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Textiles, Plastic Waste and Innovation

Pierfrancesco Morganti[1,2], Maria Beatrice Coltelli[3], Gianluca Morganti[4], Vladimir E Yudin[5] and Hong-Duo Chen[6]

[1]R&D Unit, Academy of History of Healthcare Art, Rome, Italy

[2]Dermatology Department, China Medical University, Shenyang, China

[3]Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy

[4]R&D Unit, ISCD Nanoscience Centre, Rome, Italy

[5]Institute of Macromolecular Compounds, Russian Academy of Sciences, Saint Petersburg, Russia

[6]Dermatological Department, China Medical University, Key Laboratory National Health Commison, Ministry of Education, China

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***Corresponding author:** Pierfrancesco Morganti, R&D Unit, Dermatology Department, China Medical University, Shenyang, China, Academy of History of Healthcare Art, Rome, Italy.

Abstract

Plastic waste, invading land and oceans and entering into animal and human food, contributes to planet warning and worldwide disasters. Among the sources of this waste there are textiles used to produce bandages, hygiene single use products, disposable medical masks and gowns, and dressings. Actually, the majority of these products, made by non-degradable plastic fibers, are landfilled or incinerated. Thus, the necessity to produce biodegradable textiles changes the actual linear economy in the circular economy at zero waste, modifying lifestyle and way of food and cloths' consumption. Consequently, it will ameliorate the human wellbeing and health, and safeguarding the environment integrity and biodiversity. The textile systems require therefore a radical reworking by new innovative ideas, remembering that up to 80% of the product's environmental impact is determined at its designed phase. Consequently, the necessity to establish more collaboration between product supplier and consumer for becoming to produce biodegradable ingredients, biopolymers, and fiber for making innovative textiles skin- and eco-friendly. At this purpose, the gelation method to produce innovative block polymeric micro-nanoparticle (NPs) using Chitin Nanofibrils and Nano lignin in water solution, is reported and discussed. These NPs, having the capacity to encapsulate varies active ingredients, have been bound to polymeric natural fibers which were electrospun for producing biodegradable smart tissues. By these innovative nanotechnologies and the use of different natural ingredients, it will be possible to realize plastic-free and biodegradable advanced medications, surgical and beauty masks as well as innovative hygiene single use products and a new generation of dressings. So doing, it will be possible to reduce waste and pollution, safeguarding human wellbeing and wealth, increasing jobs, reducing poverty, ameliorating the global quality of life and increasing the planet biodiversity.

Introduction

By using textiles, bandages, hygiene products, disposable medical Surgical masks and gowns and apparel, all possibly produced by sustainable technologies and by-product materials at zero waste and emissions, should be possible safeguarding lives and livelihoods for all, maintaining human prosperity and wellbeing [1]. But it is to remember that Fashion industry, accounts for 58 million tons of plastic waste per year, (3th position after packaging and construction), 20% of global waste water, 10% of global/carbon emissions, contributing to the biodiversity loss also, caused by 33% of the insecticide used worldwide for the tissues production. On the other hand, disposable medical masks and gowns accounted for 119 million units per year,while single use feminine and baby pads accounted globally for 89 billion units by 2019,contributing to the oceans waste [2,3].

However, apparel is responsible for 35% of microplastics invading oceans each year as part of textiles' fibers (0,5 million tonnes of microfibers a year!) (Figure 1 and 2). This high quantity of waste is due to the increased purchased of fashion that, translating in the last years to USD 1.2 trillion annually, is made by non-degradable synthetic fibers [2,3]. Unfortunately, only 1% of global clothes are recycled while 87% have been incinerated or were landfilled, due principally to the actual inadequate recycling methods and technologies [4,5]. Thus, the necessity to transform the actual linear economy, based on the taking making and producing waste, in circular economy based on redesigning, reducing, reusing and recycling at waste zero [6,7]. Therefore, it become urgent to organize a new productive model for making textile and fashion based on a new eco design production and contemporary persuade consumers to make small behavioral changes, such as reducing washing temperature and purchasing eco-friendly fibers, donating clothing no more used [4,5,8]. It is to underline in fact, that on the one hand 30% of European's wardrobes have not been used for at least a year, while on the other hand a single laundry load of polyester clothes can discharge 700.000 microplastics fibers, than can end up in the animal and human food chain [4,8,9]. Microplastics in fact, recovered in teacups, human placenta and blood [9-11], might be cause of probable toxic side effects not well known until now [12].

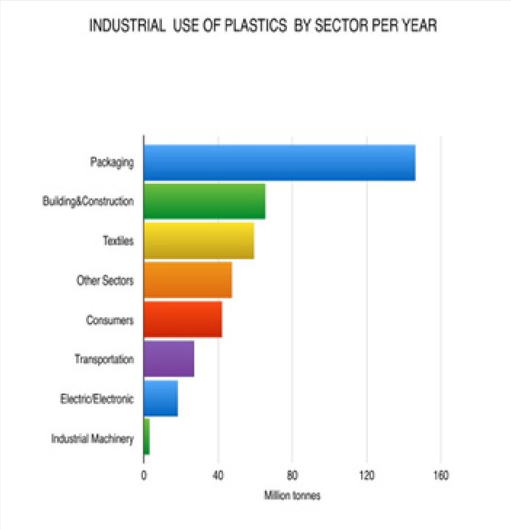

Figure 1: Global plastic waste by sector per year

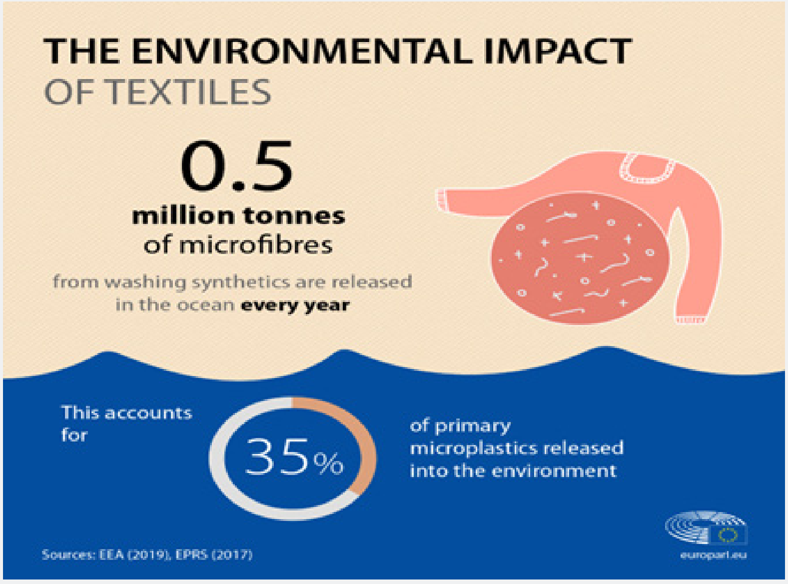

Figure 2: The textile impact on the environment of oceans (by courtesy of EEA).

Thus, textile system requires a radical reworking by new creativity for both planetary and human health, remembering that up to 80% of the product's environmental impact is determined at its design phase. Therefore, the necessity to establish more collaborations between supplier and consumer [9]. Fortunately, the shift to more closed-loop systems is underway driven by regulatory efforts which supporting the circular economy by innovations, new recycling solutions, efficient use of natural resources, use of by-products and creation on new jobs will be beneficial for safeguarding the environment, ameliorating a better

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quality of life (QoL) and reducing waste pollution and poverty [13-17]. Therefore, the need to make innovative high-quality products designed, engineered and processed to meet specifications for a future and different economy and society, rethinking raw materials processes and services selected and investing in people and technology. At this purpose, the use of biodegradable non-woven tissues made by natural polymers obtained from food and agro-forestry waste is proposed [18,19]. These bio-tissues, based on the use of natural polymers embedded by chitin Nanofibrils and Nanolignin may be utilized to make advanced medications, smart cosmeceutical-tissues, and probable innovative fashion [20,21]. Moreover, fabricated by Biomaterials and sustainable biotechnologies they will be useful to minimize the environment impact and ameliorate the quality of life, being also beneficial to customers, business partners and employees [16,18-23].

Biomaterials, biopolymers ecosystems and quality of life

A major challenge for using biodegradable polymeric fibers to make bio- and eco-compatible tissues is to choose Biomaterials which capable to fabricate the right scaffolds that mimic native extracellular matrix[ECM],may guide resident stem cells to regenerate and/or rejuvenate the skin layers [24].Therefore, each tissue/scaffold has to be biodegradable and with a structure similar to the tissue to be regenerated.Consequently the scaffold should be porous enough to allow cell growth favouring penetration and transport of nutrients, oxygen, bioactive ingredients,and waste for promoting cell adhesion and differentiation [25]. It is to remember, in fact, that native ECM prevalently composed of water and polymeric substrates such as polysaccharides, is the main component of each tissue providing physical support and fulfilling a key role in its morphogenesis and differentiation [24-26]. Naturally all the steps necessary to produce and distribute the tissues have to be Environmentally friendly as well as the ingredients used should be biodegradable and verified for their effectiveness and safeness. Thus the necessity to go versus a global sustainability, utilizing renewable sources of energy and bio-based ingredients produced from harvested biological raw materials, leaving the use of petroleum-based chemicals [15-16]. Therefore, to make transition towards a model resulting in balance with nature requires a deep knowledge and understanding of the linkages between environmental wellbeing and quality of life.

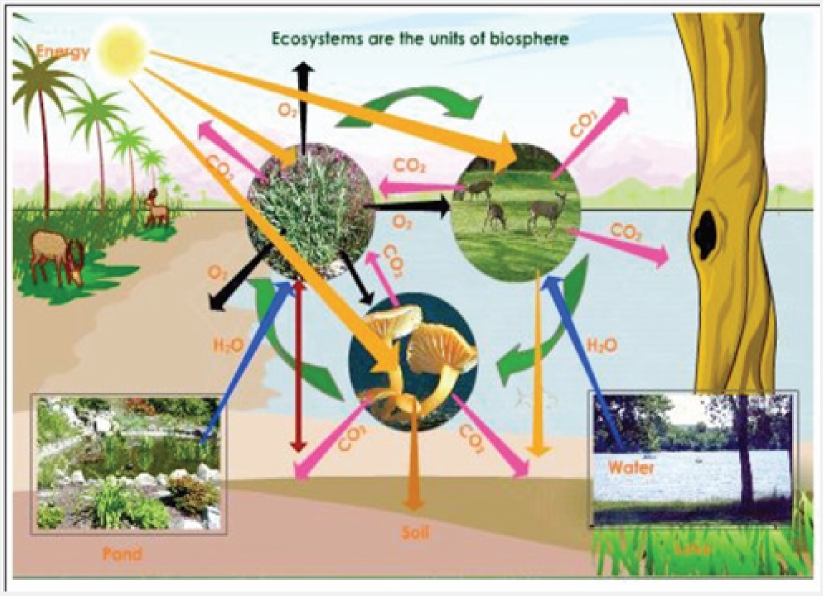

Figure 3: Organism ecosystems of our planet.

Thus, according to Fritj of Capra [27], it is to remember that “survival of humans will depend on the capacity to understand the fundamentals of ecology, living in respect of them”. Humans and nature, in fact, are inextricably coupled with each other because people depend on plants, microorganisms and animals, living all in an important and balanced ecosystem (Figure 3). Plants take energy and carbon dioxide [CO2] from the sun and air releasing oxygen (O2). Moreover, their structures take nutrients and water from the ground through the roots and the microbial activity necessary for producing organic compounds. On the other hand the most prominent process of animals and humans is to release CO2 and adsorb O2 through the respiration processes, as well as eat organic compounds for converting consumed carbohydrates and proteins into polymers and macromolecules to make the tissue and organ structures, by the adenosine triphosphate (ATP)’ aerobic cellular energy [27]. Thus, the necessity to build

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a circular economy by an efficient use of natural resources with a reduction of waste and greenhouse gas (GHG) emissions, for maintaining the Earth' equilibrium and biodiversity to safeguard environmental integrity and global wellbeing [28]. It isn't to forget that climate change is shifting and destroying the Planet natural capital such as glaciers forests and ocean ecosystems necessary to provide raw materials and services to human consumption [17,28]. Conservation restoration of forest land and natural raw materials by management actions that increase carbon-storage and avoid GHG emissions using waste material, offer a way to address the actual economic crisis and environmental disasters [28,29]. Consequently, the need to create a bio-economy able to manage land and natural organic resources more efficiently by the use of renewable feed stocks engineered and processed to meet specifications for a society characterized by more equity free of poverty and capable to recover new jobs for all.

Biopolymers could be the right basic material for the realization at low cost of scaffold/tissues skin- and environmentally friendly for medical and cosmetic use [30].

Biopolymers, polysaccharides and macromolecules

Among the biopolymer's polysaccharides and macromolecules, such as chitin and lignin, have gained great attention because of their high degree of degradability excellent biocompatibility and non-toxicity renewability and ready availability at low cost [30,31]. These sugar-like polymers, which may derive from various sources of biomass such as plants and animals, may have many applications because of their particular structure easily workable industrially. Found in nature in both amorphous and crystalline form nano saccharides, such as chitin, are referred to as Nanocrystals, nano wiskers or nanofibers.

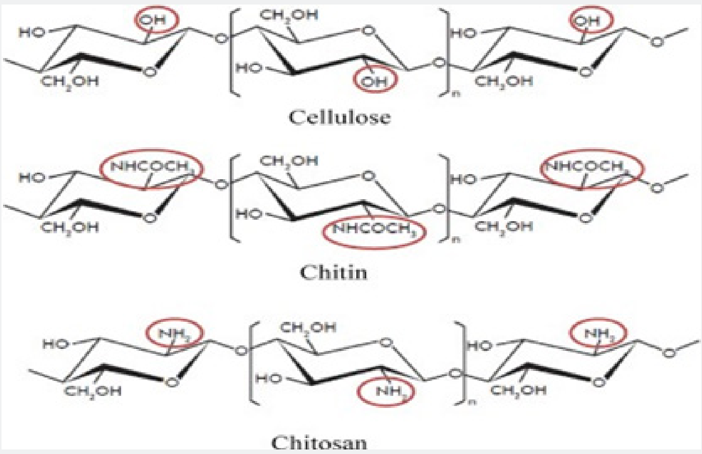

Figure 4: Cellulose compared to chitin and chitosan

Chitin

Alpha Chitin with a backbone similar to cellulose and the antiparallel arrangement of its polymers (Figure 4), is the principal source of carbon and nitrogen (6-8%) for chitinolytic organisms recovered in marine organisms such as exoskeleton of arthropods (i.e.mollusk, shell oysters, squid pen), crustaceans (i.e.crabs, lobsters and shrimps) and insects as well as in cell wall of soil-fungi and bacteria [32]. Its crystalline structure, composed of poly-(1,4]-linked N-acetyl-2-amino-2-deoxy-beta-D-glucose, is organized In hierarchical fibrillar structures composed of nanoscale building blocks that show outstanding mechanical and optical properties [32,33]. The Nanofibrils are held together by hydrogen bonds organized in micro sized bundles embedded with proteins (Figure 5). Depending on the orientation of the microfibrils, 3 different allomorphic forms of chitin are distinguished: alpha-chitin (antiparallel conformation), beta-Chitin (parallel shape) and gamma-Chitin (a mixture of the reported forms). Thanks to the antiparallel orientation of the microfibrils, alpha-Chitin owns Inter- and intramolecular bonds that prevent diffusion of small molecules into the crystallin phase, favouring its Industrial applications [32,34,35]. Chitosan is alpha chitin deacetylated from 70 to around 90%, while chitin nanofibrils (CN) may be deacetylated from 50 to 60%, depending on the adopted productive process [36]. The degree of deacetylation is an important industrial parameter because the minor presence of methylated groups seems to favor the adsorption of polymer through the skin layers [35]. However, the chitin nanofibrils activity is also connected to its molecular dimension because the nanosized increases the polymer' effectiveness due to its inherent properties such as the high surface area to volume ratio and a major reactivity with increased mechanical and antibacterial

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activities that favor its biomedical and cosmetic use, among other applications [36,37]. Additionally, It is to underline that a lower degree of acetylation determines an increase of the fibril mechanical properties modulating its flexibility also. Moreover, because of the right quantity of -OH and-NH free groups, Chtin nanofibrils are amenable to chemical modifications, that may potentiate some of their properties and applications in different fields [38,39].

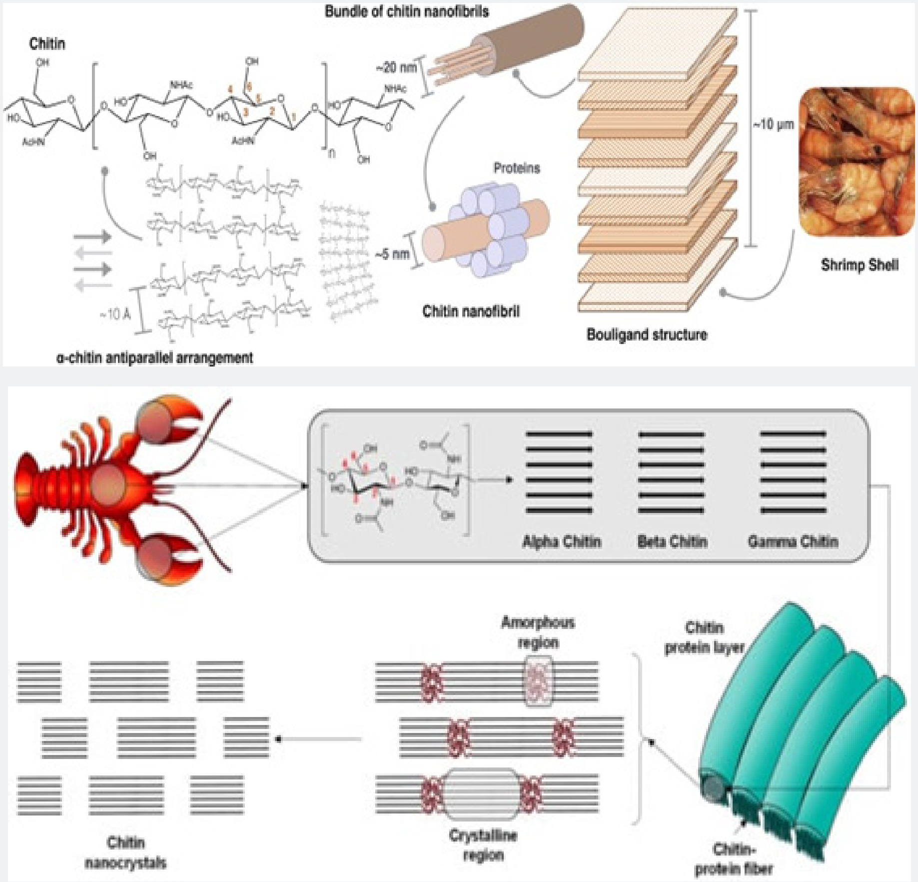

Figure 5: Bundle organization of the chitin Nanofibrils structure.

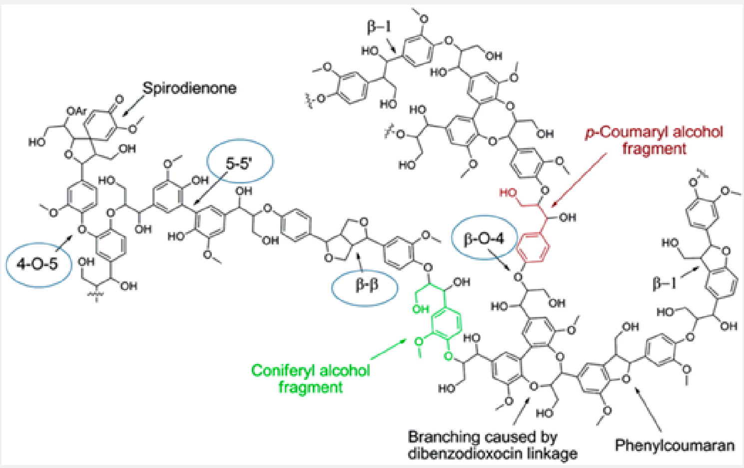

Figure 6: Supposed structure of Lignin.

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Lignin

Industrialized Lignin as renewable raw material characterized by intensive R&D efforts is made by a group of phenolic polymers available in large quantity as by-products of the manufacture of paper from the wood-pulp and ethanol from ligno-cellulosic biomass [39]. Its chemical structure, that varies depending on the utilized source, such as plant species and part of plant, is mainly built from 3 monomers: p-coumaryl alcohol (H-Lignin Unit), coniferyl alcohl (G-Lignin Unit) and Synapyl alcohol (S-Lignin Unit) (Figure 6)[40].

Thus, Lignin in hardwood contains a higher quantity of S-Lignin units while soft lignin contains more G-Lignin units. The G and H units, contained principally in softwood or grass and characterized for more reactive sites at the benzene ring are the more used at industrial level because more reactive toward chemical treatments [40,41]. For these reasons the global Lignin market size was estimated at USD 954.5 in 2019 and is Expected to expand at a Compound Average Growth Rate (CAGR) from 2.0% to 3.60 % in terms of revenue, from 2020 to 2029 according to different sources (Figure 7)[42,43].The major expansion of this market is due to advancement in technologies and the increasing demand for natural-derived products such as animal feed, bio-bitumen and green-friendly cosmetics made by purified lignin [42,43].Europe has been the largest market in 2019 while the Asia Pacific ones is expected to register the fastest CAGR of 2.9% until 2027[42,43].

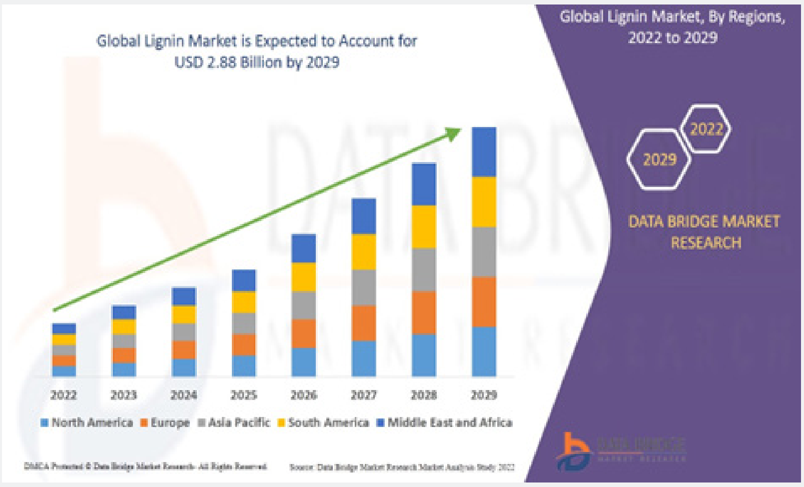

Figure 7: Lignin market provisional increase per region by 2029(by courtesy of Data Bridge Market Research [43]).

It is of interest underline the possibility nano lignin (NG) has to be complexed with chitin nanofibrils (CN) by the ionic gelation method, being the polymers covered by electronegative and electropositive charges respectively. At this purpose our research group has dedicated many studies to characterize the block polymer CN-NG complexes verifying their activity when embedded into non-woven tissues made by the electrospinning technology [16,18-21]. It is to remember that electrospun' architecture, obtainable by the engineered-scaffold tissue, has the ability to guide morphology, survival and proliferation of the cells [16,44]. Smart tissues in fact, made by a blend of biopolymers organized by a particular fibers-structure, provide mechanical support and he right cell environment. Thus, mimicking the natural skin conditions they result fundamental to facilitate the biological functions, such as the diffusion of nutrients, waste and signalling molecules [16,44].

Non-Woven dressings and chitin Nanofibril-Nanolignin complexes

Fabric bandages and disposable medical non-woven dressings represent an important market valued at USD15,9 or USD19,71 billion in 2021and expected to hit USD 24,22/27,81 billion by 2029 and 29,06 by 2030 by the prevision of two different Research Companies (Figure 8) [45,46].This market is estimated to increase rapidly over the forecast period owing to the increased focus on the health care-associated infection[HCAIs]that patients acquire while receiving treatment for medical or Surgical conditions. HCAIs regard yearly more than 4 million people in Europe and 7 million in USA only,occurring more frequently in low- and middle-income countries [47]. Moreover, the worldwide more aged population, mobility, income and COVID pandemic are further influencing and fueling the demand for incontinence hygiene products and disposable medical products, while the development

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in the nanotechnology of manufacturing nonwoven disposables is driving the production.

However, it is to remember that in healthcare, nonwoven tissues are utilized to a large extent in products also (i.e.protective apparel).They are designed to provide barriers (i.e. between patients and themselves patient and the physician/caregiver and also between patients), as well as the incontinence pads, diapers and feminine hygiene products, used to improve quality of life of elderly people, babies and women respectively. These tissues, in fact, are able not only "to create barriers either from the structure of the nonwoven itself or from an additional active coating for personal protective apparel"[48], but may have also antiseptic and adsorbent quality with capacity to neutralize odors. Moreover, coming into direct contact with skin and mucous membranes, they have to be made by fibers characterized for their effectiveness and safeness for humans and the environment. Thus these tissues have to be manufactured by sustainable processes,meeting the regulations of the local approving body (i e FDA,EMEA etc)also [48]. As a consequence, the increased focus on the Life Cycle Analysis of these tissues, combined with an high barrier-effectiveness, biocompatibility, eco-compatibility, and low productive cost, became an high priority.

Figure 8: Medical nonwoven dressings (courtesy of Precedence Research [46]).

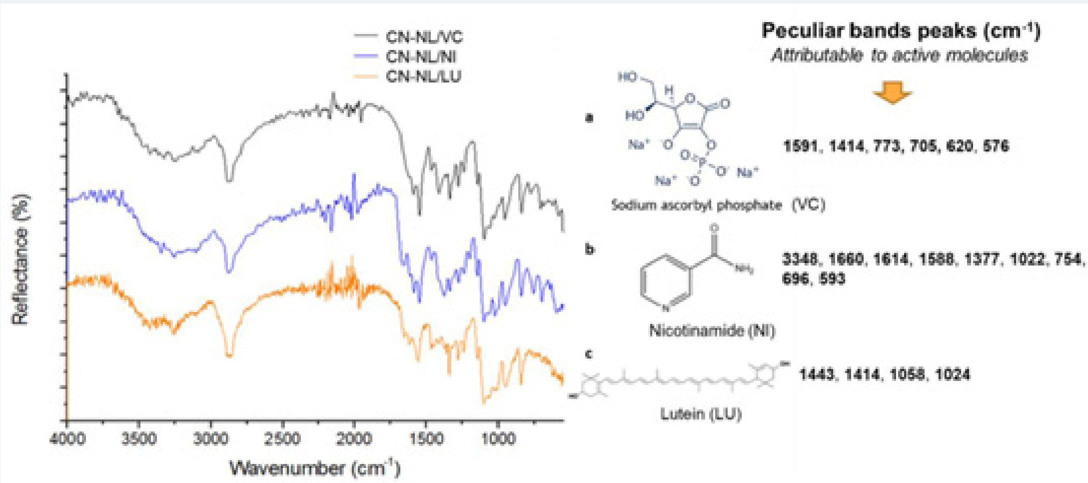

Figure 9: FTIR Spectra of nanochtin-nanolignin (CN-NG) encapsulating sodium Ascorbyl phosphate, nicotinamide and lutein respectively (by courtesy of Coltelli et al[54])

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Therefore, nonwoven tissues are generally prepared by combining multiple fibrous layers of different types of biodegradable polymers and fibers generally bound to micro-nanoparticles necessary to characterize their designed activities, when used for making surgical or beauty masks, wound dressings, incontinence pads or innovative clothes.

At this purpose our research group has realized smart tissues embedded by CN-NG micro-nano particles encapsulating various bioactive ingredients known for their effectiveness, such as anti-inflammatory, antibacterial, immunomodulating and skin repairing activity [49]. Consequently, they have been made accordingly to the supposed and desired activity and therefore designed and programmed to obtain products, such as advanced medications to repair a burned skin [50,51] or innovative cosmeceuticals to rejuvenate a prematurely aged skin [50,51]. The obtained CN-NG complexes have been controlled by physicochemical methods such as the Fourier Transform Infrared Spectroscopy (FT-IR) (Figure 9) or by the Scanning Electron Microscopy (SEM) to verify both concentration and supposed activity of the encapsulated active ingredients (for example nicotinamide, sodium ascorbyl phosphate and Lutein) as well a their chemical and morphological structure respectively (Figure 10) [50,53-56]. Effectiveness and safeness of both Nanoparticles and tissues have been verified in vitro on human keratinocytes and fibroblasts cultures [49,50] and a in vivo in hospitalized subject affected by burns of first and second grade [51].

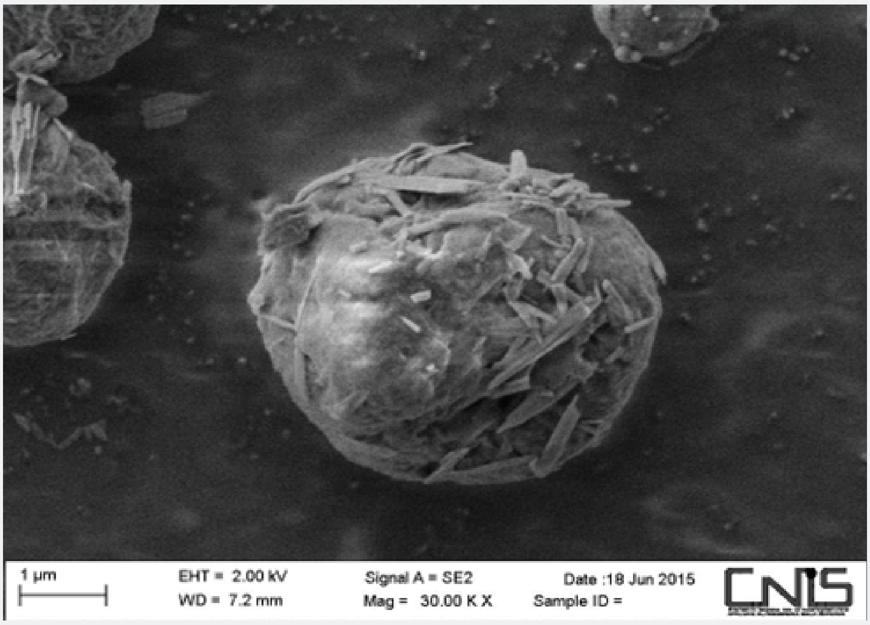

Figure 10: Morphological structure at SEM of Chitin nanofibrils-Lignin block polymeric complex.

Conclusive Remarks

As supposed, the world wide global waste generation income from 2.01 billion tonnes in 2016 should range 3.40 tonnes in 2050 with more than double population growth over the same period [57]. This waste representing a mean of 0.74 Kg per person per day will be probably generated by 40% or more from low-middle income Countries and 19% from High-income Countries by 2050 [57,58]. Thus the urgent necessity for a better handling of all in-house and Industrial by-products by a global cooperation between Statist men and Citizens to save our Environment and ameliorate our wellbeing and wealth. As previously reported in fact, the majority of waste come from our way of living[i.e. kind of consumed food and excessive use of dressings].Thus changing a few habits can make a big difference (Figure 11) [2-5,48,57,58]. Therefore, the use of the proposed non-woven tissues made by biopolymers go in this direction. The tissues in fact, produced by the use of natural polymers, obtained from agro-forestry by-products and food waste, may be used for many purposes such as: production of (1) advanced medications;(2) biodegradable surgical and beauty masks; (3) innovative dressings as well as (4) smart cosmeceuticals and (5) nutraceuticals, contemporary reducing waste invading land and oceans. As shown the biopolymers, such as nanochitin, nanolignin and their complexes, as well as these innovative tissues,may be used as new active ingredients and smart carriers capable to load and deliver active ingredients at the wright skin layers, at the right dose and time for treatment of deep skin wounds also [56,57]. Chitin nanofibers, in.

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fact, has shown to modulate the regular synthesis and disposition of lipid lamellae, while Nanolignin has the ability to reinforce the antioxidant network of the skin, by the polyphenol groups present in its molecule. Thus, while the CN-LG block polymeric complex acts as a carrier both the polymers chitin and lignin metabolized by the human enzymes, to acetyl glucosamine and glucose or to polyphenols respectively have shown to possess, antimicrobial, and UV screening and skin repairing properties also [18-21,19,33-35]. Moreover, these polymers have shown to have an interesting potential role for many other fields such as drug and gene delivery cell imaging sensors as well as in treatment and diagnosis of some of us diseases like cancer [54,57]. Therefore,by the use of new nano-technologies innovative, sustainable productive processes and ingredients [i.e. natural biopolymers],it seems possible to realize innovative and smart microporous carriers and tissues, promoting an ecological management of by-products.In conclusion by maximum utilization of the available resources, real reduction of GHG emissions and energy-efficient management,it will be possible to eliminate the actual great waste and pollution ameliorating our health, quality of life, and wellbeing [7,16,55-63]. This our future hope.

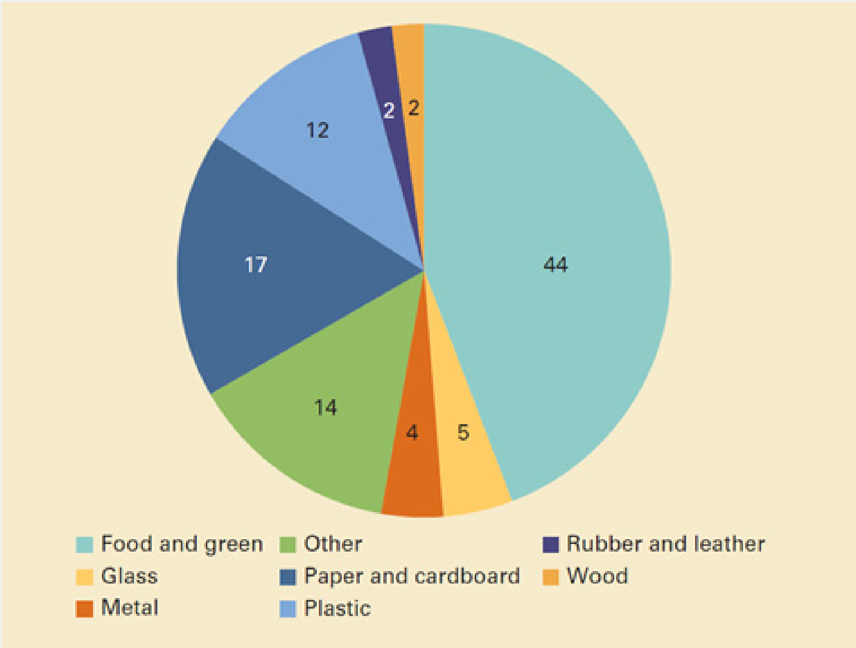

Figure 11: % Waste collection rates by income level (Courtesy of World Bank Report [55]).

Author contributions

Idea of manuscript PM; Writing-original draft preparation PM, GM; writing-review and editing PM, MBC; Supervision MP, VEY, H-DC, MBC. All the author read and agree to the publishing version of the manuscript.

Conflict of Interest

The authors declare non conflict of interest

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