cosmetics

*Review*

# Natural Polymers and Cosmeceuticals for a Healthy and Circular Life: The Examples of Chitin, Chitosan, and Lignin

**Pierfrancesco Morganti [1,2,*], Gianluca Morganti [3] and Maria-Beatrice Coltelli [1,4,*]**

1 Academy of History of Healthcare Art, 00186 Rome, Italy
2 Dermatology Department, China Medical University, Shenyang 110122, China
3 ISCD Nanoscience Centre, 00165 Rome, Italy
4 Department of Civil and Industrial Engineering, University of Pisa, 56122 Pisa, Italy
* Correspondence: pierfrancesco.morganti@iscd.it (P.M.); maria.beatrice.coltelli@unipi.it (M.-B.C.)

**Abstract:** The present review considers the design and introduction of new cosmeceuticals in the market, based on natural polymers and active molecules extracted from biomass, in a biomimetic strategy, starting with a consideration of the biochemical mechanisms, followed by natural precision biopolymer production. After introducing the contest of nanobiotechnology in relationship with its applicability for skin contact products and classifying the currently available sustainable polymers, some widely selected abundant biopolymers (chitin, chitosan, and lignin), showing specific functionalities (anti-microbial, anti-oxidant, anti-inflammatory, etc.), are described, especially considering the possibility to combine them in nanostructured tissues, powders, and coatings for producing new cosmeceuticals, but with potentialities in other sectors, such as biomedical, personal care, and packaging sectors. After observing the general increase in market wellness and beauty forecasts over the next few years, parallelisms between nano and macro scales have suggested that nanobiotechnology application expresses the necessity to follow a better way of producing, selecting, and consuming goods that will help to transform the actual linear economy in a circular economy, based on redesigning, reducing, recycling, and reusing.

**Keywords:** biopolymers; cosmeceuticals; circular; nanobiotechnology; polysaccharides; polypeptides; polynucleotides; chitin; chitosan; lignin; hyaluronic acid



**Citation:** Morganti, P.; Morganti, G.; Coltelli, M.-B. Natural Polymers and Cosmeceuticals for a Healthy and Circular Life: The Examples of Chitin, Chitosan, and Lignin. *Cosmetics* **2023**, *10*, 42. https://doi.org/10.3390/cosmetics10020042

Academic Editor: Enzo Berardesca

Received: 3 January 2023
Revised: 7 February 2023
Accepted: 22 February 2023
Published: 28 February 2023



## 1. Introduction

Natural polymers, also named biopolymers, are represented from a class of natural substances which are both renewable and biodegradable. They are made up of long chains or networks of smaller molecules called monomers, and they are built by following precise sequences and specific structures of macromolecules with different shapes and sizes. Biopolymers touch almost every aspect of our lives and can be seen to belong to homopolymers, copolymers, or precision polymers (Figure 1) [1]. The latter group indicates sequence-defined polymers that are very difficult to be obtained by chemical synthesis [2], but are, on the contrary, very common in natural organisms, where they are obtained by enzymatic pathways.

In microorganisms, fungi, plants, and animals, the biological system components of these polymers are produced to maintain the integrity of organs, tissues, and cells, defending them against the environment and pathogenic aggressions. In terms of chemical structure, natural polymers include polysaccharides, polypeptides (present in proteins), and polynucleotides (in nucleic acids) (Figure 2).

Proteins and polysaccharides are mainly present in structural materials typical of plants, fungi, and animals (such as wood, bones, skin, and exoskeletons), where they undergo nano-assembly in crystals and assume a fibrillar hierarchical structure, similar to collagen, cellulose, and chitin. However, they can also be present as more specific macromolecule, such as an enzyme or transport macromolecule. Natural polymers include cellulose, lignin, chitin, alginate, pullulan, collagen, hyaluronic acid, and other polymeric compounds made of long chains of repeating units (which have unique properties, depending on their structures, when obtained from natural materials) [3]. Furthermore, as they are all biodegradable, skin-friendly, and eco-friendly, these polymers may be used for multiple medical, food, and cosmetic applications [4].

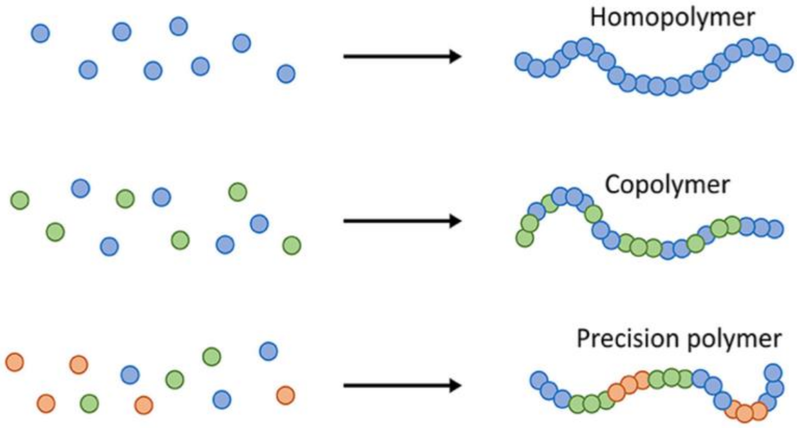



**Figure 1.** Differences between homopolymers, copolymers, and precision polymers.

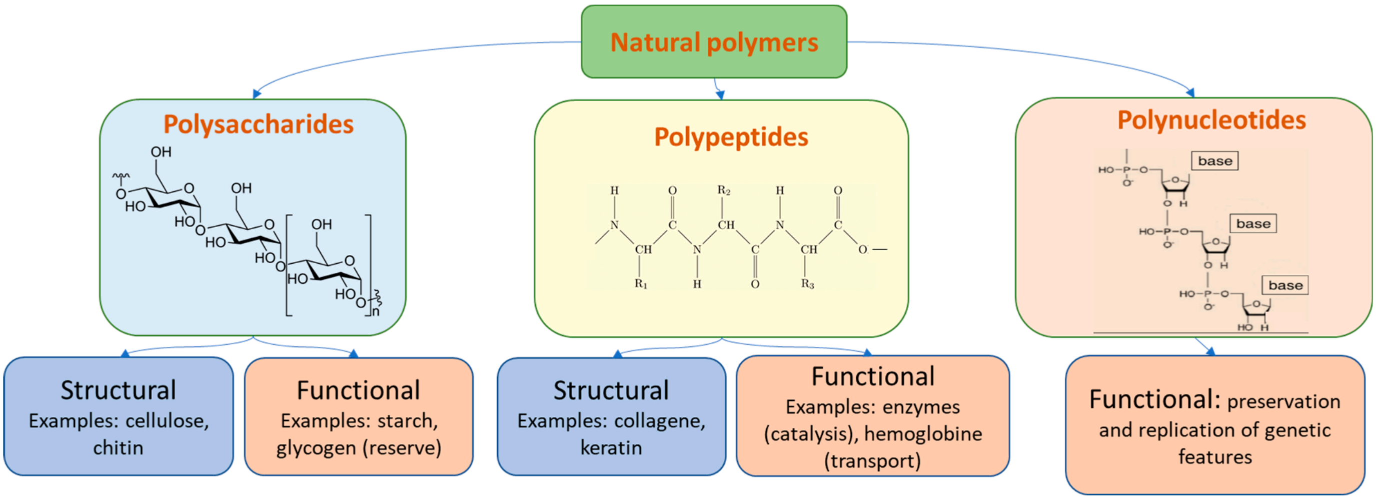



**Figure 2.** Scheme about the chemical structure of natural polymers and their main generical functions.

It is important to remember that life is an ecological system, especially for a single organism or a single species. No one may live alone so that, for their energetic necessities, animals depend on the plant's photosynthesis, while plants depend on carbon dioxide produced by animals and from nitrogen fixed at their roots from bacteria. Thus, plants, animals, and microorganisms regulate the entire biosphere by their genome, also maintaining the condition for the life of humans. That said, all the living organisms are made from cells which represent the basic element of the life, containing polymers such as deoxyribonucleic acid (DNA) (which stores genetic information and is also responsible for cellular auto-replication) and ribonucleic acid (RNA) (which reads them to build proteins). DNA and RNA, made up of pentose, phosphates, and bases, consist of two strands arranged in a double helix and a single helix, respectively (Figure 3) [5,6]. DNA is made up of four chemical components (nucleotides), referred as T, C, A, and G, while RNA is made up of U, C, A, and G (Figure 3).

To add further clarity, the human genome comprises all the chromosomes present in a cell; the chromosome is made up of a long DNA molecule associated by some polymeric proteins divided in genes; the gene is part of the DNA that is utilized to produce a particular protein, meaning that human genes codify about 100,000 proteins which compose the human body [7].

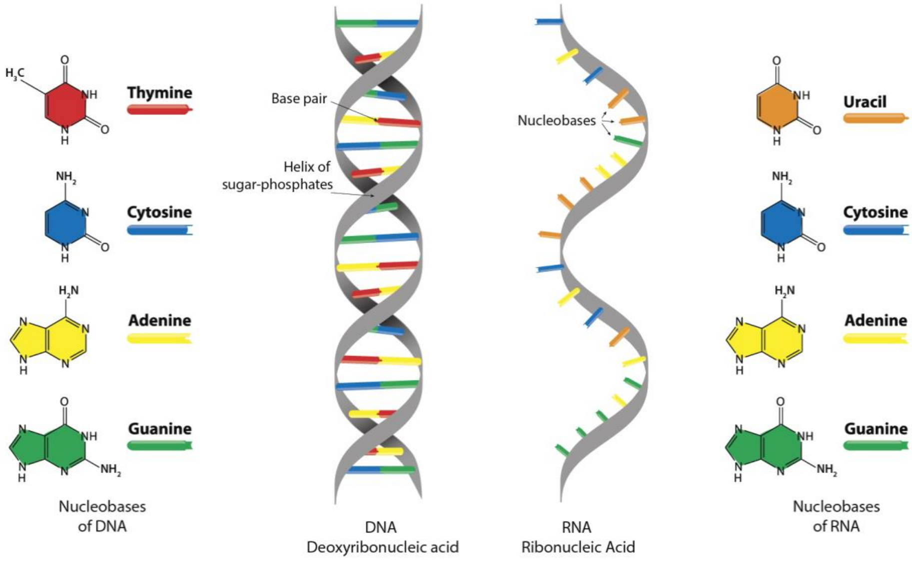



**Figure 3.** Scheme about chemical structure of natural polymers and their main generic functions.

However, life is involved with, and depends on, cellular processes and interactions that are strictly connected to the molecular mechanisms of polymers activity, regulated from DNA and RNA functions [5–7]. The cell organization occurs based on specific paths, as well as by continuously recycling and reusing different materials, such as the polymeric polysaccharides and polypeptides at micro and nano sizes (because they are more accessible in a biochemical reaction). Different metabolic processes may occur through continuous fluxes of chemicals and energy from food and catalyzed by specific enzymes. Thus, life is intrinsically characterized and regulated by the same macro-circularity principles that should be necessary for producing and consuming food in modern times in order to eliminate the no-longer-sustainable waste and pollution that invades our planet. Therefore, mounting evidence suggests the transition to the so-called green economy focuses on improving human wellbeing, health, and wealth, based on biomimetic nanobiotechnology. This innovative technology involves the use of local by-products, as well as green energy and renewable resources, through a molecular self-organization mechanism in physiological manufacturing sustainability conditions. So, with this, raw materials will be saved and social inequity will be reduced over the long term by increasing investments in the sustainable use of bio-waste materials and eco-services.

In conclusion, "enabling a green economy means creating a context in which economic activity increases human wellbeing and social equity and significantly reduces environmental risks and ecological scarcities" [8]. The production and use of innovative biopolymers via nanobiotechnological technologies both follow this direction, making, for example, advanced cosmeceuticals.

This review reports on various examples of biopolymers that are available from biomass by-products or waste valorized by their specific structures and functionalities. Their use in combination with active molecules extracted from renewable sources can help to propose cosmeceuticals of high effectiveness, especially thanks to a combination with nanotechnology-based manufacturing methodologies.

## 2. Nanobiotechnology and Biopolymers

Nanobiotechnology, based on the convergence of engineering and molecular biology, is a novel bottom-up technology that covers important topics on human health and environmentally friendly products and processes that are essential for a cleaner and healthier planet [9]. This new branch of science brings new possibilities, offering new avenues to make things through the control of matter structure based on the molecule-by-molecule control of products and by-products using innovative processes, according to the vision of Eric Drexler [9]. Therefore, nanobiotechnology, as an integration of physical science, molecular engineering, biology, and chemistry, holds considerable promise in spurring pharmaceutical and healthcare developments, as well as in food and cosmetic fields using innovative diagnostic tools, electronic-based biosensors, innovative delivery systems, lipid- or polymer-based nanoparticles, and specialized nano-polymers [10]. Therefore, advancements in this new branch of science have the potential to profoundly change the current economy and improve our standard of living, thus resulting in a new era of regenerative medicine and innovative cosmetic dermatology [10,11]. Given the use of biotechnological techniques, it has been possible to make new scaffolds, adopting a new class of polymers and tissue-specific strategies to ameliorate, for example, the skin penetration, effectiveness, and safeness of selected bio-ingredients. Cosmetic products, in fact, have to restore the skin functions that regenerate skin layers and slow down the appearance of fine lines and wrinkles, and drugs have to repair would healing, avoiding the formation of scars and hypertrophic skin. Thus, most skin repair, regeneration, and rejuvenation attempts have been mainly focused on promoting the barrier function by generating layers of keratinocytes or fibroblasts [12]. Because of this, it is essential to use natural-derived and selected materials to also avoid the risks of immune rejection. Consequently, it is necessary to identify the ideal combination of ingredients such as specialized biopolymers which can play a crucial role in the skin repair and regeneration processes, and can possess an appropriate water uptake ratio, modulating the skin moisturizing activity or hydrating the globular proteins to facilitate their biological functions [13,14]. In addition, these ingredients may have the capacity to make scaffolds similar to the natural extracellular matrix (ECM), thus influencing the nature of cell interactions. It is important to remember that the ECM is a three-dimensional network gel consisting of extracellular macromolecules that are vital for cell and tissue development (Figure 4). Among the biomaterials that are more frequently used, fish collagen and its derived-peptides exist, as well as hyaluronic acid, polysaccharides, chitin, chitosan, lignin, and many other natural compounds that may be used as bioactive ingredients to make selectively controlled and purified micro/nano-structures, allowing the phenomena of allergy and the sensitization and/or transmission of human diseases to be avoided [15–18]. Thus, for example, hyaluronic acid, as important component of ECM, is essential in order to maintain cell viability by facilitating the proliferation and migration of fibroblasts, and also by modulating the regular collagen deposition that acts in the same way of polysaccharides and chitin in its nanosized form (i.e., chitin nanofibrils) [19,20].

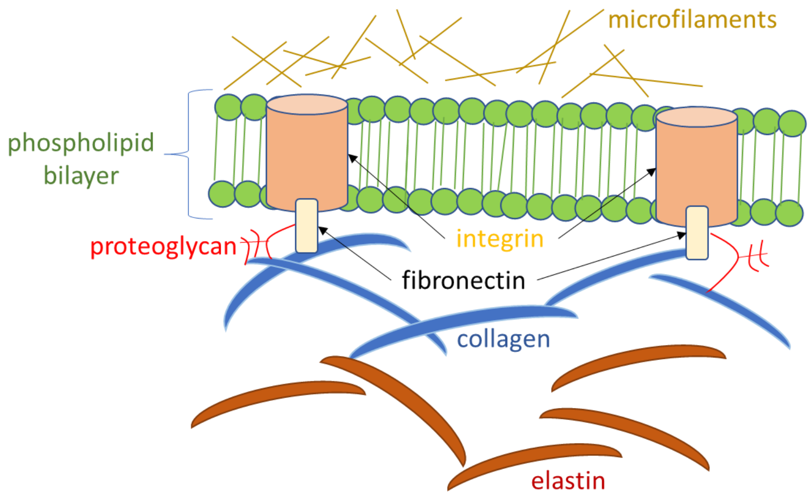



**Figure 4.** Components of the extracellular matrix (ECM).

## 3. Sustainable Biopolymers

Natural sustainable biopolymers spontaneously assemble into nano- and micro-scaled materials [21]. As an example, hair may be represented as a polymer made up of a self-assembly of collagen and keratin molecules to form a complex hierarchical structure, involving hydrogen bonds, electrostatic interactions, as well as van der Waals and hydrophobic forces [21].

Thus, they are generally used as assembled fibers because of their different advantages, including robustness, degradation facility, and the ability to mimic ECM architecture in three dimensions.

However, biopolymers may be divided into natural, artificial, and synthetic polymers. The more commonly used compounds of the first group are collagen, cellulose, starch, lignin, hyaluronic acid, chitin, and chitosan. Artificial polymers, historically considered the first developed polymeric materials in the nineteenth century (before the use of petrol as main chemical source in the 1930s), are obtained from natural polymers using chemical or physical treatments, inducing the partial modification of biopolymers with repeating units (for example, the production of cellulose acetate from cellulose or chitosan from deacetylation of chitin). Among the man-made polymers, obtained by the polymerization of biobased monomers, the most common are biopolyesters such as poly(lactide) (PLA), poly(butylenesuccinate) (PBS), and polyglycolide (PGA). Polyhydroxyalcanoates (PHAs) are also bio-polyesters obtained using biotechnology [21], because they are produced by microorganisms. All these bio-polyesters, including PHAs, are both bio-based and biodegradable, and are characterized by the ability to detect monomers (e.g., to obtain specific copolymers) and design macromolecular structures based on synthesis and processing conditions (as well as the type and availability of selected additives) [22]. Generally, natural, artificial, and synthetic biopolymers are selected for biomedical and biotechnological applications, depending on their degradation time, non-toxicity, easily sterilization possibility, biocompatibility, and skin agreeability and environmental friendliness; all biopolymer classes may be used to make non-woven tissue using electrospinning technology, allowing tissues with a similar architecture and porosity to the natural ECM (Figure 5) to be produced, providing a physiological microenvironment for the cells.

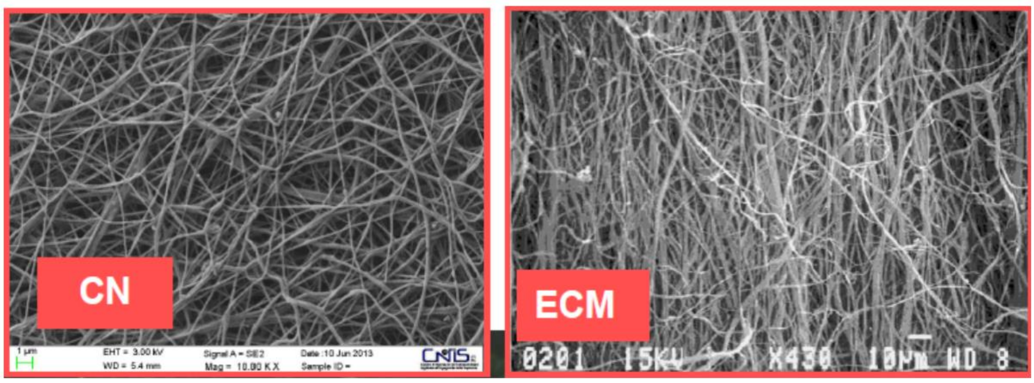



**Figure 5.** Architecture and porosity of the Chitin nanofibril scaffold (**left**) in comparison with the ECM ones (**right**).

The high surface-to-volume ratio and porosity obtainable by this technology help to fasten the wound healing process, as well as the regeneration of precociously aged skin. Nanofibers, made up of nanocomposite biopolymers, can also be functionalized, modifying the plasma treatment of the tissue surface or incorporating bioactive ingredients throughout the processed spun nanofibers [23]. Unlike synthetic biopolymers, natural ones have the inherent ability to more easily bind to cells, favoring their adhesion, viability, growth, proliferation, and differentiation. However, synthetic polymers are, on the one hand, less bioactive than natural ones, and, on the other hand, are easily manufactured on a large production scale and are characterized by a longer durability and easily tailored to specific applications [24]. However, it is fundamental for all biopolymers to have a micro/nano size that, in order to mimic biological systems, can selectively bind to their molecules [25]. Thus, the obtained scaffolds may be used as biological substitutes which replace, restore, maintain, or improve damaged tissues, rejuvenating, for example, prematurely aged skin. It has been shown that biopolymers and fibers rightly oriented at the level of nano-topographic scaffolds can modify cell geometry, in turn influencing their migration speed [25]. Moreover, the organized scaffold structure, influencing cell–fiber interaction, establishes cell–cell communication and provides mechanical signals and biochemical events by stimulating secondary messengers [26]. This is why biomaterial scaffolds, based on the right geometry and porosity levels with fibers at the micro/nano scale, receive great attention in tissue engineering applications [23,25]. As previously reported, chitin, chitosan, and lignin are among the most commonly used biopolymers to make physiological scaffolds for biodegradable tissues, because of their bio- and eco-compatibility and the possibility to obtain them using organic waste at low costs. Thus, they will be discussed in the following sections. However, it is necessary to demonstrate that many other biopolymers are widely used in cosmetic applications, such as hyaluronic acid [26], alginate [27], carrageenan [28], pullulan [29], microbial cellulose [30], proteins [31], etc.

## 4. Chitin and Chitosan

Chitin and chitosan are natural biopolymers (Figure 6) consisting of linear monomeric units of N-acetyl glucosamine and glucosamine. Chitin is present in the shell of crabs, shrimps, and insects, as well as in cell wall of fungi and algae [32]. It is partially crystalline and with a fibrous hierarchical structure (Figure 7a).

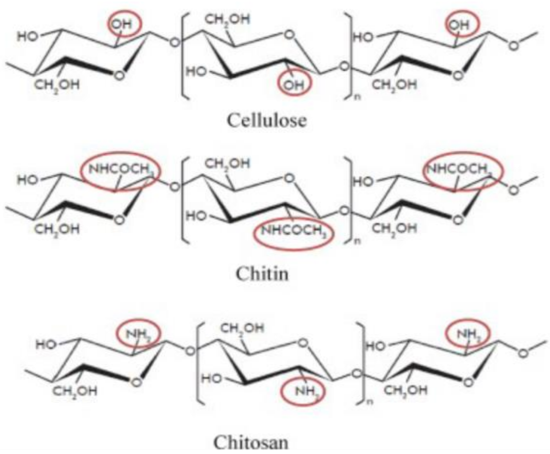
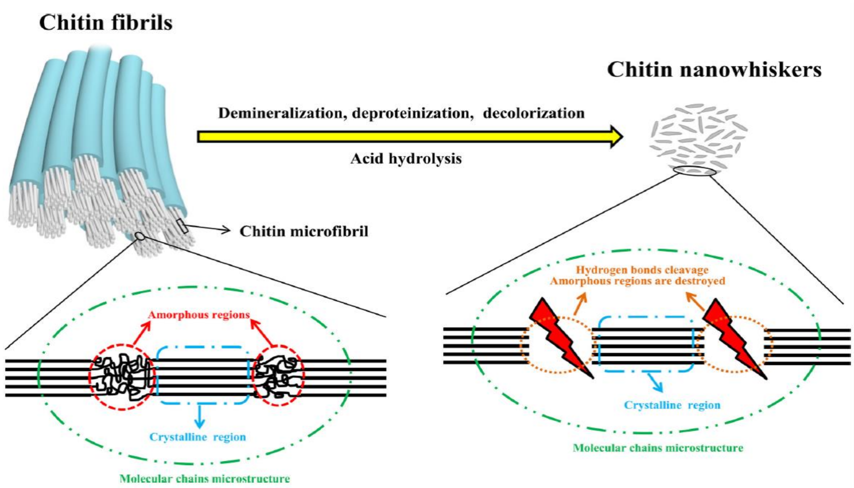
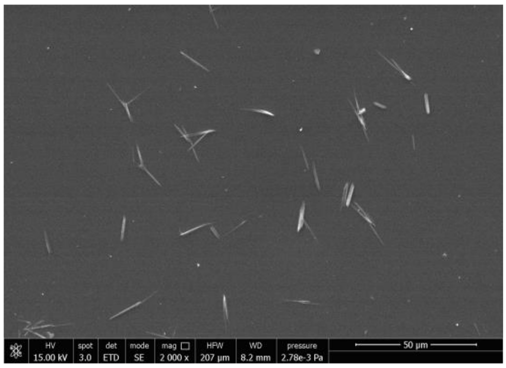



**Figure 6.** Cellulose, Chitin and Chitosan compared.

Chitosan, present especially in fungi, is produced industrially from chitin by a deacetylation process (with the moles of acetyl units ranging from 70% to 95% and a degree of crystallinity depending on the adopted method) [33]. On the other hand, chitin, obtained by a patented technology at its nano size, such as chitin nanofibrils (CNs) (Figure 7b), presents a deacetylation rate from 50% to 60% [34]. CNs represent the crystalline part of chitin. However, CNs are organized as fibers that possess exceptional chemical and biological properties, such as biocompatibility, biodegradability, non-toxicity, and adsorption properties. Furthermore, when at their pure state, they can be used in pharmaceutical, biomedical, food, and cosmetic sectors to make scaffolds for tissue engineering and interesting innovative carriers. For this purpose, from many years, several research groups have worked on the production and use of chitin nanofibrils, specifically in the pharmaceutical and cosmetic fields as smart carriers and innovative active ingredients, as well as components of biodegradable packaging [35,36]. Chitin nanofibrils and chitosan have been widely used to modify cellulosic [37,38] and biopolymeric surfaces [39,40] by depositing specific coatings on them [41]. These findings, considering chitin and chitosan from different sources, such as shrimps, fungi, and insects [42,43], can open several applications for these biopolymers in consumer goods in contact with food, human skin [44], and the body [45].




(**a**)



(**b**)

**Figure 7.** (**a**) Crystalline and amorphous structures of chitin nanofibrils (nanowiskers), in which the amorphous section is destroyed from 50% to 60%; (**b**) the needle-like structure of chitin nanofibrils.

Unfortunately, until today, both chitin and chitosan are underutilized. Moreover, if they are proven to be of great utility in order to make interesting biological products that are both skin- and environment-friendly, they may help to improve human health, reducing the impact of products on the environment [46].

Because of this, it is useful to show some of the physicochemical and biological characteristics of chitin at its nanosize. The biopolymer has a semicrystalline structure and is made up of nanosized fibrils that become linked by many hydrogen bonds, including–CO and -NH bonds (Figures 6 and 7b). Each CN crystal, composed of 20 molecular line chains of biopolymers, has an average dimension of $240 \times 7 \times 5$ nm with a needle-like structure (Figure 7b) [47]. All the crystals, obtained by a patented technology in a 2% water acidic suspension containing around 300 trillions of CN micro/nano crystals per ml, are characterized by a positively charged surface which stabilizes the suspension of needles differently to the cellulose ones which tend to aggregate themselves in larger bundles [47]. Consequently, the positively charged primary amino-groups react easily with other negatively charged polymers, such as hyaluronic acid and lignin, forming micrometric nanostructured complexes in the water solution when ionic gelation technology is used (Figure 8). These nano-structured systems, capable of entrapping different active ingredients, may be bound to polymeric fibers during electrospinning to form the designed cosmeceutical tissues.

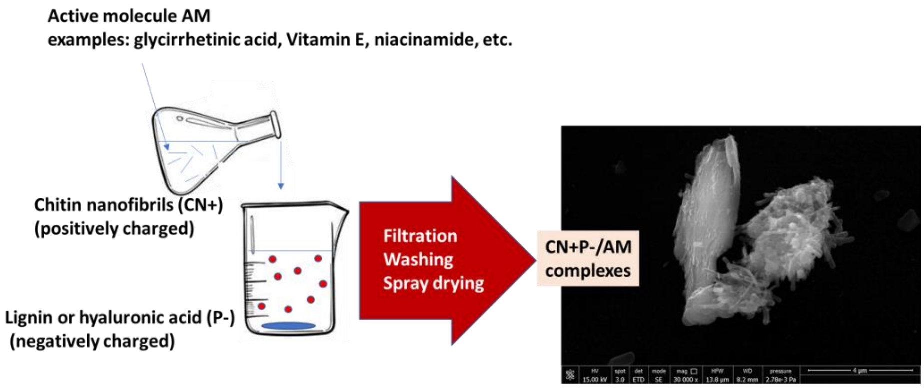



**Figure 8.** The ionic gelation method to produce the complex between hyaluronic acid and chitin nanofibrils.

## 5. Lignin

Lignin is a phenolic biopolymer made up of three propanoid units (sinapyl alcohol, coniferyl alcohol, and p-coumaryl alcohol), linked together by different bonds to form a macromolecule structure (Figure 9) that differs and is dependent on the type of plant and the extraction method used [48]. This polymer, a by-product of biorefinery and the chemical pulping industry, has also shown interest in the cosmetic field, because of its antioxidant, anti-inflammatory, UVA-UVB screening, and DNA repair activity, due to the macromolecular structure of numerous phenolic and chromophoric groups [49]. For all these activities, lignin has been selected from our research group for identifying the polymeric nanostructured microparticles that are made with chitin nanofibrils (CN-LG) using the ionic gelation method [50]. The various nanostructured systems, entrapping different active ingredients, have been controlled to determine the size distribution, zeta potential, and morphology using zetasizer, SEM, and FTIR spectra, respectively, while the relative cytotoxicity was evaluated by the MTT reduction method on the human cell cultures of fibroblasts [51]. However, the effectiveness and safeness of chitin nanofibrils and nanolignin, as well as the CN-LG complex, depend on the raw material source and on their physicochemical characteristics, purity, and size. In fact, the nano-scaled size is one of the more important criteria governing the biophysical, biochemical, and biological behaviors of final products, as previously discussed. Chitin has shown its anti-inflammatory effectiveness at the <40 millimicrons size, stimulating IL-10 activity, whereas 40–70 millimicrons have inflammatory effects, activating both TNF and IL-17 [52].

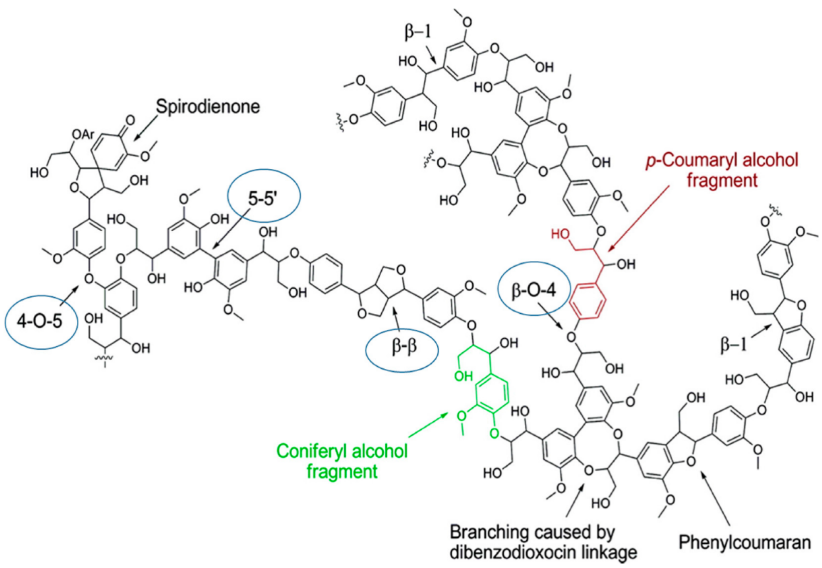



**Figure 9.** The supposed macromolecular structure of lignin rich in polyphenolic groups.

## 6. Cosmeceuticals

The term cosmeceuticals is used to recognize and emphasize the functional aspects of cosmetics and toiletries which, when penetrating through the skin barrier, positively affect the skin structure and function [53]. The skin, through the function of stratum corneum, acts as a rate-controlling membrane, constituting the limit step for the penetration of lipophilic water-insoluble compounds. Thus, a new generation of cosmetic products that can truly prevent or reverse signs of aging is appearing on the market. They are formulated by the use of innovative carriers, such as liposomes, niosomes, polypeptides, and non-woven tissues, as previously described, which should contribute to the overall effectiveness of cosmetics by loading and delivering antioxidants, free radical scavengers, vitamins, and other active ingredients. Moreover, the encapsulation of active ingredients plays a further role in the final formulation of cosmeceuticals, giving them protection from interior and exterior aggressions. In addition, the encapsulation process determines a better time release with long-lasting effects, due to the progressive opening of capsules determined by the body enzymes. Consequently, these subclasses of cosmetics could be characterized as products which, by showing significant interesting effects on normal or near-normal skin, are affected by minor disorders or mild skin abnormalities, and are controlled by in vitro and in vivo methods to verify their effectiveness and safeness [48–52]. Consequently, every single raw material that is used to formulate products which have to come into contact with the human skin or mucous membranes must be subjected to advanced health tests and assessments, also considering their eco-sustainability.

However, the previously reported and proposed cosmeceutical tissues seem to represent innovative safe carriers that can load and release active cosmetic ingredients at the skin level. It is possible to characterize the tissues based on the function they have to fulfill. Thus, they may act as smart active carriers and, since they have the capacity to load and release antioxidants, vitamins, and other cosmetic active ingredients, they may be defined as cosmeceutical tissues [32,54–58]. The CN-LG micro/nanocapsules not only act as vehicles but also as active ingredients hydrolyzed by skin enzymes and transformed into units of glucosamine, acetyl glucosamine, and polyphenols, and are utilized by human cells to make glycosaminoglycans or act as antioxidant defensive compounds. Thus, by using CN-LG particles, loaded with active molecules and bound to polymeric biodegradable tissues, Morganti et al. realized an advanced medication that has shown to repair burned skin more quickly and without the formation of scars or skin hypertrophic phenomena, in comparison to commercial products [55,56]. In the same way, a gel made up of CN and chitosan has shown to repair serious skin wounds without the use of antibiotics [57]. Moreover, the same CN-LG complex, loaded with vitamins C and E, nicotinamide, and other active ingredients, has been used to make biodegradable tissue that can rejuvenate precociously aged skin [32,58–60] as well as repair hair damaged by excessive brushing and decolorizing agents [61,62].

## 7. Discussion

The use of biopolymers, valorized by their peculiar structures and functionalities, and integrated by proper active compounds, represents an interesting opportunity of innovation for the formulation of cosmetic products. These particular ingredients, given their increased effectiveness, improved the knowledge of structure–property relationships and the exploitation of nanotechnology with healthier and environmentally friendly activities, based on the use of biomass waste and by-products. The effectiveness of products is the main objective for consumers. Personal appearance is considered a necessity for every-day life and people dream of eternal youth, a radiant appearance, as well as mental and physical wellbeing. The topic of wellness is a mega-trend and a metaphor for the extra that we expect from life in a modern society, combining the desire for self-respect and our personal needs. However, people have begun to realize that physical and mental wellbeing can be fostered by personal behavior, such as preventive health care, body care, hair care, and fitness. Thus, "the wellness idea has been in updating all spheres of life, from health and sports to the home environment". As a consequence, the entire economic sector, represented by personal care and beauty, physical activity, wellness tourism, healthy eating and nutrition, preventive medicine, traditional complementary medicine, and mental wellness, has developed a market worth USD 4,4 trillion as of 2020 (Figure 10) [63]. "Personal care & beauty" represents the major sector (USD 955 billion), followed by healthy eating/nutrition/weight loss products (USD 946 billion) and physical activity (USD 738 billion).

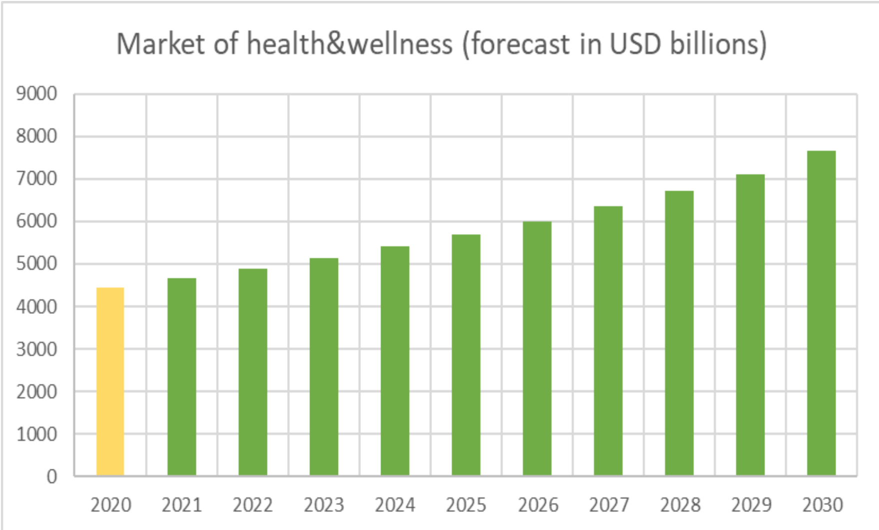



**Figure 10.** Forecasted health and wellness market size, from 2020 to 2030, based on market data [64].

Based on the forecast of the Precedence Research Company, wellness economy, which represents 5.1% of the global economy, could be worth USD 7.65 trillion by 2030, with a CAGR of 5.5% from 2021, dominated by personal, beauty, and anti-ageing segments, which account for around 24% market share (Figure 10) [64]. "Based in region, North America dominated the global Health and wellness market in 2020 in term of revenue and is estimated to sustain its dominance during the forecast period" as of 2020–2030 (Figure 11) [64]. Thus, the cosmetic market and the innovative cosmeceutical tissue market are expected to show interesting growth levels.

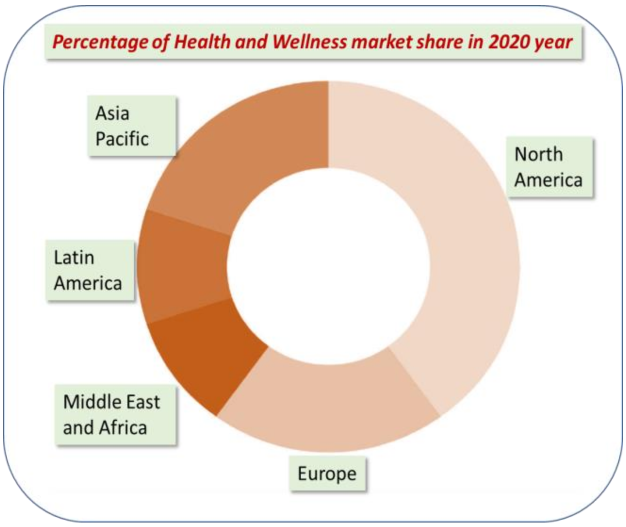



**Figure 11.** Regional market share in 2020, based on market data [64].

Nanotechnologies and nano-structured materials will most probably become essential elements in medical, chemical, and biological applications, as well as in basic genomic research. The genomics of RNA, based on the study of proteins and their relation to genes (proteomics), allow genes to be translated into proteins (transcriptomics), and the key chemicals and biopolymers involved in metabolism (metabolomics) represent a new basis for research and innovation in a wide range of applications in human and animal health and wellbeing, as well as in cosmetics, food agriculture, and forestry. Thus, among the basic technologies resulting from the rise of genomics, it has been possible to realize fast and sustainable tools for high-throughput molecular analysis in order to identify the structure of natural molecules and biopolymers. Moreover, the fundamental role played by scaffolds in providing a microenvironment, as well as in providing and selecting innovative and effective active ingredients to make smart cosmeceuticals for aged skin, can influence cell perception and responses to substrate mechanics [65]. The use of global gene expression profiling (i.e., genomics), together with in vitro human cell cultures, provide a means to identify both key pathways that affect aged skin, such as the altered function of ECM, cells shape, and signaling [66,67]. Moreover, innovative technologies, such as tissue engineering, have allowed physiological scaffolds and smart biodegradable and specialized cosmeceutical tissues to be made [32,44,54,58–60]. These innovative scaffolds/tissues, which play a critical role in tissue engineering by directing the growth of cells, seem able to guide and promote controlled cellular growth and differentiation, which is necessary in order to regenerate and rejuvenate various human skin layers, for example. As a consequence, their increased use in the market of a new generation of cosmeceuticals should prevent or reverse the signs of aging, directly modifying skin structures and functions [67]. Thus, on the one hand, the role of dermatologists and plastic surgeons "in testing, promoting and introducing new cosmeceuticals to their patient" has grown in importance [67]. On the other hand, demand is growing for multifunctional products, such as proposed cosmeceutical-tissues, which offer excellent efficacy, reducing the time spent on grooming to a few minutes per day, also due to global biodegradability. In fact, both women and men are looking for natural and safe products that can rejuvenate their skin, are not a burden for the environment based on scientific soundness and pure sustainable ingredients, and are packed in bio-based and compostable containers.

In conclusion, progress and innovations in these reported branches of science were found to be fundamental in order to protect human health and the environment, as well as to avoid the worldwide waste that invades land and oceans. Because of this, it is important to not forget the reduction in the world's forested area, which has decreased the Earth's capacity to store future carbon emissions and has contributed to more than 18% of global greenhouse gas emissions, with a consequential increase in temperature, i.e., the main cause of related worldwide disasters and the loss of biodiversity [68], as well as the loss of mammal habitats due to temperature increases.

## 8. Future Directions

"The most important factor in developing an innovation strategy is recognizing that innovation is not an isolated activity, but rather the result and driver of growth and collaboration, based on the necessity to transform challenges into opportunities for business growth and competitive advantage" [69]. Thus, given the various future challenges, it is necessary for academics to teach more topics related to biopolymers and to point out the novel chemical and physical properties of different carbon-based materials at their nanometer-sized structures, as well as the human biological systems at the cellular, molecular, and atomic levels, using the existing programs [70]. Thus, it is also important to provide students with advanced knowledge on the different activities and the industrial usage of polymers using the novel platform (Community Resource for Innovation in Polymer Technology (CRIPT)) [71]. Therefore, the larger use of biopolymers will be probably useful in order to stimulate the industry's R&D, increasing the market growth of innovative cosmeceuticals produced by the utilization of food loss and agroforestry waste that is necessary to safeguard the Earth's precious natural raw materials for future generations. In a biomimetic way, circularity principles [72] will be applied based on the conceptualization of new products, from the nano scale to macro scale. Moreover, these new fields of research could even lead to smarter functional bio-cosmetics with more health benefits than the proposed cosmeceutical tissues. Finally, a better way of producing, selecting, and consuming goods will help to transform the actual linear economy, based on taking, making, and producing waste, in a circular economy, based on redesigning, reducing, recycling, and reusing. This new vision for the future will give us a healthier life, also reducing worldwide poverty.

**Author Contributions:** Conceptualization, P.M.; writing—original draft preparation, P.M., M.-B.C. and G.M.; writing—review and editing, M.-B.C.; visualization, M.-B.C.; supervision, all; All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References


1. Cook, A.B.; Bibic, L. Macromolecules, Actually: From Plastics to DNA. *Front. Young Minds* **2019**, *7*, 126. [CrossRef]
2. Dong, R.; Liu, R.; Gaffney, P.R.J.; Schaepertoens, M.; Marchetti, P.; Williams, C.M.; Chen, R.; Livingston, A.G. Sequence-defined multifunctional polyethers via liquid-phase synthesis with molecular sieving. *Nat. Chem.* **2018**, *11*, 136–145. [CrossRef]
3. Silva, A.C.Q.; Silvestre, A.J.D.; Vilela, C.; Freire, C.S.R. Natural Polymers-Based Materials: A Contribution to a Greener Future. *Molecules* **2021**, *27*, 94. [CrossRef]
4. Maitz, M. Applications of synthetic polymers in clinical medicine. *Biosurface Biotribol.* **2015**, *1*, 161–176. [CrossRef]
5. Hudson, W.; Ortlund, E. The structure, function and evolution of proteins that bind DNA and RNA. *Nat. Rev. Mol. Cell Biol.* **2014**, *15*, 749–760. [CrossRef]
6. Consolino, F.; Iacobucci, I.; Monaco, V.; Monti, M. Protein- DNA/RNA Interactions: An overview of investigation methods in the—Omics era. *J. Proteome Res.* **2021**, *20*, 3018–3030.
7. Coen, E. (Ed.) *The Art of Genes: How Organisms Make Themselves*; Oxford University Press: Oxford, UK, 1999.
8. UNEP. *Towards a Green Economy Pathways to Sustainable Development and Poverty Eradication*; United Nations Environment Programme: New York, NY, USA, 2011. Available online: https://wedocs.unep.org/20.500.11822/9158 (accessed on 30 December 2022).
9. Khan, F.A. (Ed.) *Biotechnology Fundamentals*; CRC Press: Boca Raton, FL, USA, 2012.
10. Drexler, E.; Peterson, C.; Pergamit, G. (Eds.) *Unbounding the Future: The Nanotechnology Revolution*; William Morrow & Co.: New York, NY, USA, 1991.
11. Morganti, P. What does Cosmetic Dermatology mean. *J. Appl. Cosmetol.* **1996**, *13*, 51–54.
12. Krishnan, U.M. Bioengineered Skin: Progress and Prospects. In *Biomaterials and Nanotechnology for Tissue Engineering*; Sethuraman, S., Krishnan, U.M., Subramanian, A., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 109–115.
13. Rawling, A.V.; Leyden, J.J. (Eds.) *Skin Moisturization*, 2nd ed.; Marcel Dekker Inc.: New York, NY, USA, 2009; pp. 153–170.
14. Markov, M.S. Contribution of water in the stabilization of biological membranes. In *Interfacial Phenomena in Biological Systems*; Bender, M., Ed.; Marcel Dekker: New York, NY, USA, 1991; pp. 153–170.
15. Ramanathan, G.; Singaravela, S.; Raja, M.D.; Sivagnanam, U.T. Synthesis of highly interconnected 3D scaffold from Arothtrun stellatus skin collagen for tissue engineering application. *Micron* **2015**, *78*, 28–32. [CrossRef]
16. Tangsadthakun, C.; Kanokpanont, S.; Sanchavanakit, N.; Banaprasert, T.; Damrongsakkul, S. Properties of collagen scaffolds for skin tissue engineering. *J. Metal. Mater. Miner.* **2006**, *16*, 37–44.
17. Morganti, P.; Del Ciotto, P.; Morganti, G.; Fabien-Soulé, V. Application of Chitin Nanofibrils and Collagen of Marine Origin as Bioactive Ingredients. In *Cosmeceuticals: Trends and Prospects*; Kim, S.-K., Ed.; CRC: Boca Raton, FL, USA, 2011; pp. 267–290. [CrossRef]
18. Garabska-Zielinska, S.; Siokowska, A. Surface properties of collagen, hyaluronic acid and chitosan films with neodymium laser. *Polysaccharides* **2022**, *3*, 178–187. [CrossRef]
19. Pardue, E.L.; Ibrahim, S.; Ramamurti, A. Role of hyaluronan in angiogenesis and its ability to angiogenic tissue engineering. *Organogenesis* **2008**, *4*, 203–214. [CrossRef]
20. Tucci, M.G.; Belmonte-Mattioli, M.; Ricotti, G.; Biagini, G. Polysaccharides: Health-Environment Binomial. *J. Appl. Cosmetol.* **1999**, *17*, 94–101.
21. Verna, G.; Hassan, P.A. Self-assemble approach for biomaterials development. In *Trends in Biomaterials*; Kothiyal, G.P., Srinivasan, A., Eds.; Pan Stanford Publishing Ltd.: Singapore, 2016; pp. 49–84.

22. Chang, W.; Shah, M.; Lee, P.; Rosa, R.; Kong, K.; Kandl, W.; Yu, X. Biomaterials and nanotechnology for tissue engineering: Neural regeneration. In *Biomaterials and Nanotechnology for Tissue Engineering*; Sethuraman, S., Krishnan, U.M., Subramanian, A., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 153–171.
23. Murthy, C.S.K.; Mandal, B.B. Biomaterials based on natural and synthetic polymer fibers. In *Trends in Biomaterials*; Kothyal, G.P., Srinivasan, A., Eds.; Pan Stanford Publishing Ltd.: Singapore, 2016; pp. 121–174.
24. Ozdil, D.; Aydin, H.M. Polymers for medical and tissue engineering applications. *J. Chem. Technol. Biotechnol.* **2014**, *89*, 1793–1810. [CrossRef]
25. Sharma, P.; Sheets, K.; Elankumaran, S.; Nain, A.S. The mechanistic influence of aligned nanofibers on cell shape, migration and blebbing dynamics of glioma cells. *Integr. Biol.* **2013**, *5*, 1036–1044. [CrossRef]
26. Hashimoto, M.; Maeda, K. New Functions of Low-Molecular-Weight Hyaluronic Acid on Epidermis Filaggrin Production and Degradation. *Cosmetics* **2021**, *8*, 118. [CrossRef]
27. Eskens, O.; Villani, G.; Amin, S. Rheological Investigation of Thermoresponsive Alginate-Methylcellulose Gels for Epidermal Growth Factor Formulation. *Cosmetics* **2020**, *8*, 3. [CrossRef]
28. Tafuro, G.; Costantini, A.; Baratto, G.; Francescato, S.; Busata, L.; Semenzato, A. Characterization of Polysaccharidic Associations for Cosmetic Use: Rheology and Texture Analysis. *Cosmetics* **2021**, *8*, 62. [CrossRef]
29. Coltelli, M.-B.; Danti, S.; De Clerck, K.; Lazzeri, A.; Morganti, P. Pullulan for Advanced Sustainable Body- and Skin-Contact Applications. *J. Funct. Biomater.* **2020**, *11*, 20. [CrossRef]
30. Oliveira, T.J.; Segato, T.C.M.; Machado, G.P.; Grotto, D.; Jozala, A.F. Evolution of Bacterial Cellulose in Cosmetic Applications: An Updated Systematic Review. *Molecules* **2022**, *27*, 8341. [CrossRef]
31. Kazimierska, K.; Kalinowska-Lis, U. Milk Proteins—Their Biological Activities and Use in Cosmetics and Dermatology. *Molecules* **2021**, *26*, 3253. [CrossRef]
32. Subramanian, A.; Swaminathan, S. Nanofibers design for guided cellular behavior. In *Biomaterials and Nanotechnology for Tissue Nanoparticle Engineering*; Sethuraman, S., Krishnan, U.M., Subramanian, A., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 17–31.
33. Pillai, C.K.; Paul, W.; Sharma, C.P. Chitin and chitosan polymers. chemistry, solubility and fiber formation. *Prog. Polym. Sci.* **2009**, *34*, 641–678. [CrossRef]
34. Ioelovich, M. Crystallinity and hydrophility of chitin and chitosan. *J. Chem.* **2014**, *3*, 7–14.
35. Malafeev, K.V.; Moskalyuk, O.A.; Yudin, V.E.; Morganti, P.; Ivan'Kova, E.M.; Popova, E.N.; Elokhovskii, V.Y. Biodegradable polylactide/chitin composite fibers: Processing, structure and mechanical properties. *J. Appl. Cosmetol.* **2017**, *35*, 163–173.
36. Morganti, P.; Coltelli, M.-B. A New Carrier for Advanced Cosmeceuticals. *Cosmetics* **2019**, *6*, 10. [CrossRef]
37. Panariello, L.; Coltelli, M.-B.; Buchignani, M.; Lazzeri, A. Chitosan and nano-structured chitin for biobased anti-microbial treatments onto cellulose based materials. *Eur. Polym. J.* **2019**, *113*, 328–339. [CrossRef]
38. Panariello, L.; Coltelli, M.-B.; Giangrandi, S.; Garrigós, M.C.; Hadrich, A.; Lazzeri, A.; Cinelli, P. Influence of Functional Bio-Based Coatings Including Chitin Nanofibrils or Polyphenols on Mechanical Properties of Paper Tissues. *Polymers* **2022**, *14*, 2274. [CrossRef]
39. Panariello, L.; Coltelli, M.-B.; Hadrich, A.; Braca, F.; Fiori, S.; Haviv, A.; Miketa, F.; Lazzeri, A.; Staebler, A.; Gigante, V.; et al. Antimicrobial and Gas Barrier Crustaceans and Fungal Chitin-Based Coatings on Biodegradable Bioplastic Films. *Polymers* **2022**, *14*, 5211. [CrossRef]
40. Panariello, L.; Vannozzi, A.; Morganti, P.; Coltelli, M.-B.; Lazzeri, A. Biobased and Eco-Compatible Beauty Films Coated with Chitin Nanofibrils, Nanolignin and Vitamin E. *Cosmetics* **2021**, *8*, 27. [CrossRef]
41. Gigante, V.; Panariello, L.; Coltelli, M.-B.; Danti, S.; Obisesan, K.A.; Hadrich, A.; Staebler, A.; Chierici, S.; Canesi, I.; Lazzeri, A.; et al. Liquid and Solid Functional Bio-Based Coatings. *Polymers* **2021**, *13*, 3640. [CrossRef]
42. Triunfo, M.; Tafi, E.; Guarnieri, A.; Salvia, R.; Scieuzo, C.; Hahn, T.; Zibek, S.; Gagliardini, A.; Panariello, L.; Coltelli, M.B.; et al. Characterization of chitin and chitosan derived from Hermetia illucens, a further step in a circular economy process. *Sci. Rep.* **2022**, *12*, 6613. [CrossRef]
43. Coltelli, M.-B.; Panariello, L.; Vannozzi, A.; Gigante, V.; Gagliardini, A.; Morganti, P.; Cinelli, P.; Lazzeri, A.; De Bonis, A.; Falabella, P. Chitin and Its Derivatives: Nanostructured Materials from Different Marine and Terrestrial Sources. *Chem. Eng. Trans.* **2022**, *93*, 295–300. [CrossRef]
44. Teno, J.; Pardo-Figuerez, M.; Hummel, N.; Bonin, V.; Fusco, A.; Ricci, C.; Donnarumma, G.; Coltelli, M.-B.; Danti, S.; Lagaron, J.M. Preliminary Studies on an Innovative Bioactive Skin Soluble Beauty Mask Made by Combining Electrospinning and Dry Powder Impregnation. *Cosmetics* **2020**, *7*, 96. [CrossRef]
45. Morganti, P.; Yudin, V.E.; Morganti, G.; Coltelli, M.-B. Trends in Surgical and Beauty Masks for a Cleaner Environment. *Cosmetics* **2020**, *7*, 68. [CrossRef]
46. Morganti, P.; Morganti, G.; Yudin, V.E.; Chen, H.-D. Chitin and Lignin: Old Polymers and New Bio-Tissuecarriers. *J. Dermatol. Dermat.* **2021**, *6*, 1–11. [CrossRef]
47. Morganti, P.; Gagliardini, A.; Morganti, G. Nanochitin and nanolignin: Activity and safeness. *Dermal. J. Cosmet. Laser Ther.* **2022**, *1*, 17–35.
48. Lora, J.H. Industrial commercial lignins: Sources, properties and applications. In *Monomers, Polymers and Composites from Renewable Resources*; Belgacem, M., Gandini, A., Eds.; Elsevier: Oxford, UK, 2018; pp. 225–241.

49. Nichols, J.A.; Katiyar, S.K. Skin photoprotection by natural polyphenols: Anti-inflammatory, antioxidant and DNA repair mechanisms. *Arch. Dermatol. Res.* **2009**, *302*, 71–83. [CrossRef]
50. Morganti, P.; Carezzi, F.; Del Ciotto, P.; Morganti, P. Chitin nanoparticles as innovative delivery system. *Pers. Care* **2012**, *5*, 95–98.
51. Morganti, P.; Palombo, M.; Tishchenko, G.; Yudin, V.E.; Guarneri, F.; Cardillo, M.; Del Ciotto, P.; Carezzi, F.; Morganti, G.; Fabrizi, G. Chitin-Hyaluronan Nanoparticles: A Multifunctional Carrier to Deliver Anti-Aging Active Ingredients through the Skin. *Cosmetics* **2014**, *1*, 140–158. [CrossRef]
52. Lee, C.G.; Da Silva, C.A.; Lee, J.Y.; Hartl, D.; Elias, J.A. Chitin regulation of immune responses: An old molecule with new roles. *Curr. Opin. Immunol.* **2008**, *20*, 684–689. [CrossRef]
53. Kligman, A.M. Cosmeceuticals: A Broad-Spectrum Category between Cosmetics and Drugs. In *Cosmeceuticals and Active Cosmetics. Drugs versus Cosmetics*, 2nd ed.; Elsner, P., Maibach, H., Eds.; TaILor & Francis Group: Oxford, UK, 2005; pp. 1–9.
54. Morganti, P.; Morganti, G.; Gagliardini, A.; Lohani, A. From cosmetics to innovative cosmeceuticals-non-woven tissues. *Cosmetics* **2021**, *8*, 65. [CrossRef]
55. Donnarumma, G.; Fusco, A.; Morganti, P.; Palombo, M.; Anniboletti, T.; Del Ciotto, P.; Baroni, A.; Chianese, A. Advanced medications made by green nanocomposites. *Int. J. Res. Nano Sci.* **2018**, *5*, 261–270.
56. Anniboletti, T.; Palombo, M.; Moroni, S.; Bruno, S.; Palombo, P.; Morganti, P. Clinical activity of innovative polymeric nanoparticles and non-woven tissues. In *Bionanotechnology to Save the Environment*; Morganti, P., Ed.; MDPI: Basel, Switzerland, 2019; pp. 340–360.
57. Mezzana, P. Clinical efficacy of a new chitin nanofibrils-based gel in wound healing. *Acta Chir. Plast.* **2008**, *50*, 81–84.
58. Morganti, P.; Morganti, G.; Coltelli, M.B. Chitin nanomaterials and nanocomposites for tissue repair. In *Marine-Derived Biomaterials for Tissue Engineering Applications*; Coi, A.H., Ben-Nissan, B., Eds.; Springer: Singapore, 2019; pp. 523–544.
59. Morganti, P.; Morganti, G.; Colao, C. Biofuntional textiles for aged skin. *Biomedicines* **2019**, *7*, 51. [CrossRef] [PubMed]
60. Danti, S.; Trombi, L.; Fusco, A.; Azimi, B.; Lazzeri, A.; Morganti, P.; Coltelli, M.-B.; Donnarumma, G. Chitin Nanofibrils and Nanolignin as Functional Agents in Skin Regeneration. *Int. J. Mol. Sci.* **2019**, *20*, 2669. [CrossRef] [PubMed]
61. Morganti, P.; Morganti, G. Natural polymers for natural hair: The smart use of innovative carrier. In *Nanocosmetics: Fundamentals, Applications and Toxicity*; Nanda, A., Nanda, S., Nguyen, T.A., Rajendran, S., Slimani, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2020; pp. 267–286.
62. Morganti, P.; Morganti, G.; Coltelli, M.-B. Smart and Sustainable Hair Products Based on Chitin-Derived Compounds. *Cosmetics* **2021**, *8*, 20. [CrossRef]
63. GWI. *Wellness Industry Statistics & Facts*; Global Wellness Industry: Miami, FL, USA, 2022. Available online: https://globalwellnessinstitute.org/press-room/statistics-and-facts/ (accessed on 30 December 2022).
64. Precedence Research. Health and Wellness Market-Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2021–2030; 2022 Report; Ottawa, ON, Canada. Available online: www.precedenceresearch.com (accessed on 29 December 2022).
65. Osborne, R.; Hakozaki, T.; Laughlin, T.; Finlay, D. Application of genomics to breakthroughs in the cosmetic treatment of skin ageing and discoloration. *Br. J. Dermatol.* **2012**, *166*, 16–19. [CrossRef]
66. Gilbert, P.M.; Havenstrite, K.L.; Magnusson, K.E.G.; Sacco, A.; Leonardi, N.A.; Kraft, P.; Nguyen, N.K.; Thrun, S.; Lutolf, M.P.; Blau, H.M. Substrate Elasticity Regulates Skeletal Muscle Stem Cell Self-Renewal in Culture. *Science* **2010**, *329*, 1078–1081. [CrossRef] [PubMed]
67. Peoples, J.E.; Ferland, C.A. *The New Generation of Cosmetics, 1990–2000*; Decision Resources Report: Burlington, MA, USA, 1991.
68. UN. Climate Action 2022, United Nations Report; UN: New York, NY, USA. Available online: https://www.un.org/en/climatechange/reports (accessed on 29 December 2022).
69. Gerhardt, C.; Hubbert, J. *Innovation, Sustainability and the "Triple Botton Line"*; Marketing & Communications Report; A Kearney Inc.: Chicago, IL, USA, 2009.
70. Velez, M.J.; Velez, J.J. The eminent need for an academic program in universities to teach nanomedicine. *Int. J. Nanomed.* **2011**, *6*, 1733–1738. [CrossRef]
71. Deafen, M.E.; Walsh, D.J.; Audus, D.J.; Kroenlein, K.; De Pablo, J.J.; Aou, K. Wetworks an Interfaces as Catalysts for Polymer Materials Innovation. *Cell Rep. Phys. Sci.* **2022**, *3*, 101126.
72. Morganti, P.; Coltelli, M.B. (Eds.) *An Introduction to the Circular Economy*; Nova Science: Hauppauge, NY, USA, 2021.