubility of the samples in 1 % NaOH was determined in accordance with TAPPI Standard method designated T212. The sample (2 g) was put in a 250 mL beaker, 100 mL of 1 % NaOH was added and placed in a water bath maintained at 100 oC for 60 min. After 60 min, the sample was filtered and washed with 100 mL of hot water. Then 25 mL of 10 % acetic acid was added and allowed to stand for 1min. The sample was then washed with hot distilled water until the acid was completely removed. The sample was dried in the oven at 105 oC to constant weight. 1% NaOH soluble entails the degree of fungus decay that can take place in a given pulping raw material.

Solubility in 1 % NaOH was calculated using equation 2.

Solubility in 1 % NaOH (%) = $\frac{w\_{1}-w\_{2}}{w\_{1}}$ X 100 ………………………………. (2)

w1 = weight of the sample before extraction, g

w2= weight of the sample after extraction, g

1. ***Determination of Ethanol-Benzene Solubility***

 This was determined using TAPPI standard method (TAPPI, 1997) designated T 204. The air-dried sample (2 g) was wrapped in a filter paper and placed in a 200 mL Soxhlet extractor containing (1:2) ethanol – benzene solution mixture as the extracting solvents. After extraction, the solvent was evaporated from the flask. The extraction flask and its contents were dried to a constant weight in the oven at 105 oC. Ethanol-benzene extractives were calculated using equation 3.

Ethanol benzene solubility = $\frac{w\_{2}}{w\_{1}}$ X 100 ………………………………….. (3)

Where w1= weight of the sample g

 w2 = weight of the extract g

***2.3 Determination of fibre characteristics of different parts of* Raphia hookeri**

Samples were prepared into slivers of about 1 cm x 2 mm x 2 mm, and macerated in equal volume of ethanoic acid and hydrogen peroxide (1:1) in an oven at about 100° C for 48 hours. 30 random samples of macerated fibres were mounted on the slides and fibre length (FL) and fibre diameter (FD) were measured directly using a stage micrometer mounted on an Olympus light microscope (CH Series). Lumen width (LW) and cell wall thickness (CWT) were determined using equation 4 and 5 respectively.

Lumen width (LW) = $\frac{FD}{2}$ ……………………………………………. (4)

Cell wall thickness (CWT) = $\frac{FD-LW}{2}$…………………………………….. (5)

**Fibre morphological indices** are calculated parameters that describe the **shape, structure, and mechanical potential** of individual fibres. These indices are essential for evaluating the **suitability of wood and non-wood sample as a raw material** for **papermaking**. They were calculated as given below:

Runkel Ratio (RR) = $\frac{2 x CWT}{LD}$ …………………………………….………….. (6)

Slenderness Ratio (SR) = $\frac{FL}{FD}$ ………………………………...…………………(7)

Flexibility Coefficient (FC) = $\frac{LD}{FD}$………………………………………………. (8)

Rigidity Coefficient (RC) = $\frac{2 x CWT}{FD}$……………………………………………..(9)

**Results and Discussion**

**Table 1: Percentage solubles of different part of Raphia hookeri**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Samples | Solubility incold water(%) | Solubility in hot water(%) | Solubility in 1% NaOH (%) | Solubility in ethanol/benzene(%) |
| Piassava | 66.5 | 68.0 | 28.0 | 15.0 |
| Tietie | 21.5 | 18.5 | 23.0 | 23.0 |
| Frond | 19.5 | 24.5 | 17.5 | 13.0 |
| Petiole | 23.0 | 40.5 | 24.5 | 35.3 |

The results of the percentage soluble content of different part of Raphia hookeri are presented in Table 1 and illustrated in Figure 2. Solubility in cold and hot water revealed the presence of **water-soluble components** such as **simple sugars, tannins, gums, starches, and other low-molecular weight compounds.** **Piassava** shows **extremely high solubility** in both cold (66.5%) and hot water (68.0%), indicating high levels of **degraded materials**, extractives, or non-cellulosic impurities , this may be because of the present of pitch on the surface of piassava. while **Frond and Tietie** exhibit **moderate to low solubility (19.5 – 24.5 %) and (18.5 – 21.5 %) respectively**, which is preferable since they contain lower extractive content which may contribute to **better pulp yield** and **less chemical interference**. 1% Sodium hydroxide solubility revealed that the frond has the lowest solubility content (17.5 %) while piassava has the highest (28.0 %). According to **Rowell *et al*,, (2000)** **NaOH solubility below 20 – 25 %** is desirable for **most non-wood fibres**. High values suggest the need for **chemical optimization** in pulping. Hence, Frond is the **most chemically stable**, ideal for strong and high-yield pulp. **Tietie** is also acceptable with moderate degradation while **Petiole** and **Piassava,** with higher solubility, may need **process adjustments** and raw material treatment to ensure good pulp quality.

### Ethanol-Benzene Solubility measures lipophilic extractives like resins, fats, and waxes which can interfere with the pulping process. Petiole (35.3%) and Tietie (23.0%) have very high values, which could lead to pitch problems during pulping. Piassava (15.0%) and Frond (13.0%) show moderate values, indicating fewer resinous substances, and thus better papermaking compatibility.

**Table 2: Fibre length (FL) and fibre diameter (FD) of different parts of Raphia *Hookies***

Figure 2: Percentage soluble of different part of Raphia hookeri

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Tietie | Piassava | Petiole | Frond |
| **S/N** | **FL (mm)** | FD **(µm)** | **FL (mm)** | FD **(µm)** | **FL (mm)** | FD**(µm)** | **FL (mm)** | FD**(µm)** |
| 1 | 0.9994 | 13.92 | 0.7084 | 11.385 | 10.7525 | 22.77 | 1.170 | 27.93 |
| 2 | 1.3915 | 12.65 | 0.8981 | 10.12 | 1.8975 | 12.65 | 1.862 | 13.30 |
| 3 | 1.1638 | 15.18 | 1.7710 | 22.77 | 1.2017 | 12.65 | 1.409 | 17.29 |
| 4 | 1.1764 | 22.77 | 2.5300 | 12.65 | 1.7836 | 24.03 | 1.729 | 15.96 |
| 5 | 1.2523 | 12.90 | 1.3915 | 13.92 | 1.2144 | 11.38 | 1.596 | 13.30 |
| 6 | 1.2144 | 15.18 | 1.1005 | 12.65 | 1.2650 | 12.65 | 1.955 | 14.63 |
| 7 | 1.3409 | 17.71 | 2.7324 | 12.65 | 1.7710 | 12.65 | 1.476 | 13.30 |
| 8 | 1.0373 | 12.65 | 2.4035 | 13.92 | 1.2776 | 11.38 | 1.742 | 11.97 |
| 9 | 1.1765 | 13.92 | 2.1505 | 17.71 | 1.7204 | 12.65 | 1.463 | 14.89 |
| 10 | 1.0892 | 15.18 | 2.4288 | 18.98 | 1.2397 | 13.92 | 1.011 | 13.30 |
| 11 | 1.2768 | 15.96 | 0.7448 | 11.97 | 1.8088 | 13.30 | 1.113 | 26.56 |
| 12 | 1.4098 | 18.62 | 0.9443 | 10.64 | 1.3034 | 14.63 | 1.657 | 11.38 |
| 13 | 1.0906 | 13.30 | 2.5270 | 14.63 | 1.2635 | 13.30 | 1.391 | 14.17 |
| 14 | 1.2369 | 14.63 | 2.2610 | 18.62 | 1.8753 | 25.27 | 0.961 | 12.65 |
| 15 | 1.1451 | 15.96 | 2.5536 | 19.95 | 1.2768 | 11.97 | 1.518 | 12.65 |
| 16 | 1.0507 | 14.63 | 1.1571 | 13.30 | 1.3300 | 13.30 | 1.859 | 13.91 |
| 17 | 1.4630 | 13.30 | 2.8728 | 13.30 | 1.8620 | 13.30 | 1.404 | 12.65 |
| 18 | 1.2236 | 15.96 | 1.8620 | 23.94 | 1.3433 | 11.97 | 1.771 | 12.65 |
| 19 | 1.2369 | 23.94 | 2.6600 | 13.30 | 11.305 | 23.94 | 1.342 | 16.44 |
| 20 | 1.3167 | 13.56 | 1.4630 | 14.63 | 1.995 | 13.30 | 1.644 | 15.18 |
| 21 | 1.0065 | 14.01 | 1.4014 | 14.01 | 10.829 | 22.93 | 1.596 | 13.30 |
| 22 | 1.4014 | 12.74 | 1.1084 | 12.74 | 1.911 | 12.74 | 1.955 | 14.63 |
| 23 | 1.0447 | 12.74 | 2.7518 | 12.74 | 1.210 | 12.74 | 1.476 | 13.30 |
| 24 | 1.1848 | 14.01 | 2.5480 | 12.74 | 1.796 | 24.21 | 1.742 | 11.97 |
| 25 | 1.0969 | 15.29 | 0.7134 | 11.47 | 1.223 | 11.46 | 1.463 | 14.89 |
| 26 | 1.2230 | 15.29 | 0.9045 | 10.19 | 1.274 | 12.74 | 1.391 | 14.17 |
| 27 | 1.3504 | 17.84 | 1.7836 | 22.93 | 1.783 | 12.74 | 0.961 | 12.65 |
| 28 | 1.1721 | 15.29 | 2.4206 | 14.01 | 1.287 | 11.46 | 1.518 | 12.65 |
| 29 | 1.1848 | 22.93 | 2.1658 | 17.84 | 1.733 | 12.74 | 1.859 | 13.91 |
| 30 | 1.2613 | 12.99 | 2.4461 | 19.11 | 1.248 | 14.01 | 1.864 | 13.89 |
| **Mean** | **1.207** | **15.502** | **1.8467** | **14.96** | **2.45935** | **14.959** | **1.529** | **14.649** |
| **Standard Error** | **0.0228** | **0.5564** | **0.1334** | **0.7069** | **0.52892** | **0.8404** | **0.0521** | **0.6718** |
| **Standard Deviation** | **0.1250** | **3.0478** | **0.7305** | **3.8715** | **2.8970** | **4.6031** | **0.2856** | **3.6795** |

 **Table 3: Fibre dimensions of different parts of Raphia hookeri**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Samples | FL(mm) | FD (µm) | LW (µm) | CWT (µm) |
| Tietre | 1.21 | 15.50 | 7.55 | 3.975 |
| Piassava | 1.85 | 14.96 | 7.48 | 3.74 |
| Frond | 1.59 | 14.65 | 7.33 | **3.66** |
| Petiole | 2.46 | 14.96 | 7.48 | **3.74** |

As presented in Table 3 and Figure 3, the fibre length of Tietie, Piassava, Frond and Petiole are 1.21, 1.85, 1.59 and 2.46 mm respectively. Pulping raw materials with fibre of less than 1.0 mm is considered to be shot; 1.0 - 2.0 are medium fibre while fibre length of 2.0 mm and above is classified as long fibres (Fagbemigun *et al*., 2016). The fibre length of Tietie, Piassava, and Frond are medium fibre lengths. These fibre are comparable to the fibre length of Rice straw (1.41mm), Wheat straw (1.48 mm), Bagasse (1.70 mm) and Reed grass (1.5 mm) ( Hunter, 1988) and *Nypa fruticans*frond (1.59 mm) ( Akpakpan *et al*., 2012a) and higher than that of Bahamas grass (0.85 mm) (Ekhuemelo, 2013) . These fibres may be best suited for **blending with longer fibres** or for use in **surface-finish-focused papers** (e.g., writing printing papers). While petiole has a long fibre which compares favorably to softwood fibres and some non-woody raw materials such as Jute (2.5 mm), Hemp (2.0 mm) and Kenaf bast (2.5 mm) ( Hunter, 1988), making it excellent for high-strength applications e.g., sack and packaging papers (Ademiluyi *et al*., 1979).

Figure 3: Fibre dimensions of different parts of Raphia hookeri

The fibre diameter of the four samples ranges from **14.65 - 15.50 µm**. These fibre diameters are comparable to hard wood fibres (10-20 **µm)**. Thicker fibres tend to be **stiffer and less flexible,** which can reduce bonding potential. However, the fibre diameters obtained are moderate; suggesting a good balance between **rigidity and flexibility** (Atchison, 1993).The lumen width is the diameter of the internal cavity of the fibre. It is the distance between the inside diameter and the outer cavity. The larger the fibre lumen width, the better the beating of pulp because of the penetration of liquids into empty spaces of the fibres. **Lumen width of the samples ranges from 7**.33 – 7.55 µm. These values are lower than that of Bamboo (8.09 – 9.54 µm) reported by Ogunjobi *et al.* (2017) and higher that the value of lumen diameter reported by Akpakpan *et al*., (2012a) for *Nypa fruticans* frond and petiole (5.79 and 4.96 µm) respectively. This range indicates a **moderate lumen size. Lumen size affects flexibility and collapse:** wider lumens promote better fibre collapse and inter-fibre bonding during papermaking, improving sheet strength and density (Casey, 1980).

Cell wall thickness**ranges** from 3.66 – 3.975 µm indicating **medium-thick cell wall,** suggesting that the fibres are neither too rigid nor too thin-walled. Thicker walls add strength but reduce flexibility; thinner walls improve collapsibility but can weaken fibre strength. The values obtained are lower than 5.64 μm reported by Ogunjobi *et al*. (2018) and greater than 2.90 μm observed by Oluwadare and Ashimiyu, (2007) for *Leucaena* *leucocephala* wood*.*

**Table 4: Fibre morphological indices of different parts of Raphia hookeri**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Samples | Runkel Ratio | slendernessRatio | FlexibilityCoefficient (%) | Rigidity Coefficient (%) |
| Tietie | 1.053 | 78.06 | 48.71 | 25.65 |
| Piassava | 1.000 | 123.66 | 50.00 | 20.00 |
| Frond | 0.998 | 108.47 | 50.03 | 24.97 |
| Petiole | 1.000 | 164.44 | 50.00 | 25.00 |

Results for fibre morphological indices of different parts of Raphia hookeri are presented in Table 4 and also illustrated in Figure 4. Runkel ratio is an important morphological parameter for the measurement of raw material suitability for pulp and paper making (Runkle, 1952, Casey 1980). The results of Runkel ratio revealed that frond with Runkel ratio (0.998) is comparable to the runkel ratio of Pineapple leaf and maize stalk (0.9) reported by Ekhuemelo *et al*. (2013). Runkel ratio <1 implies that the fibre has thin-walled and will have good fibre collapse and better bonding which is ideal for papermaking. Runkel ratio = 1 means moderate collapsibility and Runkel ratio **>1** implies that the fibres has thick-walled, stiffer, and less collapsible, hence may result in production of **bulkier paper** with **lower bonding strength**, but potentially better porosity and stiffness, which are useful for specialty papers such as filter or insulating papers. **Tietie** with higher Runkel ratio of 1.053 may be less suitable for fine papers but could be advantageous for applications requiring more **rigid or porous structures**.

Figure 4: Fibre morphological indices of different parts of Raphia hookeri

Fibre with Slenderness ratio above 70 will form a paper with good strength properties. Higher slenderness ratio will give more flexible and better fibres entanglement. All the four samples exceed 70, with Petiole and Piassava showing excellent values (>120), which Suggests good fibre entanglement and tensile strength potential. All samples have Flexibility coefficient above 50 % indicating **good fibre flexibility and moderate collapsibility, implying that the sample pulps is ideal** for forming strong inter-fibre bonds (Ojo *et al*., 2008). **Fibres with Rigidity coefficient less than** 30 %, imply softer and more flexible fibres. All the results of **Rigidity coefficient obtained** fall between **20 – 26 %,** indicating **acceptable rigidity.** Piassava is the most flexible (20 %) and ideal for making soft paper. Since *Raphia* hookeri is from ***Arecaceae*** family, it can be converted into pulp using soda or soda alcohol pulping (Akpakpan *et al.,* 2011; Akpakpan *et al*., 2012b).

**Conclusion**

This work determined the soluble contents and fibre characteristics of different parts of *Raphia* hookeri in order to evaluate their suitability or otherwise for paper making. The solubility characteristics of different parts of Raphia hookeri offer essential insights into their potential use as raw materials for pulp and paper production. Solubility values indicate the presence of extractives, hemicelluloses, and other non-cellulosic components, which may affect pulping process and **pulp yield. Fibre dimensions of all** samples fall within or above the typical range for **non-wood fibres**, suggesting their **suitability for papermaking**. All four sample fibres showed **morphological indices suitable for papermaking,** the fibres have **good flexibility, low rigidity, and moderate collapsibility,** which would favour the productionof **papers with balanced strength and smoothness.** *P*etioleand Piassava have the best mechanical potential due to high slenderness ratio, and frond showed best collapsibility since its Runkel ratio is less than 1. Hence, the pulp from these raw materials can be used in the production of different grade of papers.

**Disclaimer (Artificial intelligence**)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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