

Unlocking the Suitability and Potential of Agricultural Residues as Sustainable Non-Wood Fibre Sources for Paper Production: A Chemical Composition Evaluation

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Abstract—This study evaluated the chemical composition of agricultural residues such as corn sheaths and pineapple crowns in order to assess their suitability for paper production. The analyses of chemical composition of corn sheaths and pineapple crowns were carried out using standard laboratory procedures including TAPPI standards. Corn sheaths exhibited 43.31 % of cellulose; hemicellulose was 16.15%, lignin 6.41%, extractives 14.97% and ash content 7.65%. Hot water solubility, cold water solubility and 1% sodium hydroxide solubility were found to be 25.10%, 17.82% and 64.10% respectively while pineapple crowns exhibited 31.42 % of cellulose, hemicellulose was 15.25%, lignin 5.64%, extractives 5.49% and ash content 4.00%. Hot water solubility, cold water solubility and 1% sodium hydroxide solubility were found to be 17.22%, 11.65% and 63.87% respectively. The cellulose content in corn sheaths was found to be higher than that of pineapple crowns, indicating that corn sheaths will produce more pulp yield than pineapple crowns which shows that corn sheaths are more desirable pulp yield is of essence for in paper production. Hemicellulose contents in corn sheaths and pineapple crowns were found to be 16.15% and 15.25% respectively, an indication that there will be easy dissolution of hemicellulose in alkaline solution during pulping. The ash content and extractives were relatively low, suggesting minimal impurities in both corn sheaths and pineapple crowns. The investigation shows that the chemical composition corn sheaths and pineapple crowns are favourable for paper production. Independent sample student t-test of GraphPad Prism, version 8.2 was used to compare the mean values for significant difference at $p < 0.05$. This study demonstrated that corn sheaths and pineapple crowns are viable non-wood fiber sources for paper production, offering a sustainable alternative to traditional wood-based pulps.

Keywords— Fibres, Corn Sheaths, Pineapple Crowns, Cellulose, Hemicellulose, Lignin, Extractives.

I. INTRODUCTION

The paper industry is facing increasing pressure to adopt sustainable and environmental friendly practices, driven by growing concerns about deforestation, greenhouse gas emissions, and waste management issues (Ayoade, 2003). In response, researchers and industry stakeholders are exploring alternative fibre sources to traditional wood-based fibres for paper production. Agricultural residues have been found to be better alternatives to forest trees that are currently and predominantly used for paper production (Madhuri, 2003). However the chemical compositions of the agricultural residues determine the quality of pulp and papers produced (Limenew, 2023). Corn sheaths and pineapple crowns, by-products of corn and pineapple processing; have been identified as potential non-wood fiber sources for papers production. With millions tons of corn sheath and pineapple crown wastes generated annually, they both present an attractive opportunity for valorization and waste reduction (Stastita, 2023). However, the chemical composition is crucial in determining the suitability of corn sheaths for paper production (Kiaei, 2014).

The research focused on analyzing the cellulose, hemicellulose, lignin, ash, and extractives content. By understanding the chemical composition of corn sheaths and pineapple crowns, this study provides

valuable insights into the potential of corn sheaths and pineapple crowns for paper production, including its strengths, limitations, and required processing conditions. The significance of this research is in its contribution to the development of sustainable paper production practices, supporting the paper industry's transition towards a more circular and environmentally friendly economy. By exploring the potential of corn sheaths and pineapple crowns as non-wood fiber sources, this study helps to reduce the industry's reliance on traditional wood-based pulps, promote waste valorization, and support the development of eco-friendly paper products.

II. MATERIALS AND METHODS

Determination of Ash Content

This was determined according to TAPPI standard T211om-93 (TAPPI, 1993). A mass of 2g of corn sheaths was weighed in a porcelain crucible, and then transferred into a furnace at the temperature of 550-600°C for 4hrs, after which the samples turned to white ash. The resulting ash was weighed after cooling in a desiccator.

$$\text{Ash content (\%)} = \frac{\text{Weight of ash}}{\text{Weight of oven dry sample}} \times 100 \dots \dots \dots (1)$$

Determination of 1% Sodium Hydroxide solubility

The solubility of the samples in hot diluted alkaline solution was determined based on ASTM designation D1109-56. A mass of 2g of air-dried milled corn sheaths was placed in two separate 200ml beakers followed by addition of 100ml 1% NaOH. The beakers were covered and placed in a water bath at boiling point for about 1hour. The contents were stirred three times at 10, 20 and 30 minutes of the extraction period. After this, the contents were filtered on tarred crucibles and washed with 100ml hot distilled water and then with 50ml of 10% acetic acid thoroughly with hot water in-turns. The crucibles and contents were dried in an oven at 100°C to constant weight. The results were reported as follows:

$$1\% \text{ NaOH} = \frac{W_1 - W_2}{W_1} \times 100 \dots \dots \dots (2)$$

Where, W_1 is the weight of moisture free milled sample,

W_2 is the weight of dried sample after 1% NaOH extraction

Determination of Hot Water Solubility

The test was carried out according to ASTM designation D1110-56. A mass of 2g of milled air dried samples of corn sheaths was placed in conical flask filled with 100ml of distilled water and attached to a reflux condenser. The flask was placed in a boiling water bath. The sample was extracted by heating the water bath gently for 3hrs; the sample was filtered, washed with hot distilled water and placed on a tarred crucible of known weight. The crucible was dried with the sample in an oven at 100±2°C to constant weight; the result was reported as a percentage of matter soluble in hot water on the moisture free basis and calculated as follows:
 Hot water solubility = $\frac{W_1 - W_2}{W_1} \times 100 \dots \dots \dots (3)$

Where, w_1 is the weight of moisture free milled sample,

w_2 is the weight of dried samples after

Determination of Cold Water Solubility

The test was carried out based on ASTM designation D1110-56. A mass of 2g of milled air dried samples, of corn sheaths was placed in 400mL beaker and covered with 300ml of distilled water. The mixture was digested at a temperature of 27°C for 48hours with thorough stirring. The sample was filtered, washed with cold distilled water and placed on tarred crucible of known weight. The crucible was dried with the sample in an oven at 100±2°C to constant weigh. Result was reported as a percentage of matter soluble in cold water on the moisture free basis and calculated as follows:

$$\text{Cold water solubility (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \dots \dots \dots (4)$$

Where w_1 = weight of moisture of free milled sample
 w_2 = weight of dried samples after extraction with cold water

Determination of Extractives Content (A)

This was carried out according to TAPPI standard T204cm-97. Corn sheaths were dried in an oven at 100±5°C and then milled. Soxhlet extraction apparatus was connected to a reflux condenser above and connected to a boiling flask below. A mass of 10g of the oven dried milled sample, of each of the agricultural residues, was wrapped in a tissue paper and placed in an extraction thimble, then covered with cotton wool. The thimble was placed in the

soxhlet extraction tube on a boiling flask containing solution of benzene and ethanol in ratio 2:1 volume for 8 hrs at rate of 6 siphoning per hour. Another extraction was done for 4 hrs using 95% ethanol. The thimble was removed from the soxhlet extraction tubes and washed with distilled water to remove residual solvents. The moist sample after extraction was dried and weighed.

Extractives (%)

$$= \frac{W_1 - W_2}{W_1} \times 100 \dots \dots (5)$$

Where, W_1 is the weight of original sample before extraction.

W_2 is the weight of oven dried sample after extraction

Determination of Hemicellulose, Cellulose and Lignin Contents

The Von Soest method was adopted for the determination of hemicellulose, cellulose and lignin contents. The method employs sequential detergent extractions (neutral and acid with boiling and washing to fractionate the fibre.

Neutral Detergent Fibre – NDF

A mass of 10g of extractives free milled corn sheaths was weighed; the sample was digested by boiling with a neutral detergent solution (sodium sulfite and octanol) ratio 1:1. The solution helped to reduce the surface tension of the fibre and helped the solution to penetrate into the fibre and solubilized the neutral detergent soluble fraction (such as sugars, starch, fats). The residue (neutral detergent fibre - NDF) consisting of hemicellulose, cellulose and lignin- the neutral detergent insoluble fraction.

Acid Detergent Fibre - ADF

The neutral detergent fibre residue was then washed in crucibles with water and then washed with acetone; the resulting residue was boiled with an acid detergent solution (containing sulfuric acid and cetyltrimethylammonium, CTAB) ratio 1:2, resulting to acid detergent fibre- ADF containing cellulose and lignin. Hemicellulose was the difference between neutral detergent fibre and acid detergent fibre. The resulting acid detergent fibre residue was then treated with 15ml of Cold 72% sulfuric acid to dissolve the cellulose, leaving lignin which was acid detergent lignin.

Hemicellulose (%) = Neutral Detergent Fibre (%) - Acid Detergent Fibre (%)..... (6)

Cellulose % = Acid Detergent Fibre (%) - Acid Detergent Lignin (%)..... (7)

Lignin % = Acid Detergent Lignin (%)..... (8)

III. RESULTS AND DISCUSSION

The chemical compositions of agricultural residues significantly impact their suitability for paper production (Jean *etal*, 2018). Table 1 shows that corn sheaths exhibited 43.31 % of cellulose; hemicellulose was 16.15%, lignin 6.41%, extractives 14.97% and ash content 7.65%. Hot water solubility, cold water solubility and 1% sodium hydroxide solubility were found to be 25.10%, 17.82% and 64.10% respectively while pineapple crowns exhibited 31.42 % of cellulose, hemicellulose was 15.25%, lignin 5.64%, extractives 5.49% and ash content 4.00%. Hot water solubility, cold water solubility and 1% sodium hydroxide solubility were found to be 17.22%, 11.65% and 63.87% respectively. Cellulose is the main source of fibre in biomasses for pulp and paper production, the more the cellulose contents the more the pulp yield for paper production (Alagbe, 2019). The cellulose content in corn sheaths was found to be higher than that of pineapple crowns, indicating that corn sheaths will produce more pulp yield than pineapple crowns under the same pulping conditions which shows that corn sheaths are more desirable where more pulp yield is needed in paper production. Hemicellulose contents in corn sheaths and pineapple crowns were found to be as low as 16.15% and 15.25% respectively, an indication that there will be easy dissolution of hemicellulose in alkaline solution during pulping and more pulp yield will be achieved, and paper with good strength will be produced, and in addition, the rate of yellowing of the paper will also reduce. High ash content affects the strength of paper, increases abrasion and issues related to retention of fillers. The low ash content (7.65%) and extractives (14.97%) exhibited by corn sheaths and ash content of 4.00% and extractives of 5.49% indicate minimal impurities in the agricultural residues, further supporting their suitability for paper production (Alagbe, 2019).

Cold water solubility and hot water solubility indicate the presence of soluble sugars, starches and other compounds in the agricultural residues; high

solubility can negatively impact the strength of paper and pulp yield. Corn sheaths and pineapple crowns exhibiting low cold water solubility and hot water solubility indicate that they are desirable for paper production. 1% sodium hydroxide (NaOH) solubility shows the presence of alkaline-soluble components affecting pulp yield and paper production, the high 1% sodium hydroxide (NaOH) solubility exhibited by corn sheaths and pineapple crowns make pulping require low sodium hydroxide concentration for more

and quality pulp yield. Corn sheaths and pineapple crowns exhibited low lignin contents similar to what was reported by Oluwadare et al, 2018 as desirable fibre sources in paper production because of their low lignin content. With low lignin content, low pulping chemical concentration will be needed for pulping. The study reveals the chemical composition corn sheaths and pineapple crowns, and also shows that they are both suitable for paper production.

Table 1: Chemical Composition of Corn Sheaths and Pineapple Crowns

| Test Sample | Ash (%) | 1% NaOH Solubility (%) | Cold water Solubility (%) | Hot water Solubility (%) | Extractives (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) |
|------------------|------------------------|-------------------------|---------------------------|--------------------------|-------------------------|-------------------------|-------------------------|------------------------|
| Corn Sheaths | 7.65±0.26 ^a | 64.10±3.72 ^a | 17.82±0.89 ^a | 25.10±1.61 ^a | 14.97±6.05 ^a | 16.15±0.22 ^a | 43.31±0.64 ^a | 6.41±0.03 ^a |
| Pineapple Crowns | 4.00±0.10 ^b | 63.87±1.16 ^a | 11.55±0.51 ^b | 17.22±0.26 ^b | 5.49±0.47 ^b | 15.25±0.31 ^a | 31.42±0.61 ^b | 5.64±0.07 ^a |

Mean ± standard error values with different superscripts in a column differ significantly at p<0.05.

IV. CONCLUSION

Conclusively, the chemical composition of corn sheaths and pineapple crowns were successfully evaluated, revealing their promising potentials as non-wood fiber sources for paper production. The results showed that corn sheaths and pineapple crowns contain favorable combination of cellulose, hemicellulose, and lignin, making them suitable for papermaking.

While some variations in chemical composition were observed, the overall results demonstrate that corn sheaths and pineapple crowns are viable alternatives to forest wood (Madhuri, 2003). These findings support the development of sustainable paper production practices, reducing the industry's reliance on wood-based pulps and promoting waste valorization. Future research should focus on optimizing pulping and papermaking processes to fully realize the potential of corn sheaths and pineapple crowns as non-wood fiber sources.

Additionally, exploring the feasibility of blending corn sheath and pineapple crown fibers with other non-wood fibers or wood fibres could further enhance their suitability for various paper products. The chemical components of corn sheaths and pineapple crowns suggest their potential for high-quality paper products, including packaging, printing

and tissue papers, and by harnessing the potential of corn sheaths and pineapple crowns, the paper industry can take a significant step towards a more circular and environmentally friendly economy, reducing wastes, and promoting sustainable development. This research contributes to the development of sustainable paper production practices, supporting the paper industry's transition towards a more circular and environmentally friendly economy.

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