Synthesis, Optimization and Characterization of Pulp from Banana Pseudo Stem for Paper Making via Soda Anthraquinone Pulping Process

Tesfaye Kassaw Bedru[1(✉)] and Beteley Tekola Meshesha[2]

[1] Department of Chemical Engineering, Kombolcha Institute of Technology, Wollo University, P.O. Box 208, Kombolcha, Ethiopia
tesfaye.kassaw@kiot.edu.et

[2] School of Chemical and Bio-Engineering, Addis Ababa Institute of Technology, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia
Beteley.tekola@aau.edu.et

Abstract. The need for pulp and paper currently in the whole world has become shooting up massively. The generation of the pulp, as well as paper from woody materials, has a challenge due to deforestation, huge chemical and energy consumptions. Now, another source for pulp and paper is lignocelluloses wastes materials, because of low cost, low energy, and chemical consumption. Among them, the pseudo stem was best for the input of pulp and paper production. This investigation was on the production and characterization of pulp from Banana Pseudo Stem for Paper Making via Soda Anthraquinone pulping process. The amount of cellulose (41.45%), ash (12.4%), hemicellulose (23.37%), extractive (12.72%), and lignin (10.46%) contents were obtained at the initial compositional evaluation of the pseudo stem. It has excellent fiber length (1.75 mm), fiber diameter (22.15 µm), an acceptable Runkle ratio (0.55), and flexibility coefficient (159.64). The effect of temperature (130, 140 and 150 °C), cooking time (45, 60, and 75 min), the concentration of soda (10, 12.5, and 15%), were examined. The maximum yield and kappa number of pulp was 36.7% and 22.8 respectively obtained at 10% of soda concentration, at 150 °C, and 63 min of cooking time from oven-dried raw material. The produced paper from the pseudo stem has a tensile index, tearing index, smoothness, and porosity were 78.75 Nm/g, 19.1 mN. m^2/g, 500–530 µm, and 50 s/100ml air respectively. This study indicates that high strength mechanical property and good surface properties paper can be produced from pseudo stem pulp with a more environmentally friendly pulping process.

Keywords: Banana pseudo stem · Fiber · Pulp · Paper · Temperature · Cooking time · Soda concentration

1 Introduction

The pulp and paper sector produces a great number of paper and other cellulose-based fiber products. The total quantities of cellulose products consumed every year worldwide exceed 400 million tons. Paper products are integrated into nearly every aspect of

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our daily lives. It is undeniably important to society [1]. In the pulp manufacturing sector, the scarcity of raw material is an issue in some regions in the world and is go with rising wood supply costs. Research on alternative fiber raw materials is well proceeding and new tree species annul plants and agricultural residual materials have been suggested for pulping and paper production [2]. Wood pays to about 90% of the conventional raw material used for pulp and paper production in the world. However, the reduction of forest resources to obtain wood had made an effect on the environment and humans. Several agricultural residues including rice husk, corn straw, wheat straw, corn stalk, plantain stalk, pineapple leaf, and corn husks which do not have abrupt beneficial applications in many communities have been suggested to prospective sources of pulp [3]. The production of the non-wood type of pulp has increased more rapidly than that of pulp from wood in the last two decades, by a factor of about two in Latin America and three in Africa and the Middle East [4]. Studies have shown that the production process of paper from non-wood fiber is significantly less expensive than wood fiber. Wood and non-wood resources are currently browbeaten for the manufacturing of pulp, paper, and soft boards [5]. Many non-wood fibers, such as bamboo, jute, straw, rice, and bagasse, are currently used in small commercial pulping operations. Other agricultural residues such as banana pseudo stem, wheat straw, cotton stalk pose a suitable characteristic for papermaking [6]. Ethiopia has an abundance of agro-waste material that has not been fully utilized to maximum production. Examples of such agro-waste materials are banana pseudo stem, coffee husk, wheat straw, rice straw, cotton stalks, corn stalks, etc. Among these agro-wastes, the banana pseudo stem holds a suitable characteristic for fiber sources suitable for textile, pulp and paper, packaging material, twines and ropes, and other industrial applications. Every year a massive amount of banana plant wastes remains leftover creating environmental pollution. For every 30–40 kg of banana sold in the market, 250 kg of waste is produced in the farm. The waste is then causing by the emission of toxic gases including CO_2 and also gives growth to the harmful fungi which attack remaining banana trees [7]. The banana plant is largely divided into three parts: pseudo stem, peduncle, and leaf. The pseudo stem possesses good physical strength properties. It consists of high cellulose, low lignin, and higher pentosane content together with gums and mucilage in the sheath of certain species of banana plant may be a suitable source for producing pulp and paper [8]. This study aimed to produce and characterization of pulp from the banana pseudo stem for paper making via the soda anthraquinone pulping process.

2 Materials and Methods

Materials: The banana (Musa Cavendish) pseudo stem was collected from Jimma agricultural site and the experiment was done in the school of Chemical and Bio-Engineering Laboratory, Addis Ababa University, Ethiopia. The 96% Sulfuric acid, 98% Toluene, 98% Ethanol, 96% Nitric acid, Safranin Solution, Sodium hydroxide, Anthraquinone, 42% Hydrogen peroxide and Potassium permanganate were used chemicals for experimental investigation.

Experimental Procedure: Fresh pseudo stem waste was obtained from Jimma agricultural site. The unwanted portions of the plant were discarded and only the needed portion; pseudo stem was used in the study. The sample was washed with water to remove all debris and unwanted particles. To measure fiber morphologic properties of the specimens, the pseudo stem was cut into the 0.5 mm thickness and 2 cm long in parallel to fiber [8]. To determine the chemical composition of the pseudo stem sample was first oven-dried and crushed to 60 meshes [9]. The ash content, moisture content, and extractive content was determined. For moisture content, the pseudo stem dried at 105 ± 3 °C for 24 h until getting a constant weight. After 24 h dried the yield was determined by using the TAPPI T 413 om-93 approach. The ash content of the pseudo stem sample was ignited at 525 °C for 4 h. After 4 h, the crucible was carefully withdrawn and cooled in a desiccator then weighed and the percentage was determined via TAPPI T 262 om-02. The content of extractive of the pseudo stem was done via Soxhlet extractor 200 mL of ethanol/toluene (1:2 (v/v)) used as a solvent for extraction for 8 h. After extraction, the sample was air-dried at 25 °C for few minutes and the percentage was determined via TAPPI T 204 cm-97. The content of cellulose was determined by using Kurschner–Hoffner approach and 5-g extractive free sample was cooking with 125 ml of alcoholic nitric acid solutions with a reflux during four cycles of 1 h. After each cycle, the alcoholic nitric acid solution is isolated and a fresh volume is added. The alcoholic nitric acid solution contained of mixing one volume of 65% (w/w) solution of nitric acid with four volumes of 96% purity ethanol [10]. At the termination of the four cycles, the cellulose was washed, dried, and weighed. The hemicellulose content was determined by taking 2 gr. of extracted dried biomass was transferred into a 250 mL Erlenmeyer flask. 150 mL of 500 mol/m^3 NaOH was added. The mixture was boiled for 3.5 h with distilled water [11]. The lignin content was determined by standard TAPPI procedure, 1.8 g of the dried extracted raw pseudo stem was weighted in glass test tubes and 18 mL of 72% H2SO4 was added. The sample was kept at 25 °C for 2 h with carefully shaking at 30 min intervals to allow for complete hydrolysis. After the first hydrolysis, 504 mL of distilled water was added. The next step of hydrolysis was made to occur in an autoclave for 1 h at 121 °C. The slurry was then cooled at 25 °C. Hydrolysates were filtered through a vacuum using a filtering crucible. The acid-insoluble lignin was determined by drying the residues at 105 °C. Then the pulping process was done using the autoclave. All the oven-dry pseudo stems were chipped into 2 cm × 1 cm size and pulped using the Soda anthraquinone (soda- AQ) method. The 40 g dried samples were cooked with 0.1% anthraquinone constantly and 10:1 liquor to sample ratio for each cycle. The concentration (10%, 12.5%, and 15%) and temperature values were 130 °C, 140 °C, and 150 °C and the time of cooking was 45 min, 60 min, and 75 min were evaluated. Next black liquor was removed after 20 min and wished with high distill water. The pulp yield and the residual lignin in the pulps were assessed by determining the kappa number.

Morphological property of banana pseudo stem: For fiber length and fiber diameter determination, the pseudo stem was macerated with 50% nitric acid. Match stick size samples were taken in test tubes, immersed completely in nitric acid solution, and kept in a water bath at 70 °C. The maceration process was taken for 5–6 h. to get many separated white-colored fibers. Then test tubes containing macerated fibers were removed from the water bath and allowed to cool at room temperature. After cooling, nitric acid was drained and macerated fibers were washed with distilled water and filtered using What Man Grade 1 filter paper for separation of fibers [12]. For slide, preparation fibers were stained with 20% safranin solution and again washed with distilled water for distaining of excess safranin and placed some amount of fiber suspension on a glass slide with the help of ink/medicine dropper and allowed for air drying and mounting by using Canada balsam [12]. Two slides were prepared per sample and images were taken with a total magnification of 40×s using a camera attached Motic BA210 compound stereo microscope. Finally, the length and width of 40 fibers were measured using Motic software.

Lumen diameter and cell wall thickness: The pseudo stem was soaked in warm water below 100 °C for one hour and sliced by 1520 μm using a Leica RM2255 automatic rotary sliding microtome. The first three slices were discarded to avoid cell deformation and the following slices were taken.

Then placed slice into safranin solution (1 gm of safranin adding to 100 ml of water) and immersed into 30%, 50%, 70%, 85%, and 97% alcohol and xylene for 1 min each respectively. In this process, safranin is used for staining, alcohol for dehydration of water, and xylene to enhance the contrast between cells. Finally, the specimen was put on a slide and one drop of Canada balsam was dropped and covered using cover slip and leaf the slide to dry. After making a permanent slide, good quality images were taken with a total magnification of 400×s by using a camera attached Motic BA210 compound stereo microscope.

FTIR Analysis: The Perkin-100 FTIR spectrometer mad of America was used for functional group assurance of the pseudo stem fiber proportionally using the technique of KBr pellet for recording the transmittances [13]. The pretreatment was carried out by tableting the mixture of each sample and KBr (where KBr has a proportion of 0.5 wt. %) into a film. The functional group peaks were noted from 4000 to 400 cm^{-1} with a resolution of 4 cm^{-1} in the spectrometer.

3 Results and Discussion

3.1 Proximate and Chemical Compositions Analysis

Table 1. Proximate and chemical compositions analysis

Raw Material	Cellulose [%]	Hemicellulose [%]	Lignin [%]	Extractive [%]	Moisture content [%]	Ash content [%]
Pseudo stem[a]	41.45	23.37	10.46	12.72	11.4	12.4
Wheat straw[b]	39.7	30.6	17.7	5.2	7.9	6.9
Bagasse[c]	55.75 ± 04	n.a	20.5 ± 1.7	3.25 ± 4.3	n.a	1.85 ± 3.7
Soft Wood[d]	40–45	25–35	25–35	n.a	n.a	n.a
Hard Wood[d]	40–55	24–40	18–25	n.a	n.a	n.a

[a][Current study], [b][14], [C][15], [d][16]

Based on Table 1 the cellulose amount of stem of pseudo banana (41.45%) is higher than that of straw of wheat (39.7%) and smaller than bagasse (54.3%). So, greater than 34% value of celluloses implies good promise for manufacturing of pulp and paper [17]. It corresponded directly with the yield of pulp and it provides stronger fiber [18]. The pulp swelling behavior depends on the quantity of hemicellulose, which implies to shoot up in burst index, tensile, and tearing resistance [19]. Additionally, the lignin content value of pseudo stem (10.46%) is lower than wheat straw (17.7%), bagasse, and below the hard and softwood materials content of lignin. A lower value of lignin means easily discard from the process of pulping and it requires less chemicals for pulping and produce quality paper [20]. The digesting of pulping and cooking process length depends on the amount of the lignin of materials. Indeed, less chemical consumption and bleaching will be easy and faster when the amount of lignin is very low [21]. The extractive of the pseudo stem was 12.72%, which is greater than that of straw wheat and bagasse. High extractive content cause high consumption of chemical during the extraction of pulp and bleaching implies pitch deposits.

3.2 Analyses of Pseudo Stem Fiber Morphology

The fiber properties (fiber length, cell wall thickness, lumen width, fiber diameter, and their second values) determination helps of lignocelluloses materials as feedstock for pulp and paper products and helps to justify their qualities [22]. According to the optical microscope, the fiber image of the pseudo stem is presented in Figs. 1 and 2.

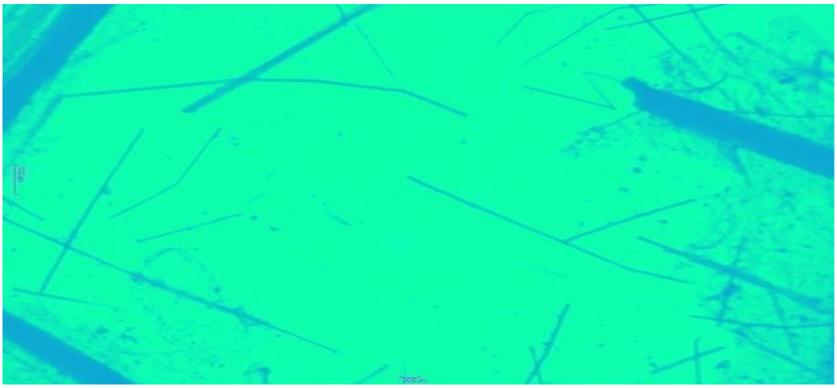

Fig. 1. Fiber length images of banana pseudo stem obtained from Motic microscope 40× magnified.

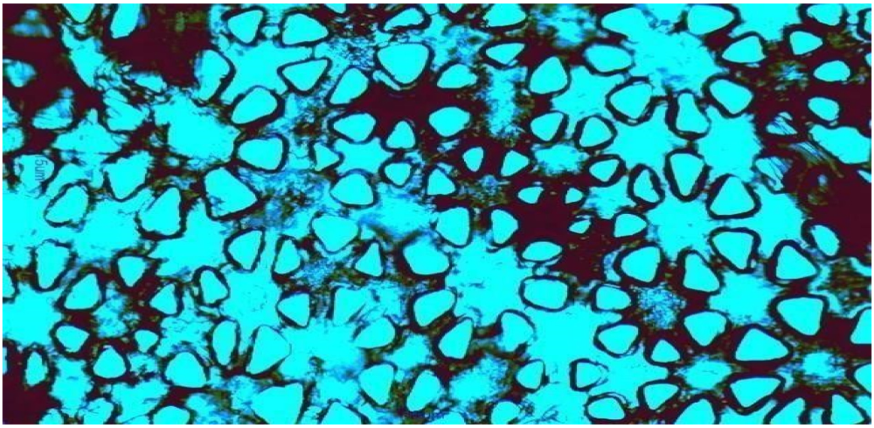

Fig. 2. Fiber diameter, lumen width, and cell wall thickness images of pseudo stem obtained from Motic microscope 100× magnified.

Table 2. Morphological characteristics of the pseudo stem and other plants

Parameter	Banana pseudo stem[a]	Wheat straw[b]	Eucalyptus Labill[c]	Enset Ventricosum stem[d]	Bagasse[e]
Fiber length [L] [mm]	1.75	1.14	0.98	1.66	1.7
Fiber diameter [D] [μm]	22.15	19.32	18.8	28.48	23
Lumen width [d] [μm]	35.361	10.54	n.a	25.87	19.55
Cell wall thickness [T] [μm]	9.7	4.39	4.9	2.88	4.77
Slenderness ratio [L/D]	79.01	0.83	n.a	58.48	73.4
Runkle ratio [2d/L]	0.55	59	n.a	0.22	0.49
Flexibility coefficient [D/L] * 100	159.64	54.55	n.a	90.83	85
Wall rigidity coefficient [d/D]	43.8	n.a	n.a	21.4	23.7

[a][Current study], [b][14], [c][15], [d][16]

Fiber Dimensions and Their Derived Values: The tear and paper machine run ability of paper strength depends on its fiber [23]. According to Table 2, the fiber average length (banana pseudo stem) is 1750 μm are with the range of non-woods, greater than of wheat straw (1140 μm), Enset Ventricosum stem (1660 μm), bagasse (1700 μm), and Eucalyptus labill (980 μm). Fiber classification is based on its length, so the stem of pseudo of banana grouped under long fiber (>1600) best to generate high tear resistance paper and classified as short below 1600 μm [18]. Still, the short and long fiber in length crucial for producing paper. More length of a fiber of wood or non-wood materials increase the formation of a matrix in the paper sheet causes great tensile strength, but shorter in the fiber of materials like grass and hardwood are essential for pulping extraction like printability, stiffness, and opacity [24]. The stem of pseudo banana thickness cell wall is 9.7 μm, which higher than of the straw of wheat (4.39 μm), Enset Ventricosum stem (2.88 μm), and bagasse (4.77 μm) eucalyptus labill (4.9 μm). The flexibility, collapsibility, and easy delignification are occurred due to thin cell walls of fiber materials during pulp generation. Whereas to produce high strengths, folding endurance and porosity of paper thick-walled materials of fiber are acceptable [29]. Accordingly, the cooking condition for the stem of pseudo banana needs higher than the others.

The beating of a paper also measured by its diameter of the fiber and lumen width, so the average diameter of the stem pseudo banana fiber was good (22.15 μm) conforms with coniferous and industrial pulping materials range as well as more than the set points (2.47–4.49 μm) of virgin raw materials [25]. Less flexibility of the fiber formed due to a small diameter of the fiber [26]. So, high strength paper easily made from the stem of banana pseudo. The conformity pulp, pulp yield, and paper are measured by the Runkle ratio (2 w/l) (typical value (=1)) [27]. Less value of the standard Runkle ratio (<1) is suitable for the properties of pulping strength. The Runkle ratio value of banana pseudo stem was 0.548, which was less than of straw of wheat (59). From this point of view, the fibers are suitable for papermaking. Less flexible, stiffer, and lower bonding properties causes due to high Runkle ratio compared to a low value (provides a large surface area and easily collapse) during the drying process [28, 29]. The bonding properties and good sheet forming characterized by the slenderness ratio (fiber length/fiber width). From Table 2 the cumulative value of slenderness ratio of the fiber (79.01) was higher than the value of 58.41 and 73.4 of Enset Ventricosum stem, and bagasse separately. Thus, the stem of pseudo banana has an approximately wonderful slenderness ratio, which indicates well for making of pulping and paper [30]. The paper during the drying and beating process can be characterized by the flexibility ratio of the fiber components. A large area and bonding form from the fiber collapsing properties implies high strength of tensile, bursting, and endurance of folding. It has higher flexibility ratio (159.64) of bagasse, straw of wheat, eucalyptus, and Enset Ventricosum stem fiber. Thus, it implies good bonding properties and the printing area also smooth [24]. The tear resistance, double-fold resistance, tensile, and burst of the paper were negatively affected by rigidity value [31, 32].

3.3 Pulp Yield and Kappa Number

The experimental values of pulp yield and kappa number obtained under different pulping conditions are presented in Table 3.

Table 3. The experimental values of pulp yield and kappa number obtained under different pulping conditions

Std.	Run	Con.NaOH (%)	Temperature (°C)	Time (min.)	Yield (%)	Kappa No
1	31	10	130	45	28.1	35.1
2	8	12.5	130	45	29.88	28.9
3	12	15	130	45	30.51	25.1
4	29	10	140	45	33.66	33.2
5	20	12.5	140	45	31.9	27.3
6	21	15	140	45	30.8	24.1
7	13	10	150	45	36.7	30.6
8	19	12.5	150	45	34.1	23.7
9	14	15	150	45	29.3	22.4
10	5	10	130	60	30.2	27.3
11	4	12.5	130	60	31.52	22.1
12	24	15	130	60	29.91	16.9
13	18	10	140	60	34.5	25.7
14	25	12.5	140	60	32.1	20.9
15	1	15	140	60	28.7	15.1
16	7	10	150	60	37.1	23.4
17	3	12.5	150	60	33.32	19.2
18	16	15	150	60	26.12	18.9
19	27	10	130	75	29.25	25.7
20	32	12.5	130	75	30.5	21.2
21	23	15	130	75	28.3	16.1
22	17	10	140	75	32.9	23.6
23	9	12.5	140	75	29.1	19.7
24	22	15	140	75	25.76	20.1
25	2	10	150	75	33.8	21.3
26	28	12.5	150	75	30.6	22.7
27	15	15	150	75	24.3	23.5
28	6	12.5	140	60	32.1	22.9
29	30	12.5	140	60	32.1	22.9
30	11	12.5	140	60	32.1	22.9
31	26	12.5	140	60	32.1	22.9
32	10	12.5	140	60	32	22.7

3.4 Process Parameters Investigation on Pulp Yield and Kappa Number

In Table 3 and Fig. 3 the soda concentration varied from 10 to 15%. In the absence of sodium hydroxide, pulping did not occur. Higher caustic soda amount causes simple delignification process and generates low lignin pulp. The increase value in the soda concentration decreased pulp yield, from 34.5% to 28.7%, and Kappa number of pulps from 25.7% to 17.9%. The pulp yield decreases due to the cellulosic fibers' degradation and solubilization of hemicelluloses in caustic soda and the kappa number decreases due to the positive effect of soda concentration on lignin delignification.

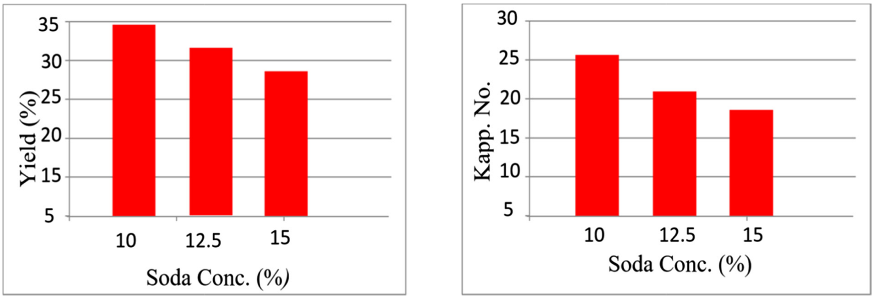

Fig. 3. Effects of soda concentration on pulp yield [a] and kappa number [b] at constant temperature [140 °C] and time [60 min.]

Choosing the appropriate temperature is avail to increase the pulp yield and decrease the kappa number. The lower temperature will make the lignin remove insufficiently, which results in a high kappa number. Higher temperature caused cellulose degradation and pulp yield decreased. Table 3 and Fig. 4 displays the influence of cooking temperature on yield and kappa number of the pulp. It is evident that the yield of pulp slightly increases from 31% to 33% with the increase in the cooking temperature this is possibly due to the bulky nature of the pseudo stem. The cooking temperature varied from 130 °C to 150 °C the kappa number decreases slightly. This shows that despite low lignin content, and the delignification of banana pseudo stems appears difficult.

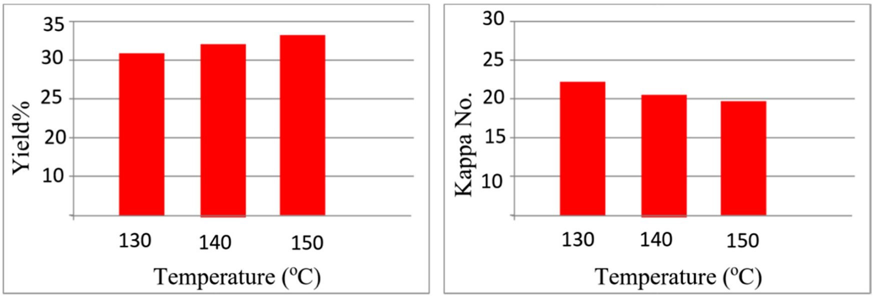

Fig. 4. Effects of temperature on pulp yield [c] and kappa number [d] at constant soda concentration [12.5%] and time [60 min.]

From Table 3 and Fig. 5 the cooking time varies from 45 to 75 min. The maximum yield was reached at 45 min, which is a short cooking time; for cooking times higher than 45 min the pulp yield decreases. According to Fig. 5 increasing the reaction time, reduced the Kappa numbers of the pulps, but at the same time encouraged polysaccharide degradation, as seen by the fall of the yield. This shows that cooking with a lesser time might offers pulps with better yield.

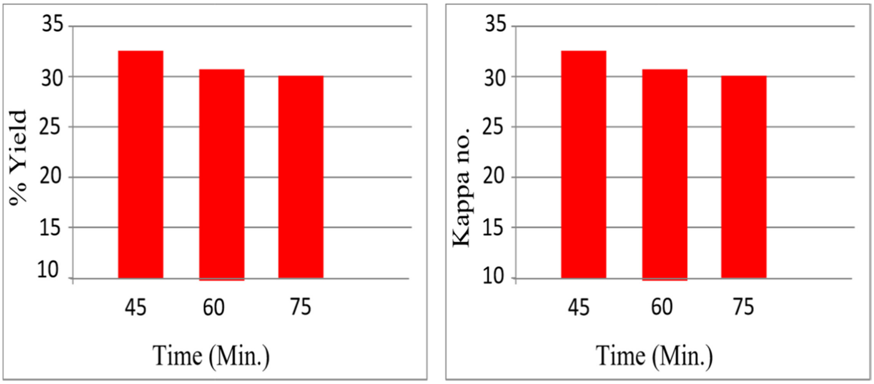

Fig. 5. Effects of time on pulp yield [e] and kappa number [f] at constant soda concentration [12.5%] and temperature [140 °C]

3.5 FTIR Analysis of Pseudo Stem and Pulp

Using the FITR the variation and clustering of the components of compounds of functional parts of materials at the micro-level can be determined. The major compositions of lignocellulosic fibers are cellulose, hemicelluloses, and lignin, while the minor constituents include minerals, pectin, waxes, and water-soluble components. To confirm the presence of functional groups and the removal of components present in the pseudo stem after the pulping process was carried FTIR analysis, illustrated in Fig. 6.

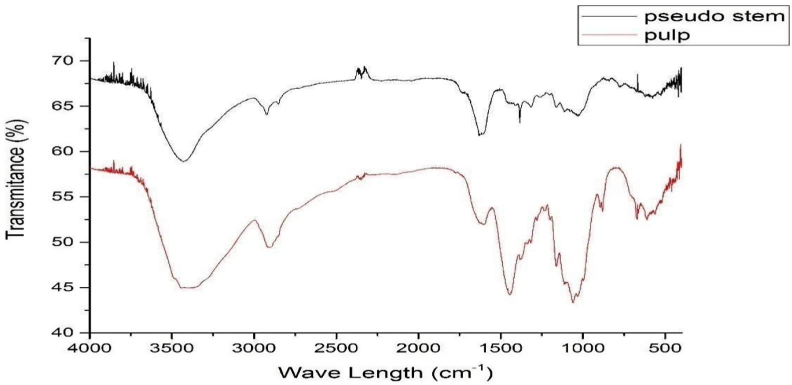

Fig. 6. FTIR spectra analysis of banana pseudo stem and pulp after the pulping process

The groups of hydroxyl and O–H functional groups fall a band between 3600–3100 cm^{-1} symbolized for holocellulose and lignin. The CH stretching bands (1500–1300 cm^{-1}) and a C–O stretching band at 1030 cm^{-1} are attributed to the presence of cellulosic structure. The pike at 1640 cm^{-1} indicates the derivatives of carboxylic acid and the functional group of carbon double bond oxygen(C=O). The aromatic groups of lignin fallen at the band of 1700–1500 cm^{-1} absorptions (1200–900 cm^{-1}) are predominantly dominated by a sequence of bands owing to C–O, C–C, C–OC, and C–O–P stretching vibrations of polysaccharides as well as CH3, CH2 rocking modes [33].

The most noticeable effect of pulping on the pseudo stem in FTIR spectra is the disappearance of the bands 1615 cm^{-1}, regarding the presence of the carbonyl (C=O), and 1247 cm^{-1}, associated with the carboxylic acid (COOH). It represents the components of lignin and hemicellulose structures. Comparing the spectra of the pulp and the in the pseudo stem, it is noticed the disappearance of the bands at 1615 cm^{-1} with the pulping process, attributed to vibrational modes of C=O and C–O groups present in lignin and hemicellulose, which were removed during the pulping process [34].

3.6 Sheet Making and Testing

After optimization of the cooking conditions of pseudo stem pulping, hand sheets were prepared from the pulp produced at the optimized pulping condition and tested for different physical properties like tensile strength, tear strength, tear factor, and tear index. The results obtained were presented in Table 4 and compared with wheat straw, eucalyptus and imported pulp paper.

Table 4. Result of paper characterization from pseudo stem pulp and comparison with others

Properties	Banana pseudo stem pulp sheet[a]	Corn sheath fibers[b]	Wheat straw[c]
Grammage [g/m^2]	60	66.052	60
Tensile strength [KN/m]	6.3	0.2576	n.a
Breaking length [m]	5250.0	n.a	n.a
Tensile index [Nm/g]	78.75	3.9	15.6–27.2
Tearing resistance [mN]	156	n.a	n.a
Tear factor [mNm^2/g]	195	95	n.a
Tear index [mN^2/g]	19.1	2.212	2.0–2.8

[a][Current study], [b][17], [c][35]

The mechanical and strength analysis of paper produced reflects the intrinsic chemistry, morphology, and structure of the individual fibers as well as the network structure of the paper. The result of paper characterization analysis done on the paper samples produced from pulp from pseudo stem pulp is presented in Table 4. The result shows that pseudo stem could be considered as a promising raw material for paper-making applications. The tear index of pseudo stem paper sample 19.1 mNm^2/g is greater than that of paper from wheat straw (2.0–2.8), and corn sheath fibers (2.212) respectively and it is good for average grades of writing and printing paper. The tear factor also higher than that of wheat straw sheet. This shows that pseudo stem has higher fiber length, flexibility, slenderness ratio, coefficient of rigidity than the others as shown in the raw material characterization because this property indicates a better formed, well bonded paper and good resistance of the paper to tear. The tensile index of the pseudo paper sample has a value of 78.75 Nm/g which was greater than of corn sheath fibers (15.6–27.2) and wheat straw sheet (3.9 Nm/g). Breaking length and tensile strength were also greater than that of imported pulp sheet and wheat straw. This is due to that the pseudo stem has a long fiber length and the Coefficient of flexibility gives the bonding strength of the individual fiber and by extension the tensile strength and bursting properties. The other properties like smoothness and porosity of the banana pseudo stem were 500–530 mμ and 50 s/100 ml air respectively and reasonable agreement with the imported pulp, so the banana pseudo stem pulp is suitable for good quality writing and printing paper.

4 Conclusions

This work was intended to study the morphological properties, the proximate and chemical composition analysis of the banana pseudo stem, the influence of pulping parameters: soda concentration, cooking temperature, and cooking time on the pulp yield and kappa number and characterization of paper sheets properties of banana pseudo stem pulp. Based on these results, the values of cellulose (41.45%), hemicellulose (23.37%), and lignin (10.46%) of the banana pseudo stem should be considered suitable for pulp and paper production. The fiber characteristics and morphological indices of the banana pseudo stem revealed that it contains long and thick-walled fiber, which gives a good Runkle ratio (0.55), and slenderness ratio (79.01), and high flexibility coefficient (159.64) indicating suitable for producing a high tear index and tensile index sheet which is suitable to produce different purpose papers. The optimized banana pseudo stem pulping conditions that have been considered high pulp yield, low kappa number, low chemical, and energy consumption with short pulping time has chosen using numerical optimization as a combination of 10% active alkali, 150 °C temperature, and 63 min, to obtain a good quality pulp (36.7% pulp yield and 22.8% kappa number). Using the optimized pulp, a hand sheet was made with the highest tensile index of 78.75 Nm/g and tear index of 19.1 mN × m^2/g. Finally, the overall results showed that the banana pseudo stem has a promising potential to be used for the paper application alone or in combination with softwood or hardwood pulps in papermaking.

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