Methods of Extraction of Cellulose from Bio Waste of Banana Plant and Applications: A Review

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Abstract

If banana plant waste is not treated, it will be regarded as environmentally hazardous. Therefore, it is essential to find alternatives to incineration for the disposal of agricultural waste from banana plants. This waste can be converted into cellulose, which can be used for a variety of biological and pharmacological applications. Therefore, this study briefly outlined the numerous extraction methods that have been used so far on distinct banana plant components. As cellulose is also accompanied by hemicellulose and lignin along with fats, proteins, and pigments, all extraction techniques used the fundamental extraction stages, such as drying, alkaline treatment, bleaching, and washing with distilled water to achieve neutral pH, to remove this non-cellulosic matter. The cellulose that was produced would help reduce the overuse of synthetic, non-biodegradable materials. Therefore, the uses of cellulose are discussed, along with the potential biomedical uses of cellulose if it is converted to nanocrystalline cellulose.

Key words: Cellulose extraction, banana peel cellulose, nanocellulose, alkaline treatment, bleaching

INTRODUCTION

Several initiatives have been made to develop ecologically friendly materials throughout the past century for a variety of uses. Because of its availability, light weight, recyclability, and biodegradability, cellulose stands out among these materials.[1] However, to maximize the effectiveness of natural resource exploitation, researchers and companies must develop alternatives to woodlands and croplands because they have a limited ability to offer cellulosic resources. Agricultural wastes or by-products of agricultural activity, such as rice-husk,[2] rice-straw,[3] maize-cob,[4] shell of coconut,[5] pruning of orange tree,[6] and peels of the fruit like pear[7] and banana,[8] have been the subject of extensive research and are now being used as cellulosic feedstock for a number of applications. This situation includes some investigations on the separation of cellulose from various vegetal sources, which are listed in Table 1. Among these natural celluloses, banana cellulose is in trend and tried in developing various biomedical and pharmaceutical purposes because of the abundant availability of banana plant waste. However, bananas are the most widely

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Table 1: Extraction of cellulose from different vegetative sources

S. No	Plant	Work done	References
1	Areca fruit	Cellulose extraction from areca fiber and its characterization	Ranganagowda *et al*. 2019[11]
2	Leaves of pineapple, pineapple peels, corncob	Cellulose isolation from agro biproducts and its characterization	Romruen *et al*. 2022[12]
3	Wood	Lignin and cellulose extraction and purification techniques from plant tissues	Radotić and Micic 2016[13]
4	Halophytes	Halophytes cellulose extraction and characterization: A new source of cellulose fiber	Singh *et al*. 2019[14]
5	Wood, lignocellulosic non-wood, and agro residues	Isolation of NCC from plant sources for use as a polymer reinforcement material	Ng *et al*. 2015[15]
6	*Calathea lutea*	leaf petiole cellulose fibre extraction and characterization	Bolio-López *et al*. 2015[16]
7	Plant fibers	A thorough analysis of green practices for cellulose isolation procedures	Khan *et al*. 2022[17]
8	Ricehusk, Eucalyptus, wheat straw, Rice straw, Flax fibers, Cotton fibers, Corn silage, Hemp fibers, Sisall fibers, Casava bran, Achira fibers	Isolation and modification of biomass-derived cellulose nanofibers for use in the environment	Menon *et al*. 2017[18]
9	*Eucalyptus lanceolata*	An innovative method for environmental friendly cellulose separation from Eucalyptus lenceolata	Rehman *et al*. 2018[19]
10	Paulownia plants	Paulownia plant cellulose extraction: An efficient technique	Mukhitdinov *et al*. 2023[20]
11	Corncob, giant cane, and garlic stalks	Extraction of CNC and high-grade cellulose from various lignocellulosic wastes from agriculture and food processing	Rovera *et al*. 2023[21]
12	cereal plants stems, plant fruit nutshells, agro wastes, wastes from garden, and grasses	Review of Extraction Methods for Non-woody Biomass	Owonubi *et al*. 2021[22]
13	Milk weed stems	Isolation of cellulose from milkweed stems and its characterization	Reddy and Yang 2009[23]
14	Medicinal plant fibers	An overview on the process for isolation of cellulose from therapeutic plants for novel purposes	Selikane *et al*. 2022[24]
15	Invasive species fibers	Isolation of cellulose from invasive plants from central Nepal	Dhakal *et al*. 2022[25]
16	Plant fibers	Determination of Plant Biomass Crystalline Cellulose Content	Dampanaboina *et al*. 2021[26]
17	Subabul tree seeds	Cellulose isolation from subabul tree seeds	Husin and Ab Nabilah 2019[27]
18	Ethiopian linseed straw	Determining the retting period and optimizing a multistep alkaline peroxide process for the isolation and characterization of fiber and cellulose from the linseed straw	Feleke *et al*. 2023[28]
19	Rice Straw Waste	A Comparative Analysis on Cellulose Fiber Extraction from Waste Rice Straw	Razali *et al*. 2022[29]
20	Water Lettuce	An innovative method for turning invasive weeds into high-value products by extraction, characterization, and manufacturing the sheets of cellulose biopolymer	Umesh *et al*. 2022[30]

(*Contd*...)

Table 1: *(Continued)*

S. No	Plant	Work done	References
21	Persian Clover	A sustainable method for the separation of cellulose and its characterization	Rehman *et al*. 2019[31]
22	Olives	Process Improvement and Expansion of Cellulose Extraction from Solid Olive Industry Waste	Thiab 2015[32]
23	Bottle guard plants	Isolation and characterization of novel cellulose fiber from the bottleguard plant's agrowaste	Saravanan *et al*. 2016[33]
24	*Calotropis procera*	*Calotropis procera* biomass derived CNC synthesis and characterization	Song *et al*. 2019[34]
25	Water Hyacinth	A Sustainable Source of Lignin-Poor Cellulose for the Synthesis of Cellulose Nanofibers from Water Hyacinth	Tanpichai *et al*. 2019[35]
26	Siam weed	Siam weed CNC: Preparation and physicochemical analysis	Ogunjobi *et al*. 2023[36]
27	Papyrus	Fiber from the Stem of the plant *Cyperus papyrus*: Isolation and Characterization	Sheferaw *et al*. 2022[37]
28	Grass	The isolation of CNF from grass using a specialized kitchen mixer	Nakagaito *et al*. 2015[38]
29	Sugarcane bagasse	Analysis of sugarcane bagasse cellulose extraction using alkali	Mzimela *et al*. 2018[39]
30	Ficus (Peepal Tree) Leaf Fibers	Ficus Leaf Fibers: Cellulose isolation and its analysis	Obi Reddy *et al*. 2015[40]
31	Banana fibers	A simple strategy for separating CNF from banana fibers	Kumar *et al*. 2019[41]
32	Corn Husk	CNC Prepared by Acid Hydrolysis: Isolation and Characterization	Kampeerapappun 2015[42]
33	Orange peel	Orange peel-derived cellulose: Separation, characterization, and potential uses	Ng 2019[43]
34	Avicel, whole corn, corn pericarp	GLC Analysis of Cellulose and obvious Hemicellulose in Plant Material	Sloneker 1971[44]
35	Flaxseed fiber	Assessment and characterization of flaxseed fiber bundles CNF's	Azhar *et al*. 2021[45]
36	Nopal Cactus	Cellulose from cactus plant: Extraction and Isolation	Ouhammou *et al*. 2022[46]
37	Mulberry	Mulberry cellulose whiskers: A unique biomass production method	Li *et al*. 2009[47]
38	Vacon stem	Yacon plant stem NFC's extraction and characterization	de Sousa *et al*. 2021[48]
39	Water Hyacinth	The Preparation of Membranes through the Isolation of Cellulose from Tropical Water Hyacinth	Istirokhatun *et al*. 2015[49]
40	Olive tree	Investigating the use of CNC's made from waste of olive tree as an environmentally friendly approach for crop protection against bacterial infections	Schiavi *et al*. 2022[50]
41	Argan press cake	Argan press cake made from leftover agrowaste: Cellulose isolation, characterization	Jodeh *et al*. 2017[51]
42	Esparto grass fibers, wood pulp cellulose, rice straw, banana peel, jute fiber, cotton silver, roselle fibers, pomelo peel, and olong tea waste	Isolation and evaluation of plant-derived MCC used as a tablet excipient	Belali *et al*. 2019[52]
43	Jute	Extraction of MCC from jute: An appropriate and cost-effective useful resource	Sarkar *et al*. 2022[53]

(*Contd*...)

Table 1: (*Continued*)

S. No	Plant	Work done	References
44	Corn plant	Isolation and analysis of putative lignocellulosic waste products and polymers from corn plant components	Ibrahim *et al*. 2019[54]
45	Rice husk, sugarcane	A new technique for obtaining cellulose from industrial and agro wastes	Hasan and Saoudi *et al*. 2014[55]
46	Mengkuang leaves (*Pandanus tectorius*)	Isolation of CNC's from mengkuang leaves	Sheltami *et al*. 2012[56]
47	Banana leaves	Cellulose fibre separation from Iraves of banana	Menon and Krishnan Nair 2013[57]
48	*Agave americana* L. and *Ricinus communis* L	CNF's from plant species: A regenerative green substance that produces of high CNC	Evdokimova *et al*. 2021[58]
49	Sugarcane Bagasse	Sugarcane Bagasse Cellulose Nanoparticles and Their Use in Biodegradable Recipients to Improve the Physical Characteristics and Water Barrier of the Latter	Brant *et al*. 2020[59]
50	Wastedfall leaves	Utilising alkaline peroxide treatment to separate cellulose and hemicellulose from discarded autumn leaves	Tezcan and Atici 2017[60]

consumed and least expensive fruit in tropical and subtropical areas of the world.[9] Between 2017 and 2019, there were 116 million tons of bananas produced worldwide on average.[10]

Banana production globally in 2019 was estimated at 119 million tons. With 31.5 million tons produced annually,[61] India is among the world's top banana producers. A substantial amount of trash is produced as a result of high production and consumption, accounting for 30–40% of the total weight and producing around 3.5 million tons of banana peel waste (BP) annually.[62,63]

As a waste product, BP can take a minimum of 2 years to decompose and biodegrade since it includes organic components rich in carbon. As a result, there are too many greenhouse gas emissions, which leads to climate change. Large volumes of BP are produced in a variety of enterprises and fruit markets, where it is either processed as agricultural trash or is just let to rot on farms to nourish the soil. Some areas practice agricultural waste incineration, which is thought to be the ideal method to clean up wastes. These fires are the main cause of soot emissions and are hazardous to both the environment and individuals. Instead of being dumped in waste disposal facilities, this trash can be turned into valuable commodities, decreasing both ecological and financial problems.[64-66] Utilizing agricultural waste decreases dangerous gases and particulate greenhouse gases, which benefits the environment. To preserve the globe from extensive global warming and the devastation it causes, experts are increasingly concentrating on using crop residue for various kinds of biological and pharmacological applications. There have been numerous reports over the past 20 years on how to make the most of agricultural trash.[67] The methods such as mechanical and chemical processes in response to allegations that the production of fruit wastes, such as banana peel, is increasing.[68] Hence, the methods yet to be developed to decompose this banana waste without affecting the environment. The transformation of banana waste into cellulose is one tactic used to deal with this problem. Hence, in this review, we discussed the various techniques used by researchers to extract cellulose from various banana segments. The overall extraction of cellulose from banana plant waste and its conversion to cellulose and its biomedical applications are illustrated in graphical abstract Figure 1. The general process of cellulose extraction includes chemical treatments such as dewaxing, alkaline, bleaching, and acid hydrolysis are depicted in Figure 2.

If this cellulose transformed into nanocellulose, it would have greater uses in the creation of drug delivery systems. Due to its great biological compatibility, ability to absorb liquids, permeability, and hardness, this nanocellulose has only recently joined the family of drug delivery carriers. However, little is known about their unique characteristics, including their high drug loading capacity, excellent stability, and particularly their capacity to respond to various environmental stimuli (such as pH, temperature, and magnetic field).[69]

PREPARATION OF BANANA PEEL CELLULOSE

Method 1

Preparation of banana peel powder according to Zaini *et al*., discussed, after thoroughly washing the banana peel with water, to get rid of dirt and dust that had adhered to the peel's surface, it was submerged in distilled water for an hour. The

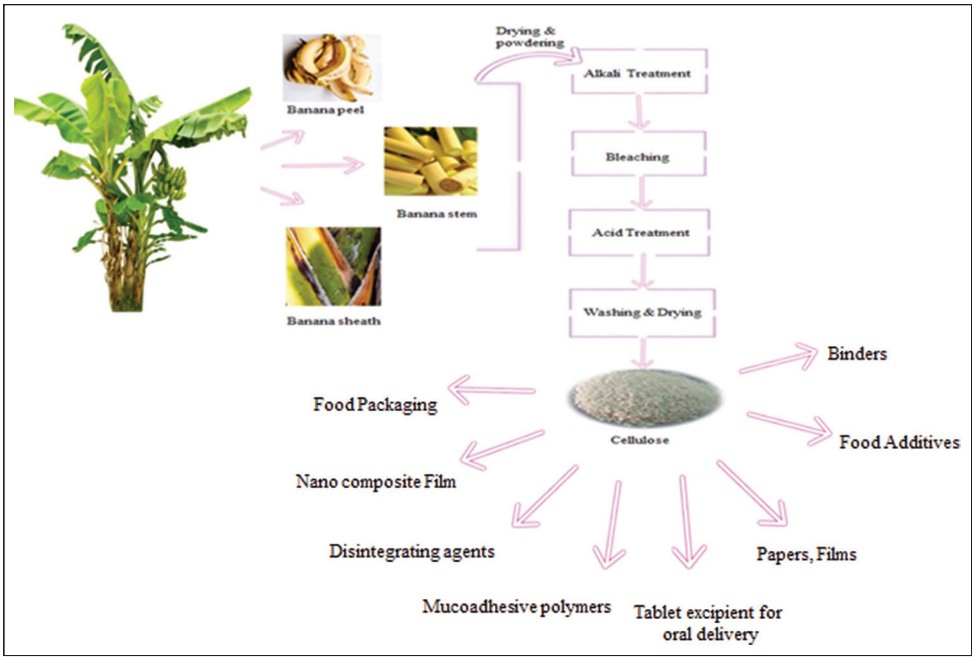

Figure 1: Graphical abstract of extraction of cellulose from distinct parts of banana plant and applications

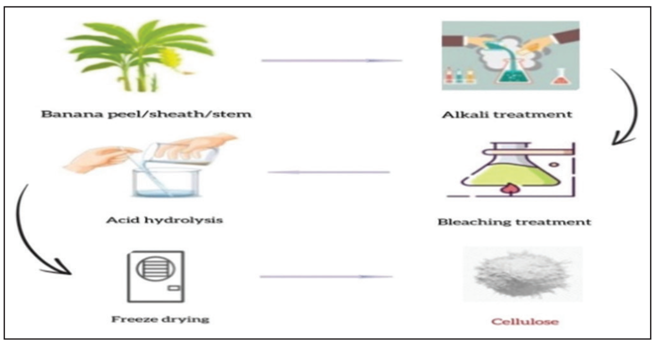

Figure 2: General process of cellulose extraction from distinct parts of banana plant

peel was allowed to air out in a hot oven at 60°C for a full day after being cleaned with tissue paper. To eliminate big particles from the powdered banana peel, the dried peel was ground in a crusher and then passed over a 35 mesh screen. Following weighting, the powder was placed in plastic bags and kept chilled at 4°C in a pharmaceutical freezer for additional extraction procedures.

Over 100 g of crushed peel from bananas was utilized in this experiment for dewaxing process. The powder was soaked in 200 mL of 70% ethanol for a total of 3 days. The sample spent 40 min in a water bath at 60°C before being washed multiple times with purified water. After reaching a neutral pH of 7, the collected material was passed through a cloth made of muslin to separate the insoluble residue.

The sample of polished banana peel underwent mechanical treatment by being placed in an ultrasound machine after it had been diluted with distilled water. A 1000 W power was used during the 30 min ultrasound treatment at 40°C. The solid component was then taken out for additional separation.

In the chemical treatment step, there were two rounds of bleaching and alkaline treatment. For the alkaline treatment, the mechanically-produced insoluble residue was dissolved in 300 mL of 4% NaOH solution and agitated for 4 h at 60°C. Continuous stirring for 3 h at 80°C with 150 mL of 10% sodium hypochlorite was used for the first and second bleaching processes. After the second phase of bleaching procedure, the neutral residue is once again subjected to alkali treatment. After that, 1% H_2SO_4 solution was used for acid hydrolysis of the insoluble residue at 80°C for 1 h. After that, distilled water was used to completely wash away the insoluble residue until the pH was neutral. After extraction, the BPC suspension was obtained, and it was dried for 48 h in a sublimation drier. Before characterization, it was weighed and kept at 4°C in a sealed airtight container.[68] Banana peel cellulose extraction is depicted in Figure 3.

Method 2

This is described by Hariani *et al*. for kapok banana peels. Peels are purified of contaminants and sun-dried for 5 days or till dry. Dried peels are then grounded and sent through a sieve with a mesh size of 100. 100 g of powdered banana peel was macerated in 100:100 ethanol/toluene mixture for a period of 3 days. In addition, 250 mL of NaOCl mixture (6%), stirred for 3 h, and heated to 80°C are used in a bleaching procedure to remove lignin. Using 300 mL of NaOH (4% w/v), mixing at 60°C for a period of 4 h, filtering, and rinsing with purified water, the hemicellulose was eliminated. In a water bath at 85°C for 1 h, the precipitation was incorporated to 400 mL NaOH and 200 mL H_2O_2 (30%), filtered and then washed with purified water. The pH was then modified by including

Figure 3: Banana peel cellulose extraction

200 mL of 10% H_2O_2 for precipitation, mixing it at 85°C for an hour, straining it, and rinsing it repeatedly with pure water. The precipitate was air-dried for a full day at 40°C in a vacuum oven.[70]

Method 3

This method tried by Singanusong *et al*. to make cellulose from Hom thong banana peels, peels from its maturity of Grade 7 were sliced into 0.3 × 2.5 cm pieces and dried for 10 h in an air oven at 55°C. 10 mL of methanol/dichloromethane (1:2 v/v) and a sample (3 g) were introduced to a screw-cap tube. This was added, and the sample tube was then left for 1 h. Samples were run over Whatman #1 filter paper, and finally centrifuged for 10 min at 25°C and 2000 rpm with 0.1 M potassium chloride added to the sample (around 20% of the total volume).[71-73] Three h were spent soaking defatted, protein-free banana peel powder in a 15% of hydrogen peroxide solution. The bleached samples were separated after being rinsed repeatedly with purified water. Utilizing Whatman #4 filter paper, it was ultimately dried in a forced air oven for 10 h at 60°C.[74]

BANANA SHEATH CELLULOSE EXTRACTION

As described by Manisha Reddy *et al*. in the step of alkali treatment of fiber, 1.5%, 2%, 5%, and 7.5% of sodium hydroxide solutions were prepared and sheath fibers soaked in it for 6 h at room temperature. This is carried out to get rid of impurities. In the autoclave process to perform steam pretreatment, NaOH-treated fibers are directly placed inside the autoclave while under high steam pressure. The mercerized sheath fibers were put under 103 Pa of pressure for 1.5 h. After the steam explosion, the fibers were removed and thoroughly cleansed with distilled water. These cleansed fibers were allowed to dry for a 4-h period at 60°C in a hot air oven.

The fibers then underwent treatment with a 5% sodium chlorite in a solution of hydrogen chloride with a pH value of 2.3 as part of the bleaching process and were immersed in the solution for an hour on a magnetic heater set to 50°C. The bleaching process is essentially used to remove any residual lignin. After bleaching, the fiber is given a little acid treatment with oxalic acid (2%, 5%, 7.5%, and 10%) for acid hydrolysis. Fibers were submerged in an oxalic acid for 1.5 h. The fibers were properly rinsed with distilled water to get rid of any acid residue, then dried and stored until further use. All chemical treatment steps are depicted in Figure 4.

For steam explosion treatment as shown in Figure 5, without the use of catalysts, the citric acid, sodium hydroxide, and water pre-treatment for the steam explosion was carried out. The biomass was steam treated for 5–10 min in a reactor at extreme pressures and temperatures of 13, 15, and 17 bar and 192, 200, and 205°C, respectively. The sudden pressure release defibrillates the cellulose bundles, making it easier for enzyme hydrolysis and fermentation to access the cellulose. The fibers were expelled through a linked pipe and stored in a container after being steam-exploded. Slurry was the end result, and the fibers were baked for 8 h at 100°C.[75]

EXTRACTION OF BANANA STEM CELLULOSE

Method 1

Banana stem cellulose produced by microwave heating according to Iliyin *et al*. is described here and it has the following steps.[76]

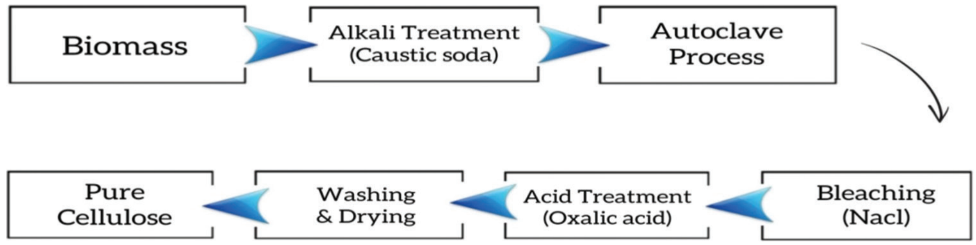

Figure 4: Chemical treatment steps in cellulose extraction

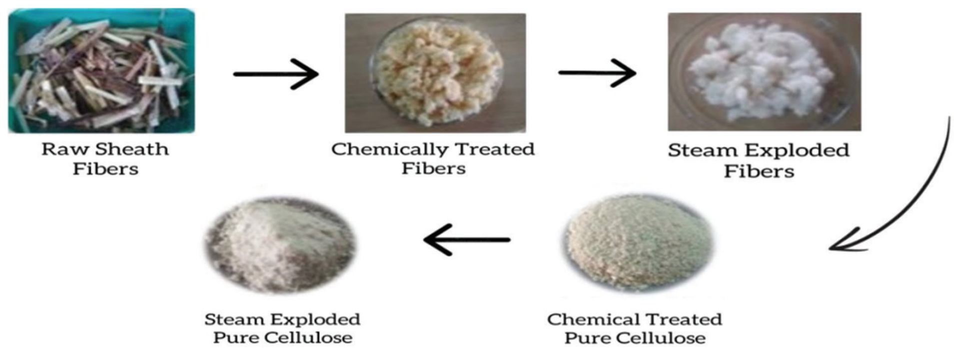

Figure 5: Banana sheath cellulose from steam explosion treatment

In the initial stage of preparing a banana stem, stems were separated into tiny pieces and let dry out in the sun. To produce a powder, the dried-out stems were ground up and passed through a sieve 70.

The second phase is cellulose isolation, and as part of this cellulose separation includes processes liquefaction, delignification, and the process of bleaching. By adding 10 g of banana stems, 150 mL of the liquid (glycerol: methanol 2:1), and 35 ml of 1.75% sulfuric acid in a beaker, the liquefaction process was carried out. After being heated in the warmth of the microwave for a total of 3 min, the liquid was passed through a filter, neutralized with methanol, and dried at 105°C in an oven. In addition, this was followed, with alterations to the heating method, in the delignification and bleaching processes. The residue was cooked in the microwave for 3 min after being mixed with 4% sodium hydroxide. The sample was also vacuum-filtered, and the vacuum-filtered residue was rinsed in distilled water until it reached pH 7 neutral. A 50°C oven was used to dry the residue until it attained a constant weight. The sample container was then filled with a 5% H_2O_2 solution, heated in a microwave for 4 min, filtrated, and the precipitate rinsed with distilled water to achieve a pH of 8. The peroxide solution treatment was administered twice at once. The bleached product was meanwhile dried until it attained a consistent weight in a 60°C oven. The microwaves' power variations were 450, 600, and 800 W.[77]

Method 2

This technique according to Thi Thuy Van *et al*. employs microwave heating. Initially, banana stem is cleaned, then chopped into 1mm sized slices and sun-dried for 8 h. The initial components will be further treated with a mixture of sodium hydroxide containing 1, 2, and 3% by mass for 10, 20, and 30 min, respectively. After a further amount of hydrogen peroxide is incorporated (with concentrations of 13, 15, and 17% w/w) after the entire mixture has been withdrawn from the microwave. The solution has been magnetically stirred for 60 min at ambient temperature with a pH of about 11.5. To generate cellulose, the resulting mixture is then passed through filters, completely rinsed with purified water, and dried for a full day at 70°C.[78]

EXTRACTION OF CELLULOSE FROM BANANA PLANT WASTE

As per Hnin and Khine, stems of bananas were dried in a 40°C microwave for a total of 5 days. The sample that has been dried is then crushed into a smooth powder in a mixer and 50 g of each sampleribs, stems, and defoliated ribsis subsequently separated using 350 mL of petroleum ether as the solvent at 60–80°C. The dried sample (stem) was placed into a flask with a round bottom after the process of extraction was completed, and 150 mL of sulfuric acid (0.1275 M) was then added. After a brief interval, 850 mL of hot sulfuric acid solution (0.1275 M) was introduced into the container and was permitted to reflux for 30 min in a boiler. The samples were passed through filters and cleansed in water that was warm to eliminate acidic residue after a period of 30 min. The taken samples were subsequently dried and quantified in a hot oven set to 40–50°C. To eradicate lignin, basic digestion was carried out utilizing (0.311 M NaOH). The following step was to obtain an unbleached cellulose fiber.[79]

Table 2: Cellulose extraction from distinct parts of banana plant

S. No	Source of banana used	Work done	Method of extraction	Reference
1	(*Musa Acuminata* Colla cv. Mas) banana peels	Preliminary analysis of the isolation of cellulose from banana peel	Chemical and mechanical treatment	Zaini *et al*. 2022[68]
2	(*Musa parasidiaca* L.) banana peels	Isolation of cellulose for procion dye adsorption	Chemical tereatment	Hariani *et al*. 2016[70]
3	(*Mus sapientum* Linn. Cv. Mali-ong) banana peels	Isolation of celluloseand its characteristics from banana peels	Chemical treatment	Singanusong *et al*. 2013[74]
4	Banana sheath	Banana sheath cellulose isolation and characterization	Steam explosion and chemical pretreatments	Manisha Reddy *et al*.[75]
5	(*Musa paradisiaca* sapientum) banana stems	Banana Stems cellulose separation and Characterization using a microwave	Microwave Heating	Iliyin *et al*. 2021[76]
6	Banana stem	Optimization of the extraction of cellulose from the stem of banana using RSM and characterization	Microwave heating	Thi Thuy Van *et al*. 2022[78]
7	(*Musa acuminata*) Stems, de-leaved ribs and trunks	Cellulosic fibre isolation from banana plant waste	Chemical treatment	Hnin and Khine 2019[79]
8	Banana Leaves	Cellulose fibre separation from leaves of banana	Chemical treatment	Menon and Krishnan Nair 2013[57]
9	(*Musa acuminata*) banana peels	Physical and chemical characteristics of cellulose isolated from peels of banana	Chemical treatment	Surattanamal *et al*. 2021[71]

Two other samples, such as leafless ribs and stems, were prepared in this manner. After grindinga pH of 11 and 70°C for 90 min was maintained and 5% hydrogen peroxide was used on weighted samples. The samples were bleached followed by rinsing in distilled water. With that, the samples were dried out at 60°C in an oven.[80] Cellulose extraction from various parts of banana plant from different researchers are shown in Table 2.

APPLICATIONS OF CELLULOSE

Cellulose is frequently used to make food additives, paper, film, textiles, and building materials. Recent research has also focused on finding answers to environmental problems, such as generating cellulose-based substances that absorb the spills of oil and pollution from heavy metals in the atmosphere and water.[81] and creating filters for the treatment of industrial[82] and municipal waste water[83] along with some researchers proved that banana stem cellulose can be used as pharmaceutical excipients.[84] For these purposes, cellulose from banana plants provides as an option.

CONCLUSION

This review provided the different methods of extraction of cellulose from different parts of banana. All extraction methods mentioned initially subjected the plant parts for drying and size reduction. For further processing of removal of the non-cellulosic matter, material pre-treated with petroleum ether, ethanol, or toluene to remove colors, wax, lipids, and phenolics. Later an alkaline procedure, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), and organic acids, has been subjected after the removal of contaminants. This alkaline hydrolysis is followed by the bleaching of cellulose fibers using either hydrogen peroxide (H_2O_2) or sodium chlorite ($NaClO_2$) to completely eliminate any lingering lignin, wax, and lipids. The obtained insoluble residue was washed many times with distilled water to get neutral pH and dried, before this step some methods like extraction of banana sheath cellulose make use of steam explosion treatment and very few like banana peel cellulose extraction employed mechanical treatments.

The techniques stated in the paper can be simply incorporated into the processes now used by industry but it only requires a minimal amount of chemical use. This assumes the production of cellulose is more economic. If this cellulose transformed to nanocrystallinecellulose can be used as tablet excipient for oral delivery, as a main component for the nanocomposite film due to its good tensile strength, and as a conductive film in biosensors and in many more applications. Hence, the banana waste cellulose could be used as a good alternative for manufacturing nanocrystalline cellulose in the future.

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