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A Review on Cellulose Nanocrystals (CNCs) as Green Finishing Material to Produce Multifunctional Textiles

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Abstract

Nowadays, all efforts aspire to develop the textile finishing using environmentally safe, bio-degradable, and more efficient green materials from biological sources such as the use of plant extract instead of chemical that harm environment and human health. In this article, discussion of organic Cellulose nanocrystals (CNCs) as green finishing material to produce Multifunctional textiles such as antimicrobial , uv protection, Hydrophilic modification, flame retardant and insects repellent in addition to several products such as filter paper and face mask and antimicrobial wound dressing films depended on (CNCs) that have valuable qualities like high stiffness, high surface area, and good mechanical properties. They are crystalline in nature and have a rod-like nano-shaped structure. (CNCs) are extracted in large quantities from natural cellulose sources, such as wood, tunicate, Red Algae, Bamboo, Bacteria, phormium tenax or agriculture wastes, among others. Their highly distinctive qualities, which include low cost, biodegradability, dye sorption, and ubiquitous metallic ionic nature, have been used to manipulate chemicals with high sensitivity and combine various critical parameters, including high mechanical strength and low density in various aspects, making them ideal for incorporating with various materials and bonding with hydrophilic polymers. Additionally, their biological sustainability, bioavailability, and low cytotoxicity make them a preferred choice for scientific and technological advancements across a range of fields.

Keywords: CNCs, Extraction, functional textile, finishing.

Introduction

Rapid nanotechnologies and material science advancements have contributed in the investigation of nanocellulose, leading in their development as desired biomaterials. Nanocellulose has been extensively researched in a variety of fields, including renewable energy, electronics, the environment, food production, biomedicine, and healthcare. Cellulose nanocrystal (CNC) is produced through the organic crystallizing of macromolecular components found in bacteria's capsular polysaccharides and fibers from plants. Because of the various reactive groups of chemicals on its surface, physical adsorption, surface grating, and vapor deposition of chemicals can all be employed to improve its performance, which is why it has such a broad range of uses. [1] Cellulose nanocrystals (CNCs) have a lot of potential as excellent matrices and sophisticated materials, and they've already been used in terms of changing and inventing new applications for them. This paper examines CNC synthesis, characteristics, and industrial applications **[2].** This paper also covered CNC's common usage as a fire retardant, sensor, and acoustic insulator. **[3]** Plant walls of cells and crystalline areas evolved in the biosphere from a linear polymer of dehydrated beta units. The glycoside bond is a chemical connection that binds one to four carbon atoms. CNCs are attractive as biodegradable and renewable materials due to their low-level substitution of functional groups. CNCs are derived in large quantities from natural cellulose sources such as pulp from wood, cotton, algae, or bacteria, and have valuable qualities such as high stiffness, high surface area, and superior mechanical properties. They are crystalline in nature, with rod-like nano-shaped particles.**[4]** Their highly unique properties, such as low cost, biodegradability, dye sorption, and ubiquitous metallic ionic nature, have been exploited for high sensitivity chemical

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modification and combinations of different key parameters, such as strong mechanical properties and low-density characteristics in different aspects, which make them suitable for bonding with hydrophilic polymers and incorporating with various substances, while their biological sustainability, bioavailability, and bioavailability, have been exploited. Because of their high aspect ratio, several polymer systems are being investigated as reinforcing agents.**[5]**

CNCs enable massive quantities of fully renewable and biodegradable nanocomposites with distinct properties when compared to bulk materials. Individual cellulose nanocrystals particles require high comparability, transparency, and strength, making them an appealing option for various protective layered structures..**[2]** It also demonstrated a significant improvement when compared to grapheme oxide hydrogel with a smooth surface of different axes of the cellulose crystal with water, demonstrating typical qualities of a water-friendly confinement cellulose, alginate, and hydroxyapatite are known for their distinct adsorption ability. CNCs also feature great stiffness, low efficiency, optical transparency, self-organizing ability, and variability.**[6]**

It is a great biological material with a wide range of potential uses, including polymeric nano composites, transparent flms, and hydrogels, as well as large-scale commercial applications, particularly in the food packaging, textile, and paper industries. Its structure is not uniform, with both crystalline states and disordered domains that are usually thought to be amorphous; these amorphous regions are considered defective (taken out by acid hydrolysis) for the preparation of high strength/value CNCs. Recent work in this review demonstrates that significant progress has been made in exploring and exploiting these multimodal properties, and that CNCs have the ability to be used in many different high-tech applications, such as textile finishing material.**[3, 5]**

CNC Properties

Cellulose is common in plants and microorganisms and influences the production of macrostructure polymer components greatly. Because of its superior material properties, cellulose nanocrystals have demonstrated their usefulness in a variety of industrial applications. Cellulose nanocrystals are unique nanoparticles made from cellulose, the most common and seemingly natural polymer. The chemical, rheological, optical, and mechanical features of these nanostructures have piqued people's curiosity. Cellulose nanocrystals, which are frequently created from pre-existing fibers of cellulose are biodegradable and renewable, which renders them perfect for a variety of applications. **[8][7].**Despite being naturally hydrophobic, these nanoparticles can be surface-functionalized to fulfill a variety of demanding needs, such as generating high-performance nanocomposites with water-resistant polymer matrixes. **[2, 3]**

Mechanical Properties

Cellulose nanocrystals (CNCs) are promising recyclable nanomaterials with high mechanical properties that can be used in a variety of applications. According to studies, CNCs can be classified into bundles and have a potential tensile strength that is significantly higher than wire of steel. The bending test is used to determine the elastic modulus and transverse elasticity of CNC. CNC has an excellent elastic modulus as well as a transverse modulus. The structure of atoms of cellulose nanocrystals is illustrated in three dimensions (3D) in Figure 1 a, with Purple spheres representing carbon atoms, Green spheres representing oxygen atoms, and white spheres representing hydrogen atoms. Figure 1b depicts a 3-dimensional and cross-sectional image of a five-CNC bundle with different colored particles. **[8],[7]**

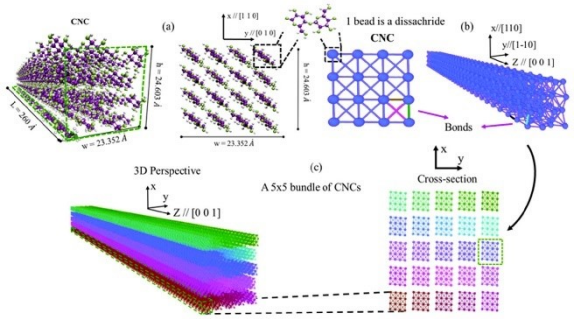

Fig 1: Cellulose nanocrystals (CNCs) structure (3d)

Thermal Properties

Cellulose nanocrystals (CNC) are the most abundant biopolymer found in nature. CNC has been used in a variety of applications due to its ubiquitous availability and distinct qualities. It has a decreased size, a high degree of crystallinity, tensile force, and modulus, and can be manufactured in large quantities at a reasonable cost.**[7]**

Nanocellulose's high crystallinity index and mechanical properties could affect thermal characteristics such as thermal capacity and expansion; as a result, the usage of nanocellulose in electrical appliances and packaging is growing. The decreased heat stability of nanocellulose may limit its use in high-temperature nanocomposite manufacturing. As a result, determining the high service temperature for the products needed and consumed necessitates an in-depth examination of the thermal properties**.** As a result, defining the high service temperature for the products required and consumption requires a thorough analysis of the thermal properties. As a result, this article looks at

the literature on the thermal properties and measures of nanocellulose and nanocomposites. This work intends to draw attention to recent studies on the impact of CNC on the thermal characteristics of nanocomposites and their wide range of applications in diverse industries. CNC's thermal deterioration, thermal transitions, conductivity of heat, and thermal expansion were all investigated. CNC on the thermal properties of nanocomposites and their numerous uses in diverse industries. CNC's thermal deterioration, thermal transitions, conductivity of heat, and the expansion of heat were all investigated. **[3, 8]**

Sources of Cellulose Nanocrystals (CNCs)

CNCs Extraction from Rotten Seedless green grapes (Komagataeibacter Bacteria)

Rotting seedless green grapes were collected from the Surathkal market in Karnataka, India. The rotting fruit was weighed and gently cleaned with distilled water. They were then placed in Erlenmeyer flasks with sterilized Hestrin Schramm (HS) medium. Glucose, bacteriological yeast extract, bacteriological peptone, sodium hydrogen phosphate, and citric acid are all ingredients in the Hestrin and Schramm medium. Before autoclaving, the pH of the growth media was adjusted to 6 with acetic acid. Autoclaving took 20 minutes at 121 degrees Celsius.

To prevent fungal/mold contamination, the media was added with cycloheximide after sterilization. The flasks were well agitated for 30 minutes before being incubated in static mode at 30 C for 120-168 hours. To separate the bacterial strains, a flask with white gelatin pellicle at the interface of air and liquid was chosen and serially diluted. The stock culture of bacteria plates were kept at 4 degrees Celsius and routinely subculture. Individual colonies isolated on HS agar plates were used to perform gram staining as well as other biochemical tests such as HS-Calcofluor white staining method and CaCO3 supplemented medium (Dextrose; peptone; yeast extract; CaCO3; agar, and ethanol) method, which confirmed that the isolate was able to producing cellulose.**[9, 10]**

Production and optimization of bacterial cellulose:

Single colonies of bacteria were placed in Erlenmeyer flasks filled with HS media. Later, the conical flasks were left at ambient temperature for static incubations (30±2°C). A thin floated gelatinous film was seen at the air-liquid interface after 48 hours of incubation, indicating bacterial cellulose generation; the film steadily thickened as the incubation duration rose. After a week of incubation, the pellicle was taken down from the media..**[11]** .To clean the pellicle's surface, a gentle wash with water was used. It was then cooked in NaOH for 90 minutes at 80°C to dissolve the bacterial cell mass adhering to the pellicle surface before being washed with deionized water till the filtrate achieved neutral pH. The cleaned pellicles were then oven dried for roughly 5 hours at 40 degrees Celsius until their weight remained uniform.

The weight of the pellicle was measured. The HS medium was optimized to determine the greatest concentration of BC utilizing various carbon sources, such as monosaccharides, disaccharides, polysaccharides, and sugar alcohols, at a concentration of Nitrogen sources, which comprised both organic and inorganic sources. **[9, 11]** pH and temperature are also important factors in the formation of BC. As a result, the medium's initial pH was optimized using HCL and NaOH, as well as the previously tuned variables (carbon and nitrogen supplies). In addition, the temperature was adjusted from 20 to 45 degrees Celsius to determine the greatest amount of cellulose polymer in the HS medium. The overall BC productivity and yield rate were calculated using a kinetic analysis of the production of BC with respect to incubation time duration..**[9-11]**

CNCs Extraction from (Tunicate Sea animal)

Tunic Preparation

The cellulose-carrying tunics were manually isolated from the protein-rich internal organs after they were harvested. We are currently looking into more cost-effective ways, such as automated tunic separation and a biorefinery-style approach that uses the complete tunicate as a process input. The tunics used here were cleaned, dried, and ground by hand. While others have used the internal organs to make animal feed48 or bioethanol53, we elected to concentrate on T-CNC isolation and simply discarded the interior organs. The utilization of such wastes is reserved for future projects. The tunic is typically one-half of a tunicate's weight, though this varies depending on tunicate species, environmental conditions, and life cycle stage. We discovered that Styela clava tunicates taken from PEI waters produced tunic that was 90% water, generating tunic powder when dried. **[12, 13]**

CNCs Isolation

To separate T-CNCs from tunic powdered form, the cellulose must be purified and noncellulose components eliminated, resulting in an abundant cellulose feedstock for acid hydrolysis. To do this, the tunic powder was transferred to the Forest Products Laboratory, where it was modified by alkaline deproteination procedures and bleaching. The overall yield for deproteination and bleaching was 31%, which was comparable to the yield. The

feedstock for the acid hydrolysis of T-CNCs was to final bleached material. **[12]**

Fig.2 .: Tunicate sea animal

CNCs Extraction from (RED Algae)

Red algae is abundantly available around the world, and its use in the development of agar goods has grown in importance in recent years. The manufacturing of red algae produces a huge amount of solid fiber debris, which is a major cause of environmental hazards. The use of red algal waste as a raw material to manufacture excellent cellulose nanocrystals (CNC) has been investigated in this study, as has the potential of the as-isolated CNC to reinforce polymer. To obtain solely cellulose microfibers and CNC, red algal waste was chemically processed using alkali, bleaching, and acid hydrolysis procedures.**[7]** Several analysis techniques were used to characterize the raw waste and as-extracted cellulosic components at various phases of treatment. **[14, 15]**

It is shown that the addition of 8 wt % CNC into the PVA matrix increased the Young's It was found that needle-like shaped CNC were successfully isolated at nanometric scale with diameters and lengths ranged from 5.2 ± 2.9 to 9.1 ± 3.1 nm, and from 285.4 ± 36.5 to 315.7 ± 30.3 nm, respectively, and the crystallinity index ranged from 81 to 87 %, depending on the hydrolysis time (30, 40 and 80 minutes). The as-extracted CNC were used as nanofillers for the production of polyvinyl alcohol (PVA)-based nanocomposite films with improved thermal and tensile properties, as well as optical transparency. modulus by 215 %, the tensile strength by 150 %, and the toughness by 45 %. Furthermore, the nanocomposite films retained the same level of transparency as the tidy PVA film (transmittance of 90% in the visible range), indicating that the CNC were scattered at the nanoscale. **[14]**

Production of cellulose fibers

As detailed in, CNC were successfully recovered from AW using alkali and bleaching processes then an acid hydrolysis method. [14, 16, 17]. The as-received AW samples were chopped into small pieces before being processed with a precision grinder coupled with a sieve screen. The ground AW fibers had been washed for 1 hour in distilled water at 60 °C with mechanical agitation. The prewashed AW fibers were then treated three times with NaOH solution for two hours at 80 °C with stirring. The resulting alkali-treated algae waste (ATAW) was bleached three times at 80 °C for two hours with a solution of equal parts (v:v) acetate buffer NaOH and glacial acetic acid, diluting to distilled water) and aqueous sodium chlorite, yielding pure white colored cellulose fibers, which were defined as bleached algae waste (BAW). The overall CNC extraction steps and digital pictures of each obtained products are presented.

Isolation of CNC

To isolate CNC, the as-produced bleached algal waste (BAW) was subjected to a sulfuric acid hydrolysis. The acid hydrolysis was carried out using a solution of sulfuric acid and mechanical stirring for various hydrolysis times: 30, 40, and 80 minutes. The liquid was then diluted with ice cubes to stop the reaction, centrifuged for 20 minutes at each step at 15°C, and dialyzed against distillated water till it achieved neutral pH. After that, the produced CNC aqueous solution was homogenized for 5 minutes in an ice bath using a probe-type ultrasonic homogenizer. Following that, CNC aqueous solutions isolated in the form of white gels were produced. Finally, a little amount of the homogeneous CNC solution was freeze-dried in order to get the CNC in a solid state for characterisation.CNC30, CNC40, and CNC80 samples were coded to represent CNC isolated at 30, 40, and 80 minutes, respectively. **[7, 14]**

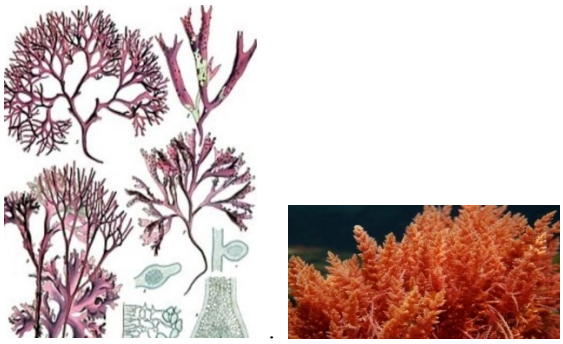

Fig.3: Red Algae

Cellulose nanocrystals extraction from (Bamboo)

Pre-treatment of bamboo fiber

To eliminate fatty acids, residual lignin, and other contaminants, oven dried bamboo fiber was treated with a NaOH aqueous solution at 170°C for 90 minutes. Furthermore, amorphous cellulose expanded during this pretreatment process, allowing sulphuric acid to permeate the bamboo pulp during hydrolysis. Finally, the pulp was screened with Somerville and spin dried at 103°C for 24 hours before being tested for moisture content. The bamboo pulp was then bleached for separating the lienin and hemicellulose. To further reduce the ph, acetic acid at 70-80°C was added. Above 70°C, bamboo pulp was added to the solution and agitated at 700 rpm for 30 minutes. Then I washed for ten minutes. In order to remove the remaining lignin from the pulp, it was treated with NaOH and swirled in the solution for 30 minutes at a steady speed of 500 rpm. **[18]**

Preparation of cellulose nanocrystals

The pre-treated bamboo pulp was hydrolyzed in an ultrasonic bath at 20 kHz with constant shaking in an ultrasonic bath at 45 C for 45 minutes. After a few minutes, when the color of the suspension turned dark yellow, deionized water was added to the cellulose suspension to stop the hydrolysis reaction, and all of the suspensions were multi-layered and the top layer was decanted off and washed with water repeatedly till there was no more layers. The suspensions were then rinsed with de-ionized (DI) water using repeated centrifuge cycles at 6000rpm for 5 minutes. The supernatant was removed from the sediment and refilled with fresh DI water before being mixed again. This operation was halted when the supernatant became turbid. Then it was thoroughly rinsed multiple times with DI Water till the PH of the water remained constant. After oven drying the cellulose nanocrystals at 55°C for 24 hours, CNC powder was obtained.

Fig.4: Bamboo

Cellulose nanocrystals extraction from (Phormium fiber)

Pre-treatment of phormium fiber

Before extraction of cellulose and nanocrystal synthesis, phormium fibers were pre-treated. The fibers were washed many times with distilled water and dried in an oven at 80 degrees Celsius for 24 hours. After that, they were roughly cut. Finally, the wax was removed by boiling for 6 hours in a toluene/ethanol mixture. The fibers were filtered before being washed in ethanol for 30 minutes and dried. Following that, cellulose extraction was accomplished by the use of a treatment technique. Phormium fibers were first treated with sodium chlorite $NaClO_2$; the fibres were then boiled for 2 hours, and the solution pH was reduced to around 4 by using acetic acid for bleaching. A sodium bisulphate solution treatment was performed, and at the end of this early chemical procedure, holocellulose (acellulose + hemicellulose) was obtained by the progressive elimination of lignin. The holocellulose was rinsed with distilled water after being treated with NaOH solution. The obtained cellulose had been dried in a vacuum oven at 60°C until it reached a consistent weight. **[19, 20]**

Cellulose nanocrystals Production

Cranston and Gray's recipe was used to make cellulose nanocrystal (CNC) suspension from phormium-treated fibers via sulphuric acid hydrolysis. Sulphuric acid was hydrolyzed for 30 minutes at 45 degrees Celsius with vigorous stirring. This reaction duration was chosen to ensure reaction efficiency while avoiding crystal deterioration. To stop the reaction, the suspension had been diluted 20 times with deionized water immediately after the acid hydrolysis. To concentrate the cellulose crystals and eliminate the excess aqueous acid, the suspension had been centrifuging at 4,500 rpm for 20 minutes. The precipitate was washed, recentrifuged, and dialyzed for 5 days against deionized water until a steady neutral pH was reached. The suspension has been sonicated several times (while cooling processes in an ice bath) to produce colloidal cellulose crystals. The final yield after hydrolysis was calculated as a percentage (of the initial weight) of the employed pre-treated phormium fibers. **[21]**

Fig.5: phormium fiber

Cellulose nanocrystals extraction from (Wood Wastes)

Preparation Samples

The MDFw samples were gathered by hand from a pile of domestic debris, thus there are a mix of wood species, adhesives (urea-formaldehyde (UF) or MUF), and finishes (PVC foil, impregnated papers, paints, and so on). As a result, before beginning the trials, all of the MDFw samples were combined together and ground. MDFp was also ground to a particle size of no more than 500 lm. Before beginning the studies, all of the wood fiber samples were dried.

Cellulose Isolation

Polar and non-polar extracts were extracted from the fibers in a Soxhlet system over 6 hours using a toluene: ethanol mixture. The extractives-free fibers were subsequently treated for 4 hours with aqueous sodium hydroxide solution under conditions of reflux and magnetic stirring. The resulting alkali-treated fibers (ATF) were filtered and carefully washed using water until the pH of the filtrate was neutral, and then dried overnight at 60 degrees Celsius. Finally, the ATF were rinsed with water and bleached with chlorine dioxide in acid acetic at 70 degrees Celsius. The bleaching process was repeated six times every hour. The reaction media was left at 70 degrees Celsius overnight; the bleached fibers (BF) were recoverable by filtration and washing with water till the pH of the filtrate was neutral before drying at 60 degrees Celsius overnight. **[22]**

Preparation of cellulose nanocrystals

The BF was mixed with water and then put into an ice bath. Then, drop by drop, sulfuric acid (96%) was added under magnetic stirring to achieve a final sulfuric acid concentration of 58%. At this time, the flask was placed in a bath of oil at 68 degrees Celsius for roughly 25 minutes with steady stirring. The process was stopped by adding an excess of cold water, followed by many centrifugations until the supernatant became murky. The latter collected and dialyzed toward water for 5 days to neutrality. The leftover electrolytes were removed for a day at 4 C using a mixed bed resin. The CNC solution in water that was distilled had been sonicated in a bath of ice, filtered through cellulose esters, and ultimately kept at 4 C. Depending on the source of the basic samples, the resulting nanocrystals were called CNCMDFw. All experiments and characterization approaches were duplicated or tripled.

Fig.6: wood wastes

<u>Cellulose nanocrystals (CNCs) applications in textile finishing</u>

Hydrophilic polyester textile by CNCs finishing

A hydrophilic surface finishing compound containing nanocrystalline cellulose (NCC) was applied to a polyethylene terephthalate (PET) fabric. NCC was further cationically modified through quaternization by grafting glycidyl tri-methyl ammonium chloride (GTMAC) to improve hydrophilicity. The finishing system now includes a textile binder, PrintRite595®. The fabric's surface treatment was applied utilizing a rolling-drying-curing technique. The coating durability, moisture recovery, and wettability of the modified cloth were all evaluated. Six washing procedures were used to test the surface finish's endurance. After treatment with heat with the NCC-containing surface finishing product, the fabric's surface characteristics changed from hydrophobic to hydrophilic. The washing fastness, SEM, FTIR, and EDX tests all verified that the cationic NCC-containing textile finishing adhered to the cationic dyeable (anionic) PET surface better than the unmodified NCC. In addition, the cationic textile finish of the surface could resist many washing cycles. **[23, 24]**

Preparation of Cationic CNC

For the cationic modification of NCC that has been given water dispersible freeze, a semi-dry water-based technique was adopted. Dryed NCC and the powdered sodium hydroxide were thoroughly combined for 5 minutes at room temperature with a mortar and pestle before being allowed to cool to room temperature. The solid material was subsequently moved to a polyethylene bag, and water was added. The cationization agent (GTMAC) has been added to the prior mixture

dropwise and thoroughly mixed by hand kneading. Following that, the reaction mixture was held at 65 degrees Celsius in a thermostated ultrasonic water bath. The following were the reaction conditions: water content of the GTMAC reaction system to anhydroglucose molecules in CNC catalyst (NaOH), temperature of 65°C. During the reaction, the reaction mixture was manually kneaded every 15 minutes. The reaction was terminated after 4 hours by precipitating the reaction mixture into ethanol. Centrifugation was used to remove unreacted chemicals and byproducts. The sediment was preserved after centrifugation, and the waste product was removed, replaced with fresh ethanol, and recentrifuged. The substance was then redispersed in deionized and distilled water and diluting four times. The suspension was then dialyzed for three days using a cellulose membrane for dialysis against deionized and distilled water to eliminate any remaining unreacted chemicals and by-products. During the first day, the purified and deionized water was replenished every 2 hours, and then twice a day for the next two days. The product's concentration was then raised through evaporation in a rotating evaporator. **[24]**

Application of CNC coating on Polyester fabric

The coating recipe was created using two common textile substances, a self-crosslinking acrylate binder and a SC6477 thickener. the SC6477 is an alkali swellable acrylic copolymer emulsion that is commonly used in coating formulations to thicken them. An electromagnetic stirrer was used to mix an aqueous suspension of NCC, the binder, and the thickener until the coating paste reached a sufficient viscosity to be applied. To initiate the thickening mechanism, a minor quantity of alkali was also applied. . Prior to the application of the surface finish. The fabric was etched with alkali, rinsed with distilled and deionized water, then oven dried. The coating paste was utilized to the fabric piece using an RK Print Coat Instruments K303 Multicoater. The two sides of the fabric were coated with paste. After utilizing the coating, the cloth was dried at 80 degrees Celsius for 20 minutes and cured at 160 degrees Celsius for 15 minutes. **[23, 24]**

Antimicrobial Wound dressing film using CNCs:

People with diabetes with foot ulcers had a 150-fold greater danger of amputation, which is caused mostly by microbial infection. Silver ions are often used in wound dressing to improve antibacterial properties. However, there has been some concern concerning the growth of bacterial immunity to heavy metals. **[25]** We evaluated the in vitro and in vivo efficiency of cellulose nanocrystal film as an antibacterial medication delivery method in a diabetic wound dressing in this work. Cellulose nanocrystals were extracted successfully from medical grade cotton fibers. Under a transmission electron microscope, we see needle-like cellulose nanocrystals with average diameter of 159 nm. The curcumin-treated film has a uniform yellow tint and a thickness of 0.4 mm. Based on the mechanical characterization of the film, the resulting film is soft and flexible. The curcumin release test hits a plateau at 36 hours, with an overall release of 98.9% of the cellulose nanocrystal film. During the testing period, no release of burst effect was seen. The film inhibited the growth of three Gram positive bacteria, two Gram negative bacteria, and one yeast.**[26]**

With the help of curcumin-loaded film, all test microorganisms exhibited considerable growth reduction in the Hohenstein challenge test. 5 of 6 test microorganisms exhibited a 99% reduction in growth compared to the control. We also saw that the film's antibacterial properties remained even after 15 washing. In an in vivo investigation employing diabetic rat models, a substantial reduction in wound size was found beginning on Day 7 with the topical administration of curcumin-loaded film. The lesion had been covered by tissue of the epithelium by the end of the trial, and hair began to grow from the skin. The skin sample extracted from the animal models reduced bacterial growth by 99.99%. Histological investigation of skin samples revealed that the curcumin-loaded film dramatically increased skin hair follicle and sebaceous gland regeneration. Our findings suggest that curcumin-loaded cellulose nanocrystal films could be employed for diabetic wound healing. **[25, 26]**

UV-Protection finishing with Cellulose nanocrystals

The chitosan (CS)/cellulose nanocrystal (CNC) nanocomposites (0, 0.2, 0.5, 0.8, and 1 wt%) were used as a modifier and subsequently coated on the surface of cotton fabric using a pad-dry-cure process. The morphological, mechanical, hydrophilicity, and UV-blocking properties of produced fabrics were thoroughly examined. The results demonstrated that CS/CNC could clearly improve the UV-Protection quality of cotton fabric. After 30 times of water laundering, CS/CNC 0.5 fabric demonstrated the most exceptional UV-blocking property as well as excellent washing durability, indicating that CS/CNC may be employed as an effective and durable UV blocker for cotton fabric. Furthermore, CS/CNC can improve the mechanical characteristics of cotton fabric while decreasing its hydrophilicity. **[3, 27, 28]**

Application of CNCs on Cotton fabric

First, different concentrations (0, 0.2, 0.5, 0.8, and 1 wt%) of CNC suspension were homogenized at 15,000 rpm for 10 minutes. The CNC suspension was then treated with chitosan (CS) particles &

acetic acid. To obtain the functional finishing liquid, the mixture was vigorously agitated at 60°C for 2 hours. The cotton cloth was then impregnated in a solution of sodium hydroxide for 30 minutes at 60 degrees Celsius, followed by another wash with deionized water. The cotton fabric was then immersed in CS/CNC solution for 1 hour before being padded through two dips and two nips to achieve an average pickup of 80%. The padded materials had been dried at 60 degrees Celsius for 30 minutes before curing at 90 degrees Celsius for 10 minutes. The fabrics that were created were labeled as CS/Cotton, CS/CNC0.2, CS/CNC0.5, CS/CNC0.8, and CS/CNC1.0, respectively. **[3, 27]**

Phase-Change materials (PCMs) with Cellulose nanocrystals (CNCs)

Because of its superior thermal characteristics and shape stability, shape-stable solidsolid phase-change material (PCM) has received a lot of interest. In this study, cellulose nanocrystal (CNC) was employed as a high thermal conductivity nanoskeleton material and polyethylene glycol (PEG) as a solid-liquid phase-change functional material. Shape-stable CNC-based solid-solid phase-change material was synthesized using a green, simple aqueous phase polymerization with radical's process. The substance structure, crystallization capacity, thermal stability, and ph When the temperature had been less than 300 °C, all PCM samples demonstrated outstanding thermal stability. The synthesized PCM, in particular, had a melt temperature at the phase transition of 47.1°C and a phase transfer enthalpy of up to 82.3 J/g after 12 hours. Furthermore, after 120 heating and cooling scans, the phase change enthalpy and temperature of PCM-12h were not affected considerably. After thermal treatment, the PCM-12h demonstrated thermal dependability, form stability, controlled phase-change behaviors, and good heat storage/release capabilities. The PCM could be used in smart thermal storage and control of temperature textiles/clothes, ase transformation features of the PCM were examined using different reaction periods. **[29, 30]**

Production of PCMs

To obtain the CNC suspension, a sample of commercial microcrystalline cellulose (MCC) and a solution of hydrogen peroxide were introduced to an Erlenmeyer flask and reacted at 60 °C for 2 hours. At the same time, PEG and Maleic anhydride (MAH) were combined in a three-necked flask and reacted for 3 hours at 70°C with stannous octoate as a catalyst in a nitrogen atmosphere to produce MPEG. The CNC suspension was then treated with MPEG and ferrous ammonium sulfate for the prescribed period (416 h) at 80°C. The reaction was halted by the addition of ethanol. The obtained products were rinsed many times with ethanol to eliminate the unreacted compounds. Finally, the samples were dried at 60 °C and given the name PCM-xh, where x represents the reaction time.**[30]**

Multifunctional fibers with electrospinning (PLA/CNCs)

For advanced bio-based degradable textile composites, achieving ultrafast water vapor movement and evaporation, robust mechanical properties, rapid dissipation of heat, and outstanding antibacterial activity is still extremely difficult. Multi-purpose biodegradable composite fibers were created by turning cellulose powder into solvent-free sphere cellulosic crystal fluids (CNCfs) and electrospinning them into a bio-based polylactic acid (PLA) fibrous membrane. The as-prepared bio-based membranes that are fibrous with customizable surface chemistry and outstanding physical characteristics (simultaneous plasticizing and reinforcing) were produced by taking full use of the low viscosity, amphiphilicity, and high dispersion of CNCfs.**[31]**

The fibrous membrane exhibits prominent a high level of (water contact angle of 0) as well as enhanced absorption capacity for water and water vapor transmission rate (WVTR) of 3.612 kg m 2 h 1 (81 times higher than the pure PLA fibrous membrane) due to the distinctive a bilayer ion structure of the CNCfs formed on the outside of PLA fiber after the electrospinning process**.** Furthermore, the hygroscopicity-inspired design confers antistatic performance, rapid dissipation of heat (decreased by 2 C compared to the PLA bulk) with high thermal conduction of 0.27 W/mK, and excellent antibacterial activity of 98.5% and 92.7% against S. aureus and E. coli, accordingly Overall, this simple and successful technique opens the door to the production of multifunctional biodegradable fiber membranes for use in sustainable medical textiles, personal protection, and human health applications.. **[31, 32]**

Preparation of PLA/CNCs fibrous membrance

The solid component of spherically shaped CNC was manufactured using the conventional method of hydrolysis by acid reactivity and freeze drying procedure. CNC was then using ultrasound dispersed in water that had been de-ionized in a water bath for 1 hour. DC5700 was progressively added to the solution while stirring it at the ambient temperature for 24 hours. Then, for 24 hours, a water-based solution of Nonylphenol polyoxyethylene ether sodium sulfate (NPES) was added to the combined solution while stirring at 70 C. The mixed solution was then passed through a membrane used for dialysis for 7 days to completely remove the accumulated NPES, followed by 48 hours of drying in an oven at 60

degrees Celsius to obtain CNCfs. Dimethylformamide (DMF) and CHCl3 were mixed with polylactic acid (PLA). CNCs fluids were added into the solution after it had been forcefully agitated for 2 hours. The syringe pump was used to accurately maintain the solution flow rate. The needle-to-collector electrospinning process was measured. At last, the PLA/CNCfs fibrin membranes were dried in the oven at 65 C. As a result, the PLA/CNCfs fibrous membranes developed at varying concentrations of 0, 5, 10, 15, and 20 wt% were denoted as PLA/CNCfs0, PLA/CNCfs5, PLA/CNCfs10, PLA/CNCfs15, and PLA/CNCfs20. **[31]**

Summary

This review summarizes CNC advances have seen significant progress in addressing its multiple qualities, such as thermal, mechanical, adhesives, and coating, among others. CNCs have the ability to be used in a wide range of typical applications, including industrial level, particularly in the textile industry. CNCs also have valuable qualities such as high stiffness, large surface area, and good mechanical properties. CNCs also exhibit remarkable efficiency in all relevant areas. Finally, it is feasible to respond; CNCs can be modified using a variety of techniques and methodologies. Superior standards of practice and precise methodological reporting are required for the results to be credible, justifying the cost and time put in research for the growth of such content.

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Conflict of Interest

There is no conflict of interest in the publication of this article.

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