



Synthesis and Characterization of a Novel Maize Cob Based Nanocellulose

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Nanocellulose is a renewable nanomaterial that has received a lot of attention due to its use in a variety of applications from the biomedical field to food packaging. In this study, Nano cellulose (NC) was extracted from Maize cob, using the Acid hydrolysis process. The extracted NC was characterized using Particle Size Analyzer (PSA) for particle size, Fourier Transform Infrared Spectroscopy (FT-IR) for functional groups, Scanning Electron Microscope (SEM), and Transmission Electron Microscope (TEM) for getting the morphology of NC and X-Ray Diffraction (XRD) for crystallinity analysis. The result showed that, the synthesized NC with a particle size of 213.5nm and zeta potential of -34.5mV. The FT-IR analysis showed that the functional groups stretched at C-O, C=O, and S=O with a wavenumber of 1216cm⁻¹, and 1737cm⁻¹, 1365cm⁻¹ in NC. XRD analysis shows a peak around 2θ = 15.80, 22.03, 26.69, 40.44 which shows the structure of cellulose. SEM and TEM images of the extraction process of NC show the morphological and structural information of cellulose and Nanocellulose.

Keywords: Acid hydrolysis; alkali treatment; bleaching; maize cob; nanocellulose.

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1. INTRODUCTION

One of the most adaptable crops, that has been able to thrive in a wide range of agro-climatic conditions is Maize (*Zea mays* L.). Maize is known across the world as the "Queen of Cereals" because it has the largest genetic production potential of all cereals. Maize is the third most important crop in India after rice and wheat. [1] reported that the overall cellulose output from biomass varied from 10^{10} to 10^{11} tons per year, accounting for roughly 40% to 50% of plant fibres. In India, the total amount of Maize cob waste produced per year is 5 million tonnes. Tamil Nadu generates approximately 2700 tonnes of waste per year [2]. In the twentieth century, maize became a key staple grain that was transformed into important cuisines and industrial items all across the world. The harvested maize crop is typically milled either dry or wet, as well as cleaned or conditioned, to yield maize kernels and waste residues such as maize cobs (MC). The MC is an extremely fibrous rachis made from the female inflorescence of maize ear as a by-product of maize processing. The cellulose content of maize cobs was estimated to be around 45 percent. As a result, using maize cob as a source of refined cellulose is a positive step forward. The most abundant type of renewable organic matter on earth is cellulose with has a biosynthetic production that is annually estimated to be over 10^{11} tons. It is a carbohydrate polymer composed of repeating β -D-glucose units. There are both amorphous and crystalline parts in it. Cellulose is a renewable natural polymer that comes in the form of fiber and is used to make a variety of materials and products. Nanocellulose (NC) is a new renewable nanomaterial with a wide range of uses in food, medicines, and personal care products. Alkalization, bleaching, and acid hydrolysis are all used to recover cellulose from agro-waste. A hydrolysis reaction occurs when one molecule splits into several smaller ones. Corn cob residues (CCR) are typically burned to recover heat, causing environmental issues [3]. As a result, converting CCR into value products is a concern worthy. Because the hemicellulose in corn cob has been hydrolyzed, the CCR is permeable and might be one of the most easily obtainable lignocellulosic resources for nanocellulose fabrication. Numerous ways for producing nanocellulose have been developed. Cellulose Nano Crystals (CNCs) are rod-like crystalline particles with a width of 10-30 nm and a length of several hundred nanometers

that are typically formed by rapid acid hydrolysis [4]. Sulfuric acid hydrolysis is a common approach for isolating CNCs with good water dispersibility. Other acids, such as hydrochloric acid, nitric acid, or a combination of acids, were also utilized in the fabrication of CNCs [5]. These processes remove all other components from the fiber, leaving behind highly crystalline cellulose. With the help of a Nano miller, Ultrasonicator, High pressure homogenizer cellulose is converted into Nanocellulose (NC) particles. This study examines the utilization of non-woody lignocellulosic biomass sources, particularly those classified as agro-waste, to create Nanocellulose (NC). Nanocellulose is cellulose with a fiber width at the nanoscale lattice that exists in many morphologies such as Cellulose Nanocrystals (CNCs), Cellulose Nanofibrils (CNFs), or Cellulose Nano Whiskers (CNWs), and Bacterial Nanocellulose (BNC). Nanocellulose is a biologically innovative substance that is continuously being researched for novel applications. NC materials are gaining popularity due to their appealing and great attributes such as abundance, high aspect ratio, enhanced mechanical properties, renewability, and biocompatibility. cellulose-based materials are becoming more popular as a result of their intriguing properties. The origin of the cellulose, the separation and processing conditions, as well as any pre- or post-treatments, all influence the shape, size, and other attributes of each nanocellulose type.

The nanocellulose market is expected to reach USD 783 million by 2025, according to Markets. The increasing demand for nanocellulose and the use of novel applications has prompted researchers and industry to expand their use of the materials. In this work, NC was created by acid hydrolyzing corn cob powder [6]. Enzymolysis and Chlorine Oxidation Degradation are two further mechanisms that can be used to make NC. Although these other procedures have been tried and each has its own unique effects on the resulting NC, Acid Hydrolysis is a well-known method for successfully dissolving cellulose's amorphous areas. [7] reported that Cellulose nanoparticles are remarkable materials that have applications in almost every sector of human activity. There are various advantages to scaling down lignocellulose biomass to nanocellulose. [8] reported Nano Cellulose Production Technology and Application.

2. MATERIALS AND METHODS

2.1 Raw Materials

The fresh Maize cobs were collected from Maize Research Station, Vagarai, Tamil Nādu, India. Then they were dried in the sunlight for two days. After two days, these cobs were grinded to a fine powder and used for the extraction of cellulose. The chemicals used in the study for NC extraction would include sodium hydroxide pellets (purity: 99%), acetic acid (purity: 99.75%), sodium hypochlorite (12.5%), and oxalic acid (91.53%). oxalic acid and acetic acid were purchased from Astron Chemicals P Ltd, Ahmedabad. sodium hydroxide and sodium hypochlorite were purchased from Sigma Aldrich Chemicals P Ltd, Bangalore.

2.2 Extraction of Cellulose from Maize Cob (Figs 1 & 2)

Maize cobs are good source of cellulose and hemicellulose, but they also have a lot of lignin. To extract cellulose from maize cob, three major techniques were used, Alkali treatment, Bleaching, and Acid hydrolysis. In the Alkali treatment.

100g of fiber was mixed with 1L of 2% sodium hydroxide (NaOH), and it was placed in an autoclave at 20 lb for 1 hour at 121°C, during this process the lignin and other contaminants present in the cob powder were dissolved and washed with water & decanted. Next bleaching

process was done by mixing of sodium hydroxide, acetic acid, and 4% sodium hypochlorite in 1:3 ratio and kept it undisturbed for overnight. After that bleaching solution was washed with water (H₂O) to remove the bleaching agent, and this process was repeated 3-4 times until the fiber color changes from brown to white. The bleaching process is followed by acid treatment, by adding 11% oxalic acid (the ratio of fiber & oxalic acid 1:4) and kept in an autoclave at 20lb for 15 minutes. Finally, acid treated solution was rinsed with water until the pH is back to neutral. The final product was white colored powder cellulose in micro size.

2.3 Conversion of Microcrystalline Cellulose into Nanocellulose

The obtained microcrystalline cellulose is converted into nanocellulose using a ultrasonication process. The cellulose suspension was dispersed using Ultrasonicator for 15 minutes with the temperature and amplitude of 45°C & 27m. The NC obtained from the Ultrasonicator was characterized using different instruments. [9] reported that to separate the nanocellulose, the cellulose suspensions were sonicated for 30 minutes at 20–25 kHz with a 1000 W output power using an ultrasonic processor. [10] reported the extraction of cellulose nanocrystal from cotton by Ultrasonication process. [11] reported the Agricultural wastes derived from walnut shells are used in the synthesis of cellulose nanocrystals using Acid hydrolysis process.

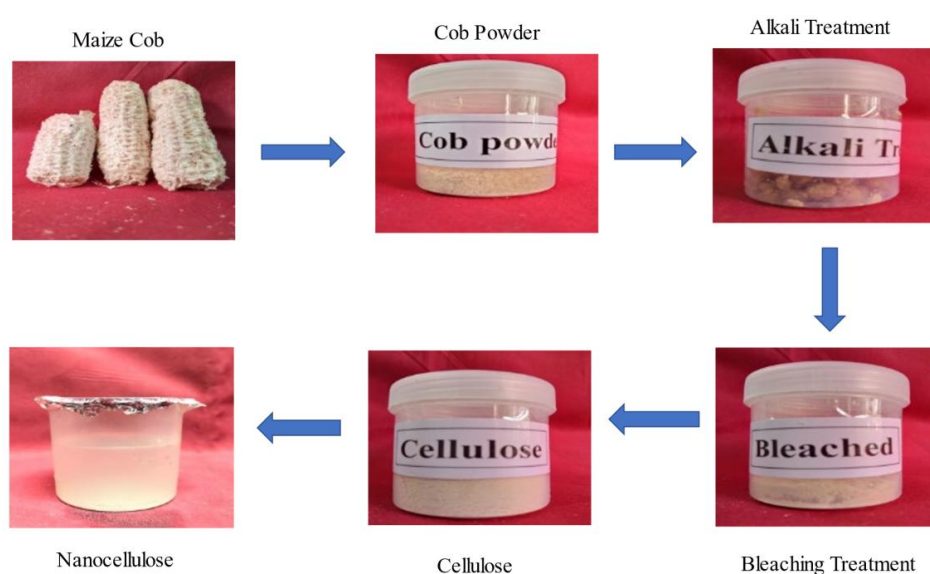


Fig. 1. Extraction of Nanocellulose from Maize Cob

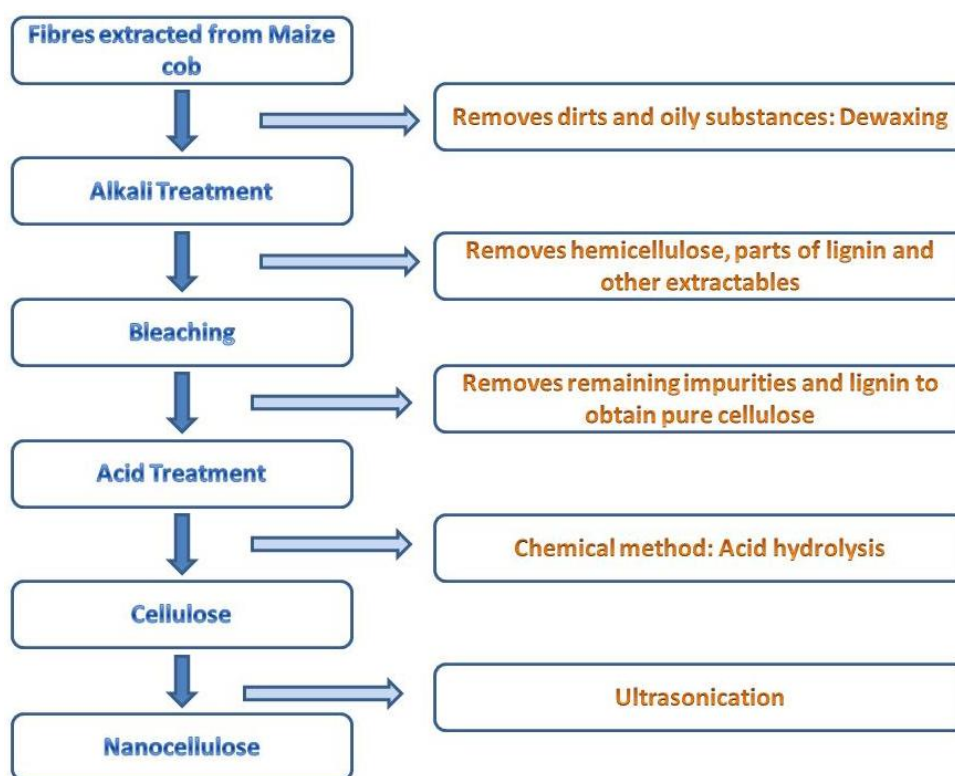


Fig. 2. Flow chart for extraction of Nanocellulose from Maize Cob

2.4 Characterization

2.4.1 Particle size analysis (PSA) & zeta potential

Particle size and distribution of particles was measured using Nano Particle size analyzer (Model HOR1BA -52-100). The powdered NC was dispersed in water (RI 1.333) at 25°C in a disposable cuvette and run for 60 seconds where particle size distribution graph was plotted. Value of zeta potential indicates the surface charge of nanoparticles, suggesting their electrophoretic mobility. The measures of dispersion stability were measured using the same instrument in which the zeta potential electrostatic forces were measured between -200mv to +200mv) at ambient temperature

2.4.2 Fourier transform infrared spectroscopy (FTIR)

To identify the functional groups, the FT-IR analysis was done for alkali treated, bleached, acid treated cellulose and nanocellulose using a Jasco FT-IR 6800 spectrometer (JASCO Japan) equipped with Attenuated Total Reflectant Unit (ATR) sensor. For this study, about 1.0 mg of sample was used and the spectra were taken

with a spectral resolution of 4.0 cm^{-1} spanning the wave number range of 4000–400 cm^{-1} .

2.4.3 X-RAY diffraction (XRD)

The XRD images was taken for Cellulose and Nanocellulose samples X- ray diffraction system (Model Ultima IV, RIGAKU, Japan). The analysis was performed on X- ray diffractometer operated at 40kV and 30mA, the pattern was recorded by Cu-K α radiation with of 1.5401 Å. The sample of 0.5g was placed on glass substrate and it was mounted on sample stage and diffraction was measured.

2.4.4 Scanning electron microscopy (SEM)

The size and morphology of samples at different stages were investigated using a Quanta 250, FEI, Netherlands Scanning Electron Microscope. The samples were mounted on aluminum stubs with conductive carbon tape and sputtered with gold using a plasma sputtering apparatus under vacuum at 20mA for two minutes. The samples were then observed and imaged.

2.4.5 Transmission electron microscopy (TEM)

The size and internal structure samples at different stages were investigated using a FEI

TECHNAI SPRIT Transmission Electron Microscope with 120 kV accelerating voltage. A drop of aqueous suspension was deposited on a copper grid (360 mesh) and allowed to dry under vacuum. The copper grid was then inserted into the instrument and images of the nanocellulose particles were captured under different magnifications.

3. RESULTS AND DISCUSSION

3.1 Particle Size Analysis

The graph showing the particle size and zeta potential is depicted in Fig. 3. From the distribution graph, the size of the nanocellulose was found in the range of 213.5nm. Similar result was obtained by [6]. He reported that, the size of the nanocellulose was 178nm, however the size differs among different synthesis strategies for nanocellulose. As per the graph, the zeta potential for the synthesized NC as -34 mV. [12] reported that the zeta potential of -48mV was obtained for nano cellulose and it indicates the stability of suspension in water solvent. The zeta potential of particles with more than ± 30 mV are normally considered as stable. So the obtained results indicates good stability of NC suspension. [13] reported the Zeta potential of -34.66mV, which is similar to obtained results.

3.2 Fourier Transform Infrared Spectrometer (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) spectra of cellulose and nano cellulose provided information on functional groups present in the sample (Fig. 4). FT-IR is a technique for identifying organic, inorganic, and polymeric materials by scanning them with infrared light. The results showed that an absorbance peak at 1217,1370, 1741 cm^{-1} for cellulose and the 1258,

1365, 1737 cm^{-1} for nanocellulose was observed. Both cellulose and nanocellulose absorbance peaks at 1217 and 1216 cm^{-1} show strong C-O stretching under the compound class alkyl aryl ether. The FTIR absorbance peak also shows strong S=O stretching at 1370 cm^{-1} in cellulose and 1365 cm^{-1} in nanocellulose under the compound class Sulfonamide and strong C=O stretching at 1741 cm^{-1} in cellulose and 1737 cm^{-1} in nanocellulose under the compound Aldehyde. Similar result was obtained by [14,15] reported that the absorbance peak at 1050 cm^{-1} is due to C-O Stretching, the peaks at 1730,1720 cm^{-1} are assigned to the C=O stretching indicates the microcrystalline cellulose. [16] also reports the C-O stretching to confirm the presence of cellulose.

3.2.1 FTIR spectra at different stages of cellulose extraction

The Fig. 5 depicts the FTIR spectra of extraction process of cellulose. The result showed that, the absorption band at 1744.35 cm^{-1} showed the aromatic compound at C-H bending at weak appearance in all stages of hydrolysis process. The absorption band at 2969.33 cm^{-1} showed medium appearance of C-H stretching under the compound Alkane. The absorption band at 3453.79 cm^{-1} showed strong broad appearance at O-H stretching under the compound Alcohol due to intermolecular bonding. [17] reported in their study about C-H bending, C-H stretching and O-H stretching at the wavenumbers of 1430 cm^{-1} , 2891 cm^{-1} and 3461 cm^{-1} respectively. The result indicated that the chemical composition of microcrystalline cellulose was not altered during the nanocellulose extraction by alkaline treatment, acid hydrolysis, and nano milling. The gradual increase in a spectral band indicates the successful removal of lignin and hemicellulose during acid hydrolysis.

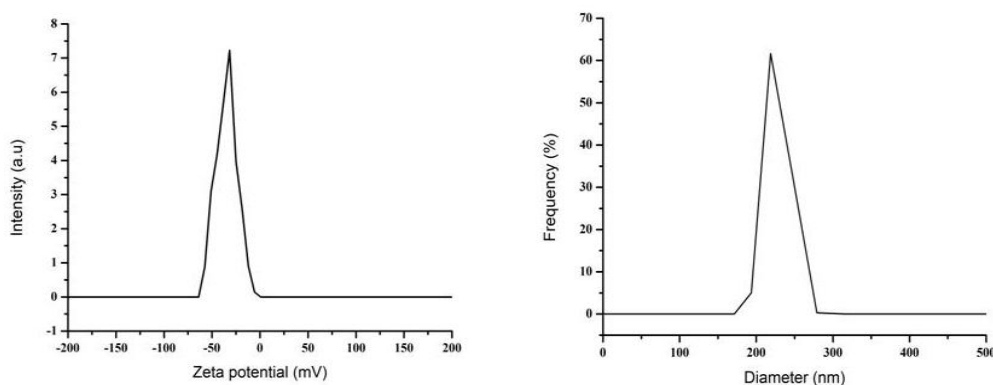


Fig. 3. Particle size and zeta potential of nano cellulose

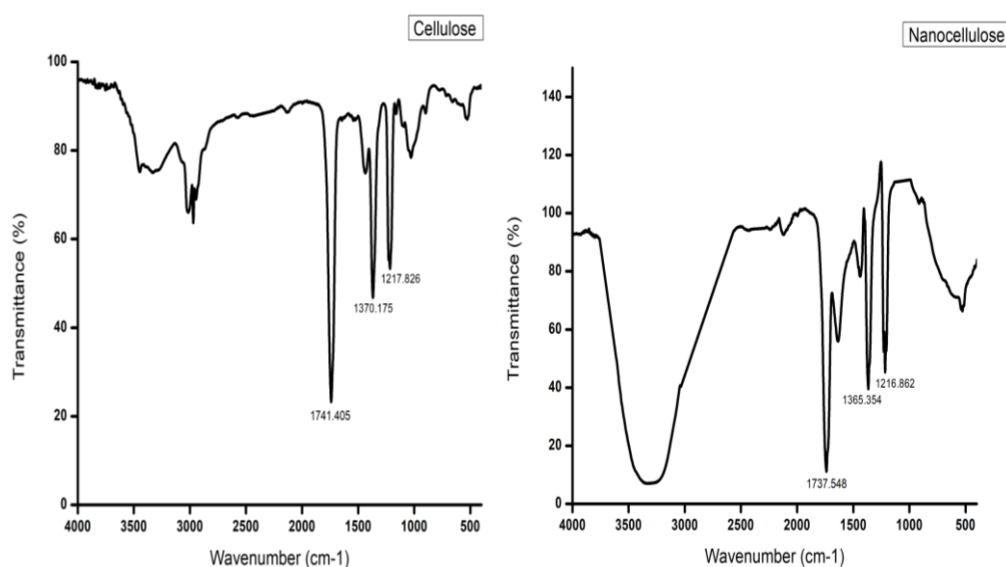


Fig. 4. FTIR Spectra of cellulose and Nanocellulose

3.3 SEM Characterization

The SEM images of different stages of cellulose extraction are shown in Fig. 6. The image showed that, the corn cob image (a) shows a rough surface of different sizes and orientation of particles. This can be attributed to the fact that the corn cob powder contains all the components that give plant cell its rigidity and therefore rough appearance. After pre-treatment and subsequent hydrolysis increased homogeneity and lustre was observed (image e & f). Increased homogeneity and shine were found after pre-treatment and subsequent hydrolysis. These side effects are the result of the Maize cob's chemical treatment. Hemicelluloses, lignin, and pectins were successfully eliminated, resulting in the appearance of cellulose in the SEM image [18]. The image of a different extraction stages reveals a rough surface with particles of various sizes and orientations. The cluster of fibres diameter ranging from 160nm to 780nm. [19] reported that cluster of particles with varying diameters ranging from 24 μ m to 200 μ m was observed.

3.4 TEM Characterization

The ultra-structural morphology of sample at different stages was investigated using a Transmission Electron Microscope. the results are given in Fig. 7. The result clearly depicting the cluster of particles with fiber separation process to obtain cellulose. The bleached fibers had greater aggregation and inadequate defibrillation, according to the TEM analysis. The

steam coupled chemical treatment improved the extraction of pure crystalline nano fibrils from Maize fiber, according to TEM measurement. The similar result was obtained by [19] and they reported that cluster of particles with varying diameters was observed.

3.5 XRD Analysis

XRD pattern of Cellulose & Nanocellulose is shown in Fig. 8. The result showed that the diffraction pattern with wide peak around $2\theta = 15.80, 22.03, 26.69, 40.44$ and it showed the structure of cellulose [20] reported that, for nanocellulose, the XRD diffraction peak of around $2\theta = 16.5^\circ, 22.5^\circ$ and 34.6° was obtained. The high intensity peak located at 22.79° for nanocellulose describes the crystalline nature of the material and the intensity value shows the amount of crystalline structure. There are two major peaks for all samples around 2θ of 15 degrees and 22 degrees. The characteristic peak at the 002 plane ($2\theta = 22^\circ$) is associated with crystallinity. The broadening of the peak is attributed to increased amorphousity as the corn cob contains all the amorphous cellulose. It is generally accepted that in the cellulose community that peak broadening is due to amorphous cellulose. [21] reported that the occurrence of peaks at $2\theta = 15^\circ, 17^\circ, 21^\circ, 23^\circ$ and 34° indicates a predominance of Nanocellulose. [22] reported the diffraction peaks were observed at $2\theta = 16^\circ, 22.5^\circ$ and 34.5° , for extracted cellulose sample. [23] reported the crystallinity configuration of cellulose is shown by the peak at 2 values of 22.47° .

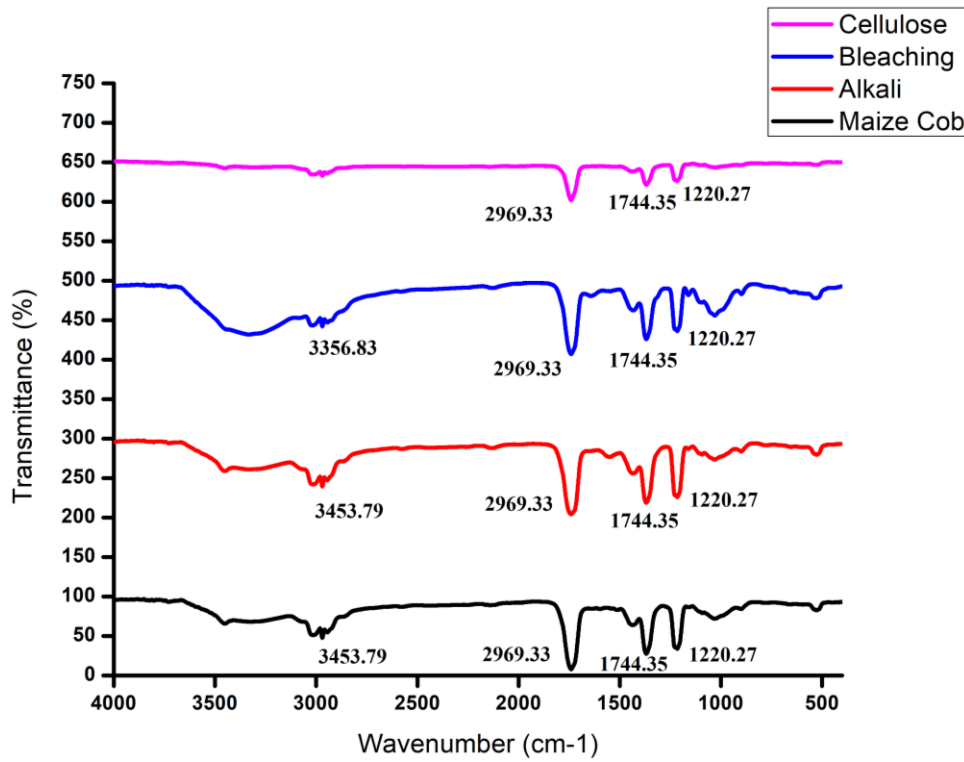
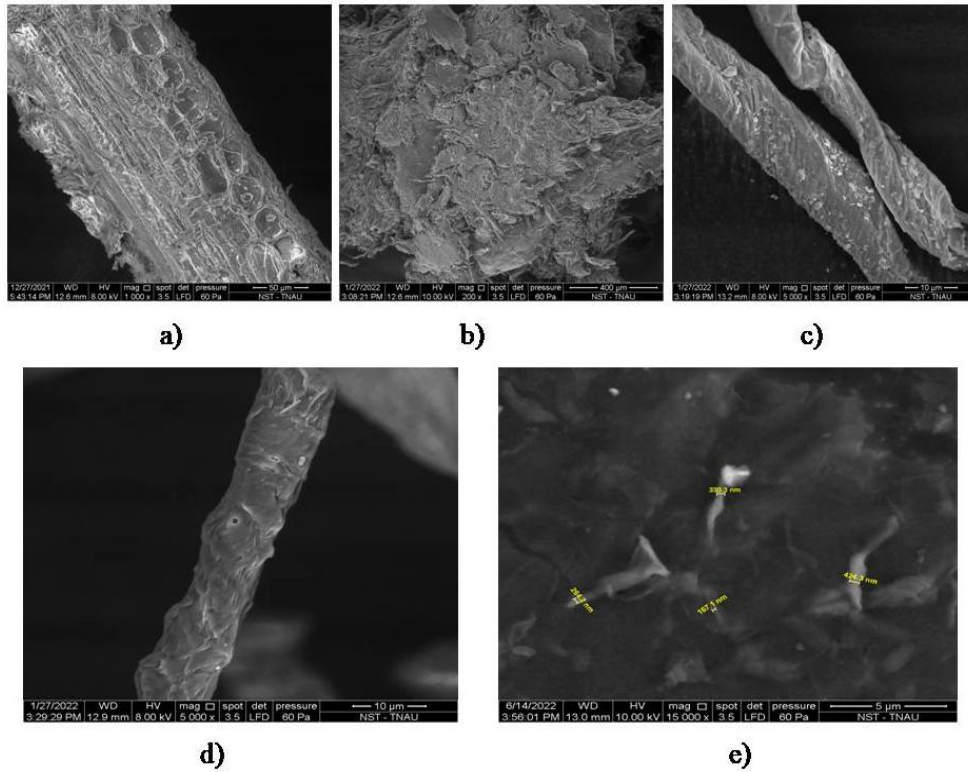
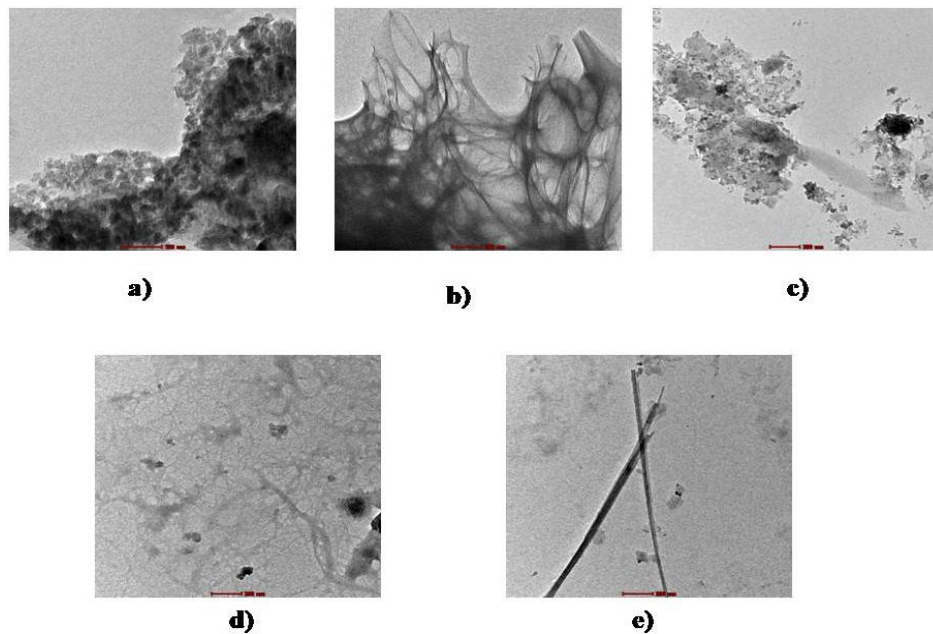


Fig. 5. FTIR spectra of different stages of cellulose extraction



(a) Maize cob, b) Alkali Treatment, c) Bleaching, d) Cellulose, e) Nanocellulose

Fig. 6. SEM images of different stages of cellulose extraction



a) Maize cob, b) Alkali Treatment, c) Bleaching, d) Cellulose, e) Nanocellulose

Fig. 7. TEM images of different stages of cellulose extraction

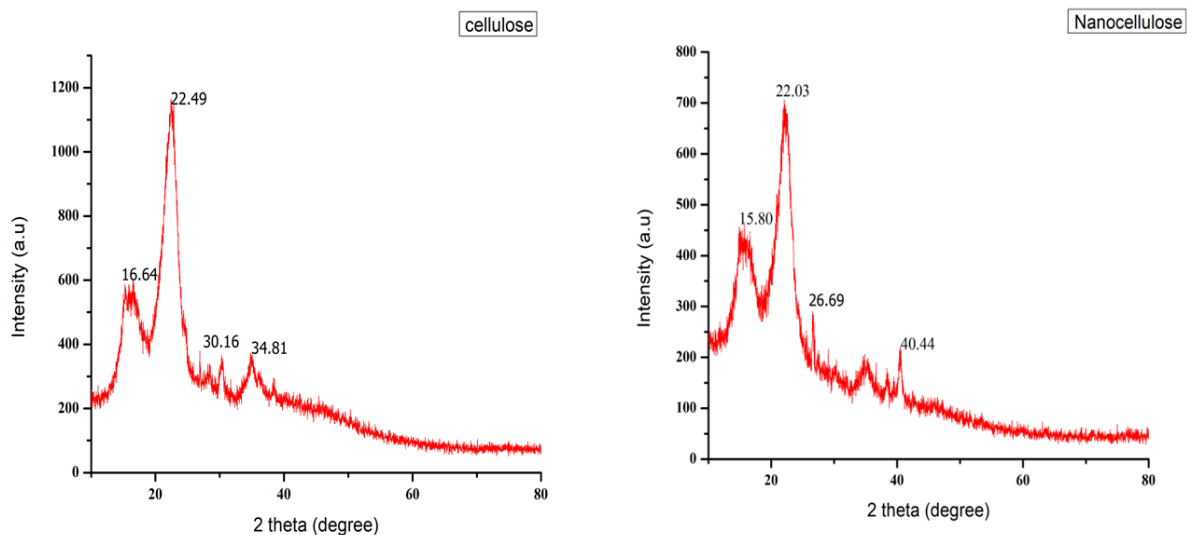


Fig. 8. XRD Analysis of Cellulose and Nanocellulose

4. CONCLUSION

The acid hydrolysis procedure was used to extract nanocellulose from corn cobs. FT-IR, SEM, TEM, and PSA were used to characterize the extracted NC. The chemical treatment of the Maize cob improves the surface characteristics of the cellulose, which aids interaction between the cellulose and other molecules, according to the results. The obtained results confirm the Nanocellulose with the particle size of 213.5nm

and zeta of -34.5mV and FTIR absorbance peak also shows strong S=O stretching at 1370cm^{-1} in cellulose and 1365cm^{-1} in nanocellulose and strong C=O stretching at 1741cm^{-1} in cellulose and 1737cm^{-1} in nanocellulose. Both cellulose and nanocellulose absorbance peaks at 1217 and 1216cm^{-1} show strong C-O stretching under the compound class alkyl aryl ether. The XRD analysis also shows peak around $2\theta = 15.80, 22.03, 26.69, 40.44$ shows the structure of cellulose. The SEM and TEM images clearly

depicts the process of Acid Hydrolysis process, the fiber defibrillation and formation of cellulose and Nanocellulose. Nanocellulose-based paper appears to be the best packaging material because it provides adequate protection and packing for the product while also being ecologically friendly due to its renewable source and biodegradability. Nanocellulose is one of the most promising materials right now since it can be mass-produced and used in a wide range of applications.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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