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Nanocellulose: a brief review of production and regulation

Nanocellulose: a brief review from production to regulation

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SUMMARY

The production of nanocrystalline (NCC) and nanofibrillar (NFC) cellulose and their applications in composite materials has attracted the attention of researchers and basic industries due to its high strength and rigidity, combined with its low weight and environmental availability. Nanocelluloses can be produced through various extraction methods involving chemical, mechanical, and enzymatic processes.

These processes can be used in combination or separately to obtain a final product with unique characteristics. New materials, such as CNF and CNC, will bring significant benefits to the improvement and discovery of new ways of producing bioingredients that allow for the enhancement of various properties in a matrix, whether polymeric or not. This contributes to the development of new materials as well as their sustainability.

Keywords: Wood, cellulose, nanocellulose, regulation.

ABSTRACT

Extraction of nanocrystalline cellulose (CNC) and nanofibrillar cellulose (CNF) and its applications in materials have attracted the attention of researchers and industries. This nanomaterial presents high resistance and rigidity, combined with the fact of low weight and availability in the environment and sustainability. Nanocelluloses can be produced by various extraction methods that involve chemical, mechanical and enzymatic production processes.

These processes can be used combined or not to obtain a final product with unique characteristics. New materials, such as CNF and CNC, will bring great benefits to the improvement and discovery of new ways of producing bioingredients that allow the modification of various properties in a matrix, whether polymeric or not. In this way, contributing to the construction of new materials as well as their sustainability.

Keywords: Wood, cellulose, nanocellulose, regulation.

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1. INTRODUCTION

Nanocellulose, a lightweight, transparent material that is stiffer than stainless steel, has sparked academic and business interest in studies and potential applications of its production. It is an abundant material originating from natural plant fibers, renewable and biodegradable, and has a competitive advantage over fossil and industrialized materials.

Nanomaterials consist of particles with at least one of their dimensions in nanometers. Nanotechnology is a multidisciplinary science and the study of nanomaterials every day they provide valuable discoveries, not only for the development of new products, but also by allowing greater exploration of resources in a more intelligent. Today, the number of sectors that employ products and by-products on a large scale is immeasurable nanometric.

Among the best known and most used nanomaterials, nanocelluloses stand out, that can be obtained by different processes and in different structures. To obtain nanocelluloses there are many relevant factors, especially regarding the techniques of individualization of cellulose microfibrils, which are immersed in a matrix linked to complexes of hemicelluloses and lignin, forming the wood of trees.

The application of new ingredients such as CNF (nanofibrillated cellulose) and CNC (cellulose nanocrystalline) in various materials has attracted the attention of researchers and basic industries. The great interest is mainly due to the intrinsic characteristics of high strength and rigidity, combined with low molecular weight, environmental availability and biocompatibility. In this scenario, the transformation of wood into nanocelluloses further reinforces plus the biorefinery concept practiced by the pulp and paper industries. In this way it becomes necessary to understand the processes involved in the organization of this polymer in wood, as well as its transformation and modification.

2. NATURAL FIBERS

Natural fibers are classified according to their origin as: mineral, animal or vegetable. Plant fibers are formed mainly by cellulose chains, with fibers standing out wood and non-wood (MARINELLI et al., 2008). Among the non-wood fibers, those that stand out and have diverse origins, such as bamboo fibers, coconut, grass-elephant, sisal, straw, sugarcane bagasse and many others.

Among the various advantages presented by natural fibers, in relation to synthetic ones, its reduced energy demand for extraction (production) stands out, in addition to its biodegradability characteristics (BALZER et al., 2007).

According to Souza (2010), natural fibers can be considered natural composites, which are composed primarily of aggregates of cellulose fibrils incorporated into a matrix of lignin and hemicelluloses. Cellulose fibrils are aligned in the cell wall along along the length of the fiber, which results in maximum tensile and flexural strength in this axis, providing rigidity along the fiber axis. The efficiency of reinforcement when fibers are used natural in composite materials is related to the natural organization of cellulose chains and their crystallinity (LEÃO et *al.,* 2009 and LEÃO et *al.,* 2005).

Natural fibers have a number of advantages that allow them to compete with fossil and industrialized materials. There are different sources of lignocellulosic fibers, which occur naturally throughout tropical and subtropical regions that have high potential for use. Some are cultivated commercially, such as wood itself, sisal, bamboo, sugarcane bagasse and straw, and others that are considered as waste: rice husk, wheat straw, cellulose from effluent from the pulp and paper industry, among others. All these sources have great potential in the production and application of these natural fibers in composites whether on macro, micro or nano scales (SOUZA et al., 2010).

3. CELLULOSE

Cellulose is the most abundant organic polymer on the planet, with an estimated production of more than 7.5 x 1010 tons per year, and is present in the structure of plants, in most marine animals, in algae, fungi, bacteria, animals invertebrates and even protozoa (HABIBI et al., 2010). Furthermore, it is the main polysaccharide component of the cell wall of wood fibers, about 50% of its chemical composition. The properties of this material are closely related to its structure, size, and the molecular forces involved in its constitution. It is a high molar mass polysaccharide, which appears as a linear chain polymer, composed exclusively of ÿ-D-glucopyranose units linked by bonds of the type (1-4) (FENGEL et al., 1989).

The hydrogen bonds formed by the –OH groups (Figure 1) of the molecules of cellulose can be intramolecular or intermolecular, and it is these bonds that make that cellulose is a stable polymer and appreciated as reinforcement in composites. According to Moreira (2009), intramolecular bonds are responsible for the rigidity of the chain of cellulose. Intermolecular bonds, in turn, form microfibrils, which also aggregate to form fibrils, which, when ordered, form the cell walls of the cells of fibers. In other words, intermolecular bonds are responsible for the formation of plant fiber.

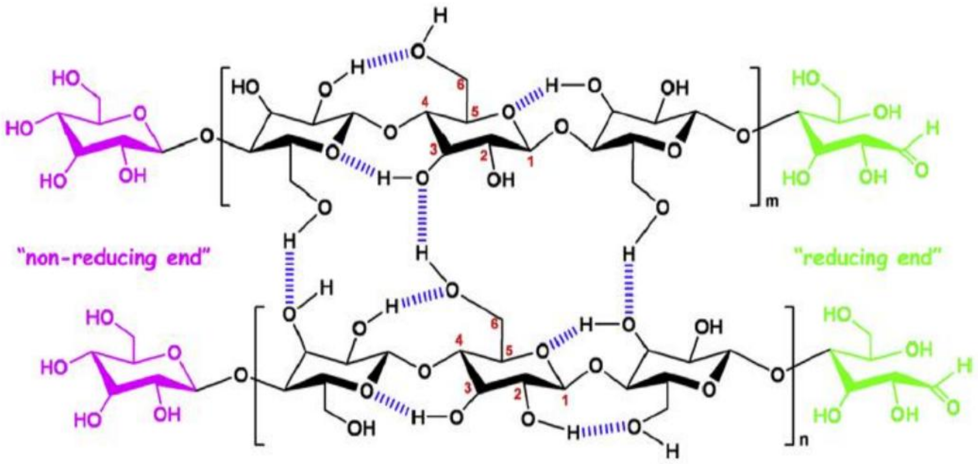

Figure 1 – Intramolecular and intermolecular hydrogen bonds in the cellulose chain (LIN, N & DUFRESNE, A, 2014).

Figure 1 – Intramolecular and intermolecular hydrogen bonding in the cellulose chain (LIN, N & DUFRESNE, A, 2014).

Cellulose biosynthesis is promoted by the multimeric transmembrane complex cellulose synthase (CESA), which forms a six-lobed structure, called a rosette, in the surface of the plasmalemma of plant cells. This rosette was clearly observed by electron microscopy (KIMURA et al., 1999). It is believed that each rosette synthesizes simultaneously 36 cellulose molecules. The parallel chains of cellulose are susceptible to formation of many hydrogen bonds between them, leading to their crystallization as rods insoluble rigids, the cellulose microfibrils. The elongation of cellulose molecules can occur through the movement of CESA complexes within the plasma membrane

(DÉJARDIN et al., 2010). Studies that aim to elucidate the formation of the cell wall of cells vegetables contribute to identifying materials more suitable for certain uses, since the mechanical properties, mainly of the secondary wall, are strictly related to fiber strengths in general.

4. NANOCELLULOSES: CLASSIFICATION AND PROPERTIES

The study of nanocelluloses as reinforcing material in composites and nanocomposites has advanced considerably from the 1990s (FAVIER et al., 1995) to the present day. The production and research on natural raw materials as sources of nanofibers has gained much attention in the recent years due to the characteristics of nanocelluloses such as their resistance potential intrinsic, low weight combined with sustainability characteristics. Despite the countless applications and advantages, energy expenditure during the nanocellulose isolation process is still a negative factor that should be further investigated (SIRÓ & PLACKETT, 2010).

Since then, different nomenclatures for nanocelluloses are often used. The various terms used describe nanofibers according to their main morphological characteristics (length, diameter and aspect ratio).

The main reason for using nanocellulose as reinforcement in composites is due to its high rigidity, which according to Eichhorn et al. (2010) CNC-type nanocelluloses have a modulus specific (GPa Mg^{-1} m^3) higher than that of many materials such as steel, aluminum and glass. This is particularly important for the automotive industry, for example (DUFRESNE, 2008).

There are several methods for extracting nanocelluloses from different plant biomasses (EICHHORN et al., 2010). According to Fujisawa et al (2010) to date nanocelluloses can be divided into three major groups, namely: (A) Nanocrystals of cellulose (CNC), prepared by extraction using a chemical acid hydrolysis process followed by mechanical agitation of the nanocrystal suspension in water; (B) microfibrillated cellulose (MFC), prepared from a mechanical disintegration method of the cellulose pulp in water; (C) nanofibrillated cellulose (NFC), prepared using a combination of oxidation chemistry through the 2,2,6,6-tetramethylpiperidine-1-oxy radical (TEMPO) followed by mechanical disintegration in water, or only by the mechanical disintegration method.

Microfibrillated cellulose (MFC) and nanofibrillated cellulose (NFC) are terms commonly found in the technical literature. Thus, Sehaqui et al. (2011) states that MFC serves to describe fibers with a diameter between 25-100 nanometers (pulp fibers wood cellulose), while CNF are nanocelluloses with a diameter between 5-30 nanometers and variable length between 2-10 micrometers (cellulose pulp fibers of wood). Both MFC and CNF present amorphous and crystalline zones composing their structure. Terms such as *nanowhiskers,* cellulose *nanocrystals* (CNC), nanocrystals, crystals of cellulose or just *whiskers* refer to cellulose nanoparticles that have undergone hydrolysis in controlled conditions that lead to the formation of structures in the form of small cylinders highly crystalline. Also according to Sehaqui et. al., (2011) CNC has a diameter of 3-50 nanometers depending on the extraction source.

In this way, cellulose microfibrils (elementary fibrils that make up the cell wall) of the fiber) can be extracted from the cell walls by basic processes involving chemical, mechanical, enzymatic and combined methods. Depending on the process used, nanocelluloses with differentiated structures can be obtained for unique applications. Thus, depending on the raw materials used and the defibrillation and extraction techniques employed there is a change in the degree of polymerization of the nanocellulose obtained, that is, the size of cellulose fiber, morphology and aspect ratio of nanofibers will be different according to methods of obtaining employed (WANG and SAIN, 2007).

In addition to mechanical properties, nanocelluloses have other characteristics advantages such as biocompatibility, transparency and high reactivity due to the presence of hydroxyl groups (ZIMMERMANN et al, 2010). The modulus of elasticity along the chain of the original cellulose crystal was calculated by different authors, using the methods of X-ray diffraction and Raman spectroscopy (GILLIS, 1970; SAKURADA, NUKUSHINA, & ITO, 1962; TASHIRO & KOBAYASHI, 1991) and was estimated between 130 and 250 GPa.

An indication for the high potential of mechanical performance may be the chain length and the relationship between the dimensions of cellulose fibrils, evaluated by determination of the degree of polymerization (DP) or even by light scattering techniques dynamics (DLS).

Thus, nanocelluloses are characterized as the most recent advance in the industry. of biomaterials derived from different biomass sources, with great potential for use in various industrial areas producing durable and non-durable consumer goods.

4.1. Nanofibrillated Cellulose (NFC)

Cellulose nanofibrils are formed due to the disintegration of cellulose fibers, especially on their surfaces, promoting the rupture of the cell wall and subsequent exposure position of the fibrils and microfibrils previously located inside the fibers (TURBAK et al., 1983 cited by SYVERUD et al., 2011). This process results in an increase in the surface external, allowing a larger contact area and better connection between the microfibrils of cellulose at the reactive hydroxyl terminals.

Currently, nanofibrillated cellulose aggregates can be successfully isolated from extracting plant fibers using processes that employ high shear forces, homogeneneization or refining (IWAMOTO et al, 2007; ZIMMERMANN et al, 2004).

It is important to emphasize that the microfibrils that form the cell wall have different nanometric dimensions, about tens of nanometers in diameter. The elementary fibrils that give rise to nanofibrillated cellulose, it comprises aggregates of elementary fibrils that, in con-together they form microfibrils (CHINGA-CARRASCO, 2011).

As for their dimensions, the length of the nanofibrillated cellulose chains is several micrometers larger than their diameter. Natural nanofibers have a modulus of elasticity very high compared to steel and this is particularly relevant for several industries (DUFRESNE, 2008).

The CNF presents areas with high intensity of fibrillations due to the forces of cir-shearing that the fibers are subjected to in the production process. Nanofibrillated cellulose presents amorphous and crystalline regions that make up its most elongated chain in one direction, while nanocrystals are exclusively crystalline regions of the cellulose molecule. This forms the length of the nanofibrillated cellulose chains and its surface with the presence of several exposed hydroxyl groups end up enhancing large areas of fibrillation networks that guarantee numerous hydrogen bonds (PÄÄKKÖ et al., 2007).

4.1.1. CNF PRODUCTION

The cell wall of wood cells is composed of layers formed by aggregates of microfibrils combined with hemicelluloses and lignin (SJÖSTRÖM, 1993). The in-individualization and obtaining of cellulose nanofibrils from the cell wall require some type of chemical and/or mechanical treatment.

The isolation of cellulose nanofibers or other relatively pure structures de-derived from the polymer cellulose, with minimum dimensions between 1 and 100 nm, generally require a multifaceted process involving chemical stages and/or continuous mechanical operations (CHINGA-CARRASCO, 2011). The methods for producing cellulose nanofibrils can be subdivided into mechanical, chemical, physical and biological (FRONE et al., 2011). In addition of these methods, a combination can be carried out to improve the quality of cell wall fibrillation. CNF production can combine these different methods still with the use of pre-treatments to improve their isolation.

The fibrillation of plant fibers has, for the most part, employed medical treatments. mechanical, using homogenization, grinding and refining (ABE et al., 2007). All these methods all lead to the production of gel with a high water content, which can further be transformed in powder using the spray drying technique (KOLAKOVIC et al., 2011).

Bleached kraft pulp has often been used as a starting material for research on the production of nanofibrillated cellulose (IWAMOTO et al., 2005; JANARDHNAN and SAIN, 2006; SAITO et al., 2006; SAITO et al., 2007; SAITO et al., 2009). Recently, researchers managed to isolate cellulose nanofibrils from cellulose pulp using the mechanical grinding process, allowing the production of nanofibrillas with an average width of 15 nm and a few micrometers in length (ABE et al., 2007; ABE and YANO 2010; WANG et al., 2013).

The physical-mechanical principle of operation of the equipment for isolating the CNF con-consists of the action of a set of discs, a rotating disc and a fixed disc, in a compartment pressurized pump. There is an adjustable gap between the discs so that through contact mechanically the cellulose fibers are defibrillated by high shear forces generated by the grinding stones/discs (VIANA, 2013).

During the mechanical defibrillation process there is a significant decrease in the size of the fibers and a consequent increase in their specific area due to the constant exposure to friction of the cellulose microfibrils that make up the cell wall. A greater specific area allows the greatest number of bonds between nanofibrils and less empty space or smaller pore size between them, resulting in greater density and greater transparency (JONOOBI et al., 2009; VIANA, 2013). Despite this, the high consumption of of energy required in processes that use the mechanical principle of grinding, since promotes influence on production costs.

Delignification of cellulose fibers favors fibrillation and reduces energy consumption. mida during the grinding process and obtaining smaller particles (ABE et al., 2007; IWA-MOTO et al., 2008; MORÁN et al. 2008). Thus, the removal of lignin from the middle lamella of the cell wall of wood cells through delignification processes is one of the initial steps of great importance for the individualization of fibers and obtaining cellulose nanofibrillated

Zimmermann et al. (2010) state that the most important thing for the reinforcement potential for new materials is the quality of the fibrillation. High-quality fibrillation can be achieved by choosing the appropriate pretreatment and raw material.

Several industrial sectors have been developing products based on biopolymers used using natural fibers and their derivatives as mechanical reinforcement in composites and nanocomposites. sites, especially the automotive, construction and packaging industries. This In this way, the use of CNF is characterized as an exponential potential for use and application. immediate industrial cation.

4.2. CELLULOSE NANOCRYSTALS (CNC)

Cellulose nanocrystals are similar to small cylinders or rods in character crystalline, isolated from the acid hydrolysis of the fibers. The mechanism for obtaining nano-crystals by means of acid hydrolysis according to Pääkkö et al., (2007), demonstrates that the the action of hydrolysis agents promotes the extraction of amorphous regions from elementary fibrils of cellulose, leaving only the crystalline regions (Figure 2).

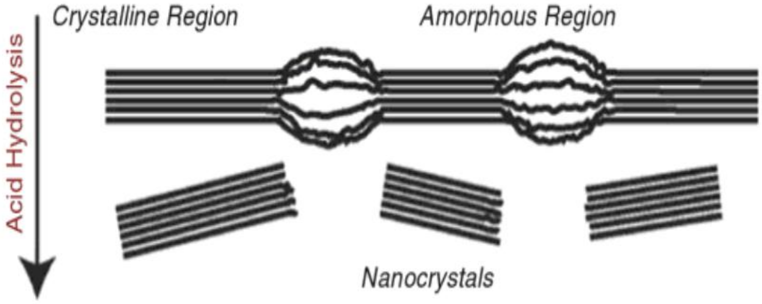

Figure 2 – Hydrolysis mechanism of cellulose nanocrystals
(PÄÄKKÖ et al.,2007).

Figure 2 – Nanocrystals hydrolysis mechanism
(PÄÄKKÖ et al.,2007).

Cellulose nanocrystals may have different terminologies according to the literature: cellulose nanowhiskers (CNW), whiskers, cellulose nanocrystals (NCC), cellulose nanocrystals talin (CNC), nanofibers (NF), nanocellulose, and others (SIQUEIRA et al., 2010).

According to Milewski (1994), cellulose nanocrystals are regions that grow under concontrolled conditions, which allows the formation of high-purity individual crystals. This highly ordered structure can confer not only high strength, but also changes significant in some important properties when used in the composition of mamaterials, such as electrical, optical, magnetic, ferromagnetic, dielectric and conductivity.

The cellulose polymer that makes up the nanocrystals is formed by glucose units which contains three free hydroxyl groups attached to carbons 2, 3, and 6, which are responsible for intermolecular interactions. From these interactions, successive structures are formed made, giving rise to the fiber's cell wall. Therefore, the microfibrils that make up the fifibers, resulting from the arrangement of cellulose molecules, are made up of crystalline regions, highly ordered and disordered amorphous regions. Crystalline regions are the result of combined action of biopolymerization and crystallization of cellulose controlled by processes zymatic. Amorphous regions are the result of poor structure formation due to alteration in the crystallization process (HABIBI et al., 2007).

CNC can be isolated from different sources of vegetable cellulosic fibers (DUFRESNE et al., 2000; LU et al., 2005; CHERIAN et al., 2008). Among the different sources of biomasses used there is a great variety and use, and even agro-industrial and agroforestry waste can be used. Among them we have bamboo soybean hulls (YU et al., 2012; NETO et al., 2013) and some biomass sources such as banana pseudostem, sisal fibers, coconut fibers, and pineapple leaves. In addition, large source of cellulose fibers mainly in Brazil, the chemical pulps of short fiber kraft eucalyptus.

Cellulose nanocrystals have several advantages compared to other nanomaterials such as, for example, ease of production process, low cost of raw materials, diverse characteristics depending on the natural substrate of origin and also the properties mechanical properties compared with those of carbon nanotubes and inorganic nanofibers (SILVA and D'ALMEIDA, 2009).

4.2.1. CNC PRODUCTION

The process for isolating cellulose nanocrystals from raw materials lulosicas consists of several stages, starting with the pre-treatment of the raw material, where the material is delignified and a large part of the hemicellulose content is extracted, if necessary. necessary. Immediately after, the acid hydrolysis step is carried out in which the domains are preserved crystalline. Acid hydrolysis, using strong acids such as sulfuric and hydrochloric acids, currently mind is the most widely used method for obtaining cellulose nanocrystals. After this step washing occurs by centrifugation, dialysis of the suspension until neutrality, dispersion of the nano-cellulose crystals and filtration of the suspension (SILVA and D'ALMEIDA, 2009).

Generally, the dimensions of nanocrystals range from 100-200 nm in length. ment and 20-40 nm wide, according to Cao et al., (2010). It can be said that the amorphous region in cellulose is more easily accessible to acid and more susceptible to hydrolytic action than the domains crystalline. The attack of strong acid on cellulose fibers occurs primarily in the re-amorphous regions of cellulose, since in addition to having a lower density in relation to the crystalline regions, talinas, are regions of easy access (Figure 3).

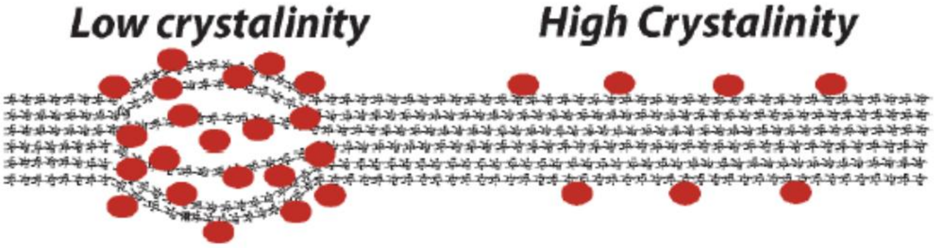

Figure 3 – Hydrolysis promoting agents in red in crystalline regions and amorphous ions. Adapted from Oke (2010).

Figure 3 – Hydrolysis initiators in red in crystalline and amorphous regions. Adapted from Oke (2010).

Various acid hydrolysis conditions have been studied with the aim of evaluating the nature of physicochemical properties of manufactured cellulose nanocrystals. Among these various methodologies, ologies, the use of sulfuric acid stands out, in which, in the condition studied by Sonesso (2011), promotes the esterification of hydroxyls by the sulfate ions of the acid. This fact causes the nanocrystals have a negative surface charge. This anionic stabilization via attraction forces tion/repulsion of the electric double layer is probably the reason for the stability of the suspension colloidal nanocrystals, according to Lu et al. (2010).

Habibi et al., (2010) also highlight that in addition to sulfuric acid, phosphoric and hydrobromic acid can also be used in acid hydrolysis, although on a smaller scale. According to Elazzouzi-Hafraoui et al. (2008) when sulfuric acid was used, the CNC obtained had a higher dispersion in aqueous medium compared to that obtained with hydrochloric acid. When using hydrochloric acid it was observed that their dispersions tended to flocculate. Furthermore, there is a difference in the thermal and rheological behavior between the produced nanocrystals. According to Araki et al. (1998) hydrolysis with sulfuric acid results in more stable nanocrystals in suspension due to the high negative charge generated by the sulfate groups present on the surfaces of the crystals thallites occurring by the esterification of hydroxyls.

4.3. BIOPRODUCTS: COMPOSITES AND NANOCOMPOSITES

Nanocellulose is considered the new biomaterial of today mainly due to to add, in addition to the characteristic of abundant biological material, its physical and mechanical properties, resistance-enhancing techniques, which are of interest in application for the production of various materials. The study of this new material enables its use in various applications. tions in the structural constitution of composites and nanocomposites that require properties unique features such as mechanical resistance, transparency and biocompatibility.

Composites are materials formed from the dispersion of a reinforcement or filler in a matrix. It is, therefore, a material formed by the joining of two or more materials, where uses the main properties of each of them. Thus, nanocelluloses act as a reinforcement to the chosen polymer matrix. Wood is a natural example of a composite, where cellulose serves as reinforcement and lignin as the matrix (LEÃO, 1997).

Nanocomposites constitute a new class of composites with one of their components components presenting dimensions on the nanometric scale, that is, at least one dimension less than 100 nanometers, which often have significantly different properties best and differentiating features. Cellulose is considered a very interesting material to be used used as reinforcement at the nanometric scale. The study of cellulose nanofibers as reinforcement in nanocomposites began about 15 years ago (FAVIER, 1995).

The degree of adhesion between the fiber and the matrix is one of the main requirements in the construction of a resistant composite/nanocomposite (LEÃO et al., 2005). Several industrial sectors have been developing products based on composites reinforced with natural fibers in matrices polymeric industries, especially civil construction, automotive and packaging. What can differentiate the properties of a composite from those of a nanocomposite, both produced with the same types of materials, can be explained by the greater surface area presented by nanocomposites.

Different applications of composites reinforced with lignocellulosic materials are related by LEÃO et al. (2005), such as geotextiles, filters, absorbents/adsorbents, com- structural composites, non-structural composites, molded products, packaging and combinations with other materials.

Biodegradable polymers have some limitations that prevent them from being substituted completely replace plastics, such as: narrow processability window due to its tempermelting temperature, thermal degradation and brittleness. Therefore, obtaining bionanocomposites tos is a possible route to improve the properties of biodegradable polymers. In this in this case, composites can be bioplastics or biomaterials (SOUZA, 2010).

Countries like Japan and the United States (USA) are currently the leaders in the production of composites using plant fibers. In the last decade, the production of these products has increased exponentially. In Germany, 19,000 tons of natural fibers were used in 2005 in automotive composites, according to KARUS and GAHLE (2006).

In the US, the use of nanocomposites by automakers could save 1.5 billion liters of gasoline annually, and consequently reduce carbon dioxide emissions to more than 7.5 million tons (LEÃO et al., 2005).

Thus, nanocelluloses, because they have a high modulus of elasticity, are a strong alternative for increasing physical-mechanical properties in the production of sustainable nanomaterials.

4.4. NANOCELLULOSE AS A BIOINGREDIENT AND ITS REGULATION IN THE HEALTH, BEAUTY AND FOOD SECTORS

Highly biocompatible and non-toxic, cellulose is a natural polymer that presents such properties. Their variations and chemical derivations in form and physical state depend on of the treatments carried out for its production and obtaining can influence its properties. biocompatibility and toxicity.

Nanocelluloses have the potential to be qualified as bioingredients for various sectors, among the most challenging are beauty, health and food as being those in which regulations and toxicity and safety tests are required and mandatory. rivers for their use in final products. Such tests and legal requirements are not required not only for this class of biopolymers, but for all possible new ingredients.

Ingredients are compounds that are part of a recipe, or a mixture of components. Bioingredients are those derived from a renewable source and in turn present the prefixed bio, which may present the same challenges regarding safety and regulatory issues in the same way as the classes of non-renewable ingredients.

The pharmaceutical industry classifies active bioingredients according to the glossary from the FDA (Food and drug administration, 2025) for drugs:

> “An active ingredient is any component that provides pharmacological or other direct effect on the diagnosis, cure, mitigation, treatment or prevention of disease, or that affects the structure or any function of the body of man or animals.” (FDA - Food and drug administration, Drug glossary, 2025).

Nanocelluloses only, when without the absence of any chemical modification or structural, they do not have pharmacological activity, however when combined with other substances can present and even increase the synergy of the existing activity due to to the already known interaction effects or even enhance and become a transporter specific to the compound to which it binds.

For the cosmetics industry, for example, sustainability is a central theme. evolution of cosmetics. Companies are investing in sustainable production practices and in ingredients that do not harm the environment and its users (Mana Cosméticos and Accessories, 2025). Nanocellulose as well as other cellulose derivatives fall into this category. However, the definition may change when it comes to a new area such as cosmetics. tics:

> “In accordance with FR-T21 (Title 21 of the United States Code primarily concerns Food and Drugs, 2025) Section 700/Subsection A/item e: The term ingredient means any chemical entity or mixture used as a component in the manufacture of a product cosmetic."

The U.S. Federal Food, Drug, and Cosmetic Act does not require that cosmetic products and ingredients are approved by the FDA before being marketed, except color additives not intended for use as tar-based hair dyes coal. However, they must be safe for consumers, according to the conditions of use indicated on the label or for common use. Companies and individuals that sell cosmetics tics have legal responsibility for the safety of their products and ingredients (Federal

Food, Drug, and Cosmetic Act (FD&C Act, Title 21). This definition favors the development-development and rapid delivery of new solutions using nanocelluloses as bioingredients, in However, as with all regulations, it leaves all responsibility for future developments to the information about the company that will use the product containing the new bioingredient.

The same occurs for the food sector and its regulation changes according to the de-FDA definitions (FDA regulation for Food Additives and GRAS Ingredients, 2025):

> “The Federal Food, Drug, and Cosmetic Act defines different types of food ingredients based on how they are intended to be used and the FDA authorities related to them. Working within these authorities, the FDA administers separate programs for the use of ingredients that are food additives and generally recognized as safe (GRAS). And even those that directly or indirectly, being part of components that come into contact with food such as packaging (FDA regulation for Food Additives and GRAS Ingredients, 2025).”

In the United States, the FDA regulates a list of substances that may present direct and indirect food contact (21 CFR). This database contains an inventory of substances authorized under Title 21 of the U.S. Code of Federal Regulations (21 CFR) for use in contact with food. The database contains information on the identi-substance and the regulations listed by the FDA for the specific intended uses and the authorized conditions of use. The list includes Substances in Contact with Food (FCSs), including indirect food additives listed in Parts 175-178, 179.45, and 180.22 of 21 CFR, as well as secondary direct additives listed in 21 CFR 173, food ingredients-previously approved mentitials listed in 21 CFR 181 and substances considered generally-recognized as safe listed in 21 CFR 186.1 (FDA, Inventory of Food Contact Substances Listed in 21 CFR, 2025). The inventory also contains information on substances substances listed in 21 CFR 189 whose use is prohibited as food contact substances.

A brief search of all these databases will allow a producer, researcher, or regulatory agent to check whether the new bioingredient is already listed or not, and if so what information is available.

4.5. FUTURE CONSIDERATIONS

Nanocelluloses such as CNF and CNC are biopolymers that can be extracted from numerous lignocellulosic materials. Wood is one of the main forest resources available levels, however there are numerous new non-timber sources that are being explored and bring innovative functionalities linked to nanocelluloses. Nanocelluloses are nanomaterials-rials with characteristics of rigidity, transparency, biocompatibility and biodegradability that allow their application and use in the formulation of a vast number of products, whether as durable or non-durable goods. The areas of application of these materials are becoming increasingly expanding in conjunction with the standardization and regulation of the use of these nanomaterials. In this way, knowledge of the physical-chemical structure of nanocelluloses, as well as the pro-processes that govern their production, is of great importance, since it is expected that these nanomaterials bring great benefits to the improvement and discovery of new forms of production and use of biopolymers, which allow the increase of various properties in materials and products from sectors beyond the production of pulp and paper but also their application cation in cosmetics, food and pharmaceutical sectors. Only then will it be possible to achieve a level of scientific knowledge for the employment and use of these new bioingredients teeth.

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