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Valorization of maize husk nanocellulose for different food applications

Yashi Chauhan

Abstract
Cellulose is a material that is found in abundance on earth and from various sources which includes plants, algae, bacteria etc. The selection of cellulose is based on its biodegradability, biocompatibility, easy availability, low toxicity and mechanical properties. Owing to, agricultural waste as a source of cellulose biomass, several attempts have been made to extract cellulose from a variety of agricultural wastes, including forest residues, cotton stalks, fruit wastes, corn husk, marine biomass, and rice straw. In recent years, many edible active packaging films for food packaging have been produced. Chitosan, soy protein, and tragacanth are examples of common biopolymers used in food packaging film. Because the polymer is abundant in nature, the manufacture of modified cellulose is progressing. The most refined biopolymer created from natural resources includes cellulose from fungi, plants, algae and bacteria. Nanocellulose, nano fibrillated cellulose, and bacterial cellulose are all examples of cellulose. Fibre-rich byproducts, such as maize husk, may also be used to provide functional food additives and ingredients, as well as dietary fibre. They can be employed as effective, low-calorific bulking agents in food items to partially replace wheat, fat, and sugar, like water and oil retention enhancers, and also to boost emulsion and oxidative stability.

Keywords: Maize husk nanocellulose, food applications, biodegradability

Introduction

Currently, there is a need to shift from polymer-based materials to something more biodegradable that does not hamper the environment more. Which will thus in return be found beneficial in the long run such as leaving a carbon footprint, plastic pollution and better sustainability (Bharimalla *et al*., 2015). Cellulose is a material that is found in abundance on earth and from various sources which includes plants, algae, bacteria etc. The selection of cellulose is based on its biodegradability, biocompatibility, easy availability, low toxicity and mechanical properties (Cazon *et al*., 2020). Owing to, agricultural waste as a source of cellulose biomass, several attempts have been made to extract cellulose from a variety of agricultural wastes, including forest residues, cotton stalks, fruit wastes, corn husk, marine biomass, and rice straw (Farooq *et al*., 2020) [4]. In recent years, many edible active packaging films for food packaging have been produced. Chitosan, soy protein, and tragacanth are examples of common biopolymers used in food packaging film (Kunwar *et al*., 2016) [12]. Because the polymer is abundant in nature, the manufacture of modified cellulose is progressing. The most refined biopolymer created from natural resources includes cellulose from fungi, plants, algae and bacteria (Zinge *et al*., 2020) [2]. Due to its amazing physical characteristics, unique surface chemistry and good biological capabilities nanocellulose have been given a lot of attention for antibacterial use. Nanocellulose's hydroxyl groups keep it stable in water. Nanocellulose (NCC), nano fibrillated cellulose (NFC), and bacterial cellulose are all examples of cellulose (BC) (Islam *et al*., 2018) [10]. Maize (Zea mays) is the world's most popular crop, and worldwide maize output has climbed by 40% in the previous decade (Wojcieszak *et al*., 2020) [6]. It is a monoecious grass that grows once a year and is farmed primarily for feed, food, and industrial raw materials. It is also a good source of excess raw materials. An ideal candidate material would be modest in cost, readily accessible locally, and easily regenerated or disposed with minimum environmental effect (Maepa *et al*., 2015) [7]. Fibre-rich byproducts, such as maize husk, may also be used to provide functional food additives and ingredients, as well as dietary fibre. They can be employed as effective, low-calorific bulking agents in food items to partially replace wheat, fat, and sugar, like water and oil retention enhancers, and also to boost emulsion and oxidative stability. Enzymatically, functional oligosaccharides may also be produced from maize husks. (Bernhardt *et al*., 2019).

Structural chemistry of Cellulose

Of all the sustainable polymers found on earth, cellulose is the one that is found to be in abundance. It can be obtained from various sources which include plants, algae, tunicates etc. Being the most plentiful polymer which is obtained naturally cellulose promises easy renewability, degradability, biocompatibility and cost-effective green resource. The most prevalent used cellulose is wood-derived cellulose which is later used as wood pulp (Zhu *et al*., 2016) [21]. Hemicellulose is found in plant cell walls and they provide antibacterial effects, strength and stiffness, and water impermeability in the plant cell wall.

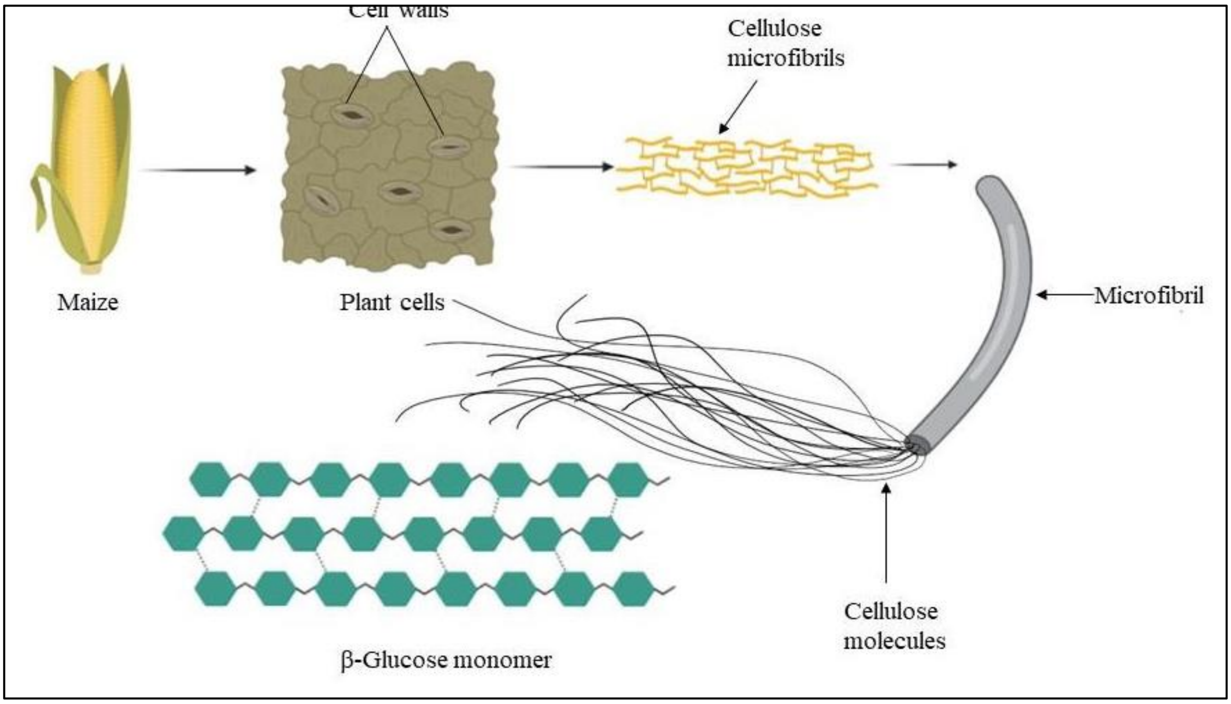

Fig 1: Cellulose structure from maize crop

The foundation of the cellulose polymer chain is the anhydrous D-glucose monomer which has a formula of (C6H10O5)n, where (n 20,000). Now all these anhydroglucose units are connected by β-(1,4)-glycosidic bond. Every repeating unit is generally rotated at 180 degrees along with the cellulose backbone axis which is in relation with the adjoining rings. (Tajvidih *et al*., 2016).

Oxygen and hydrogen atoms are electrostatically bound, and this results in a much more stable glycosidic linkage sequence, linear chain structure, and poor solubility in polar solvents (Hoeng & Bras 2016) [23]. Furthermore, van der Waals forces (which occur between polymer chains) and cross-functional and cross hydrogen bonds also promote parallel stacking, which may also lead to micron-scale precursors from cellulose primary fibrils.

Electrostatic forces between the oxygen and hydrogen atoms of neighbouring rings, including intramolecular hydrogen bonding, resulting in a significantly more stable - glucose bond sequence, linear chain structure, and low polar solvent solubility (Hoeng & Bras 2016) [23]. Additionally, cross-functional and cross-hydrogen bonding (which occurs between polymer chains), as well as van der Waals forces, encourage parallel stacking, which mostly results in cellulose primary fibrils, which may aggregate into micron-scale precursors. The non-covalent intra- and inter-chain interactions mentioned above are critical for cellulose's stability and hardness. The majority of cellulose may have varying degrees of hydrogen bonding based on the primary and secondary alcohols on the surface; C3-OH, C3-OH, and C6-H2OH (Zhu *et al*., 2016) [21]. The different types of cellulose include:

- **Bacterial cellulose:** While plants are the principal manufacturers of cellulose, numerous bacteria, notably those of the genus Glucanobacter, are also involved. In the future, owing to its special mechanical and structural qualities, this type of cellulose may be exploited in a variety of applications. The Glucanobacter hansenii UCP1619 generally produces bacterial cellulose in the Hestrin-Schramm (HS) medium. When compared to cellulose bacterial cellulose has different physicochemical properties (Liu *et al*., 2020) [24].

- **Cellulose acetate:** Cellulose acetate is a major cellulose ester. Based on how it will be processed, cellulose acetate can be used for a variety of applications including films, membranes, and fibres. The creation of amorphous, spherical particles known as cellulose beads is a unique use for cellulose acetate (Wsoo *et al*., 2020) [25].

- **Ethylcellulose:** Ethylcelluloses are cellulose components having specific hydroxyl groups connected to the repetitive anhydroglucose units, which eventually change into ethyl ethers and are referred to as non-iconic ethyl ethers of cellulose. Microencapsulated drug delivery systems based on ethylcellulose (EC) have been studied in order to enhance the duration of drug release and preserve the core material from degradation (Shi *et al*., 2020) [26].

- **Hydroxypropyl cellulose:** Among the cellulose derivatives accessible in water and organic solvents is hydroxypropyl cellulose (HPC). It can be used to make lubricants. It is also employed in the treatment of keratoconjunctivitis sicca, corneal erosions, and neuroparalytic keratitis. Furthermore, people with artificial eyes utilise it as a lubricant (Gosceki *et al*., 2021).

There are two types of cellulose fibrils: highly organised (crystalline) and disorganised (amorphous). There are several methods for isolating cellulose nanocrystals, cellulose nanofibrils, and cellulose nanocrystalline from a cellulosic source; Bacterial cellulose, or BC for short, is the third type of cellulose produced by Gram-negative bacteria; unlike CNC and CNF, it is produced naturally through bottom-up processes rather than top-down methods (Douglass *et al*., 2018) [28].

Methods for the extraction of cellulose

For the separation of cellulose-based nanocrystals from the plant sources such as maize husk, there are mainly three phases. The first step is to purify the raw materials in order to remove the nanocellulose from the selected plant material. The process of purification can be availed by using potassium or sodium hydroxide which is proceeded by bleaching with sodium chlorite. This method is repeated various times for a thorough cellulose purification method. The chemical treatment, which is generally done with acid, is the second phase. The process hydrolysis is mainly performed to break the amorphous domains and to remove local interfibrils (Khawas *et al*., 2016) [15]. The different techniques available for extracting cellulose (Tian *et al*., 2017) [16]:

Pulping and Bleaching: The pulp and paper business is a lignocellulosic biorefinery that uses a vast quantity of woody biomass to produce pulp and paper, such as with the soda pulping process, which is the focus of this research. Despite its lengthy history, this conventional bio-system is characterised by little innovation, high reliance on fossil fuels, and substantial greenhouse gas emissions (Bajpai 2015).

Table 1: Methods and chemicals used in the extraction of cellulose

Method	Chemicals used & Composition	Reference
Pulping		
Kraft pulping	Sodium hydroxide & Sodium sulphide (3:1)	Ashrafi *et al*., 2015 Wood chemistry 1981
Sulphite & Soda pulping	Acid sulphite = Ca2+, Mg2+ (Base alternatives HSO3 H+ (Active reagent)	
Alkaline Hydrolysis		
NaOH		Bandyopadhyay 2015
Acid Hydrolysis		
H2SO4, HNO3, Phosphoric acid		Hafid *et al*., 2021
		Zinge *et al*., 2020 [2]

Enzymatic hydrolysis: The enzymatic hydrolysis includes the cellulose enzymes trying to break down the cellulose chains into the glucose molecules which is a similar process that takes place inside a cow's stomach which converts the fodder or grass cellulose into sugar. Therefore, many cellulosic agricultural leftovers can be transformed into fermentable sugars by xylanose and hemicellulose enzymes (Pino *et al*., 2019) [17]. So, to hydrolyse the cellulose to glucose monomers, the chemical is used which is mainly acidic or a biological catalyst is utilised. Acid hydrolysis is a fast process but has various several limitations which include the high energy needs, higher capital costs, high corrosion resistance, high disposal costs, and the production of breakdown particles (Kumar & Murthy 2016) [18].

Alkaline hydrolysis: Alkaline hydrolysis partly separates cellulose fibres from the cellular membrane. The treatments are normally done with diluted NaOH (1-10%) solutions at low or high temperatures and with concentrated NaOH solutions at low temperatures. NH4OH and anhydrous NH3 are also used for activating organic substances (gas or fluid) (Ghosh *et al*., 2015). The maize husk will be rinsed many times with distilled water and dried in an oven at 90 °C for around 24 hours. When this is done, the husk is grounded and sieved at room temperature. Next, the ground maize husk will be treated with sodium hydroxide at 80 °C for about 2 hours. The alkaline treatment is repeated twice (Kampeerapappun 2015).

Acid hydrolysis: Pretreatments of acid are conducted under conditions of dilute acid, which resolve hemicellulose and lignin regions by the acidic conditions (Mishra *et al*., 2018). The wood/plant structure is distinguished by an acid action. H2SO4 is the widely used industrial cellulose acid; hydrochloric acid, phosphoric acid, etc. are a few of the acids that are utilised (Zinge *et al*., 2020) [2]. Following alkaline treatment, we will conduct acid hydrolysis using strong acid (H2SO4) and a weak acid as part of our environmentally friendly extraction process (HNO3) (Hafid *et al*., 2021).

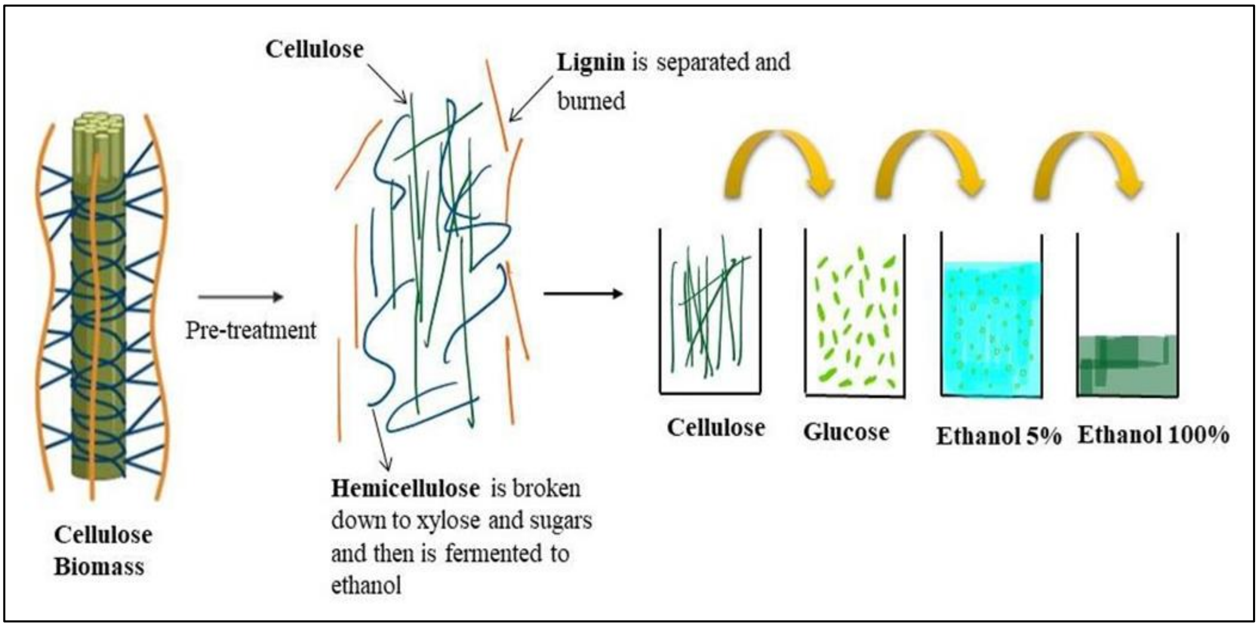

Fig 2: Ethanol extraction from biomass

Maize and its characteristics

Maize is one of the world's leading grain crops. It provides many populations with stable food. Maize is a significant source of revenue in developed countries for farmers, many of whom are poor farmers. The food supply and plant chemicals. It is a source of nutrition. The prevention of chronic diseases involves phytochemicals in the process. Maize farming is restricted by diseases that cause seed losses of around 11% of total production (Shah & Kumar 2015). The presence of Galanthus nivalis agglutinin (GNA) lectin or GNA maize is supposed to have a possible anti-HIV activity. The requirements for essential fatty acids for a healthy child or adult are met by a tablespoon of maize oil. Maize silk, roots, leaves and cob decoction is used for bladder issues, nausea, vomiting and abdominal diseases. Zein an alcoholic prolamine contained in maize endosperm has special and new uses in the drug and nutraceutical industries. The risk of cecal cancer, atherosclerosis, and obesity-related complications is reduced by the resistant starch of maize (Kostic *et al.*, 2017). The uses of maize husk are seen in the removal of fluoride from water along with soybean husk, which is harmful to health. Thus, the burning of soybean husk and maize husk produces activated carbon which removes the fluoride from the water (Kharche *et al.*, 2019). Husks from maize and rice are abundant byproducts after grain ground milling. These residues are rich in lipophilic compounds were identified as fatty acids and acylglycerols which forms around 88% of total extractive substances in maize fibres and up to 95% in rice husks (Marques *et al.*, 2020).

Table 2: Composition of edible maize/100g

		Reference
Carbohydrate	71.88 g	Shah *et al.*, 2015 Balasubramaniann *et al.*, 2007
Fat	4.57 g	
Protein	8.84 g	
Ash	2.33 g	
Fibre	2.15 g	
Vitamin C	0.12 mg	
Amino acids	1.78 mg	

Nanocellulose

Agricultural residues are unusable materials that can form a solid or liquid as a by-product of processes of food production, such as pesticides, crop waste and livestock waste. Cellulose is the world's largest polymer formed by cell-free systems, plants and microorganisms. It is made up of repeated monomers of ß-d-glucose linked by the β-(1,4) glycoside link chemically. Natural cellulose morphology is mostly fibrous and involves intermittent crystalline and amorphous parts (Dungani *et al.*, 2017). Cellulose nanofibre (NFC) is one of the most attractive, modern green materials. Their mechanical and physical properties are responsible. Nano- Flexible Cellulose (NFC) is composed of cellulose nano-fibres that are about 10–100 nm in diameter and several micrometres in length. There are three types of nanofilaments: crystalline, amorphous, and long flexible. Three types of nanocellulose can be distinguished: (I) nanocellulose (NFC), (II) cellulose nanocellulose (NCC), and (III) bacterial cellulose. Nanocellulose (BC) (Brown *et al.*, 2016). Several studies are focused on nano-cellulosic- supported biodegradable polymers. Dimensions, geometry and properties are directly dependent on cellulose extraction, preparation methods, processing factors/conditions, and pre- or post-treatment. For the extraction of nanocellulose, abundant sources of them are available (Tang *et al.*, 2017):

Table 3: Sources of nanocellulose

Source	Example	Reference
Plants	Wood (pine, spruce), Natural fibres (cotton, jute, bamboo), Industrial and agricultural waste (rice husk, sawdust, dry	Kim *et al*., 2016
	bleached kraft eucalyptus pulp, and potato peels	
Algae	Valonia, Microscroperias denticulate, Microscroperias rotate Cladophora, Boerogesenia, Erythrocladia, Vaucheria	Xiang *et al*., 2016
Bacteria	Bacillus megaterium, Agrobacterium, Alcaligenes, Psedomonas, Rhizobium, or Sarcina	Nanoscale horizons 2019
Tunicates	Ascidiacea and Ciona intestinalis are marine species	Chenot *et al*., 2019

Nanocomposite products based on polymeric materials have a high potential for use in many fields, including automotive, aviation, optoelectronics and biomedical packaging, as well as food packaging (Thomas) *et al*., 2018) [30]. Due to their nanometer size and high aspect ratio, the composites not only exhibit good mechanical properties comparable to those of micrometre filler-reinforced compounds, but also have a high aspect ratio; they also exhibit excellent combinations of optical, electrical, thermal, magnetic, and other physicochemical attributes (Fang *et al*., 2019) [31].

Extraction of nanocellulose

Grinding, homogenizing, pulverizing, steam blasting, high-intensity ultrasound and other processes, etc. NFC may essentially be produced from processes that require pulping. They can also be prepared via an energy-dependent method from a variety of different cellulosic sources (Ullah *et al*., 2017) [32]. NFC is generated following heavy mechanical shear applied through a homogenizer or grinding system on a cellulose lining. NFC showed a higher specific region, leading to higher interactions with hydrogen, compared to other suspensions based on cellulose fibre, and have a gel texture with a solid content of 2 to 5%. So far, many devices have been developed to improve the production output and NFC quality based on a high-pressure homogenisation method such as a homogenizer system, a microfluidic, a suspension and, more recently, a purification unit (UlIslam *et al*., 2016) [33]. Some pretreatment has been recommended to produce fibres with lower vibrational energies (Ul-Islam *et al*., 2016) [33]. That involves pretreatment by enzyme, pretreatment by TEMPO, carboxymethylation and acetylation, and pretreatment by alkaline peroxide (Huang *et al*., 2020) [34].

Characterization of nanocellulose

The nanocellulose was separated by adding 0.7 per cent (w/v) sodium chlorite (NaClO2) solution to pH 4 acidified acetic acid. NaClO2 fibres were cooked for 2 hours at 70-80 ° C, with a fibre-to-NaClO2 ratio of 1:50. The bleaching process is repeated four or five times before the fibre is white and then filtered (Huang *et al*., 2019). Several times after filtration, the residue was rinsed with filtered water and dried in the air. After bleaching cellulose with sodium sulfite, it is heated to around 70 to 80°C for two hours in a solution of 5% (w/v). This process includes filtration, washing, and drying. Under heavy agitation, the cellulosic materials were hydrolyzed for 45 minutes after alkaline treatment with fibres. Solution of 100 per cent sulfuric acid. The treatment was followed by the use of cold water to prevent the response. The diluted suspension was centrifuged for 11000 to 10 minutes to precipitate it. During the 3-day dialysis, the pH of the suspension was again tested (Afrin & Karim 2017) [35].

Extraction of nanocellulose from lignocellulosic biomass

A mixture of various chemical treatments such as alkaline, bleaching, and acid hydrolysis was used to remove nanocellulose (Deepa *et al*., 2015) [36]. Extraction of nanocellulose from two main activities of lignocellulosic biomass. First, pretreatment removes non-cellulosic elements, including lignin, hemicellulose and others. Nanocellulose is then extracted by several extraction methods from cellulose fibrils (Q *et al*., 2017). The main purpose of biomass pretreatment is to remove recalcitrance, change its structure and size and enable access to the microstructure of the cellulose (Vilarinho *et al*., 2017). The two pre-treatment methods are acid-chlorite treatment and alkaline treatment. In the pulp industry the acid-chloritic procedure is commonly used, often referred to as the delignification or bleaching method (Phanthong *et al*., 2018) [39]. The white holocellulose fibre shows that lignin and other impurities have been removed successfully (Phanthong *et al*., 2015) [40]. The procedure with alkaline is used to remove hemicellulose amorphous polymer and the rest of lignin (Phanthong *et al*., 2018) [39]

Particle size distribution analysis

We will use the DLS technique (dynamic light scattering) to assess the particle size of the isolated microcrystalline cellulose. The particle size distribution of cellulose is primarily determined by its source and method of separation, namely the form of acid, acid concentration, reaction time, temperature, hydrolysis process, and mechanical treatment (Oun *et al*., 2016) [42]. Particle size can also be measured by Nano-zs particle size (Yang *et al*., 2017) [9].

Fourier transform infrared spectroscopy analysis (FTIR)

We will use the Fourier infrared transform spectroscopy, which is a technique that allows the absorption, emission and photoconductivity of solids, fluids and gas to be obtained from an infrared spectrum. It is used in PHB in order to detect various functional groups. Between 4000 and 400 cm−1, FTIR spectrum is registered (Faghihgzadeh *et al*., 2016). Through researching the spectrum against a database of reference spectra, unknown materials are identifiable. An FTIR material characterization technique may be used to quantify materials as long as a standard curve of known component concentrations can be developed (Mohamed *et al*., 2017) [44].

X-ray Diffraction analysis (XRD)

We would imply that X-rays are primarily used in XRD analysis to detect materials based on the diffraction pattern. XRD gives the specifics as well as the steps for recognising that the actual structure is different from the ideal due to internal stresses and defects since its wavelength (α) is often the same as between crystal d planes (1-100 angstroms)

(Morsi & Menazea 2019) [45]. To calculate the crystallinity index of the samples obtained from the X-ray diffraction patterns can be done by the formula (Tajil *et al*., 2020)

Scanning electron microscopy

We will imply the usage of a Scanning electron microscope (SEM) to produce a range of signals on the surface of solid specimens with a concentrated high-energy electron beam. Information on the sample including the external morphology (texture), chemistry composition, crystalline structure and orientation of materials from the sample is seen in the signals derived from electron-sample interactions (Mondal *et al*., 2015). Via a concentrated electron beam, SEM creates magnified detailed images of an object. This works differently for electron transmission microscopes (TEMs) since the beam of electrons crosses the object directly (Barroo *et al*., 2020) [47].

Thermal stability & Thermal analysis

Thermogravimetric analyses will be done (TG/SII Nanotechnology INC, 6200 model) employing a term analyzer at 10°C / min (Smyth *et al*., 2017) [48]. We will report and use the TGs and thermogravimetric derivatives (DTG) curves as the result of temperatures (Bernhardt *et al*., 2019).

Applications of nanocellulose

Nanocellulose is a versatile material with several applications. Nanocellulose appears to be the perfect solution in a variety of fields, ranging from packaging to the military sector, design of the electronics. The key advantages of using nanocellulose:

In the production of paper and cardboard, it can act as a strengthening agent. It can be used as a protective material against oxygen, water vapour, grease, and oil when used in food packaging coatings. Additionally, it may be utilized in pharmaceuticals, military, design and electronics. In addition to the design of flexible OLED displays, it could also be used for the construction of aerial vehicles and even the manufacture of military clothing (Mikhailidi *et al*., 2019).

By replacing Kevlar or carbon with cellulose nanocrystals, the first advantage is certainly economic. For its production, which is not particularly expensive (around ten dollars per kilo), wood waste such as shavings and sawdust can be used. Waste materials can be recycled this way, and at the same time, the rural sector is also able to participate in areas of application different from the usual (Bigdilou *et al*., 2020).

By using natural materials for the production process, which is also renewable, we reduce the use of fossil fuels and the emission of greenhouse gases. Nanocrystals of cellulose would therefore be equally durable and more ecological than the current materials (Panchal *et al*., 2019).

There is, however, one contraindication: the material should not be used in a humid environment. Researchers in the lab discovered a way to remedy the hydrophobic properties of the material by using nanocrystals in padding or coating it with special paints.

Different applications of nanocellulose around the world:

Nanocellulose used in papermaking

The papermaking industry mostly depends on lignocellulosic materials which are basically woody species. Thus this provides a good amount of cellulose without harming the environment more. Cellulose nanofibres (CNF) seems to have good property of biodegradability, approved mechanical strength, found in abundance, micron-long length and low density which are its unique properties (Du *et al*., 2017). The strength of the paper can be determined by how long the fibres are, the strength of the fibre, the contact between them and the strength of the hydrogen bonds. The CNFs on the paper can be explained by two techniques:

(a) by making a macro-scale network that will increase the load capacity of the paper by modifying its structure. The process includes the storing of fibre surfaces before the sheet framing technique that is done by using maintenance help. Which then relaxes the fibre surface and accordingly it builds the holding in a way like dry strength polymers, rather than rely on anionic CNF to make up for the shortfalls and pores between the filaments, cationic starch (CS) can be used to assist with the retention of anionic CNF on the fibre surface (Dai & Fan 2013). In addition to being used to fill pores between filaments, CNF is also commonly utilized to create channels between filaments, expanding the holding region, and increasing the sheet's strength. In papermaking, the filaments frame an organizational structure (Zhou *et al*., 2014). Nanocellulose seems to have potential in the pulp and paper industry due to its outstanding properties, the ability to improvise paper strength, the fibres and fillers are retained, the coating improves printing performance or the filter improves paper performance. On the surface of Nanocellulose, the free hydroxyl groups are clustered together. Now when the pulp is added, it will thus fill in the gaps between the fibres and on the fibres and thus mixes with the pulp fibres. This will strengthen the fastening between the fibres, filling the spaces in the paper and thus enhancing the paper's strength (Belbekhouche *et al*., 2011).

Nanocellulose used in tissue engineering and tissue culture

Skin is the part of the body that deals with sensation, protection and immunization which acts as a barrier to the environmental conditions and thus destroys the organisms from any kind of physical damage or any form of microbial attacks. Skin mainly consists of the dermis and epidermis and under the dermis comes the hypodermis (Dai *et al*., 2014). Nanocellulose has numerous qualities which include physical, chemical and biological ones. Its capability of adsorbing a huge range of atoms, ions, molecules and microbial cells tends to have a huge specific surface area and a nanocellulose which seems to be porous and can segregate various chemicals and thus retain the microbiological organism. Materials based on nanocellulose are usually chemically inert, highly mechanically resilient, have tailored morphology, physical, chemical, electrical, thermal, optical, and mechanical properties, and have low or zero toxic properties, or are not toxic at all (Chávez-Guerrero *et al*., 2018). Reconstructing an injured bone is the most anticipated task in the medical sciences. Some injuries last for a long time and thus some never repair back to their initial form although after various rounds of therapy. Thus molecular nanocellulose is a safer application for cartilage restoration due to its brilliant water retention capacity and higher mechanical strength. Bacterial nanocellulose is a non-degrading material that has a higher content of cellulose and now is thus considered to be an excellent material for auricular cartilage repair (Shvedova *et al*., 2015). Laser-based BNC substrates for the culture of chondrocytes which is obtained from the cartilage which is covering the femoral condyles for the articular cartilage engineering. They have also stimulated chondrocyte proliferation and differentiation within the scaffolds, as well as the deposition of the newly synthesized extracellular matrix (Avila *et al*., 2015).

Nanocellulose used in cosmetics

Some biopolymers have gained popularity in the "green" cosmetics industry not only because they are biodegradable and environmentally friendly, but also because they are skin-friendly due to their biocompatibility. The body has a diverse spectrum of proteins and polysaccharides (for example, collagen and wheat proteins), and hyaluronic acid is widely employed in cosmetic formulations to improve product attributes (e.g., texture and consistency) or to improve their influence on the body (e.g., hydration and wrinkle reduction) (Augustine *et al*., 2013). The use of BNC in cosmetics has been researched and shown throughout the years, particularly as a support material for sheet face masks for active component distribution to the skin. BNC, on the other hand, has been used in natural scrub cosmetics and as a structural ingredient in personal care formulations (Ullah *et al*., 2016) [33].

BNC has garnered a lot of attention because of its unique characteristic of releasing active substances of interest in fields such as biomedical and cosmetics. Because of its outstanding mechanical performance, loading capacity, and membrane-like structure, the acceptability and utility of BNC as the support material of sheet facial masks coupled with active compounds have been actively explored in recent years (Carvalho *et al*., 2019). Sheet masks are often constructed of cotton, non-woven fabric, and synthetic polymers (e.g., poly (vinyl alcohol) (PVA), and they are one of the most popular and fastest-growing items on the market, representing an important and competitive section of the cosmetic business. When compared to other mask types, the attractiveness of face sheet masks arises mostly from their ease of application and removal, short usage, and effective results, which make them particularly appealing to today's clients. (Morganti *et al*., 2019).

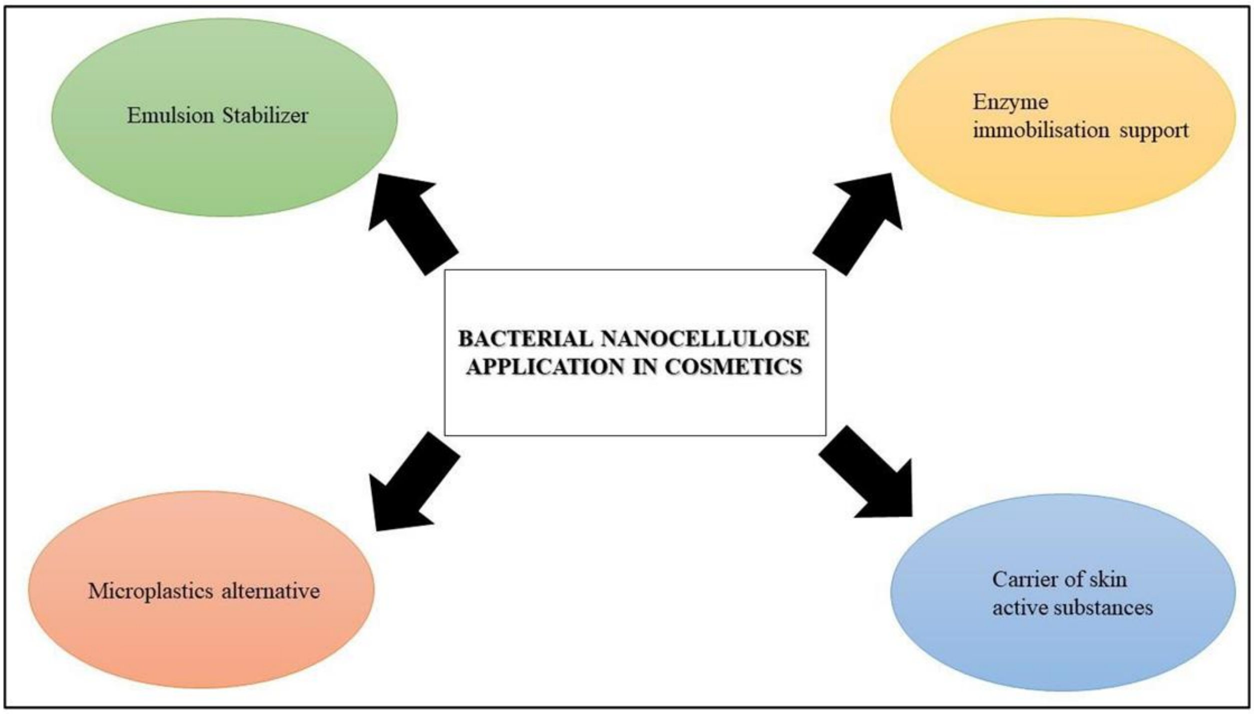

Fig 3: Nanocellulose incorporated in cosmetics and it's properties

Nanocellulose used in the food industry

As natural cellulose hydrolysates, nano celluloses have many of the same physical and chemical properties as cellulose and nanoparticles, such as pure natural qualities, no odour, safety, non-toxicity, good rheology, and high water retention capacity, and are widely used in a variety of industries, including the food industry (Serpa *et al*., 2016).

It is being used in baked food. Nanocellulose is more hygroscopic and rheological than microcrystalline cellulose. The primary application of nanocellulose in food can benefit not only from the size impact of its nanoparticles, but also from its physiological qualities, which make nanocellulose valuable. Dietary fibre is becoming increasingly important in food research and development. Select Gluconoacetobacter to ferment in order to produce bacterial nanocellulose, which will be added to wheat bread. By comparing the rheological properties of wheat bread before and after the addition of bacterial nanocellulose, it was discovered that the addition of bacterial nanocellulose can enhance bread quality. It increases the specific volume, porosity, luminosity, and moisture retention, decreases the browning index, softens the crumbs, and softens the bread (Corral *et al*., 2017).

It is being used in frozen food. By incorporating micro cellulose into frozen meals, it is possible to improve their lubricity, increase their stability, and reduce the production of big ice crystals during freezing or repeated freezing and thawing, therefore retaining the frozen foods' flavour (Qian *et al*., 2021).

Nanocellulose used in pharmaceuticals

Particle size, surface charge, modification, and biocompatibility are all crucial aspects of a successful drug delivery system when it comes to drug release and distribution. NCC is a great drug carrier for hydrophilic medicines due to its huge surface area and negative surface charge. As a result, medications with precise dose control may stick to the NCC surface (Jackson *et al*., 2011). The surface chemistry of NCC is controlled by hydroxyl groups, which may be altered to generate various functional groups. Some properties of nanocellulose, such as moisture sensitivity and low heat stability, may limit its application. Several techniques to overcome these constraints have been presented throughout the last decade. Surface modification and fibre pre-treatment procedures have now been well investigated and can be used to improve certain attributes (Roman *et al*., 2004).

Table 4: Application of Nanocellulose in other products

Nanocellulose incorporated	Final product	References
Conductive polymers	NC is added to conductive materials to provide with conductive hybrid materials with high mechanical strength, flexibility and foldability.	Du *et al*., 2016, Ko *et al*., 2017
Luminescent materials	Fluorescent materials with high UV absorbance materials have been constructed using NC such as luminescent CDs.	Ng *et al*., 2020, Song *et al*., 2020, Yan *et al*., 2018
Textile industry	Producing rejuvenated cellulosic fibres and these fibres are smooth and gleaming silk resemblance	Navard *et al*., 2013, Chen *et al*., 2015
Electronic devices	Used in making screens, solar panels thus making flexible devices.	Nanoscale journal 2016
Aerogels	NC based aerogels are used to restrict the usage of thermal insulations because they have a porous constituency.	Jiang *et al*., 2014, Cervin 2012

Formation of bio-based film

Due to its environmentally friendly and recycled packaging is growing in popularity on the global market. For renewable packaging materials from bio-based resources like cellulose acetate, starch, polylactic acid (PLA), for example, or other healthy materials for use in food and packaging industries, bioplastic is widely used (Miri *et al*., 2015). However, the vast use of oil-based plastic, which is used for a short term but then takes hundreds to degrade, is becoming increasingly worrying. In packaging, most synthetic plastics are recyclable. Smart organic packaging is a possible alternative, combining sustainability and real-time food quality monitoring to ensure health and economic and environmental benefits (Klemm *et al*., 2018). While biodegradable and highly available, biopolymers often achieve less than their oil-based counterparts. Composite technology has developed as an approach to combining biopolymers with different characteristics to use the best features of individual components to boost their performance (Sangroniz *et al*., 2019). Vegetable and derivatives of cellulose are widely used in the manufacture of paper, pharmaceutical, textile and packing of compounds. The cellulose- based materials traditionally used in food packaging include paper, paper boards, and cellophane TM. More recently nano cellulose (NC), comprising nanocrystals (CNCs) and nano fibrillated cellulose (NFCs), have become industrially available and give unique features, such as high specific surface areas and thus the high concentration of active surface modifying groups (Khalil *et al*., 2016). The ultimate purpose of the packaging is to ensure a cost-effective containment and that food item is safe from the external environment while meeting market, regulatory and customer expectations. Protection of the package is an integral part of the conservation process chain for most food items (Baran 2020). For fresh, frozen, dehydrated, thermal or aseptic product packaging systems, the requirements depend (i) on the substance of the food product, such as water activity and its capacity for perishability; (ii) on external factors, namely the storage temperature, relative humidity and exposure, and (iii) on the shelf- life needed. The required barrier capacities for water vapour, oxygen and other gases, including aromas and light, must be considered when specifying all these factors. During manufacturing, packaging and handling through the supply chain, the physical and mechanical properties are critical too (Singh *et al*., 2017). Alternative solutions have been searched for biopolymers such as polylactic acid (PLA), polyhydroxyalkanoates (PHA) and thermoplastic starch (TPS). PLA, used mostly for packaging applications, is the most commonly used (Vilarinho *et al*., 2018) [38]. For relative short and mild touch conditions, such as fresh salads and beverages, the label is used as films or as thermoformed or injected containers, due to its low-temperature tolerance.

The high price and commercial scarcity compared with traditional plastics are some of the main constraints widely mentioned (Sharma *et al*., 2019). Corn is currently the main raw material in the production of PLA, but a feedstock of the second generation is being designed. While commonly considered a biodegradable material, PLA is in reality poorly degradable and only compostable at higher temperatures under simulated ocean and soil conditions (Garrison *et al*., 2016). The most widely studied, easier to manufacture, and considered to be an alternative to polypropylene (PP) in food packaging, although for much less commercial applications PHAs, and particularly poly-(3-hydroxybutyrate) (PHB) are among the most widely studied biopolymers (Pellisari *et al*., 2019). The use of polymeric films as supports for various active compounds, such as natural extracts, that can be integrated during the production phase of the packaging itself, comprises active food packaging. A substance with an antibacterial activity that can stop the growth of bacteria on the material surface can be caused by the antimicrobial embodiment (Kuorwel *et al*., 2015). In the food industry, the interest is more pronounced in materials enriched by antimicrobials, thus limiting the direct use of food additives. In two different ways, antimicrobial materials are used. Antimicrobial products may be inserted in or coated on the film surface or the food surface (in the form of an edible film) (Bassania *et al*., 2019). The material may either partly or entirely migrate to the food or headspace, (for example, usual for essential oils) by gradually diffusing it, or does not migrate, acting only in contact with the surface of the film and if the food contains the film and the target micro- organism comes into direct contact with the film (Brockgreitens & Abbas 2016). Food conservation antimicrobial agents are either chemically synthesised or derived from plant, animal and microorganism biomass. The prevalent food preservatives due to their low price and ease of use include conventional chemical preservatives, such as ethanol and other alcohols, organic acids and salts (benzoates, propionates and sorbates) (Broek *et al*., 2015). However, research has focused on substructuring natural antimicrobials including enzymes, bacteriocins, chitin and chitosan derivatives from crustacean shells, natural extracts and essential oils (Mlalila *et al*., 2018).

Conclusion

NC was extracted from maize husk using acid hydrolysis, FTRi, XRD, and high-intensity ultrasonication. The effects of the various preparation processes on the morphology, structure, and properties of the three different types of NC were comprehensively investigated. According to a comparative investigation, the extraction techniques had no noticeable effect on the main cellulose structure. Making biodegradable food packaging using maize husk cellulosic pulp.

As a consequence, a biocomposite with high flexibility and an apparently decent enough and smooth surface has been created, making it a viable packaging material.

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