Vaidik Savaliya 2025, 13:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Green Synthesis of Cellulose Nanocrystals from Banana Pseudo Stem and it's Characterization.

1 Vaidik Savaliya, 2 Dr. Hemangi Desai

1,2 Chemistry Department, Shree Ramkrishna Institute of Computer Education and Applied Sciences, Sarvajanik University, Gujarat, India.

Abstract

Cellulose nanocrystasl were isolated from Banana Pseudo Stem, an under-utilized agriculture biomass. Raw Banana stem was collected from Abrama Farm, Kamrej, Surat. Which were then dried in the Hot Air Oven @ 105°C for 6 hours and after cooling and desiccating, crushed in a grinder and sieved to get fine powder particles. The chemical compositions of cellulose nanocrystals from banana stem after each treatment were determined according to Technical Association of the Pulp and Paper Industry (TAPPI) standard. The lignin content was determined according to the TAPPI norm T222 om-88. The Hemicellulose content was determined according to the TAPPI T257 om-09. Cellulose content was determined by extracting hemicellulose with the aqueous sodium hydroxide (17.5%) for 5 h before quenching the reaction with ice. The obtained white powder was washed with copious amount of water until filtrate (Whatman Filter Paper No. 42) becoming neutral. Cellulose nanocrystal (CNC) was obtained by sulfuric acid hydrolysis according to the reported method. The resultant mixture was first centrifuged at 1000 rpm for 10 min ice- cooling temperature (18°C) to remove large particles, and then centrifuged at 11,000 rpm for 15 min ice- cooling temperature (-15°C) to obtain cellulose nanocrystal. The obtained cellulose nanocrystal was washed and centrifuged repeatedly for 3 times before dialysis against distilled water for 2 days. The obtained CNC was processed by ultrasonic processor (VCX 500:500 W, Sonics & Materials, Newton, CT) to suspension better before further application. The composition of Banana Pseudo Stem found after research experiment was Cellulose - 69.9%, Hemicellulose - 19.6% and Lignin - 5.7%. The chemical pretreatment removed the non-cellulosic constituents of Banana Pseudo Stem was found to be an essential and fundamental procedure for the Cellulose Nanocrystal. The pretreatment process of Banana stem included Alkali Treatment, Delignification and Bleaching Treatment. FEG - TRANSMISSION ELECTRON MICROSCOPE (HR-TEM) was used to find the size of obtained CNC. The obtained Cellulose Nano Crystal exhibited a different Category of 500 nm, 200 nm, 100 nm, and 1µm. 500 nm scale observe the (331nm, 290 nm and 271nm) diameter size of Cellulose Nano Crystals. 200 nm scale observe the (95.2nm, 87.5nm, 81.6nm, and 67.9nm) diameter size of Cellulose Nano Crystals.

Keywords- CNC, Lignin, Cellulose, Hemicellulose, FEG-TEM.

I. INTRODUCTION

- The extraction of cellulose from agricultural wastes to produce green and clean products has received most attention in the world.
- The material is versatile in various applications such as optoelectronics, adsorption catalysis, sound and heat insulation, medical materials, aerospace materials, and many other fields [1, 2, 3, 4].
- There have been many publishes on the extraction and evaluation of the quality and efficiency of the extraction process from many different materials such as rice straw, corn, sugarcane bagasse, oil palm, starch [5].
- Among these raw materials, the banana stem was evaluated as a potential source of cellulose [6, 7, 8, 9, 10].
- Banana is planted in many areas in the world and it is one of main export product of many countries. Each hectare of bananas generates about 220 tons of waste, and makes the problem on landfills and polluting the environment [10].
- Therefore, making full use of waste from banana trees to create valuable products plays an important role in improving economic efficiency and moving towards sustainable development for banana cultivation as well in treatment of agricultural waste in general.
- Cellulose is the main component of the banana stem, it takes about more than 50% of the total banana stem, and this is a natural, renewable, and biodegradable polymer that can be used in many fields such as raw materials for construction, paper, insulation materials, adsorption materials, environmental treatment [8].
- The distinctive property of cellulose nanocrystals make it useful building block in various applications, for instance as reinforcing agents [13,14], biomedical implant [15], nanocomposites [12] as well as electronic components [16].
- Cellulose is one of the most important organic compounds on earth and is obtained from plants, algae bursal, animals, and bacteria. Cellulose structures and names are clearly classified according to different geometric sizes [18].
- Micron to nano-scale applications differ and are determined by the cellulose geometric size [19].

II. REVIEW OF LITERATURE

- Nanocrystallin.e cellulose (NCC) has gained attention due to its versatile properties such as biocompatibility, sustainability, high aspect ratio, and abundance of −OH groups that favor modifications of NCC. The objective of this paper is to develop NCC by extracting and characterizing NCC prepared from banana peel powder (BPP).
- BPP was subjected to alkali and bleaching treatment to remove lignin and hemicellulose and then subjected to acid hydrolysis to prepare NCC.
- The particle size and zeta potential of the NCC were found to be 209 nm.
- All the parameters evaluated indicated that NCC was successfully prepared from BPP using alkali treatment, bleaching, and acid hydrolysis.
- Cellulose nanocrystals (CNCs) have attracted tremendous attention because of their excellent chemical and physical properties and due to their renewability and sustainability.
- Rice straw was selected as the raw material in this study. Initially, a large amount of lignin must be removed by an alkaline process to obtain a slurry.
- Thereafter, a green bleaching process can be used to remove the remaining lignin in the slurry. An UV-emitting diode with 365 nm wavelength assisted the oxidation reaction of the H2O2 solution without the use of chlorine-containing chemical bleach.
- The reaction required only 2.5 h to obtain high-purity cellulose and successfully enhanced the yield. Transmission electron microscopy images showed that the CNCs from rice straw were 100 nm long and 10–15 nm wide.

III. MATERIALS AND METHODS

3.1 Banana Stem Raw Material Collection & Treatment.

Banana Stem Sample: Raw Banana stem was collected from Abrama Farm, Kamrej, Surat. Which were then dried in the Hot Air Oven @ 105°C for 6 hours and after cooling and desiccating, crushed in a grinder and sieved to get fine powder particle.

Banana Stem

Oven-dried Banana Stem

Fine Powder Sample

Figure: 3.1 Raw Material Processes: Collection, Drying and Fine Powder

3.2 Determination of the chemical composition of cellulose nanocrystals form Banana Stem: [20]

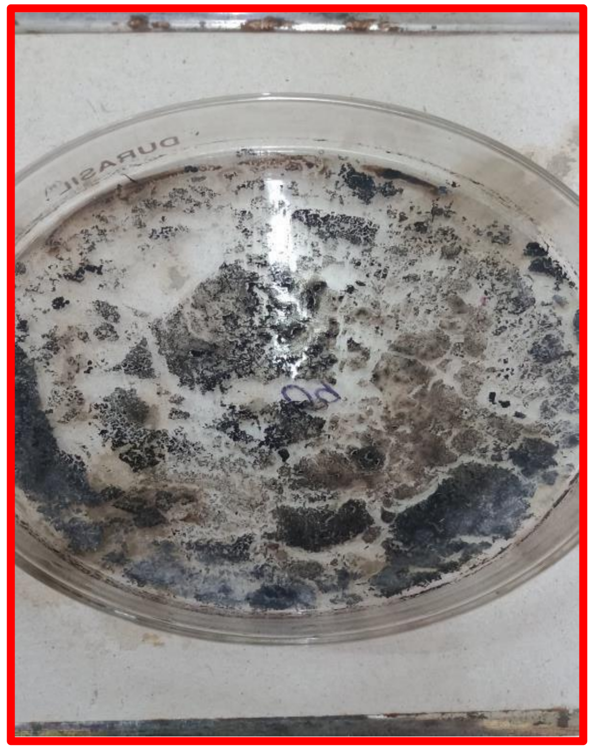
3.2.1 Lignin

- The chemical compositions of cellulose nanocrystals from banana stem after each treatment were determined according to Technical Association of the Pulp and Paper Industry (TAPPI) standard. The lignin content was determined according to the TAPPI norm T222 om-88 [21,22]
- Briefly, 1 g of sample was added into the 15 mL H_2SO_4 solution (72 wt%), and maintained at room temperature (35°C) for 2 h. Then, the distilled water, 560 mL, was added and boiled the mixture for 4 h before the centrifuge to get the insoluble lignin. The obtained lignin was oven-dried and weighted. The lignin quantity was determined using following formula.

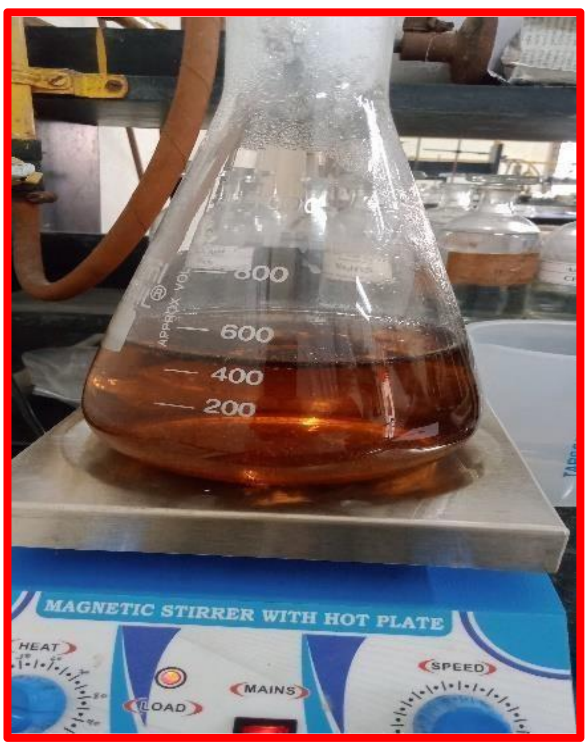
where M1 was the obtained lignin mass, M was the initial sample mass.

$$\text{Lingin } (\%) = \frac{M_1}{M} \times 100,$$

Sample + H2SO4



Oven-Dried Lignin



H2SO4 + Distilled Water

Figure**:** 3.2.1 Extraction of Lignin from Banana Stem

3.2.2 Hemicellulose

- Hemicellulose content was determined according to the TAPPI T257 om-09. Hemicellulose content was quantified with sodium chlorite treatment according to the reported procedure [23].
- Sample 1 g, was added into the solution, 30 mL, containing Acetic acid
- 0.25 mL, Sodium Chlorite 0.3 g and kept at (75 °C) for 1 h.
- The mixture is then cooled down and the residue is filtered (Whatman Filter Paper No. 42) and washed thoroughly with water. The residue was finally dried and weighted. The holocellulose content was calculated using following formula.

$$\text{Hemicellulose} = \frac{M_2}{M} \times 100$$

where M2 was the obtained residue mass, M was the initial sample mass

Sample+CH3COOH+$NaClO_2$

Filter + Wash Water

Hemicellulose

Figure:3.2.2 Extraction of Hemicellulose form Banana stem

3.2.3 Cellulose of Banana Stem

Cellulose content was determined by extracting hemicellulose with the aqueous sodium hydroxide (17.5%) for 5 h before quenching the reaction with ice. The obtained white powder was washed with copious amount of water until filtrate (Whatman Filter Paper No. 42) becoming neutral [24]. The cellulose content was calculated using following formula.

$$\text{Cellulose (\%)} = \frac{M_3}{M} \times 100,$$

where M3 was the obtained white powder mass, M was the initial sample mass.

Hemicellulose +NaOH

Washed & Neutral

Cellulose

Figure: 3.2.3 Extraction of cellulose from Banana stem

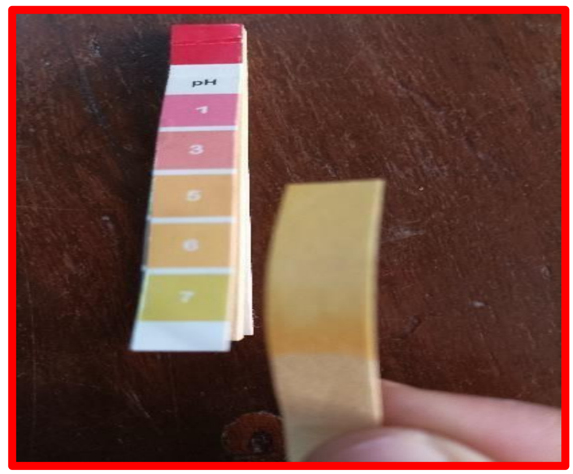
3.3 Determination of the Pretreatment: Alkali Treatment

3.3.1 Alkali Treatment of Banana Stem Sample

- The pretreatment process of Banana stem included Alkali Treatment, Delignification and Bleaching Treatment [25,26].
- Firstly, the cleaned Banana stem powder 1 g, was immersed in NaOH solution (2 wt%), 100 mL, at room temperature(35°C) and stirred (80rpm) for 3 h to finish the alkali treatment to remove the impurities including pectin, wax. The alkali-treated sample was washed thoroughly till neutral. (Whatman Filter Paper No. 42).

Sample + NaOH

Distilled Water Wash



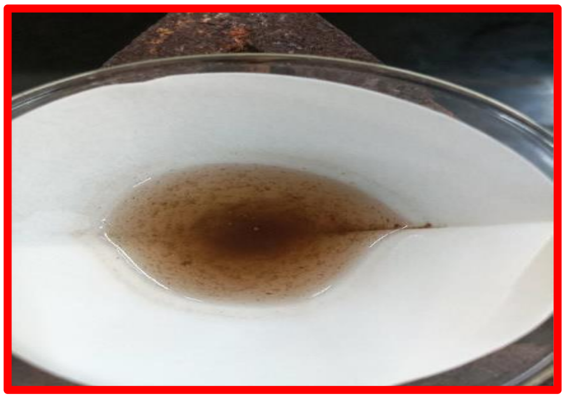
Neutral pH

Figure: 3.3.1 Alkali Treatment of Banana Stem Sample

3.3.2 Delignification Process of Sample

The delignification process was carried out with dewaxed form the above sample, 1 g, suspended in acetic acid (93% v/v), 50 mL, and hydrochloride acid solution (0.3% v/v) under strong stirring (90 rpm) for 3 h at (90°C) and then washed till neutral pH value. (Whatman Filter Paper No. 42).

Sample+CH3COOH+HCl



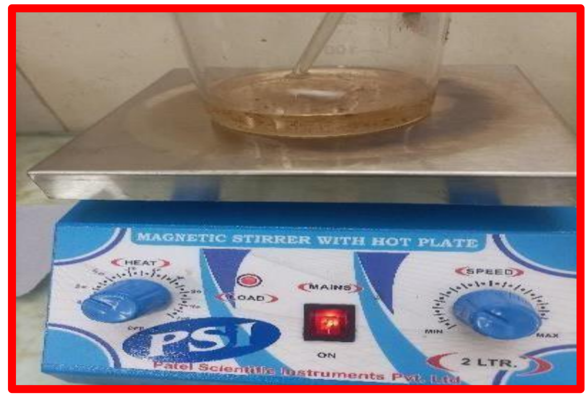
Wash till Neutral pH

Delignification

Figure: 3.3.2 The Delignification Process

3.3.3 Bleaching Process of Sample

The Bleaching Process was performed by adding the obtained delignification form the above sample into the mixture of H2O2 (5 wt%) and NaOH (3.8 wt%) at a ratio of 1:50 and stirred at (50 rpm) at room temperature (35°C) for 3 h before washing thoroughly. (Whatman Filter Paper No. 42).



Sample + H2O2 + NaOH

Washing Thoroughly

Bleaching Process

Figure: 3.3.3 The Bleaching Process

3.4 Extraction of Cellulose Nano Crystal

Cellulose nanocrystal (CNC) was obtained by sulfuric acid hydrolysis according to the reported method [27]. The pretreated Sample powder, 1 g, was slowly added into H2SO4 solution (63 wt%), 30 mL, under vigorously stirring at room temperature (35°C) for 1 h. After that, the hydrolysis was quenching by adding iced water, 300 mL, into the mixture.

Sample+H2SO4+ Iced water

Centrifuged Sample Holder

After Centrifuged

Figure:3.4 Extraction of Cellulose Nano Crystal

3.4.1Cooling Centrifuge of Cellulose Nano Crystal

The resultant mixture was first centrifuged at 1000 rpm for 10 min ice- cooling temperature (18°C) to remove large particles, and then centrifuged at 11,000 rpm for 15 min ice-cooling temperature (-15°C) to obtain cellulose nanocrystal.

Cooling Centrifuged at 1000 rpm

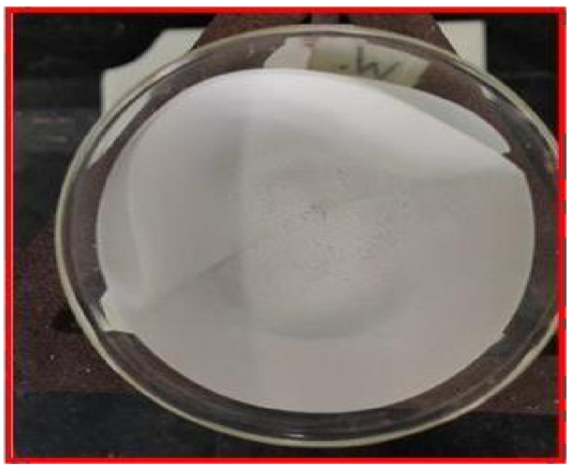
Centrifuged at 11,000 rpm

Figure :3.4.1 Cooling Centrifugation of Cellulose Nano Crystal

3.4.2 Washing and Filtration

The obtained cellulose nanocrystal was washed and centrifuged repeatedly for 3 times before dialysis against distilled water for 2 days

Filter the Solution



Impurity of Solution

Clear Solution

Figure: 3.4.2 Washing of Cellulose Nano Crystal

3.4.3 Sonication Treatment of Cellulose Nano Crystal

The obtained CNC was processed by ultrasonic processor (VCX 500:500 W, Sonics & Materials, Newton, CT) to suspension better before further application

Figure: 3.4.3 Ultrasonic Processor (120W, 90 min)

IV. RESULT AND DISCUSSION

4.1 FEG - TRANSMISSION ELECTRON MICROSCOPE (HR-TEM)

- Description:
- This automation eases the learning curve for novice operators, reduces tensions in a
- multi-user environment, and improves time to data for the experienced operator.
- The 4K X 4K Ceta aCMOS camera with large field-of-view enables live digital

Instrument Name	FEG - TRANSMISSION ELECTRON MICROSCOPE (HR-TEM)
Model	Talos F200i S/TEM (HRTEM-200KV)
Make	Thermo Fisher Scientific
Accelerating Voltage	200KV
Electron Source	Schottky Field emitter (Field Emission Gun)
Resolution	Line Resolution 0.10 nm Point Resolution less than 0.25 nm or less
Magnification	TEM Magnification 50x to 1Mx STEM Magnification: 310X to 330Mx
Diffraction Mode	Diffraction Mode camera length 14 to 5700MM (1400 M in LAD)
STEM Detector	High Angle Annular Dark Field Detector (HAADAF) STEM Resolution less than 0.16nm. STEM Magnification up to 330 Mx
EDSor EDAX	Bruker X Flash 6 30 EDS Detector Quantitative Elemental analysis and elemental Mapping Facility.

4.2 Synthesized cellulose Nanocrystals were found in Three Category.

Category 1: (Scale 200 nm)

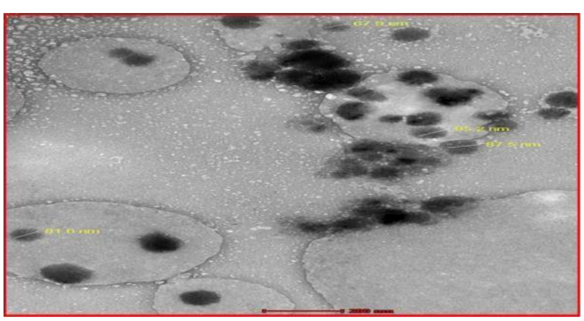
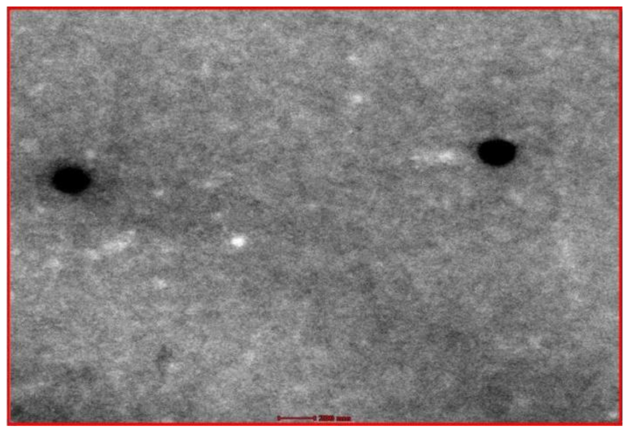


Table 4.2.1: Determination of Cellulose Nanocrystal by FEG-TEM.

Sr. No.	Scale	Specialization	Method	Observation (Scale – 65 to 90 nm) (Diameter –Size of Cellulose Nanocrystal)			
				1	2	3	4
1	200 nm	FEG- TEM	MICROSCOPY	81.6 nm	87.5 nm	95.2 nm	67.9 nm

In this scale 4 different size of cellulose nano crystals are observed by FEG – TEM: 200nm Scale Observe the (81.6 nm, 87.5 nm, 95.2 nm and 67.9 nm) diameter size of Cellulose Nano Crystal. (All Nanocrystals size is < 100 nm)

Category 1: (Scale 200 nm)



Category 2: (Scale 500 nm)

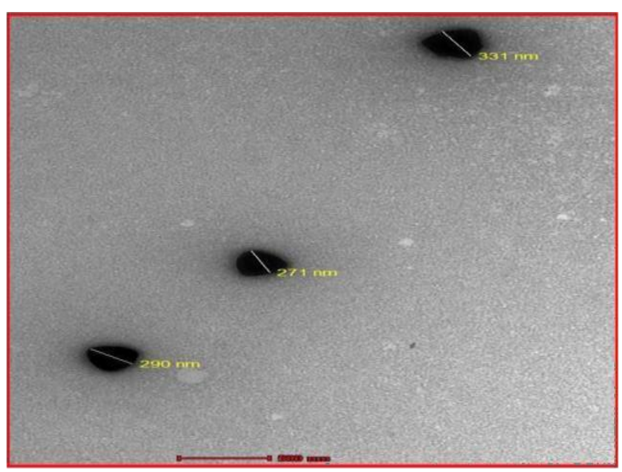
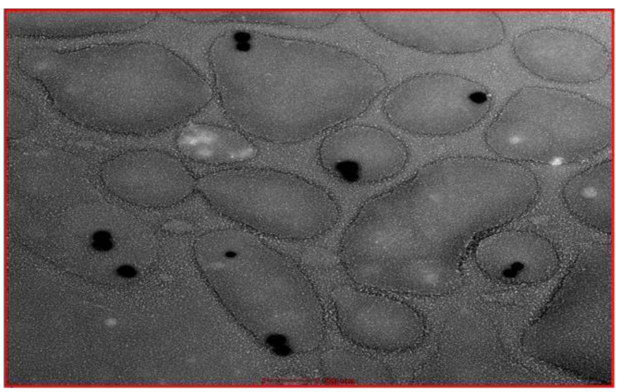


Table 4.2.2: Determination of Cellulose Nanocrystal by FEG-TEM.

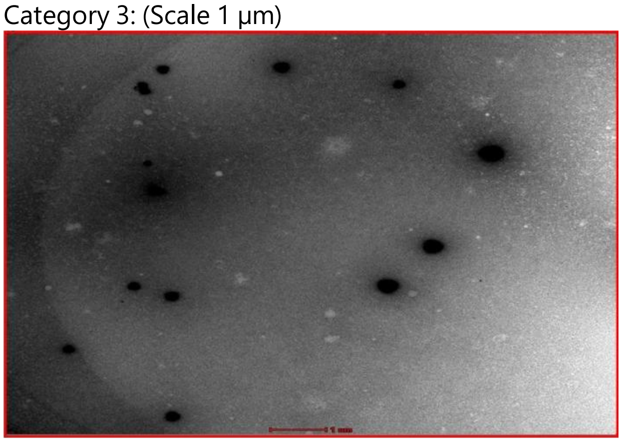
Sr. No.	Scale	Specialization	Method	Observation (Scale -250 to 350 nm) (Diameter - Size of Cellulose Nanocrystal)			
				Sr.No.1	Sr.No.2	Sr.No.3	Sr.No.4
1	500 nm	FEG- TEM	MICROSCOPY	290 nm	271 nm	331 nm	-

In this scale 3 different size of cellulose nano crystals are observed by FEG – TEM: 500nm Scale Observe the (290 nm, 271 nm and 331 nm) diameter size of Cellulose Nano Crystal. (All Nanocrystals size is < 350 nm).

Category 2: (Scale 500 nm)

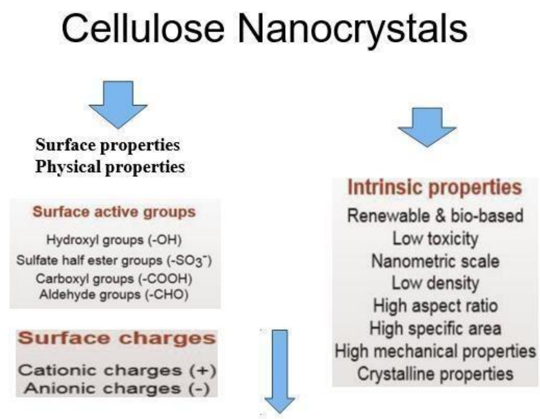


Category 3: (Scale 1 μm)



4.3: Analysis of Banana Pseudo Stem Composition:

The Banana Pseudo Stem content of the Cellulose was 69.9%, Hemicellulose 19.6% and Lignin 5.7%.



Market	Applications	Exploited CNC properties	References
Composites/films	Nanocomposites Flexible packaging Optical films	High mechanical properties Film ogenic properties Morphology	[28, 29]
Coatings/paints/ adhesives	Coatings for flexible packaging	Morphology Rheological properties	[30, 31]
Filtration	Mesoporous films and membranes	High specific surface area High mechanical properties Hydrophilicity	[32]
Energy	Supercapacitors Flexible batteries	Strength Large surface area	[33]
Cosmetics	Hydrogels and foams	Colloidal stability Emulsion interfacial stabilization	[34, 35]

V. CONCLUSION

Cellulose nanocrystal can be isolated from Banana Pseudo Stem, an under-utilized agriculture biomass. The Banana Pseudo Stem content of the Cellulose was 69.9%, Hemicellulose 19.6% and Lignin 5.7%.
The chemical pretreatment which removed the non-cellulosic constituents of Banana Pseudo Stem was

found to be an essential and fundamental procedure for the Cellulose Nano Crystal.

The obtained Cellulose Nano Crystal exhibited a different Category to 500nm, 200nm, 100nm, and 1µm. 500nm scale observe the (331nm, 290nm and 271nm) diameter size of Cellulose Nano Crystals. 200nm scale observe the (95.2nm, 87.5nm, 81.6nm, and 67.9nm) diameter size of Cellulose Nano Crystals.

REFERENCES

1. Zaman, A., Huang, F., Jiang, M., Wei, W., & Zhou, Z. (2020). Preparation, properties, and applications of naturalcellulosic aerogels: A review. Energy Built Environment, 1(1), 60–76.
2. Sen, S., Singh, A., Bera, C., Roy, S., & Kailasam, K. (2022). Recent developments in biomass derived cellulose aerogel materials for thermal insulation application: A review. Cellulose, 1(1), 1–29.
3. Nguyen, T. T. V., Tri, N., Tran, B. A., Dao Duy, T., Nguyen, S. T., Nguyen, T.-A., Phan, A. N., Mai Thanh, P., Huynh, H.K. P. (2021). Synthesis, characteristics, oil adsorption, and thermal insulation performance of cellulosic aerogel derived fromwater hyacinth. ACS Omega, 6(1), 26130–26139.
4. Nguyen, S. T., Do, N. D., Thai, N. N. T., Thai, Q. B., Huynh, H. K. P., Phan, A. N. (2020). Green aerogels from rice straw for thermal, acoustic insulation and oil spill cleaning applications. Materials Chemistry and Physics, 253, 123363.
5. Lu, P., & Hsieh, Y.-L. (2012). Preparation and characterization of cellulose nanocrystals from rice straw. Carbohydrate Polymers, 87(1), 564–573.
6. Ibrahim, M. M., El-Zawawy, W. K., Jüttke, Y., Koschella, A., Heinze, T. (2013). Cellulose and microcrystalline cellulose from rice straw and banana plant waste: Preparation and characterization. Cellulose, 20(1), 2403–2416.
7. Tibolla, H., Pelissari, F. M., Martins, J. T., Vicente, A., Menegalli, F. C. (2018). Cellulose nanofibers produced from banana peel by chemical and mechanical treatments: Characterization and cytotoxicity assessment. Food Hydrocolloids, 75(1), 192–201.
8. Li, W., Zhang, Y., Li, J., Zhou, Y., Li, R., & Zhoh, W. (2015). Characterization of cellulose from banana pseudo-stem by heterogeneous liquefaction. Carbohydrate Polymers, 132, 513–519.
9. Singanusong, R., Tochampa, W., Kongbangkerd, T., & Sodchit, C. (2014). Extraction and properties of cellulose from banana peels. Suranaree Journal of Science and Technology, 21(2), 201–213.
10. Quintana, G., Velasquez, J., Betancourt, S., & Ganan, P. (2009). Binderless fiberboard from steam exploded bananabunch. Industrial Crops and Products, 29, 60–66.
11. Gopinathan, P., Subramanian, K. S., Paliyath, G., & Subramanian, J. (2017). Genotypic variations in characteristics of nano-fibrillated cellulose derived from banana pseudostem. Bioresources, 12(3), 6984–7001.
12. Yu, H., Qin, Z., & Liang, B. (2013). Facile extraction of thermally stable cellulose nanocrystals with a high yield of 93% through hydrochloric acid hydrolysis under hydrothermal conditions. Journal of Materials Chemistry A, 1, 3938– 3944. https://doi.org/10.1039/c3ta01150j
13. Ye, C., Malak, S. T., & Hu, K. (2015). Cellulose nanocrystal microcapsules as tunable cages for nano- and microparticles. ACS Nano, 9, 10887–10895.
https://doi.org/10.1021/acsnano.5b03905
14. Song, K., Xu, H., & Xu, L. (2017). Preparation of cellulose nanocrystal-reinforced keratin bioadsorbent for highly effective and recyclable removal of dyes from aqueous solution. Bioresource Technology, 232, 254–262.https://doi.org/10.1016/j.biortech.2017.01.070Song, K., Zhu, W., Li, X., & Yu, Z. (2020). A novel mechanical robust, self-healing and shape memory hydrogel based on PVA reinforced by cellulose nanocrystal. Materials Letters, 260, 126884.
15. Rueda, L., Saralegi, A., & Fernández-d'Arlas, B. (2013). In situ polymerization and characterization of elastomeric polyurethane-cellulose nanocrystal nanocomposites. Cell response evaluation. Cellulose, 20(4), 1819–

1828. https://doi.org/10.1007/s10570-013-9960-0

16. Eyley, S., Shariki, S., & Dale, S. E. C. (2012). Ferrocene-decorated nanocrystalline cellulose with charge carrier mobility. Langmuir, 28(17), 6514–6519. https://doi.org/10.1021/la3001224
17. Trache, D., Hussin, M. H., Haafiz, M. K. M., & Thakur, V. K. (2017). Recent progress in cellulose nanocrystals: sources and production. Nanoscale, 9(5), 1763–1786. https://doi.org/10.1039/C6NR09494E
18. Mariano, M., El Kissi, N., & Dufresne, A. (2014). Cellulose nanocrystals and related nanocomposites: review of some properties and challenges. Journal of Polymer Science Part B: Polymer Physics, 52, 791–806.
19. Song, K., Zhu, X., Zhu, W., & Li, X. (2019). Preparation and characterization of cellulose nanocrystal extracted from Calotropis procera biomass. Biomass Conversion and Biorefinery, 6, 45. https://doi.org/10.1186/s40643-019-0279-z
20. de Oliveira FB, Bras J, Pimenta MTB (2016) Production of cellulose nanocrystals from sugarcane bagasse fbers and pith. Ind Crops Prod 93:48–57. https:// doi.org/10.1016/j.indcrop.2016.04.064.
21. Espino E, Cakir M, Domenek S (2014) Isolation and characterization of cellulose nanocrystals from industrial by-products of Agave tequilana and barley. Ind Crops Prod 62:552–559. https://doi.org/10.1016/j.indcrop.2014.09.017.
22. dos Santos RM, Neto WPF, Silvério HA (2013) Cellulose nanocrystals from pineapple leaf, a new approach for the reuse of this agro-waste. Ind Crops Prod 50:707–714. https://doi.org/10.1016/j.indcrop.2013.08.049.
23. Xu Y, Hanna MA (2010) Optimum conditions for dilute acid hydrolysis of hemicellulose in dried distilled grains with solubles. Ind Crops Prod 32:511–517. https://doi.org/10.1016/j.indcrop.2010.06.024.
24. Ray D, Sarkar BK, Rana AK, Bose NR (2001) Mechanical properties of vinylester resin matrix composites reinforced with alkali-treated jute fibres. Compos Part A Appl Sci Manuf 32:119–127. https://doi.org/10.1016/S1359 -835X (00)00101-9.
25. Neto WPF, Silvério HA, Dantas NO, Pasquini D (2013) Extraction and characterization of cellulose nanocrystals fromagro-industrial residue—Soy hulls. Ind Crops Prod 42:480–488. https://doi.org/10.1016/j.indcrop.2012.06.041.
26. Lin N, Bruzzese C, Dufresne A (2012) TEMPO-oxidized nanocellulose participating as crosslinking aid for alginate- based sponges. ACS Appl Mater Interfaces 4:4948–4959. https://doi.org/10.1021/am301325r.
27. Mariano, M., Kissi, N. E., & Dufresne, A. (2014). Cellulose nanocrystals and related nanocomposites: Review of some properties and challenges. Journal of Polymer Science Part B: Polymer Physics, 52(12), 791-806.
28. Hubbe, M. A., Ferrer, A., Tyagi, P., Yin, Y., Salas, C., Pal, L., et al. (2017). Nanocellulose in thin films, coatings, and pliesfor packaging applications: A review. BioResources, 12(1), 2143-2233.
29. Kaboorani, A., Riedl, B., Blanchet, P., Fellin, M., Hosseinaei, O., & Wang, S. (2012). Nanocrystalline cellulose (NCC): A renewable nano-material for polyvinyl acetate (PVA) adhesive. European Polymer Journal, 48(11), 1829-1837.
30. Mascheroni, E., Rampazzo, R., Ortenzi, M. A., Piva, G., Bonetti, S., & Piergiovanni, L. (2016). Comparison of cellulose nanocrystals obtained by sulfuric acid hydrolysis and ammonium persulfate, to be used as coating on flexible food- packaging materials. Cellulose, 23(1), 779-793.
31. Karim, Z., Mathew, A. P., Grahn, M., Mouzon, J., & Oksman, K. (2014). Nanoporous membranes with cellulosenanocrystals as functional entity in chitosan: Removal of dyes from water. Carbohydrate Polymers, 112, 668-676.
32. Yang, X., Shi, K., Zhitomirsky, I., & Cranston, E. D. (2015). Cellulose nanocrystal aerogels as universal 3D lightweight substrates for supercapacitor materials. Advanced Materials, 27(40), 6104-6109.
33. Kalashnikova, I., Bizot, H., Bertoncini, P., Cathala, B., & Capron, I. (2013). Cellulosic nanorods of various aspect ratios for oil in water Pickering emulsions. Soft Matter, 9(3), 952-959.
34. Tasset, S., Cathala, B., Bizot, H., & Capron, I. (2014). Versatile cellular foams derived from

CNC-stabilized Pickering emulsions. RSC Advances, 4(2), 893-898.

35. Domingues, R. M. A., Gomes, M. E., & Reis, R. L. (2014). The potential of cellulose nanocrystals in tissue engineering strategies. Biomacromolecules, 15(7), 2327-2346.
36. Lin, N., & Dufresne, A. (2014). Nanocellulose in biomedicine: Current status and future prospect. European Polymer Journal, 59, 302-325.