

Communication

Food Loss and Food Waste for Green Cosmetics and Medical Devices for a Cleaner Planet

Pierfrancesco Morganti ^{1,2,*}, Xinghua Gao ³ , Natalia Vukovic ⁴ , Alessandro Gagliardini ⁵, Alka Lohani ⁶ and Gianluca Morganti ⁷

¹ Research and Development Unit, Academy of History of Healthcare Art, 00186 Rome, Italy

² Dermatological Department, China Medical University, Shenyang 110001, China

³ Dermatological Department, The First Hospital of China Medical University, Shenyang 110001, China; gaobarry@hotmail.com

⁴ Laboratory of International and Regional Economics, Graduate School of Economics and Management, Ural Federal University, 620000 Ekaterinburg, Russia; shpak17121978@gmail.com

⁵ Research and Development Unit Texol Srl, 65020 Alanno, Italy; alessandro.gagliardini@texol.it

⁶ School of Pharmaceutical Sciences Moradabad, IFTM University, Moradabad 244001, India; alkalohani06@gmail.com

⁷ ISCD Nanoscience Center, 00165 Rome, Italy; lucamorgan@libero.it

* Correspondence: pierfrancesco.morganti@iscd.it

Abstract: To stay wealthy in a world where all can live in prosperity and wellbeing, it is necessary to develop sustainable growth at net zero emissions to stop climate change, neutralizing both risks and diseases such as the COVID-19 pandemic and inequalities. Changing the worldwide use of the great quantity of food loss and waste can help to move in this direction. At this purpose, it seems useful to transform food waste into richness, extracting and using its content in natural ingredients and biopolymers to make new sustainable products and goods, including cosmetics and medical devices. Many of these ingredients are not only bioactive molecules considered of interest to produce these consumer products but are also useful in reducing the environmental footprint. The active agents may be obtained, for example, from waste material such as grapes or olive pomace, which include, among others natural polymers, phythosterols, vitamins, minerals and unsaturated fatty acids. Among the polymers, chitin and lignin have shown particular interest because biodegradable, nontoxic, skin- and environmentally friendly ingredients can be obtained at low cost from food and forestry waste, respectively. According to our experience, these polymers may be used to make nanocomposites and micro-nanoparticles that encapsulate different active ingredients, and which may be embedded into gel and non-woven tissues to realize advanced medications and smart cosmeceuticals. However, to utilize food waste in the best possible way, a better education of both industry and the consumer is considered necessary, introducing all to change the ways of production and living. The consumer has to understand the need to privilege, food, cosmetics and goods by selecting products known to be effective that also have a low release of carbon dioxide. Thus, they must pay heed to purchasing cosmetics and medical devices made by natural ingredients and packaged by biodegradable and/or reusable containers that are possibly plastic free. Conversely, the industry must try to use natural raw materials obtained from waste by changing their actual production methods. Therefore, both industry and the consumer should depart from the linear economy, which is based on taking, making, and producing waste, to move into a circular economy, which is based on redesigning, reducing, reusing and recycling. Some examples will report on the possibility to use natural polymers, including chitin and lignin, to produce new cosmeceutical tissues. These innovative tissues, to be used as biodegradable carriers for making smart cosmetics and medical devices, may be produced at zero waste to save our health and the planet biodiversity.

Keywords: waste; food loss; polysaccharides; chitin nanofibrils; lignin; greenhouse gas; carbon dioxide; methane; plastics; nanocomposites; biopolymers; natural ingredients; cosmeceutical-tissues; cosmetics; medical device; beauty market



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1. Introduction

Global food lost and waste, which represent about 17% of the productive process, has become a big problem, with a cost of USD 2.6 trillion annually, which is enough to feed the millions of undernourished people in the world [1–3]. This waste averages around 931 million tons each year, 61% of which comes from households, 26% from food service and 13% from retail. Moreover, according to the United Nations report, the unconsumed food that ranges from 8–10% and releases part of global carbon emissions [2], has enormously increased after the industrial revolution (Figure 1) [4]. In addition to carbon dioxide (CO_2), anthropogenic methane (CH_4) emissions represent the second-largest driver of global warming, accounting for roughly 30% of the temperature increase [5]. Additionally, while CH_4 stays in the atmosphere for only about ten years, CO_2 stays in the atmosphere for centuries.

Atmospheric CO_2 has risen dramatically over the past 200 years.

Annual concentration of CO_2 equivalent, parts per million

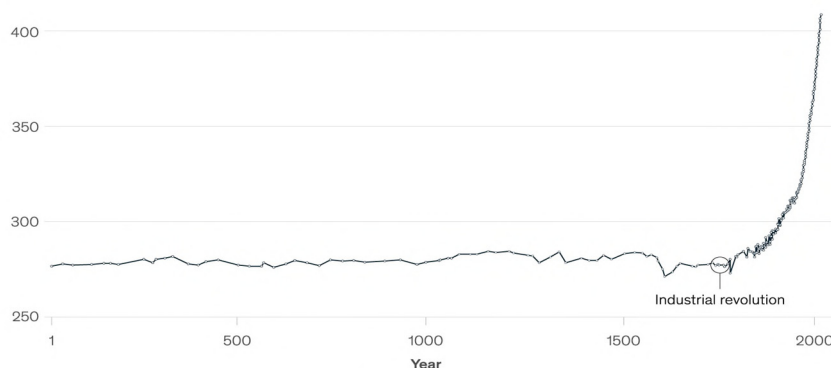


Figure 1. Atmospheric carbon dioxide concentrations during past and present years (Reprinted with permission from Doer and Narisetti (2021). 2021 McKinsey Global Publishing [4]).

Because of these emissions, the global temperature in 2021 resulted in a 1.1 degree centigrade higher temperature than preindustrial levels because of global greenhouse gas (GHG) emissions (Figure 2), and part of these emissions are represented from methane (CH_4) [5]. CH_4 comes from millions of agricultural farms around the world as the result of ruminant animals together with farming practices and rice production [1,2]. Carbon dioxide comes from the consumption of our actual household goods, food, dietary supplements, cosmetics and medical devices, which are connected to our actual way of living [6,7].

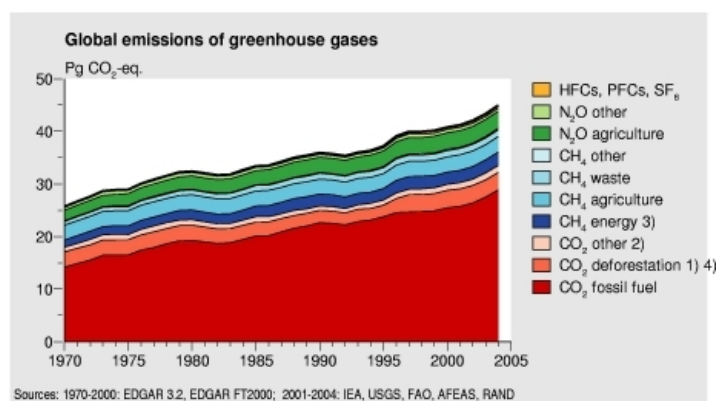


Figure 2. Global greenhouse (GHG) gas emissions.

As a consequence the urgent need to change and select all the purchased products for trying to eliminate waste coming from their formulations' ingredients and plastic-made

packagings, thus reducing the CO₂ and CH₄ emissions [8]. So doing it will be possible to organize a wellness economy eliminating any kind of waste and pollution, recycling food loss and reducing waste provoked from the plastic packagings also [9]. Global waste, in fact, has notably increased during the COVID-19 pandemic for two principal reasons: a drop in demand in restaurants, closed all the day and full of unconsumed and spoiled ailments, and a major contemporary take-away food used from consumers for the imposed lockdown [10]. This unusual consume of food, in fact, packed in containers made by non recyclable polymers has further increased the quantity of non biodegradable plastics invading land and ocean, provoked by billion of non-degradable products, including medical devices, food and cosmetics' packagings [11–13]. As for food, the cosmetic products release in the environment non biodegradable ingredients and plastic waste materials coming from the personal care and make up formulations which, including, viscosity, suspending and scrubbing agents, are packed by plastic containers estimated to be globally and yearly more than 120 billion units [14–21]. At this purpose, it is to remember the great problem of microplastics (MP) in oceans, ranging 1.8 trillion of peaces with an estimated global weight of 80,000 tons. MP debris, in fact, is ingested as toxic food from millions of marine mammals and birds, entering in the human food chain with the consequent release and bioaccumulation of toxic ingredients, including phthalates, phenolic compounds and polybrominated diphenyl ethers (PBDE) many of which are endocrine disrupting chemicals, capable to alter the homeostasis of the human immune system (Figure 3) [11–13,19]. At this purpose, it is to underline that billion of microplastics have been recovered not only into the tea-cups consumed daily from million people [22], but also into the human placenta [23]. On the other hand, fortunately, the coronavirus due to social distancing and lockdown, has kept people inside with a consequential decrease of the general pollution' levels, that for example in China was reduced by 25% [5].

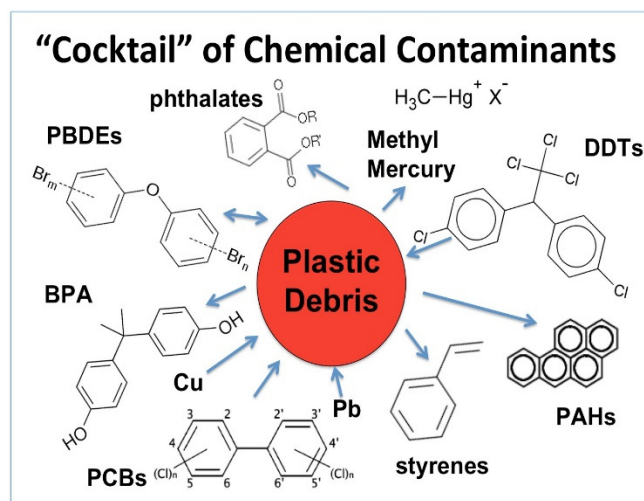


Figure 3. Toxic ingredients in microplastics (Reprinted with permission from The Ocean Foundation and earthDECKS).

However, pandemic, health and climate change are inextricably linked each other, so the need of a healthy body in a healthy planet by the use of biodegradable products, including cosmetics and medical devices. Moreover, there is a necessity to produce more food for the previsions worldwide population growth to 9.7 billion by 2050, realizing also well structured healthy green areas into the cities to neutralize the continuous increasing of the GHG emissions [24]. Therefore the urgent necessity to organize a more efficient food production chain and a better health care and cosmetic system by the use of natural biodegradable ingredients and containers as well as to build a greater resilience against the climate changing, modifying the way to produce and consume.

Consequently, preventing diseases and environmental disasters became a must of our society: prevention is better than cure both for virus and extreme weather.

In conclusion, eliminating food waste at all levels, including consumer and domestic, and using its content in active ingredients to make cosmetic and medical device also, became today a further necessity. So doing it will be possible to save precious natural resources and avoid the methane and carbon dioxide emissions, obtaining significant environment, social and economic benefits. Moreover, another need is not only to change the food supply chain, but also modify our nutritional habits selecting as much possible, the food at lower impact on CO₂ emissions (Figure 4) [4]. Additionally, there is also the urgent hard job to utilize the actual million tons of by-products coming from both the industrial food chain and the forestry waste. This waste material might be used for making different and safe goods, innovative cosmetics, surgical and beauty masks and one-use only medical dressings, incentivizing and increasing the food systems' transformation [19,25–29]. Industrial as well as the in-house food waste, in fact, are rich of proteins, sugars, carotenoids, vitamins, lignans, polysaccharides and various natural-derived polymers, precious ingredients to produce drugs, medical devices, cosmetic products, diet supplements, and innovative biodegradable tissues [25–35]. Among the fibers that may be obtained from food waste there are many natural polymers, including chitin/chitosan, lignins and pullulan by which it could be possible to make, for example, specialized medical dressings, bio colors and bioflavors for the nutraceutical and cosmetic sectors, cosmetic beauty masks and smart tissues to be used as innovative *active* carriers also [36–38]. As will be focused thereafter, our research group has realized innovative carrier complexes made by chitin nanofibrils with different anionic polymers as nanolignin (CN-LG), verifying their physicochemical characteristics and biological effectiveness when used for cosmeceutical products and medical devices [39,40]. Moreover, regarding the CN-LG complex, being easily metabolized from the environment and human enzymes to active ingredients such as glucosamine, acetyl-glucosamine, glucose and polyphenols, these derived molecules could be utilized from the skin cells as food and energy. Consequently, CN-LG acts both as carrier, due to its possibility to entrap active ingredients into its structure and as *active* compound when the complex is hydrolyzed to its single units [39–41].

Livestock supply chains are an important contributor to climate change.

Greenhouse-gas emissions produced per kilogram of food product, kilogram CO₂ equivalent

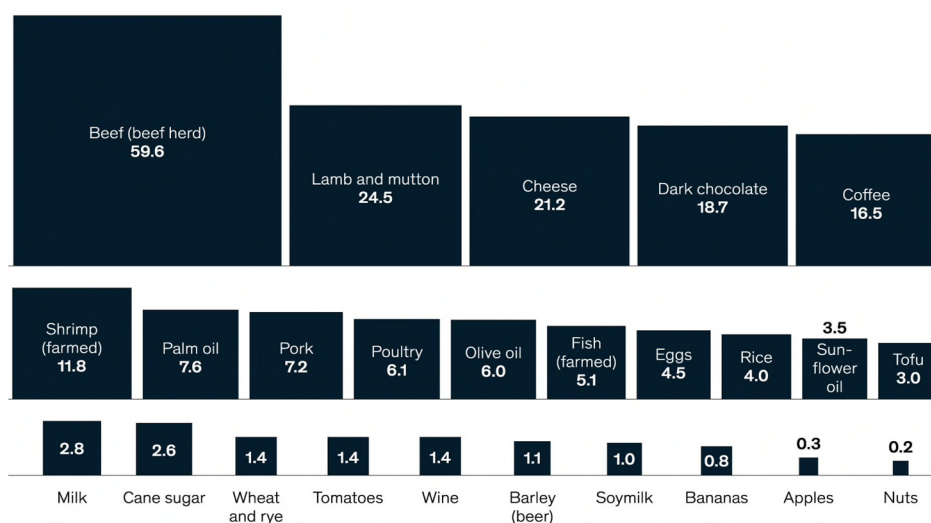


Figure 4. GHG emissions released in the environment to produce different kind of food (Reprinted with permission from Doer and Narisetti (2021). 2021 McKinsey Global Publishing [4]).

2. Agricultural Waste, Biobased Active Ingredients and Biopolymers

The quantity of agrowaste derived from various supply chains and calculated at 90 million tons of oil equivalent represents an important source of starting materials, which are used in the production of pharmaceuticals, cosmetics, diet supplements, antioxidant compounds, natural fibers, biodegradable polymers and composites as well as in bio-based plastics [42–46]. Horticulture, in fact, is one of the industries with the highest production covering around 38% of the global agricultural production, 65% of which is represented from vegetables and fruits, including tomato, onion, grapes, orange, potato, wheat etc. Consequently this Industrial field, generates food loss and waste such as orange and lemon peels, grapes and olive oil pomaces, sugarcane bagasse, wheat straw among others, all coming from specific processes such as pulping, peeling, straining, and branching [47]. Additionally this waste not only increases the deterioration of the Environment, but also contributes to the scarcity of resources, losing the opportunity to contribute to the feeding of a growing world population [47]. However, the agricultural waste has to be considered a primary source of starting materials to produce active ingredients for cosmetic and pharmaceutical use as well as polysaccharides used as essential precursors for developing biodegradable plastic-materials for sustainable packagings [48]. In any way It is to underline the biodegradable polymers for commercial application have to be based for its physical property of high tensile strength and yield [48]. In any way, the production of both active ingredients and bio-based polymers from agro-wastes is influenced by the availability of starting materials/precursors that should be cheap and available in significant quantity and designed by selected fruits and vegetables [49–53]. However, the search of green formulations for the production and packaging of Eco-friendly products, including cosmetics, diet supplement and medical devices, is mandatory in the field of green chemistry and economical sciences [49]. It is therefore necessary to try to reduce/eliminate the food losses and waste produced and generated each year. It's, in fact, to underline the food lost is estimated to be around 198.9 kg per capita in developed countries as the United States, where it accounts for the 40% of the whole food local production chain, while in Europe it represents 6% only [45–54]. But it is also to remember that among the leading economies India and China have the capacity to lead the production of fruit and vegetable-based biopolymer, given the high production capacity and shear of their total global production [55]. Thus, the majority of natural actives used in cosmetic and nutraceutical formulations are currently imported from Europe were the consumers like to return to natural products. Regarding the biotechnologies used to extract and characterize the million tons of food waste it is also to remember the utilization of the microorganisms which, cultured under different nutrient and environmental conditions, are frequently used to produce biodegradable polymers by the electrospinning technique and through the fermentation of carbohydrates obtained from agricultural by-products such as corn and wheat [52–57].

3. Biofunctional Textiles and Nanocomposites for Medical and Cosmetic Use

Biofunctional textiles protect against anything that may injure the naked human body, including weather, insects and noxious chemicals, but may also be used for wound healing purposes [29]. Moreover garments with their content of natural and synthetic polymers and chemicals such dyes, being all day long in direct contact with the skin, may interact with its functions, provoking allergic and sensitizing reactions [58]. Tissues, in fact are one of the causes of skin diseases, such as atopic dermatitis and psoriasis [59,60]. On the other hand, clothing represents an interactive skin barrier ensuring the thermal balance despite changes in ambient temperature and humidity, thus reducing radiant heat gain and thermal stress [61]. Skin sensory comfort, in fact is determined by the direct contact of textile with the skin so that garments have to possess heat insulation and moisture balance, resistance to water vapor permeability, perspiration transport and drying time, all characteristics which depend on fabric fibers [58–61]. Thus by the electrospinning technology and the use of natural polymers such as polysaccharides it is possible to produce non-woven

tissues characterized by an high specific surface area (up to 1000 m square/g), tunable porosity and mechanical resistance [62]. Various natural polymers, in fact, may be obtained from lignocellulosic fibers derived from plant waste, such as pineapple, sisal, bamboo and jute [63]. The relative fibers have interesting structural properties useful for tissue engineering and delivering of active ingredients through the skin for repairing, for example, wound healing/burns or to be used as cosmetic carriers, as reported from various studies of our research group [36–38] and better focused thereafter also. Additionally non-woven tissues, produced by different technologies, address a variety of end uses and applications so that their global consumption in 2019 has been 11.2 million tons with a growth rate valued at 5.9% for 2014–2019 [64].

Therefore, research and innovation are based on special bioactive pharmaceutical/cosmetic-emulsions and/or smart cosmeceutical-tissues capable, for example, to continually release small doses of active ingredients through the skin' intercellular or intracellular pathways for obtaining protective/moisturizing or therapeutic effects [65–71]. Moreover, tissues and clothing may impair a further antimicrobial defense, providing mechanical barrier against insect bites, mosquito and protozoa as well as has to protect from fungi, bacteria and viruses responsible for infection and allergy problems [59,60]. At this purpose, biocidal, antioxidant or antiinflammatory compounds may be bound to the surface of polymeric fibers for realizing specialized tissues of medical or cosmetic interest. Among the many active ingredients, silver is often used in wound dressings as a topical bactericidal agent for burns and wounds, taking always into account the right dose necessary to maintain the balance of both skin epidermal lipid barrier and microbial ecosystem [72,73]. At this purpose, our research group has verified in vitro and in vivo the activity of non-woven tissues made by specialized fibers and different natural or natural-derived polymers, such as gelatin, chitin, lignin, pullulan polylactic acid etc. Thus on the fibers' surface of CN, for example, has been bound a low quantity (20ppm) of nano-structured silver. The obtained tissue has shown an interesting activity on burns of 1st and 2nd grade with an high antiinflammatory and a faster skin repairing effectiveness, compared to commercial advanced medications [54–78]. Probably this activity was due to the particular characteristics of the non-woven bio-tissue made by biodegradable fibers of polysaccharide nanocomposites (gelatin lignin) bound to chitin and silver ions (Ag^+) at their nano dimension, having therefore an high area/weight ratio and an interesting antibacterial effectiveness (Figure 5) [78,79]. The high humidity of burn, in fact, seems to promote an easy silver uptake throughout the skin that justify its interesting activity [75–81].

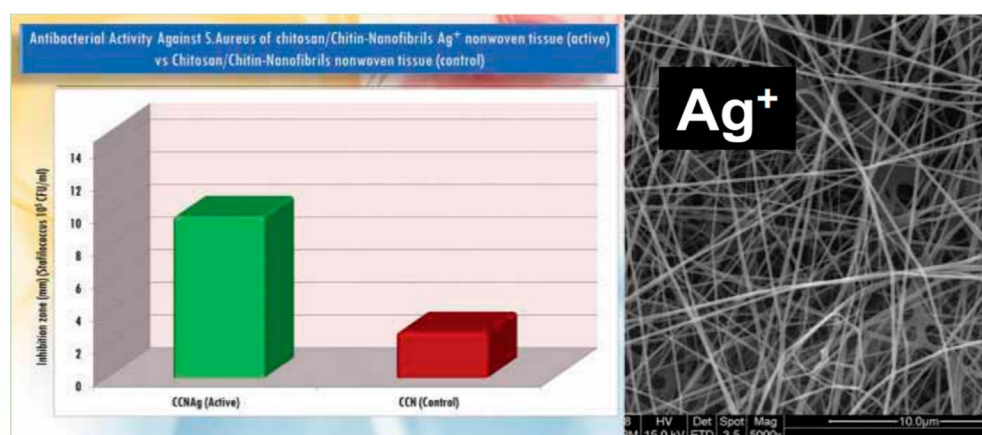


Figure 5. Antimicrobial activity of non-woven tissue made by polysaccharides and Chitin nanofibrils bound to nanosized Ag^+ [68].

Numerous are the possible natural polymers useful to make biodegradable nanocomposites and wound dressings. Among the more used to produce nanocomposites and bioactive scaffolds there are hyaluronic acid, collagen, chitin/chitosan, lignin, gelatin,

alginate and keratin, because of their non-toxicity, biodegradability, biocompatibility non immunogenicity and ready availability from by-products materials, as food waste (Figure 6) [76–78]. In particular and as previously reported, eliminating food waste throughout the entire supply chain, not only saves precious resources but also avoids the harmful methane activity [5]. Moreover, it is interesting to underline the further possibility to use these polymers for encapsulating bio-ingredients into micro-nano complexes of chitin nanofibrils-nanolignin (CN-LG). In turn these complexes, used as active agents or carriers may be embedded into biocomposite non-woven tissues with the aim to enhance the skin regenerating activity of innovative and rejuvenating anti-aging cosmeceuticals [79–84]. The tissues, in fact, are generically prepared combining multiple fibrous layers of different types of polymers, fibers or textile components to obtain structures characterized by a high surface area/weight ratio and a porosity made by an interesting pore size distribution and interconnectivity [78]. At this purpose, it is to underline that 1 g of chitin develops 2 square meters of tissue, while 1 g of chitin nanofibers (CN) develops more than 180 square meters [85]. Additionally it is also possible to make innovative bio-nanocomposites, combining for example chitin with synthetic bio-based polymers, including polylactic acid (PLA) [86,87] or Polyhydroxyalkanoates (PHA) [88] to improve their mechanical properties. Thus, the incorporation of just 1% of chitin into PLA resulted useful to enhance the mechanical properties of nanocomposites as well as to increase their viscosity and the anti adhesive and antifungal activity [87]. Bio-nanocomposites, in fact, show to be material possessing markedly improved properties when compared with pure polymers or conventional composites. However, the nanocomposite performance depends on various nanoparticles features, including size, high surface area/weight ratio, compatibility with matrix and dispersion [89]. Therefore chitin, when used at nano dimension, encourages the skin regeneration activity probably because its nanofibrils provide a three-dimensional structure that mimics the natural extracellular matrix (ECM) (Figure 7) [90]. Moreover and first of all, the different polymers and active ingredients have to be well selected, according to their therapeutic or cosmetic applications (Figure 8) [91,92]. Just as an example, our research group has encapsulated glycyrrhetic acid (GA) as antiinflammatory agent and vitamin E as antioxidant compound into the complex chitin nanofibrils and nanolignin (CN-LG), verifying their distribution on the novel textile surface and the Vit E recovery (Figure 9) [93,94]. The effectiveness of the final tissue obtained by the use of the complex CN-LG-GA has been evaluated both in vitro and in vivo [93–95]. Naturally both polymers and active ingredients used have been obtained from food waste. These and other studies in progress are considered fundamental for recovering new active compound and innovative natural carriers necessary to maintain the Earth' raw materials for the future generations and save the environmental balance.

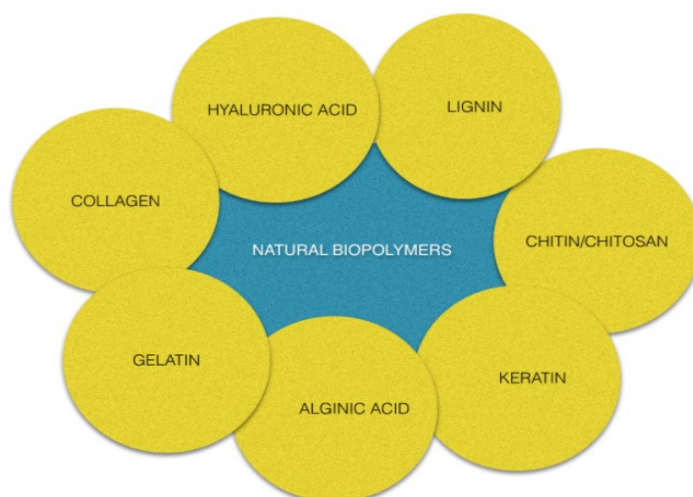


Figure 6. Some of the natural polymers used to make Nanocomposites and wound dressings.

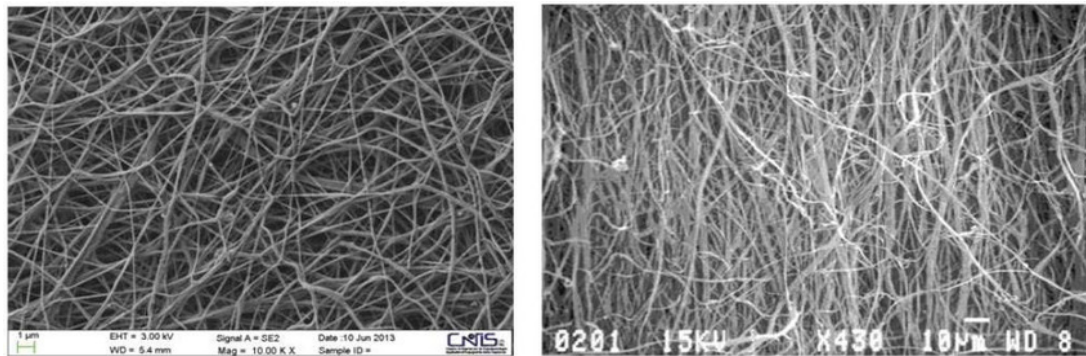


Figure 7. Structure of chitin-made tissue (left) compared to the Natural Extracellular Matrix (ECM) (right). By Scanning Electron Microscopy (SEM) (Reprinted with permission from Donnarumma et al. (2019). 2019. MDPI [89]).

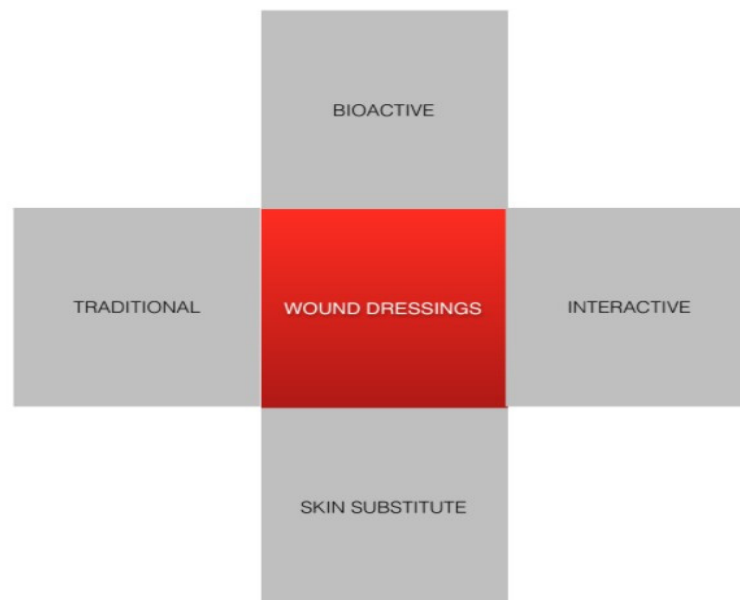


Figure 8. Classification of wound dressings according to their applications.

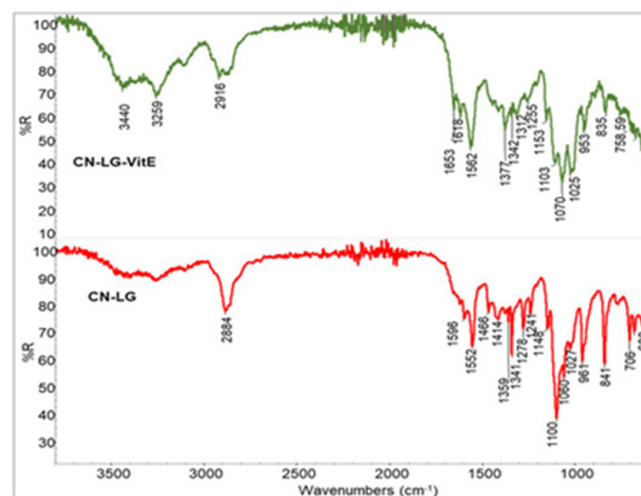


Figure 9. Infrared spectrum of the complexes CN-LG and CN-LG-VitE (Reprinted with permission from Panariello et al. (2021) MDPI [93]).

4. Conclusions

Using the actual food waste and establishing the circular economy to make biodegradable and natural-based products and packaging materials, will give the industry a business calculated around USD 7.7 trillion by 2030 [95]. Just as an example, the global Cosmetic Industry, evaluated USD 483 billion in 2020 and estimated to range USD 784.6 billion by 2025 (Figure 10) [96] could produce around USD 37 billion of non biodegradable primary packaging. In this market the global organic and natural cosmetics are expected to reach USD 25.11 billion by 2014 for the consumer's request who are looking for products made by renewable biobased ingredients preferred because considered non toxic and biodegradable [96]. Moreover the current market for sustainable, natural and green products is massive because additionally, government support are creating a favorable climate for big business players. Therefore, the chemical composition of the ingredients and their doses in the formulation decides the potential impact on health of the cosmetic product to be purchased [97]. It is, in fact, to underline the every day use and continuous exposition of humans to a wide range of different kind of chemicals derived from several sources, including cosmetics that may cause the so called "cocktail effect", due, for example, to a synergistic interaction of the same ingredients used by different products, as fragrances [97,98]. However, beauty cosmetics are the fastest-growing market worldwide not only for women but also for male consumers because after pandemic they feel more confident about their look than a year ago [99]. Thus 34% of males showed more interest in beauty/cosmetics buying them in an unprecedented rate in early 2020 in all the markets from China to Australia, North America and Europe, just as women interest showed early signs of stagnation [99,100]. Consequently, products that improve or maintain appearance seem now just important as ones that enhance it, so that people spent billions to look good and healthy during the lockdown periods! Consumers, in fact, are looking for more from the life in the past-pandemic world, and wellbeing is talking center stage to live to the fullest [101]. On the other hand, the worldwide citizens are becoming to understand the need to change their daily habits, counteracting waste at home. However, governments and consumers have finally recognized that global warming, waste disposal, air pollution and natural resources exhaustion are the main cause of many environmental disasters [102–104]. For all these reasons, food Industry has increased research studies by a manufacturer consumer-oriented approach with the aim to optimize the food-chain production and utilize its waste for obtaining active ingredients to be used for producing not only functional food but also advanced medications, diet supplements and natural cosmetics, involving in this new business other industrial sectors of developing countries also [105,106]. Thus the need to maintain and protect the authenticity of the traditional products valorizing the food processes by sustainable solutions that, balancing the energy and water consumption, may represent a responsible utilization of the natural resources with a respect for the environment [107–109]. Consequently, the studies for obtaining new pure and active bio-ingredients environmentally-friendly by the use of biochemical and enzymatic technologies are progressing day by day, as well as to treat appropriately the industrial food by-products valorizing its precious content [110–114]. Continuing to invest in research and innovation to stop the food losses and turning waste into valuable products, it will be possible to increase the profitability of food, pharmaceutical and cosmetic industries, ensuring a healthy environment in addition to a sustainable development for all [113]. According to United Nations, in fact, the sustainable development is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [115]. Therefore, the industry needs to increase its knowledge and technical know-how ameliorating the producing methodologies and utilizing the biomolecules' content of the releasing by-products adopting the circular economy approach [116]. Thus changing the way of producing, consuming and living, it will be possible to deliver a zero-plastic pollution and waste, reducing carbon emissions and helping to boost and drive a circular bio-economy capable to safeguard the environment and combat the climate change [117–123]. Circular bio-economy, in fact, based on

nature-based goods, recycling materials and investments in green initiatives by the power of bioscience and biotechnology, might represent a solution to address the resources scarcity and help to tackle the air and marine pollution [118–122]. Thus consumers education together with industry research and innovation represent the key to transitioning from a plastic-based economy to a bio-based ones, by changing the production of feedstock and non recyclable petrol-based materials in favor of degradable fossil-free goods, medical devices and cosmetics [124–127]. For all these reasons, the food and cosmetic industry are becoming to pay attention to these problems by the research of natural sources of active ingredients that, extracted from food waste by the available sustainable technologies, may be used for producing biodegradable packagings and innovative products skin- and environmentally-friendly, fundamental to reduce the by-products' negative environmental impact [125–138]. Moreover, the industries are changing the non biodegradable packaging materials, knowing, for example, that 95% of beauty packaging is thrown out after just one use, and only 14% of plastic makes it to a recycling center [18–21]. Unfortunately today only 9% of all plastic waste ever produced has been recycled, about 12% incinerated and 79% ended up in landfills [18–21,139]. Therefore, adopting a virtuous industrial comportment, it will possible not only to use the actual food waste safeguarding the environment, but also to increase the global food production, necessary to eliminate the actual worldwide hunger and poverty [122–124]. Recycling food industrial waste should not be an option rather an obligation that call for serious attention to finally achieve a circular economy [116,139]. By the actual molecular biology and biotechnology it seems possible, in fact, to obtain a sustainable development of agricultural practices as well as of food processing, improving among others production and availability of biodegradable and effective medical devices, diet supplements and cosmetics to range an healthy beauty in a clean environment. The proposed production of smart cosmeceutical-tissues packed by nature-derived materials seem to go in the right direction because made by biodegradable and natural polymers, including chitin and lignin, obtained by food byproducts through a sustainable technology at zero waste [38,39,80,124–128]. Moreover, as reported previously these innovative products don't contain preservatives, emulsifiers, fragrances and other chemical compounds often cause of allergic and/or sensitizing problems [18,58–60]. In conclusion, it is necessary to stop the planet global warming, restore biodiversity and protect lands and oceans, building an ecosystem that really enables the truly circularity of biomaterials and economy for all. Thus the urgent need to develop new value chains, and innovative technologies and infrastructures capable to create a future comfortable and green planet for the future generations.

So doing people of all countries could obtain wellbeing and sufficient money, living in more green cities consuming biodegradable and safe food produced by a circular bioeconomy, using healthy fashion, cosmetics and goods to live in a more equal world [140–147].



Figure 10. Beauty Industry Trends 2020–2025 (Reprinted with permission from Common Thread (2021) [96]).

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