Nanocellulose: Transforming Agricultural Waste into High-Value Biomaterials

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The natural fiber that can be made from cellulose is called nanocellulose. The nanocellulose fiber typically has a diameter of less than 100 nm and a length of several micrometers. Nanocellulose has a strength-to-weight ratio that is eight times greater than stainless steel and has a high tensile strength of up to 10 GPa, which is greater than cast iron. It is also translucent and loaded with hydroxyl groups that can be functionalized to have a variety of surface qualities. Nanocrystalline cellulose, nano fibrillated cellulose, and bacterial nanocellulose are the three primary subtypes of nanocellulose. Although all varieties share a similar chemical makeup, differences in morphology, particle size, crystallinity, and other features result from differing extraction techniques and source materials.

Table 1. Classification of nanocellulose materials

Type	Origin	Mean Size
Bacterial nanocellulose (BC)	Low molecular weight sugars and alcohols	Length: several micrometers Width: 5–70 nm
Cellulose nanocrystals (CNC)	Wood, hemp, wheat straw, flax, cotton, rice straw, mulberry bark, avicel	Length: 100–250 nm Width: 5–70 nm
Spherical cellulose nanoparticles (SCNP)	Wood, flax, cotton, straw, hemp	Diameter: 10–100 nm
Cellulose nanofibers (CNF)	Cotton, straw, wood, flax, hemp	Several to hundred microns in length; Few microns in diameter with finely attached nanofiber

Agricultural residue as a source of nanocellulose

Agricultural waste disposal has always been a problematic issue. The ethical use of agricultural waste can help prevent environmental contamination to some extent due to societal advocacy for the circular economy and public support for recycling agricultural waste resources. (Abdullah *et al.,* 2020). A number of techniques can be used to extract cellulose from agricultural waste, which has always been a significant supply of the substance. In this approach, agricultural waste contributes to the creation of a new renewable resource while still having a high environmental degradability. Numerous agricultural wastes have been investigated as nanocellulose resources, including cocoa pod husk, banana and coir fiber, kenaf and pineapple peel, sugarcane bagasse and corn husk. Agricultural waste can be processed chemically with alkaline treatment, bleaching, and acid hydrolysis to separate the cellulose. The most typical illustration should be sugarcane. Following the separation of sugar and alcohol, sugarcane bagasse serves as the primary source of cellulose. It is extracted from agricultural waste using ultrasonic irradiation, varying concentrations of alkali, and alkaline peroxide (Rani *et al.,* 2018). Various cellulose components are extracted using various techniques (Table 2).

Extraction methods of nanocellulose

The study of nanocellulose extraction from lignocellulosic biomass is particularly appealing, especially for the extraction from agricultural leftovers, due to the exceptional features of nanocellulose. First, the pre-treatment eliminates the non-cellulosic components including lignin, hemicellulose, and other substances. Then, using a variety of extraction techniques, nanocellulose is obtained from cellulose fibrils (Risite *et al.,* 2022).

Table 2. Nanocellulose from different agro-residues

S.No	Agro-residue	Method of extraction	Reference
1	Raw rice husk	High-intensity ultrasonication (500 W, 40min) and chemical treatments	Dilamian and Noroozi (2019)
2	Corn cobs	Mechano-chemical esterification	Kang *et al.* (2017)
3	Wheat straw	High-pressure homogenization	Suopajärvi *et al.* (2015)
4	Coconut husk	TEMPO-mediated oxidation (TEMPO/NaClO/$NaClO_2$)	Wu *et al.* (2019)
5	Citrus waste	Acid hydrolysis and ultrasonic assisted treatment	Naz *et al.* (2016)
6	Pea hull	Acid hydrolysis	Chen *et al.* (2018)
7	Raw apple stem	Acid hydrolysis	Phanthong *et al.* (2016)

Biomass pre-treatment

Biomass pre-treatment is a crucial step in the extraction of nanocellulose from cellulosic sources by eliminating other non-cellulosic components. Acid-chlorite treatment and alkaline treatment are the two traditional techniques for biomass pre-treatment. The delignification process, sometimes referred to as the bleaching process or the acid-chlorite treatment, is commonly employed in the pulp industry. By stirring lignocellulosic biomass with distilled water, acetic acid, and sodium chlorite for 4-12 h at 70–80 °C, it is possible to extract the majority of lignin and other components (Phanthong *et al.* 2016). The alkaline treatment is the application of alkali to remove the residual lignin and the amorphous portion of hemicellulose. Sodium hydroxide (4–20 wt %) is the most used alkali and it is always mixed with holocellulose for 1–5 h. The finished solid products are then dried in an oven at 50 °C after being cleaned in distilled water until the pH is neutral.

Extraction of nanocellulose

Nanocellulose can be extracted from cellulosic materials using a variety of methods (Figure 1). The primary extraction procedures are divided into three categories *viz.*, enzymatic hydrolysis, acid hydrolysis, and mechanical process. Enzymes are utilised in the biological treatment procedure known as enzymatic hydrolysis to break down or alter cellulose fibres. One of the primary methods for removing nanocellulose from cellulosic products is acid hydrolysis. The acid most frequently employed for acid hydrolysis is sulfuric acid. Due to the esterification of the hydroxyl group by sulphate ions, it can not only firmly isolate nanocrystalline cellulose but also disseminate the nanocellulose as a stable colloid system. By using a strong shear force to cleave the cellulose fibres along their longitudinal axis, cellulose is mechanically isolated into nanofibrillated cellulose. The three mechanical techniques that are most frequently utilised are ultrasonication, high pressure homogenization, and ball milling (Trache *et al*. 2020).

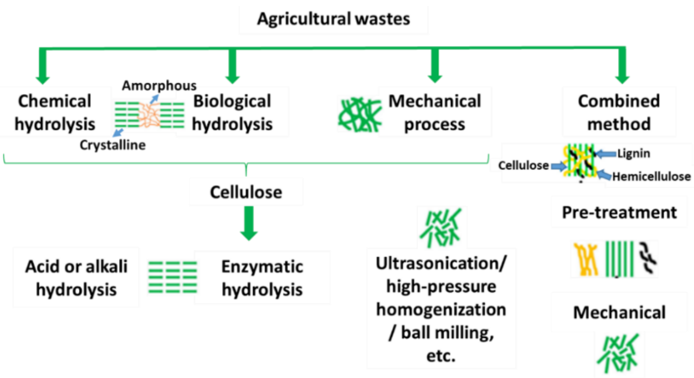

Figure 1. Schematic diagram of nanocellulose extraction techniques

Application of nanocellulose

Cellulose nanomaterials are envisioned to have a broad array of applications across numerous sectors. With its unique merits, including non-toxicity, biocompatibility, high water absorption and retention capabilities, as well as exceptional mechanical properties, nanocellulose holds immense potential for extensive use in biomedicine and pharmacy, functional food and feed, cosmetics, packaging, electronics, and optoelectronic devices (Figure 2). Notably, nanocellulose derived from various biomass wastes also demonstrates cost-effective advantages, given its wider range of raw material sources

(Dufresne, 2019). Consequently, the development of high-value products utilizing nanocellulose extracted from biomass wastes not only fosters economic growth but also plays a pivotal role in environmental preservation.

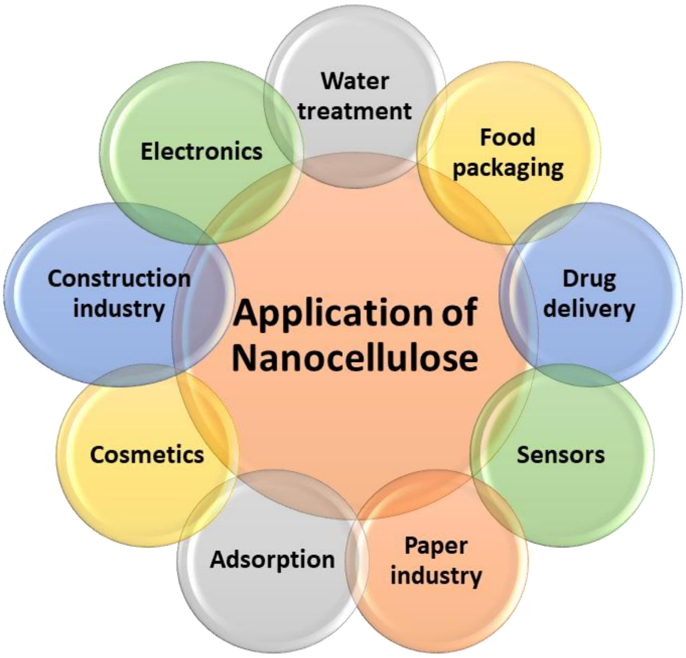

Figure 2. Various applications of nanocellulose materials

Conclusion

Nanocellulose extraction from agricultural residues via environmentally friendly processes using advanced technologies has become increasingly significant. Sustainable progress in its application relies on factors such as the choice of raw materials, extraction techniques, product design, and lifecycle considerations. The appeal of nanocellulose across various sectors stems from its renewable, biocompatible, and biodegradable properties. The utilization of these materials involves biomass waste, and the expanded utilization of rural waste for producing bio-composite agro-based products hinges on the escalating impact of the agriculture sector.

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