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Review

New Insights on Unique Features and Role of Nanostructured Materials in Cosmetics

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Abstract: The cosmetics industry has boomed in recent years as one of the markets that holds enormous growth potential. Among several industrial sectors, the cosmetics industry has considered nanotechnology-based principles and implemented in product management practices. Out of 1000 registered products available on the global market, up to 13% were referred to as products for cosmetic use. A large number of nanoscale materials with unique physicochemical properties are currently being used in the cosmetics formulations or recommended for future use as nano-systems or novel nanocarriers to encapsulate active ingredients for their efficient delivery through the skin barriers. These nano-systems have demonstrated potential in targeted-oriented drug delivery and offered remarkable features such as better stability, site-specificity, excellent encapsulation efficiency, prolonged action, enhanced skin penetration, and high drug-loading capability. Nevertheless, nanotoxicology research has raised concerns over the excessive use of nanomaterials/nanoparticles in cosmetics, as nanoparticles might enter the skin resulting in health problems. This review provides insights on the characteristic physicochemical features and the potential use of various nanostructured materials, including liposomes, noisome, nanoemulsions, nanoparticles, carbon nanomaterials (graphene, fullerenes), carbon nanotubes, dendrimers, and nanospheres in cosmeceuticals. Moreover, the regulatory aspects of nanomaterials in cosmetics, along with concluding remarks and outlook in this field, were also vetted.

Keywords: cosmetics; nanotechnology; nanostructured constructs; novel delivery systems; nanomaterials; safety

1. Introduction

The cosmetics industry has boomed in recent years as one of the markets that hold enormous growth potential. The global market for cosmetic products was valued at USD 532.43 billion in 2017 and is expected to garner USD 805.61 billion by 2023, registering a compound annual growth rate (CAGR) of 7.14% from 2018 to 2023 [1]. Over the past few years, the cosmetic industry has been flourishing with an expanding rate of around 15%, and it continues to grow [2]. With particular reference to the nanotechnology-based products, an average of 16.6% growth rate is expected in the global cosmetic market, each year [3]. These projections of significant growth have not yet been validated. However, they highlight the application of nanotech-based products in cosmeceuticals. With increasing apprehensions for beauty products, the use of cosmetics has dramatically intensified. The cosmetic industries continue to explore new ways of product development that provides for more youthful, healthier, and smoother skin [4].

With improved product features, the use and deployment of nanotech-based practices are regarded as one of the hottest technologies available. Incorporation and use of nano-scale ingredients are gaining popularity in the cosmetic industry because of their tiny size and high surface area to volume ratio [5]. These nanostructured materials often have physical and chemical characteristics and biological activities that differ from their bulk equivalents. Some of the essential technological advantages that may be achieved by incorporating nanomaterials in cosmetics are enhanced performance, unique texture, transparency, protection of active substances, and higher consumer acquiescence [6]. For instance, larger particles, i.e., zinc oxide and titanium dioxide, are white and opaque, but these substances become transparent at the nanoscale, enabling their usage in foundations and moisturizers. Aluminum oxide nanoparticles provide a "soft-focus" effect to disguise visible wrinkles and expression lines and thus can be used in foundations, face powders, and high-end concealer sticks. Similarity, due to effective skin penetrating ability, carbon "fullerene" nanoparticles are used in moisturizers and anti-aging creams. Therefore, the cosmetics industry has now routinely started the use of nano-ingredients in the formulation of cosmetic products [4].

2. Literature Review Approach—Inclusion/Exclusion Criteria

The literature evaluation was performed using a standardized methodology by following a defined inclusion/exclusion criterion. Such inclusion/exclusion criterion-based literature evaluation and discussion are mostly ignored in earlier reports. Thus, herein, an effort has been made to cover this approach. The inclusion/exclusion criterion was also adopted to justify the key points and scientific aspects of the work compiled herein. There are two main points: (1) scientific theme of the literature covered in this review and (2) cover up the literature gap as per study contents were focused on recent and relevant examples. Both points were covered by browsing the literature from the authentic databases, i.e., Scopus and PubMed. For Scopus and PubMed databases, the literature search queries were performed on 10 March 2020, at "https://www.scopus.com" and "https://www.ncbi.nlm.nih.gov/pubmed/", respectively. Initial literature survey screening was performed on available contents from Scopus and PubMed by searching the most related and revenant keywords/terms from the nanostructured materials in cosmetics. The initially screened literature data was further analyzed and confined, ensuring the inclusion/exclusion criterion. Briefly, the studies that encompass the work theme points (discussed above) were considered for inclusion purposes or else excluded at the initial screening stage. As per work contents, following key terms were considered most suitable for data access purposes, i.e., nanostructured materials in cosmetics, liposomes in cosmetics, nanoemulsions in cosmetics, nanoparticles in cosmetics, and nanotubes in cosmetics, in the article title, abstract, and keywords of the reported data at Scopus and PubMed. Table 1 summarizes the obtained data statistics from the Scopus database. While the statistics obtained from the PubMed database are displayed in Table 2.

Table 1. The search terms and data statistics obtained from the Scopus.

Search Terms	Document Types	# of Articles from All Years		# of Articles from Top Journals		# of Articles Based on Territory	
Nanostructured materials in cosmetics	Article, Review, Book Chapter, Conference Paper, Book	2020	9	Journal of Nanoparticle Research	6	United States	67
		2019	18	Environmental Science and Technology	5	Italy	32
		2018	24	Langmuir	5	Germany	27
		2017	26	Nanobiomaterials In Galenic Formulations and Cosmetics Applications of Nanobiomaterials	5	India	25
		2016	36	Colloids and Surfaces B Biointerfaces	4	China	23
		All past years	192	All other Journals	280	Other countries	131
liposomes in cosmetics	Article, Review, Book Chapter, Conference Paper, Short Survey	2020	5	International Journal of Pharmaceutics	12	United States	52
		2019	30	Journal of Cosmetic Science	10	India	49
		2018	35	International Journal of Cosmetic Science	9	Germany	38
		2017	30	Colloids and Surfaces B Biointerfaces	7	France	27
		2016	38	European Journal of Lipid Science and Technology	7	Italy	27
		All past years	289	All other Journals	382	Other countries	234
nanoemulsions in cosmetics	Article, Review, Conference Paper, Book Chapter, Book	2020	12	International Journal of Pharmaceutics	9	India	48
		2019	42	International Journal of Cosmetic Science	8	Brazil	39
		2018	42	Colloids and Surfaces A Physicochemical and Engineering Aspects	7	United States	37
		2017	26	Colloids and Surfaces B Biointerfaces	6	Italy	22
		2016	36	Journal of Applied Cosmetology	6	China	21
		All past years	146	All other Journals	268	Other countries	137
nanoparticles in cosmetics	Article, Review, Book Chapter, Conference Paper, Short Survey	2020	72	International Journal of Pharmaceutics	39	United States	318
		2019	238	International Journal of Cosmetic Science	28	India	312
		2018	255	International Journal of Nanomedicine	25	China	266
		2017	236	Colloids and Surfaces B Biointerfaces	23	Germany	183
		2016	248	Nanotoxicology	22	Italy	147
		All past years	1238	All other Journals	2150	Other countries	1061
nanotubes in cosmetics	Article, Review, Book Chapter	2020	3	Journal of Nanoscience and Nanotechnology	4	United States	37
		2019	16	Advanced Materials Research	3	India	29
		2018	19	Proceedings of SPIE The International Society for Optical Engineering	3	China	23
		2017	14	Scientific Reports	3	Brazil	8
		2016	21	Analytical Letters	2	South Korea	8
		All past years	110	All other Journals	168	Other countries	78

Table 2. The search terms and data statistics obtained from PubMed.

Search Terms	Total Articles	# of Articles Published in the Last Five Years Filtered with Best Match Term on					
		2020	2019	2018	2017	2016	All Past Years
nanostructured materials in cosmetics	11,319	63	850	1022	967	1009	7408
liposomes in cosmetics	441	5	39	28	28	27	314
nanoemulsions in cosmetics	145	4	25	23	12	13	68
nanoparticles in cosmetics	8738	88	761	862	824	819	5384
nanotubes in cosmetics	1896	6	107	157	124	162	1370

3. Nano-Systems Used in Cosmetics

A large number of nano-systems or novel nanocarriers are commonly used in cosmetic formulations to encapsulate active ingredients for their efficient delivery through skin barriers. These nano-systems can help absorption or penetration of cosmeceuticals active moieties within epidermal layers in a remarkable way of achieving burst or sustained release of actives [7]. Various nanostructured cues used in cosmetics are shown in Figure 1. This section provides insights into the unique features and role of multiple nanocarriers or nanostructured materials for the delivery of cosmeceuticals in cosmetics.

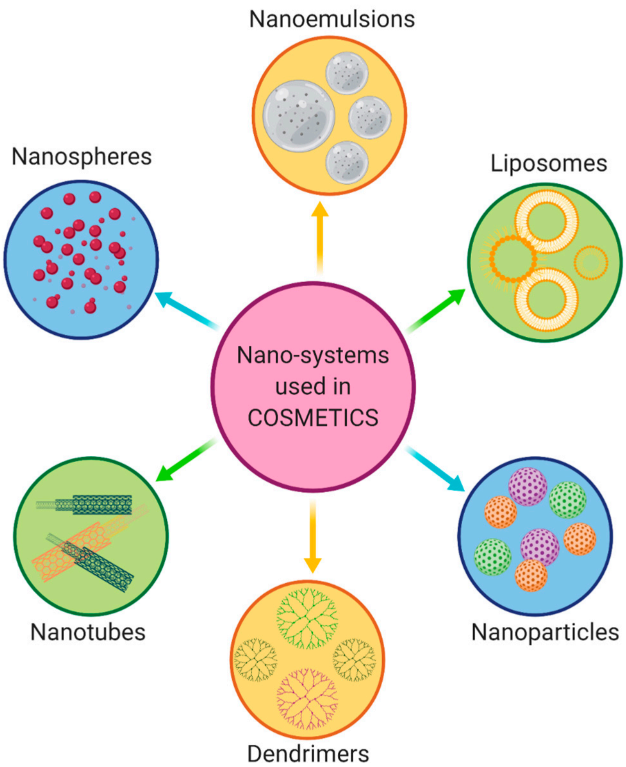

Figure 1. Various nanostructured cues used in cosmetics. The figure was created with the "BioRender.com" template and exported under the terms of premium subscription.

3.1. Liposomes and Noisome in Cosmetics

Liposomes are currently among the most widely-known cosmetic delivery system (Figure 2); thus, they are extensively incorporated in the cosmeceutical formulations [8]. The liposome-incorporated cosmeceutical formulations offer better skin penetration and help to protect the skin from harmful radiations, which otherwise cause several cancerous symptoms (Figure 3) and/or lead towards cell death via apoptosis (Figure 4). Liposomes constitute tiny vesicular spheres with an aqueous core. Furthermore, these tiny vesicular spheres are surrounded by a hydrophobic lipid bilayer [9].

Phospholipids are a principal constituent of the liposome lipid bilayer that are GRAS (generally recognized as safe) ingredients [10], thus presenting minimal adverse effects. Liposome (some manufacturers use the term "nanosomes") encapsulation protects the drug from metabolic degradation and facilitates the release of its bio-active constituents in a controlled way [11]. These are suitable to deliver therapeutic molecules with hydrophilic and hydrophobic nature. Their size ranges from 20 nm to several micrometers, a notable factor that also affects their targeting efficacy, and might have unilamellar/multilamellar structure [12]. The physical and chemical stability of liposomes in water can be improved by incorporating various antioxidants such as lycopene or carotenoids. Phosphatidylcholine is also an essential component of liposomes that have been used in many hair-care products (conditioner, shampoo) and skin care preparations (such as moisturizer creams) because of its conditioning and softening properties. Liposomes are used in a wide variety of cosmetics owing to their nontoxicity, biodegradability, biocompatibility, and ability to encapsulate active moieties [13]. Vegetable phospholipids are of particular interest for use in dermatology and cosmetics due to high-esterified essential fatty acid contents. For instance, owing to the overall surface activity and liposomes forming ability, soya and vegetable-based phospholipids have gained increasing interests. A clinical report demonstrated that the application of flexible liposomes shows beneficial effects such as intensification in skin smoothness, reduction in wrinkles, and decreasing efflorescence in acne treatment [14]. Additionally, liposomes are potential carrier candidates and extensively utilized in sunscreen, beauty creams, antiaging creams, profoundly conditioning cream, and hair products [15]. Capilene is a specific liposome-based cream in which highly concentrated herbal plant extracts are conveyed into a jelly-like liposomal vehicle and integrated with plant-originated omega-3, omega-6, omega-7, and omega -9 fatty acids, and ceramide precursors. It was observed that the use of liposomal cream significantly contributed to repair the surface lipid layer of the skin by actively delivering active substances (fatty acids, phospholipids, and ceramide precursors) in the activity site. Furthermore, it was thought to reestablish the hydrolipidic layer and regulate the loss of water from the *stratum corneum* without any damaging effect [16].

Noisome are referred to as nano-vesicles composed of self-assembly of essentially non-ionic surfactants [17], with/without the integration of cholesterol/lipids. These unilamellar or multilamellar vesicles comprise an aqueous solution of solute and lipophilic components enclosed by a membrane generated from the organization of surfactant macromolecules as a bilayer [18]. From the size range perspective, small unilamellar vesicles range 0.025–0.05 µm, large unilamellar vesicles range up to 0.10 µm, and multilamellar vesicles range >0.05 µm [19]. Cholesterol and non-ionic surfactants, including alkyl amides, brijs, tweens, spans, crown ester, sorbitan ester, steroid-linked surfactants, and polyoxyethylene alkyl ether, are the major noisome components that are widely used for its preparation [17]. Researchers from L'Oréal (Clichy, France) were the first to report the application of noisome in cosmetic products in the 1970s and 1980s. Since then, they have been mainly inspected for numerous applications, including cosmetic, pharmaceutical, and food sectors [20]. Noisome is used in cosmetic products and skincare applications since it exhibits the potential of reversible reduction of the barrier resistance of the horny layer. Thus, this increases the bioavailability of active constituent to the living tissues at a faster rate. Noisome is thought to improve drug delivery across the skin barrier [21,22]. Many factors, such as structure and nature of surfactants, the composition of the membrane, structural and functional attributes the encapsulated drug, and hydration temperature, can affect the formation of noisome [23]. Apart from conventional noisome, proniosomes are also employed to improve targeted drug delivery [9,24]. Numerous noisome-based cosmeceuticals formulations are available in the market, such as moisturizing and skin whitening cream, anti-wrinkle creams, conditioner, and hair repairing shampoo [25,26].

The use of noisome as a carrier system has gained increasing importance for cosmetic actives due to bioavailability, improved skin penetration, enhanced stability of encapsulated active substances, high surface adhesion, and constant release attributes [12]. In contrast to conventional formulations, noisome exhibit less toxicity and allow controlled transfer of the loaded active ingredients, which in turn show beneficial effects for skin soothing and tanning products [27]. Many plant-derived biologically active substances are of high interest in cosmetics because of their beneficial activities such as anti-aging and antioxidant. A vast number of bioactive substances extracted from plants have been probed using noisome to augment their beneficial effects on the skin.

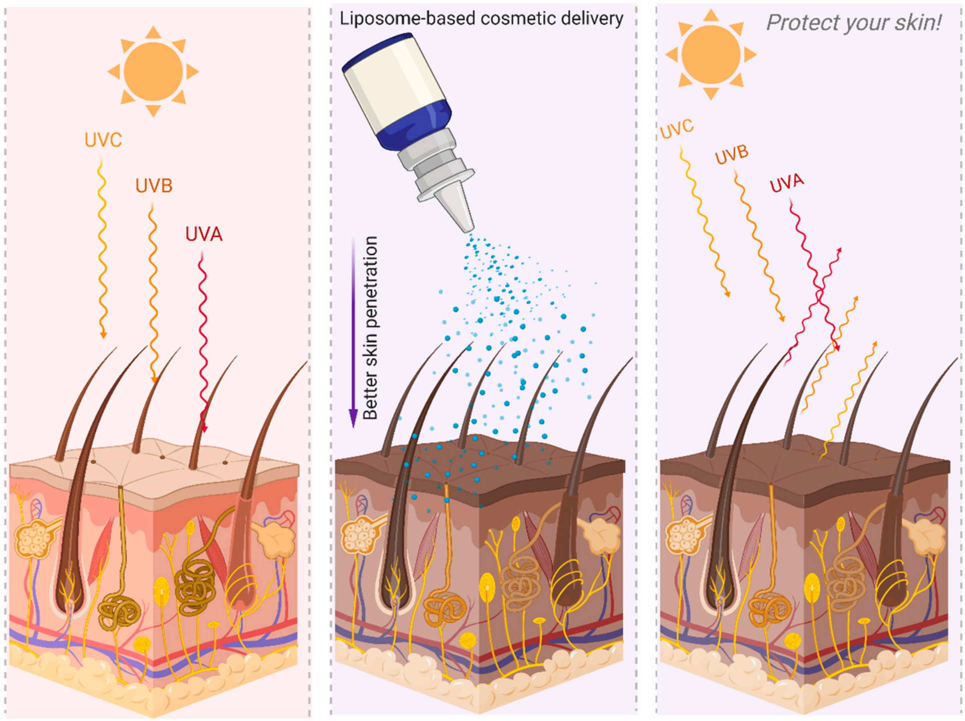

Figure 2. Liposome-based cosmetic delivery via the skin. The liposome-incorporated cosmeceutical formulations offer better skin penetration and help to protect the skin from harmful radiations. The figure was created with the "BioRender.com" template and exported under the terms of premium subscription.

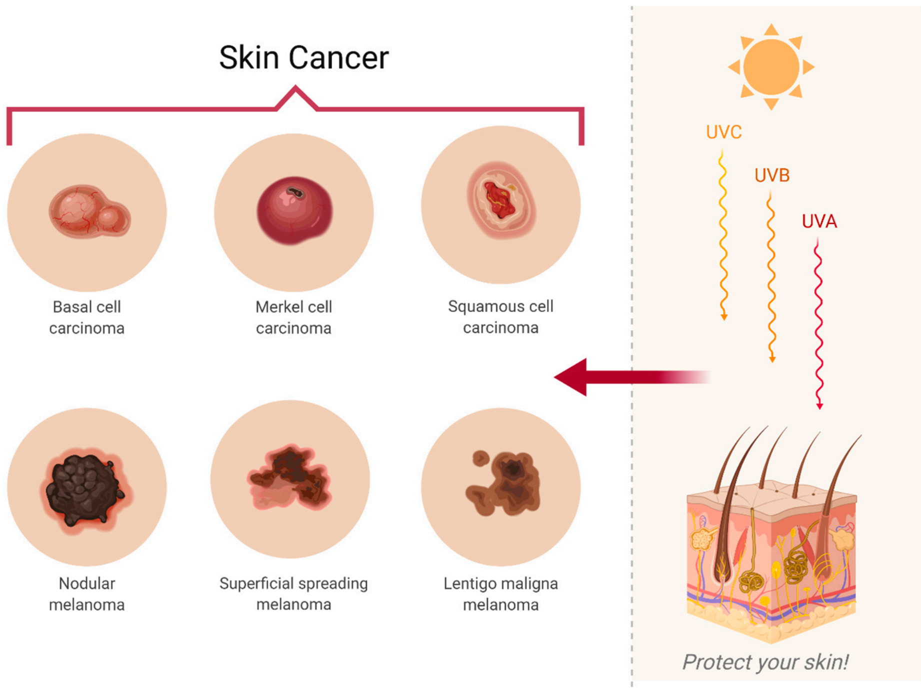

Figure 3. Skin cancer issues caused by unprotected skin health. The figure was created with "BioRender.com" template and exported under the terms of premium subscription.

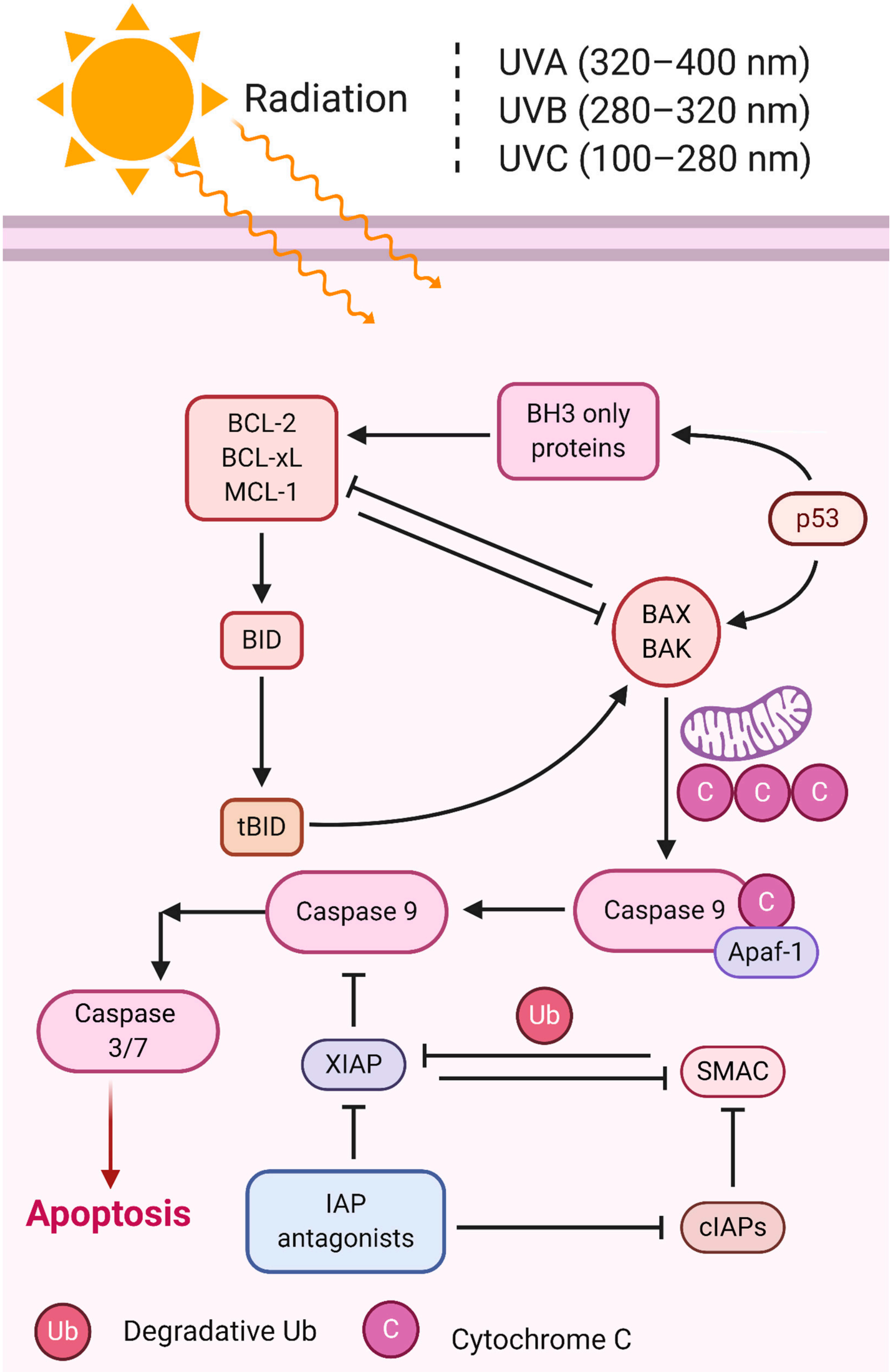

Figure 4. Intrinsic pathway of cell death via apoptosis upon uncontrolled exposure to harmful radiations. The figure was created with "BioRender.com" template and exported under the terms of premium subscription.

3.2. Nanoemulsions in Cosmetics

Nanoemulsions (20 to 200 nm in size) are transparent and kinetically stable liquid dispersions in which a water phase and oil phase are present in amalgamation with a surfactant [28]. Based on the composition, different types of nanoemulsions can be formed, namely, water-in-oil, oil-in-water, and bicontinuous nanoemulsion. A simplified illustration of nanoemulsion preparation and phenomena in the homogenization chamber is shown in Figure 5 [29]. These are the dispersed phase that consists of droplets/particles with low oil/water interfacial tension [30]. Nanoemulsions exhibit desired properties such as high interfacial area, low viscosity, high kinetic stability, and high solubilization capacity [31]. These are extensively employed as a medium for the target-oriented delivery of a range of cosmetic products such as sunscreens, deodorants, nail enamels, lotions, conditioners, shampoos, and hair serums [32]. In cosmeceutical products, nanoemulsions enable a rapid penetration of components through the skin. Potential benefits of the use of nanoemulsions in cosmetic products are due to the small droplet size and include: i) faster skin penetration of active components, ii) strong occlusive effect of keeping skin moisturized, iii) a high degree of fluidity with no creaming, (iv) enhanced infiltration in narrow gaps such as hair scales spacings and pilosebaceous follicles, and v) visual appearance (clear to slightly turbid) and glossy coating on the skin [33]. Sinerga manufactured a mixture of emulsifiers so-called Nanocream®, which allows the preparation of oil-in-water nanoemulsions. This product is envisioned to be utilized in wet wipes, hyper-fluid emulsions, and sprayable emulsions [34,35].

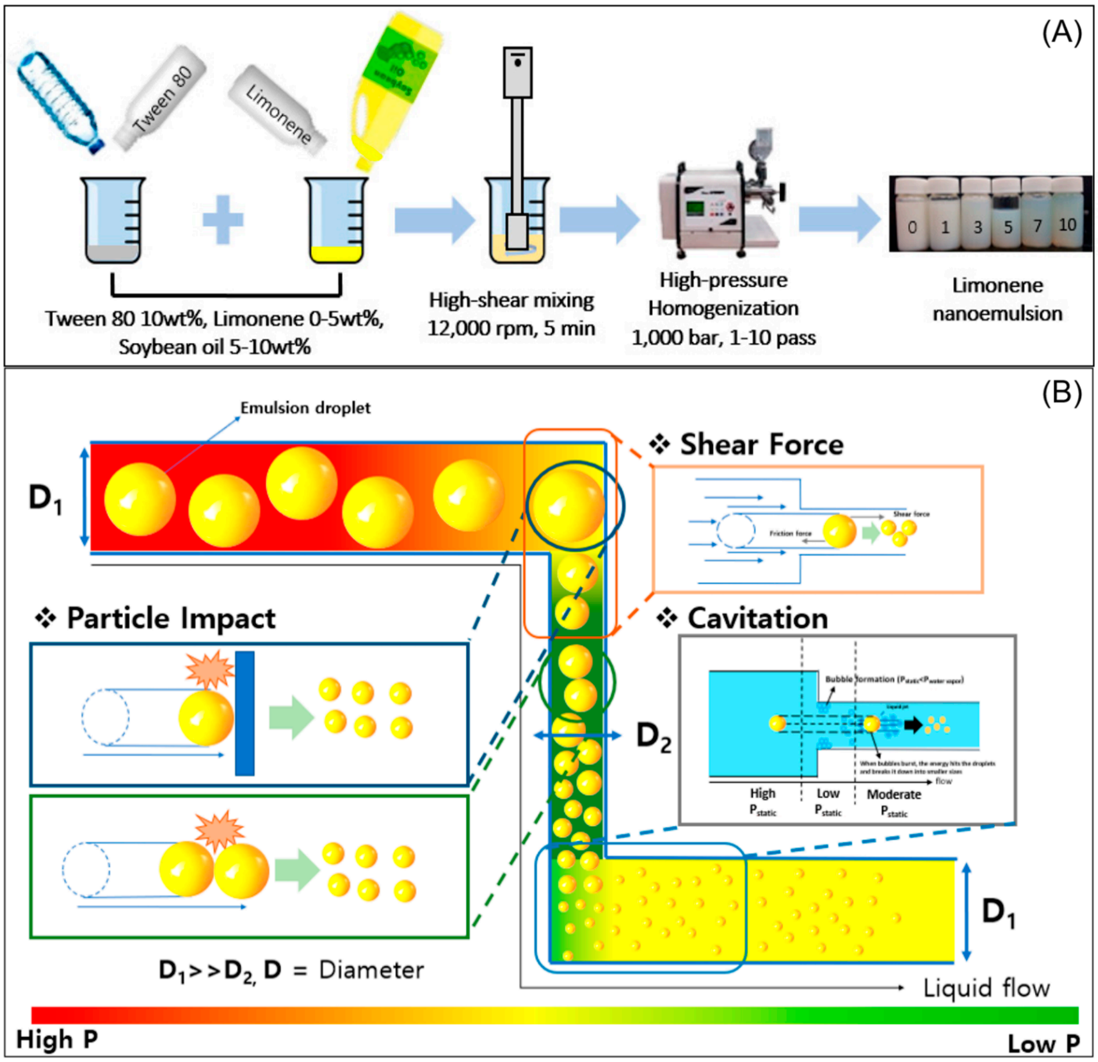

Figure 5. A simplified illustration of nanoemulsion preparation (**A**) and phenomena in the homogenization chamber (**B**). Reprinted from Hidajat et al. [29] with permission under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/). Copyright (2020) the authors. Licensee MDPI, Basel, Switzerland.

3.3. Nanoparticles in Cosmetics

Nanoparticles are recognized as important additions to the industrially pertinent compounds. The effective deployment of nanoparticles offers unique multifunctional characteristics, such as overall product efficacy, stability, catalytic performance, high surface/volume ratio, electro-magnetic features, and biological activities. Particularly, the above-mentioned characteristics of nanoparticles are appropriate to improve the overall performance of the product of interest [36]. Nanoparticles of different morphologies and chemical compositions are generally incorporated in cosmetics formulation to harnessing the advantages of shape- and size-related activities [37,38], which can intensify the performance of the products. In contrast to UV absorbers, several types of inorganic oxides-based nanoparticles, such as ZnO-nanoparticles, TiO_2-nanoparticles, ZrO_2-nanoparticles, or CeO_2-nanoparticles, are added in sunscreen preparations as physical UV filters because of their capability to scatter and reflect UV radiations. These nanostructured materials possess the UV radiation attenuation ability and result in an enhancement in the capacity to withstand UV light [39]. CeO_2 nanoparticles can provide similar UV-blocking behavior to that of TiO_2, but do not generate reactive free radicals as TiO_2 in the presence of UV radiations [40,41]. In a study, calcium-doped CeO_2 has shown a better screening of shorter UV-A radiations [42]. Cerium phosphates and cerium-titanium pyrophosphates have also been demonstrated as effective substitutes for ZnO and TiO_2 nanoparticles in sunscreen formulation [43,44]. Nanoparticles such as clay and silica are added in cosmetic formulations as thickeners [45,46]. Moreover, inorganic-organic hybrid nanoscale materials are also utilized in cosmetic products as thickening agents. For example, perfluorocarbon hydrophobically-modified alkali-soluble emulsion (HASE) polymer-grafted SiO_2 nanoparticles enable the development of a nano-sized cross-linked polymeric network structure, which protects the skin from the organophosphates exposure and toxicity [47]. Gold nanoparticles (nanogold) range from 5–400 nm in size, and display various shapes such as nanoshell, nanosphere, nanostar, nanocube, nanorod, nanocluster, branched, and nano-triangles. The resonance frequency of gold nanoparticles is strongly affected by their size, shape, dielectric properties, and other environmental circumstances. The color of nanogold varied from red to purple, to blue and virtually black due to aggregation [48]. Recently, Haddada et al. [49] reported a green synthesis of gold nanoparticles and assessed their antioxidant and dermo-protective activities as a safe cosmetic ingredient (Figure 6). Inertness, non-cytotoxicity, biocompatibility, and highly stable nature are the major characteristics of gold nanoparticles. Gold nanoparticles have gained importance owing to their potent antibacterial and antifungal properties. These nanoparticles find applications in a broad-spectrum of cosmeceuticals products, including anti-aging creams, face packs, cream, lotion, deodorant, etc. Nanogold in beauty care products is endowed with many important properties explicitly antiseptic and anti-inflammatory properties, acceleration of blood flow, delayed the aging process, improved elasticity and firmness of the skin, and energizing skin metabolism [50,51]. Lipid nanoparticles such as solid lipid nanoparticles (SLN) and nanostructured lipid carriers (NLC) are also a promising carrier system compared to emulsions, liposomes, and polymeric nanoparticles. Both SLN and NLC exhibit many advantageous features for the tropical application of cosmetics and pharmaceutics, i.e., targeted drug delivery, controlled release of actives, occlusion, enhanced drug penetration, and increased skin hydration effect. The lipid nanoparticles are a "nanosafe" carrier system exhibiting low toxicity/cytotoxicity and noteworthy tolerability because of their production from biodegradable and physiological lipids [52]. Additionally, lipid nanoparticles can increase the chemical stability of compounds, which are sensitive to light, oxidation, and hydrolysis. Improvement of chemical stability by the integration into the lipid nanocarrier system has been achieved for many cosmetic constituents, e.g., ascorbyl palmitate, vitamin A (retinol), coenzyme Q10, and vitamin E (tocopherol) [53].

Though nanoparticles are increasingly used in several applications, particularly in the field of nanomedicine and cosmetics, comprehending the mechanisms provoked by their interactions with the biological moieties is a prerequisite for their optimal and controlled use [54]. For many nanoscale particles, their safe entry into cells is a critical step to achieve potential prognostic and therapeutic efficiency. Furthermore, the intracellular fate of nanoparticles is important to their success, given that these nanostructured carriers are intended for delivering target molecules such as drugs, genes, and other actives to the cytosolic matrix, nucleus, or other targeted intracellular sites. Nevertheless, cellular penetration of nanoparticles by an efficient and controlled way remains a significant challenge. Besides their interactive effect with cell membranes, a comprehensive understanding of cellular uptake and trafficking mechanisms of nanoparticles is of high importance in developing safe and effective nanotherapies by the judicious optimization of the physicochemical properties of nanoparticles [54]. It is demonstrated that nanoparticles can modulate cell fate, initiate cell-cell communication, induce/prevent mutations, and modulate cell structure at the nano-bio interface. The nanoparticles of different compositions can also change the intracellular level of calcium in neuronal cell lines. For example, SiO_2 nanoparticles, at non-toxic doses, have modulated the electrical activity of neuroendocrine cells without exerting genomic effects [55].

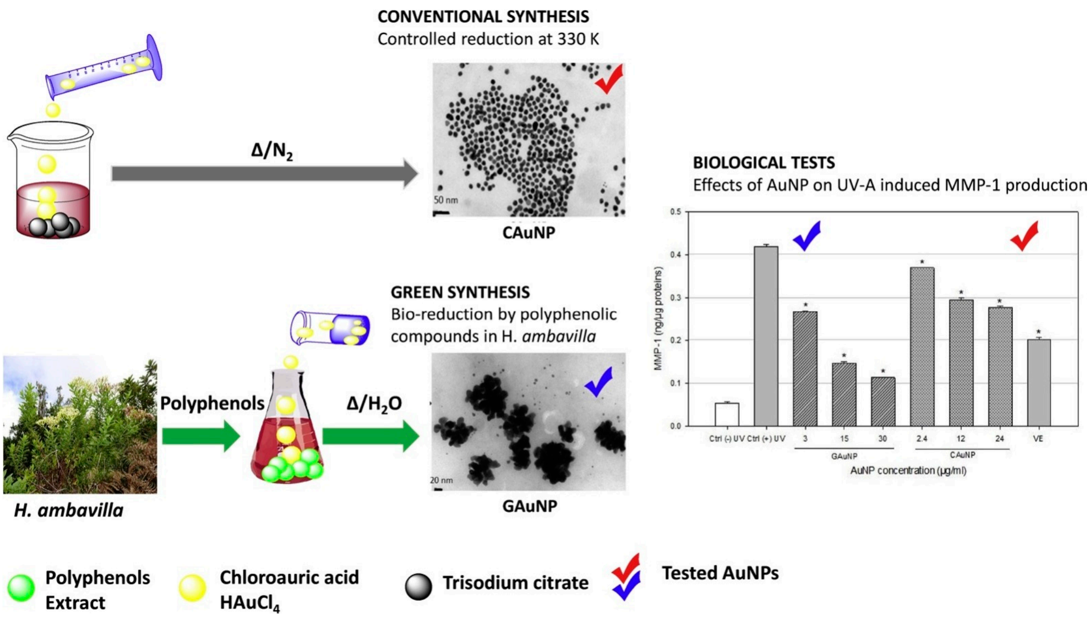

Figure 6. Green synthesis of gold nanoparticles and their antioxidant and dermo-protective activities as a safe cosmetic ingredient. Reprinted from Haddada et al. [49] with permission from Elsevier. Copyright (2020) Elsevier B.V.

3.4. Nanotubes-Based Formulations in Cosmetics

Carbon nanomaterials, particularly graphene-based ones, have demonstrated the potential for hair coloring. The amalgamation of different biopolymers (such as chitosan and graphene) produces color nanoformulations. This formulation showed high resistance to various shampoos and is endowed with heat dissipation abilities. Carbon nanotubes (CNTs) are referred to as the rolled graphene with SP^2 hybridization, cylindrical hollow fibers, and composed of graphene walls. Individual CNTs are naturally arranged into "ropes" connected by pi stacking. CNTs are incredibly light in weight and ranges from 0.7 to 50 nm in diameter, with lengths of approximately 10s of microns [56]. These can be classified into three types, including single-walled, double-walled, and multiwalled CNTs. Single-walled CNTs contain a single sheet of graphene, whereas the double-walled CNTs consist of two concentric single-walled CNTs, and multiple layers of graphene tubes result in the formation of multi-walled CNTs [57]. Various reports have documented the use of carbon nanoparticles, CNTs, and peptide-based CNTs in the formulation of cosmetics such as hair colorants [57,58]. Chemically-modified CNTs can be used for coloring hair, eyelashes, or eyebrows [58]. Peptide-based CNTs synthesized by integrating a hair-binding peptide on the surface of the nanotube, increase the affinity to hair by covalent bonding [59]. In addition to CNTS, some other kinds of nanotubes, such as silica nanotubes, halloysite clay nanotubes, nickel vanadate nanotubes, and boron-nitride nanotubes, have also shown promise for haircare formulations owing to their toxic-free aqueous processing. Adding their abundant availability, low toxicity, biocompatibility, and low price, naturally occurring multipurpose nano clay nanotubes have gained incredible usage for haircare formulations [60–62].

3.5. Dendrimers in Cosmetics

Dendrimers are a new class of nano-sized, unimolecular, and highly branched nanostructures with globular, regular branching and structural symmetry. The total number of series of branches determines the generation of the dendrimer [63]. The first-generation dendrimer has one series of branches, while there are two series in the case of second-generation dendrimers. Dendrimers are very small, with an approximate diameter of 2–20 nm [64]. A wide variety of dendrimers exists, and biological properties such as polyvalence, monodispersity, solubility, low cytotoxicity, chemical stability, self-assembling, and electrostatic interactions render dendrimers a promising carrier for drug delivery with high selectivity and precision. These nanostructures are being employed in various cosmeceutical products such as sunscreen, shampoos, anti-acne cream, and hair-styling gels [65]. The dendrimers have shown potential in the effective delivery of dermal preparations through the skin barrier [66]. Chauhan et al. [67] first studied the skin penetration properties of G4-polyamidoamine dendrimers (PAMAM). An in vitro study demonstrated an increased volume and penetration of chlorhexidine digluconate (CHG) into the skin after pretreatment of skin with PAMAM dendrimers. These findings were useful in terms of improving treatment efficacy against bacterial infection of the skin [68]. The dendrimer-based pre-treatment also enhances the skin permeation of chlorhexidine digluconate (Figure 7) [68]. Biodegradable polymers such as poly α-esters, polysaccharides, poly amidoamine, and poly alkyl cyanoacrylates dendrimers can serve as an encapsulating agent for personal care and cosmetics formulations [69]. Intrinsic viscosity is one of the important dendrimer characteristics that make them useful for cosmetic formulations [70]. Many cosmetic companies, such as Dow Chemical Company, L'Oréal, Revlon, and Unilever, have many patents on dendrimer-based cosmetic formulations for applications in skin, nail, and hair care products [71]. L'Oreal has been using terminal hydroxyl functionalized polyester dendrimers accompanied by film-forming polymers in cosmetic formulations for skin applications. An improved intensity by the use of dendrimers has been observed in various L'Oreal cosmetics products [72].

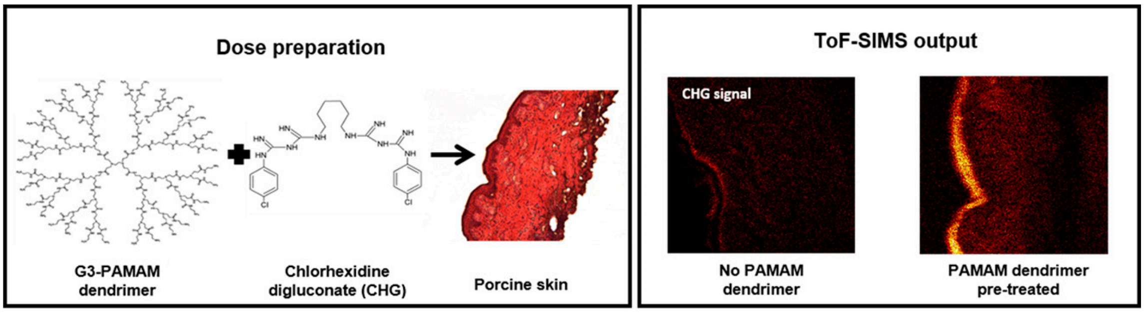

Figure 7. Dendrimer-based pre-treatment enhances the skin permeation of chlorhexidine digluconate. Reprinted from Holmes et al. [68] with permission from Elsevier. Copyright (2017) Elsevier B.V.

3.6. Nanospheres in Cosmetics

Nanospheres are the spherical particles of polymeric matrix ranges from approximately 10 to 200 nm diameter in size. These amorphous or crystalline nanoscale carriers can be categorized into biodegradable and non-biodegradable nanospheres. The notable examples of biodegradable nanospheres include albumin-based nanospheres, pristine or modified starch-based nanospheres, and gelatin-based nanospheres, whereas polylactic acid (PLA) is included in the non-biodegradable category of nanospheres. The incorporation of nanospheres in cosmeceutical related products, such as skincare or body-care items, induce the delivery of active constituents into the deep layer of the skin. This, in turn, provide some favorable therapeutic effects to the affected area of the skin more efficiently and precisely. The nanospheres have potential uses in cosmetic products such as anti-acne, anti-wrinkle, and moisturizing creams [73]. Ito et al. [74] designed ubiquinone (UQ) containing poly-(lactide-co-glycolic acid) (PLGA) nanospheres for cosmetic products. The as-synthesized UQ/PLGA nanospheres presented practical advantages such as high stability, elevated loading efficiency, and a slow release of the drug.

4. Regulatory Perspectives of Nanomaterials in Cosmetics

From the regulatory perspective, the cosmetic products and related active ingredients should be carefully regulated as safe and correctly labeled for use. For the biologics, drugs, devices, vaccines, and foods, all the ingredients and finished products are subjected to the FDA premarket approval before marketing. However, the FDA's authority takes into account the safety aspects in terms of "risk management" framework. However, such evaluations are based on a case-by-case [75], for different industrially related products, including cosmetics. The regulatory authority for cosmetic products states that the cosmetics or their ingredients shall not be adulterated nor misbranded. In this context, the FDA published separate safety guidance "Guidance for Industry: Safety of Nanomaterials in Cosmetic Products" to address the issues of nano-tech strategies and the use of nanomaterials in cosmetics formulation [76]. This final document delivers information concerning the safety evaluation of nanostructured materials in cosmetic products and is projected to support interested parties in the identification of potential safety concerns and their assessment ways (Guidance for Industry) [76].

5. Conclusions and Outlook

Based on the extensive literature inspection, it is clear that the use of nanotechnology in cosmetics is becoming a crucial tool for scientific research as well as for the development of new cosmetic and personal care products in industrial sectors. In the cosmetics formulations, a large number of nanoscale materials are already being incorporated or recommended for future use as nano-systems or novel nanocarriers to encapsulate active ingredients for their efficient delivery through the skin barriers. These nano-systems can help absorption or penetration of cosmeceuticals active moieties within epidermal layers in a remarkable way of achieving burst or sustained release of actives. The types of nanomaterials discussed here enormously differ in physical and chemical properties and include liposomes, noisome, nanoemulsions, inorganic nanoparticles, carbon nanomaterials (graphene, fullerenes), carbon nanotubes, dendrimers, and nanospheres. These nano-systems have achieved potential in targeted and controlled drug delivery and offered remarkable features such as biocompatibility, better stability, site-specificity, prolonged action, and high drug-loading capability. However, along with their immense technological potential and opportunities, a discussion has initiated the safety and toxicity risks related to nanomaterials or nanotechnologies. Various studies are being carried out to identify the possible health hazard and toxicity effects of the nanomaterials [77–81]. Therefore, further research should be directed to provide reliable scientific reports to the consumers regarding the benefits, toxicity, and related safety/regulatory perspectives of nanotechnology-based cosmetics products for the actual realization of the scientific inventions. Cosmetic products containing nanomaterials have to clearly specify the presence of the nanomaterial(s) in the products labeling and the list of ingredients.

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