ACS OMEGA
Open Access
http://pubs.acs.org/journal/acsodf
Review

# Overview of Nanocosmetics with Emphasis on those Incorporating Natural Extracts

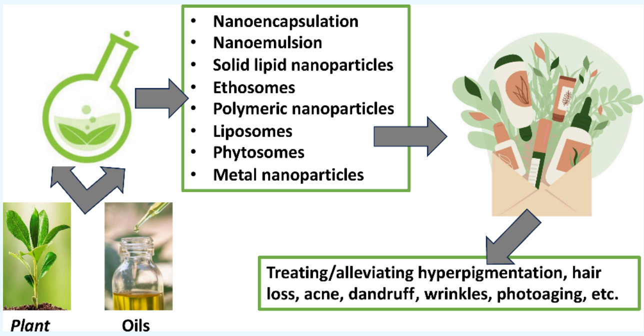
Yasmin R. Maghraby, Ahmed H. Ibrahim, Rehan M. El-Shabasy, and Hassan Mohamed El-Said Azzazy*

**Cite This:** *ACS Omega* 2024, 9, 36001−36022

Read Online

ACCESS | Metrics & More | Article Recommendations

**ABSTRACT:** The cosmetic industry is rapidly rising worldwide. To overcome certain deficiencies of conventional cosmetics, nanomaterials have been introduced to formulations of nails, lips, hair, and skin for treating/alleviating hyperpigmentation, hair loss, acne, dandruff, wrinkles, photoaging, etc. Innovative nanocarrier materials applied in the cosmetic sector for carrying the active ingredients include niosomes, fullerenes, liposomes, carbon nanotubes, and nanoemulsions. These exhibit several advantages, such as elevated stability, augmented skin penetration, specific site targeting, and sustained release of active contents. Nevertheless, continuous exposure to nanomaterials in cosmetics may pose some health hazards. This review features the different new nanocarriers applied for delivering cosmetics, their positive impacts and shortcomings, currently marketed nanocosmetic formulations, and their possible toxic effects. The role of natural ingredients, including vegetable oils, seed oils, essential oils, fats, and plant extracts, in the formulation of nanocosmetics is also reviewed. This review also discusses the current trend of green cosmetics and cosmetic regulations in selected countries.



## 1. INTRODUCTION

Cosmetics are formulations applied to the body and face to improve the overall appearance and promote beauty.[1] Besides the beautifying purposes, cosmetics products have long been used to improve diverse conditions/ailments, e.g., dark spots, wrinkles, skin dryness, dandruff, hair loss, hyperpigmentation, acne, photoaging, uneven complexion, etc.[2] Accordingly to International Regulation (CE) 1223/2009, a cosmetic product is defined as "any substance or mixture intended to be placed in contact with the external parts of the human body (epidermis, hair system, nails, lips and external genital organs) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning them, perfuming them, changing their appearance, protecting them, keeping them in good condition or correcting body odors."[3] The usage of cosmetic products is credited to the late Egyptians, which dates back to 4000 BC; then after that cosmetics were used by the Romans, Greeks, Chinese, and Japanese. By the beginning of the 21st century, the cosmetic products started to be immensely applied in different countries and, via the technological advancements, novel cosmetics were being manufactured.[1]

Currently, nanosized particles are widely used in diverse applications.[4] These are extensively added to the cosmetic formulations of whitening lotions, antiwrinkle creams, moisturizers, shampoos/conditioners, etc.[5] Diverse types of nanocarriers, e.g., niosomes, fullerenes, liposomes, ethosomes, carbon nanotubes, solid lipid nanoparticles, and nanoemulsions, are applied for delivering useful active ingredients.[5] "Nanocosmetics" is used to define cosmetics incorporating nanosized particles.[6] The main advantages of incorporating nanomaterials in cosmetic products are presented in Figure 1. They enable a sustained release of the active materials, possess an increased chemical reactivity, enhance the optical/magnetic properties, and improve solubility of the active ingredients.[6] Nanocosmetics can be added to hair care formulations for treating hair loss, besides averting hair from getting white/gray. Nanocosmetics have the ability to make fragrances last for longer durations, render skin care products superior in many angles, and augment the effectiveness of sunscreens via increasing the protection against UV rays.[7] Moreover, very small sized particles have an increased surface area; accordingly nanocosmetics enable a facile transportation of the loaded active constituents deep into the skin. Also, the attraction of nanoemulsions for usage in cosmetics is due to their kinetic stability. The nanoemulsions' prolonged physical stability (i.e.,

**Received:** January 3, 2024
**Revised:** May 30, 2024
**Accepted:** July 18, 2024
**Published:** August 16, 2024

https://doi.org/10.1021/acsomega.4c00062
*ACS Omega* 2024, 9, 36001−36022

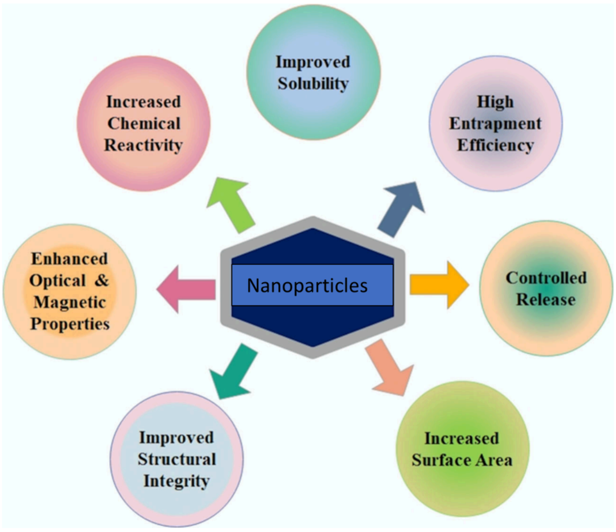


**Figure 1.** Advantages of nanomaterials. Adapted with permission from ref 9. Copyright 2020 Scientific Research Publishing.

without flocculation and coalescence) makes them distinctive. However, unless effectively stabilized against Ostwald ripening (i.e., the process of disappearance of small particles by deposition on larger particles), nanoemulsions may show an increase in droplet size and an initially transparent system may become turbid.[8]

Despite the benefits of nanoparticles, additional research is required to clearly understand their short- and long-term health consequences besides any adverse environmental impact that they might possess.[1] For instance, certain ultrafine nanosized particles (e.g., carbon nanotubes, silver nanoparticles, fullerenes, and titanium dioxide nanoparticles) were proven to possess certain levels of toxicity to humans.[5] For instance, titanium dioxide nanoparticles, added to all types of sunscreens, was proven to trigger minimal damages to RNA and DNA in rats.[8] In addition, nanocosmetics might possess harm to the environment too; i.e., their production might cause air pollution and some of their ingredients might be nondegradable, causing harm to the aquatic environment.[1]

This review presents an update on the incorporation of natural extracts in nanocosmetics. Various nanoformulations, like ethosomes, nanoemulsions, nanostructured lipid carriers, niosomes, and silver/gold nanoparticles, and liposomes are reviewed. Also, the major classes of nanocosmetics, such as moisturizing creams, lip care products, and sunscreens are presented. In addition, the environmental impact and toxicity of certain nanoparticles are briefly presented. This review also discusses the current trend of developing sustainable green cosmetics. Lastly, the ongoing regulatory guidelines for producing nanocosmetics are summarized.

## 2. BRIEF HISTORY OF COSMETICS

Cosmetic products' history dates back to about 7000 years. The cosmetics' art is believed to be the oldest form of all rituals in most cultures worldwide.[1] Even though during ancient eras, medicine, cosmetics, and religious practices were all related to each other, yet Hippocrates and Henri de Mondeville aided in meticulously differentiating the three forms of art.[1] Early Egyptians used oils, perfumes, and creams, besides several kinds of ointments and lotions, for hygiene purposes and for protecting their skins from the harmful sunrays. The storytelling art on their tombs, monuments, and walls indicates that applying cosmetics was extensive among women and all people during Egypt's ancient times.[1] Actually, almond painted eyes, which are obvious on most Egyptian ladies' paintings, besides the uncovering of Tutankhamen's tomb, exposed widespread cosmetics' usage during ancient times and also inspired a universal recognition of the black/heavily worn eyeliners.[10] On another note, during the era of 3000 BCE, Chinese people applied brightly cheerful colors of nail polishes as a way of social class distinction. To elaborate, the elite and noble classes of people used to wear colored nails to distinguish themselves. On the other hand, the middle class and poor people were not permitted to put nail polish on.[1] Besides the makeup products, perfumes also were abundantly used. Heang was the term used to describe perfumes, oud oils, and fragrances and was fundamental to the Chinese noble class. Emperors, monarchs, and lords applied perfumes excessively; whether they were staying home or going to their temples.[10] Actually, makeup usage was also an Eastern tradition that was passed to the Grecians later on by means of travelers and tradesmen. Ancient Greek women used to indulge in applying fake eyebrows and facial creams/powders. During the fifth century BCE, Athenian women added lead specifically to their creams for skin and face whitening, while, making their lips red using lipsticks composed simply from plants' roots and red seaweeds.[10] Athenians also emphasized their eyebrows with coal, darkened their eyelids with kohl made from antimony sulfide, and magnified their eyelashes with mascara which was composed from a mixture of egg whites and gum or from the dung of cows.[1] Certain archeological discoveries in the ancient Greek temples and cemeteries have exposed various items associated with the beautification of Greek women, such as combs, creams, mirrors, brushes, powders, shavers, fragrances, etc.[10] Unfortunately, throughout history humans have apparently sacrificed their safety and health for their beauty by applying toxic homemade cosmetics. For example, in the early 1800s, women used to apply toxic constituents, e.g., arsenic, lead, and mercury to have a pale face which was regarded as attractive and beautiful in that time. Fortunately, the centuries of ignorance in applying unsafe and toxic materials to augment one's self-appearance are over; still, there is always the need to be good-looking/youthful, but through the usage of verifiable science to attain that target.[10]

## 3. NANOMATERIALS APPLIED IN COSMETICS

Nanomaterials are substances that have at least one of their dimensions in the nanoscale (i.e., 100 nm) and show considerably distinct physicochemical characteristics.[11] Nanomaterials have been applied in the cosmetics' sector for several years.[11] Micromaterials have slightly bigger dimensions, starting at 100 nm up to 1000 nm. Under the condition that their physicochemical behavior and dermal delivery capabilities is superior to that of macromolecules, these are also being applied in the cosmetics industry as well in certain applications. Cosmetics incorporating microscale materials are abundant and useful, yet those incorporating nanosized materials have many more advantages.[9] Nanoparticles have large surface areas possessing high bioavailability, good transparency, and proficient absorption; besides that, they possess a sustained release of the bioactive ingredients.[12] Presently, cosmetics integrating nanomaterials are considerably promoted and marketed due to their diverse advantages in comparison to the traditional cosmetic products. Various nanomaterials, e.g.,

## Table 1. Nanomaterials and Nanoformulations Used in Cosmetics

| Nanomaterial | Advantages | Drawbacks | Distinctiveness | Kind of Cosmetic | Commercial Products | Ref |
|---|---|---|---|---|---|---|
| Dendrimers | Controlled release and high solubility of lipophilic ingredients | Cellular toxicity, elevated manufacturing costs, and not suitable for hydrophilic drugs | High shelf-lives of cosmetics | Sunscreens | Topical Resveratrol Formulation | 8 |
| Solid-lipid nanoparticles | High biodegradability/bioavailability and easiness of manufacturing | Low encapsulation of active ingredient and short shelf-lives | High drug loading and crystallinity in nature | Perfumes and creams | Chanel—Allur | 8, 13 |
| Cubosomes | Sustained release and nontoxic | Low entrapment | Thermodynamically stable | Topical creams | ND | 14 |
| Nanocrystals | Adhesiveness, uniform particle distribution, and high skin penetration | Not highly stable and aggregates easily | Very high percentage of active ingredients' loading | Toothpastes and moisturizers | Nano whitening toothpaste—Whitewash | 15 |
| Silica nanomaterials | Highly hydrophilic and has low production costs | Mild toxicity to the respiratory tract | Applied as fillers to increase the cosmetics' bulkiness | Lip balms and lipsticks | Blushers Sticks | 8 |
| Ethosomes | Premium penetration into the skin with high efficiency | Risk of coalescence and low yields | Comprises high ethanol concentrations | Moisturizers | Supravir cream | 16 |
| Nanosphere | High bioavailability and biodegradability | Possibility of aggregation | Long shelf-lives of cosmetics | Skin whitening and antiaging creams | Hosokawa Micron Prime Serum | 17 |
| Inorganic nanoparticles | Highly stable and biocompatible | Mild toxicity to the respiratory tract | High efficiency in reflecting UV rays | Sunscreens | Lotus and Phytorx UV | 8 |
| Carbon black nanoparticles | Low weight, elevated thermal/chemical stabilities, and minimal production costs | Cytotoxicity and amends the macrophages' phagocytosis | Unique color for pigmentation | Facemasks | Mascara—Lakme | 8 |
| Micellar nanoparticles | High bioavailability and biodegradability | Low entrapment | High skin penetration | Skin cleansing products | ND | 18 |
| Tris-biphenyl triazine nanoparticles | Photostable and robust filters | Not environment friendly; i.e., harmful to aquatic life | High efficiency for usage as UVB/UVA 2 filters | Sunscreens | Extra UV Gel-Allie | 8 |
| Nanohydroxyapatite | Desensitizer and polish for teeth | Fragile and brittle | Safe for pediatric toothpastes | Toothpastes | Kinder Karex | 8, 19 |
| Niosomes | High stability/efficiency and good penetration | High manufacturing costs | Surface alteration easy because of the existence of certain functional group | Antiaging creams | Lancome and L'Oréal | 20 |
| Silver/gold nanomaterials | Antibacterial/antifungal activities, high chemical stability, and modified biodistribution | Mild respiratory toxicity | Surface augmented Raman scattering | Antiwrinkle creams and facemask | Gold Nano Treatments–Chantecaille | 8, 21 |
| Buckyballs nanoparticles | Reduces skin ailments, photostability, and antioxidant potency | Extremely hydrophobic and harms tissues of brain | Acts as a scavenger for harmful free radicals | Face and body creams | Brightening Essence–Juva | 22, 23 |
| Nanocapsules | Masking bad odors | Supplementary purification step needed after the nanoformulation | Formation of micelles | Antiwrinkle creams and hair products | Primordiale Intense–L'Oréal | 8 |
| Nanoemulsions | Amphiphilicity and transparency | Possesses sensitivity to acids and low durations of action | Creams do not reveal complications of coalescence and flocculation | Face creams, body lotions, ointments, gels, and moisturizers | Vitalipid N | 8 |
| Nanoliposomes | Amphiphilic, high skin penetration, biocompatible, and biodegradable | Activates immune responses and physicochemical weakness | Capability of solubilizing lipophilic and hydrophilic ingredients | Moisturizers and antiwrinkle creams | Capture Totale | 8 |
| Nanostructured lipid carriers | Easiness of manufacturing and long shelf-life | Short action durations | Mixture consisting of liquid and solid lipids | Body and facial creams | Dr. Rimpler—Cutanova | 8 |

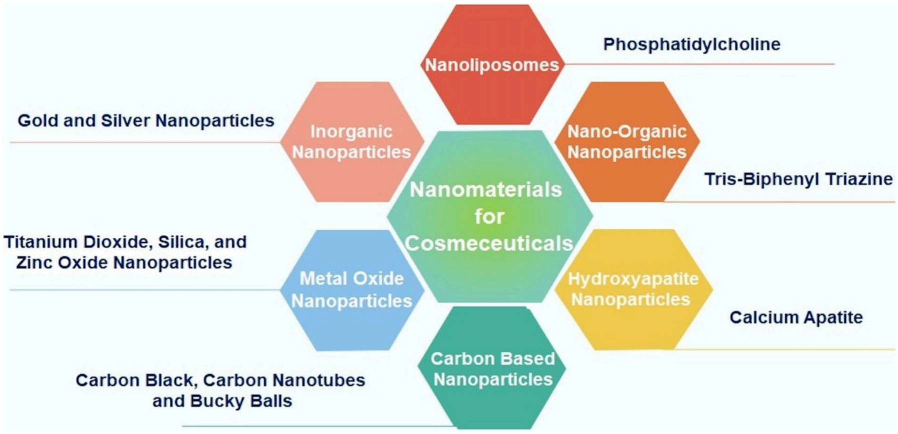


**Figure 2.** Nanomaterials applied in the cosmetics sector.

nanocapsules, liposomes, dendrimers, carbon black nanoparticles, cubosomes, nanoemulsions, ethosomes, gold nanoparticles, buckyballs, and nanocrystals, are extensively applied in the cosmetics' sector.[9] Table 1 and Figure 2 compile the different nanomaterials applied in the cosmetics industry. The next sections assemble the various nanomaterials' systems applied in the cosmetics' sectors to efficiently deliver active ingredients.

**3.1. Titanium Dioxide and Zinc Oxide Nanoparticles.** Sunscreens are photoprotective creams applied topically on the skin. These mainly absorb/reflect some of the sun's UV radiation, consequently aid in protecting against sunburns, and most crucially avoid skin diseases, e.g., skin cancer.[24] Sunscreens exist nowadays in many forms, such as sprays, creams, foams, lotions, roll-ons, etc.[24] Applying sunscreen helps in protecting the skin against many dangerous impacts of solar radiations, e.g., UVA-1, UVA-2, and UVB. Sunscreens typically include inorganic radiation filters, like titanium dioxide and zinc oxide. The latter is more efficient in UVA sun ray's blockage, and titanium dioxide is better for UVB rays. Therefore, a mixture of these inorganic materials would impart a wide range of protection against a broad spectrum of UV rays.[24] When formulated in their nanoscale, zinc oxide and titanium dioxide possess even higher sun protection factor.[25] These nanoparticles have premium effects because of their transparency, almost translucent color and reduced opacity contrary to their original color, which is white to opaque.[25] Lastly, both metal oxide nanoparticles applied as UV rays reflectors reveal advanced UV filtering activity, reduced scattering, and reflection. Due to increased filtering activity, these possess improved photoprotective activity.[25]

**3.2. Silver and Gold Nanoparticles.** Gold and silver nanoparticles are broadly applied in cosmetics' formulations, e.g., antiaging creams, antiperspirants, deodorants, body lotions, face masks, etc.[15] Silver and gold nanoparticles show antibacterial and antifungal characteristics. Thus, formulations that are silver-/gold-based could be used for controlling bacterial contamination and applied as inhibitors against many microorganisms.[26] The direct addition of silver inorganic material to cosmetics might possess some obstacles, especially because silver usually quickly precipitates. This obstacle could be resolved by means of rendering the silver inorganic material to their nanoscale.[26] Usage of silver nanoparticles in cosmetics' formulations makes the end product stable, with no sedimentation for up to 1 year of shelf-life.[5] In Egypt, gold has a long been added into beauty care products. Late Egyptians trusted that the gold enhanced the skin brightness, flexibility, texture, and composition, besides other benefits. These days, gold is being incorporated into diverse skincare formulations, like ointments, oils, creams, face masks, lotions, skincare healings, etc. Normally, colloidal gold (5−400 nm) is used in skincare products where its color ranges depending upon its size from red to lilac.[27] Gold nanoparticles have the ability of alleviating damages of the skin and improving the overall skin's smoothness, beauty, surface, brightness, flexibility, etc. Additionally, gold aids in healing skin sunburns, hypersensitivities, inflammations, etc. Gold and silver nanoparticles have the ability to be prepared in several forms, e.g., nanospheres, nanostars, nanorods, nanoclusters, nanoshells, nanotriangles, and nanocubes; besides that, their exact state controls their optical performance and cellular uptake.[27] These nanoparticles have superior properties (e.g., biocompatibility and stability) which makes them very useful and suitable for cosmetics and skincare.[5] Besides being added to cosmetics formulation, gold and silver nanosized materials are added to wound healing preparations owning to their antibacterial and antifungal properties.[27]

**3.3. Silica Nanoparticles.** Interest in using silica nanoparticles has been lately increasing in the cosmetics industry due to their highly hydrophilic surfaces and low production costs.[5] Silica nanoparticles are added to cosmetics' formulations to improve the efficiency and increase the shelf-lives of cosmetics.[28] Silica nanoparticles exist in nanodispersions' forms with sizes varying between 3 and 110 nm. These possess a distinct advantage of delivering both lipophilic and hydrophilic active compounds. Silica nanoparticles are generally added to cosmetics especially designed for face, skin, hands, lips, hair, nails, etc. Silica nanoformulations develop the appearance of different colors/shades of lipsticks and maintain the colors for long durations after application, like in the case of long-lasting lipsticks.[28]

**3.4. Carbon Black.** Carbon black has long been recognized as an important ingredient in many cosmetics' formulations. It is a black pigment that is used in many cosmetic products, like eyeliners, eye shadows, mascara, etc. Carbon black is fabricated through an inadequate combustion of carbon materials, e.g., activated carbon and coal tar.[29] Carbon black nanoparticles possess many advantages, such as making the black color more stable and stay for longer durations after application. However, carbon black nanoparticles showed a tendency for producing aggravation, cytotoxicity, and alterations in phagocytosis of human monocytes. Accordingly, carbon black has been approved for usage in the nanostructure forms as a pigment but only at a maximum percentage of 10% Reference to EU regulatory agency.[29]

**3.5. Ethosomes.** The movement of active ingredients to human skin and then to the systemic circulation is restricted due to a very thick physiological barrier (i.e., stratum corneum).[30] Ethosomes are vesicles, in the nanoscale, applied in the form carriers for augmenting the transdermal transport of a range of cosmetic materials.[16] Ethosomes could be specially tailored for a safe and highly efficient skin penetration of cosmetics integrating antibacterial/antioxidants agents, vitamins, minerals, salicylic acid, antiwrinkle agents, etc. Ethosomes, being in the nanorange, are more effective than standard liposomes specifically in delivering cosmetics that are topically applied to the skin.[31]

**3.6. Carbon Nanotubes.** Carbon nanotubes are typically portrayed as a rolled sheet of graphene having $sp^2$ hybridization. Carbon nanotubes are continuous hollow fibers having a cylindrical shape. These are encompassed of walls produced by graphene in the form of hexagonal lattices of carbon that are rolled in discrete chiral angles.[32] Carbon nanotubes are extremely light in weight. Discrete carbon nanotubes get aligned naturally in rope forms which are typically strongly held through $\pi$-stacking.[32] The diameters of carbon nanotubes cylinders range from 0.6 to 55 nm with their lengths ranging in tens of micrometers.[7] The main fabrication techniques of carbon nanotubes include arc discharge technique, silane solution technique, chemical-vapor deposition method, physical laser ablation, flame production method, etc. The main usage of these nanoparticles in cosmetic formulations is their addition in hair coloring products.[33] Combing many biopolymers (e.g., graphene and chitosan) was proven to produce distinct colors. Moreover, carbon nanotube formulations revealed elevated resistance to numerous shampoo formulations and are remarkable with their heat endurance capabilities.[33]

**3.7. Nanohydroxyapatite.** Nanohydroxyapatite formulations are added to oral products. These are mainly applied for the treatment of sensitivity of teeth. Nanohydroxyapatite are also used for the remineralization of teeth.[34] Nanohydroxyapatite is a safe preference for use in mouth as mentioned by the U.S. Food and Drug Administration.[35] Nanohydroxyapatite is added to several oral products (e.g., mouthwashes, toothpastes, and dentifrices) owing to their desensitization and remineralization characteristics. Additionally, these formulations can provide an alternative to fluoride-based toothpastes.[5]

**3.8. Nano Tris-biphenyl Triazine.** Tris-biphenyl triazines are strong and highly photostable filters added to several sunscreen products.[36] Tris-biphenyl triazine functions in a broader spectrum as a powerful UV protectant and offers more photostability when used in its nanoform. It is an accepted protectant for UV rays that is added broadly in many creams and lotions in Europe. Nano methylene bis-benzo triazolyl tetramethyl butylphenol is also widely used for UV protection in the European market. It is approved to be applied at percentages of 10% (w/w) to dermal formulations.[36] Nano methylene bis-benzo triazolyl tetramethyl butylphenol does not represent any toxicity or danger to people. Nevertheless, certain concerns were raised lately related to probable detrimental side effects after applying these formulations, being that these can bioaccumulate in some human tissues.[5]

**3.9. Fullerene.** Fullerene is a spherical and 3-D chemical compound which encompasses carbon rings, entailing odd numbers of carbon atoms. Due to its special structure, it is termed as buckyballs.[37] Fullerenes possess restricted usages due to their hydrophobicity; nevertheless, the application of surface-active agents on fullerenes in their nanoscale can enhance their aqueous solubility and thus can productively augment their usage in cosmetics and pharmaceutical applications.[5] Carbon fullerenes, in their nanoscales, are also broadly used in cosmetics formulations owning to their antioxidative properties. These are also extensively applied in skin-revitalizing creams/lotions due to their effective scavenging abilities of free radicals, therefore aiding in decreasing the adverse outcomes of UV rays, like wrinkles, dryness, hyperpigmentation, etc.[38]

**3.10. Nanoliposomes.** Nanoliposomes are vesicles containing circular bilayers of phospholipids that range in sizes from 20 nm up to hundreds of micrometers. Nanoliposomes are broadly applied for controlled release systems in pharmaceutical, cosmetics, and medicinal sectors.[39] They are useful materials when added to cosmetics due to their biodegradability/biocompatibility and because of their high stability/endurance on the skin.[40] Movement of substances to the human skin and to the systemic circulation is usually restricted due to the very thick physiological barrier, i.e., stratum corneum. The drawback is alleviated by mean of reducing the materials' sizes to the nanoscale and thus cosmetics incorporating nanoliposomes augment the skin's hydration, rendering the skin smoother. Nanoliposomes have the capability of transporting active ingredients inside the deep skin layers all the way to the systemic circulation; thus, these are applied as transdermal drug delivery.[41] Nanoliposomes are used for transporting pleasant odors through antiperspirants, shampoos, lipsticks, lip balms, deodorants, body/hand wash, etc. Nanoliposomes are likewise applied for moisturizing and antiaging purposes.[40] Phosphatidylcholine is a significant ingredient of nanoliposome that are applied to skin products (e.g., creams, lotions, and moisturizer), in addition to hair products (e.g., shampoos and conditioners) because of their high softening properties.[40]

**3.11. Nanostructured Lipid Carriers and Solid Lipid Nanoparticles.** Nanostructured lipid carriers and solid-lipid nanoparticles are innovative delivery systems produced from a single shell layer with a lipoidal center. These are described as solid-state lipid matrices having their sizes in the nanoscale. Both types of nanoparticles are broadly used in manufacturing pharmaceutical and cosmetics formulations.[42] Their very tiny sizes permit easy entry into the corneum layer, improving the penetration of beneficial components to the skin.[42] Nanostructured lipid carriers and solid-lipid nanoparticles possess an extreme biocompatibility and high safety.[43] These are also applied in film formation that aid in repairing the skin barriers, rendering them suitable for cosmetics that are applied for treating irritated skin and dermatitis.[44] Solid lipid nanoparticles are added to sunscreen formulations as carriers of tocopherol acetate, where these have shown an improved UV rays blocking ability.[45] The crystalline nature of solid-lipid nanoparticles leads to a lower encapsulation when compared with nanostructured lipid carriers that possess better encapsulation efficiency. Furthermore, solid-lipid nanoparticles have short shelf-lives and slower drug release rates when compared with nanostructured lipid carriers.[46]

**3.12. Nanocapsules.** Nanocapsules are vesicular systems composed of polymer membranes with an internal liquid core (e.g., water or oily phase) being encapsulated at a nanoscale level. Nanocapsules are used in cosmetics for masking bad odors, protecting active components, and easing incompatibility among the various ingredients in the prepared formulations. Polymeric nanocapsules are directly applied as suspensions to human skin or alternately could be formulated with semisolid systems to be used as nanocarriers.[15] Penetration degrees to the skin are easily monitored by changing the ratios of surfactants and polymers during the manufacturing steps.[47] Polymeric nanocapsules were produced for encapsulating natural plant extracts and vitamins, which were then incorporated into semisolid formulations, e.g., lotions, moisturizers, creams, etc. After application, the formulation was stimulated by the injured skin (e.g., occurrence of enzymes and pH alterations) and then induced the capsules to release the active constituents at specific parts of the skin.[47] In addition, a sustained release of fragrances is efficiently established by means of encapsulating fragrance molecules in polymeric nanocarriers.[47]

**3.13. Dendrimers.** Dendrimers are 3-D organic nanostructured entities which are comprehensively branched with their diameters ranging between 1 and 10 nm. This excessive branching accounts for their excessive adaptability as the branches' terminals deliver a huge source of nanosized particles with diverse surface functionalities.[15] Dendrimer originates from Greek terms, viz., "Dendron", which simply means a tree, and "Meros", which means a part.[7] Dendrimers are ordered branches of polymers with high stability; thus, these are beneficial in delivering active ingredients to the skin via creams and lotions. For instance, dendrimers of resveratrol, with antiaging/antioxidant properties, amended the solubility and enhanced the skin infiltration of antiaging creams.[15] Likewise, dendrimers' monodispersion and polyvalence make them efficient carriers for drug, remedies, and cosmetic formulations. Dendrimers can be added to shampoos, conditioners, and antiperspirants with an elevated efficiency of cleaning and high ability of reducing bad smells.[15]

**3.14. Cubosomes.** Cubosomes are nanosized materials with surfactants comprising sufficient quantities of water. Monoglyceride glycerol monoolein is commonly applied as a surfactant for producing cubosomes fluid crystalline nanosized particles.[14] These nanosized particles are added in cosmetics, especially in creams for skincare and hair care and also in antiperspirant formulations.[14] A study reported that cubosomes integrating $\alpha$-lipoic acid was effective for alleviating skin aging.[48] Additionally, cubosomes containing erythromycin showed better activities in preventing acne, working in a sustained-release manner.[14] Cosmetic sectors are also investigating the use of cubosomes as absorbents of pollutants during the preparation steps of cosmetics.[15]

**3.15. Nanoemulsions.** Nanoemulsions are usually either oil-in-water or water-in-oil colloids whose sizes range between 2 and 150 nm.[49] The droplets' tiny sizes make nanoemulsions alluring optically, besides possessing an improved drug delivery ability. Additionally, the nanoemulsions' high solubilization capability, low viscosity, and high kinetic consistency make them efficient for cleansing purposes. They are added to hand washes, shampoos, hand creams, body lotions, moisturizers, and sunscreen formulations. These nanoparticles are likewise applied in the design process of innovative delivery systems of lipophilic drugs, essential oils, fatty acids, flavors, and colors/pigments.[50] Oil-in-water nanoemulsions especially enhance the penetration capabilities of polar components when compared to conventional emulsions.[51] Additionally, antioxidants suffer from various limitations when added to cosmetics formulations (e.g., instability and insolubility), and accordingly, researchers have formulated antioxidants as nanoemulsions having an improved efficiency.[52]

**3.16. Niosomes.** Niosomes are nanoparticles having their centers in aqueous cavities enclosed by non-ionic surfactant layers in a lamellar phase system. Niosomes' diameters typically range from 100 nm to 2 $\mu$m.[15] Niosomes are used as efficient vesicular carriers for both cosmetics' and drugs' active ingredients. Niosomes have a high stability, possess a high entrapment efficiency, reveal an enhanced skin penetration ability, and have low production costs. Niosomes are especially useful in delivery of topical products due to their ability of elongating the residence durations of the transported active contents inside the stratum corneum and in the epidermis too.[20]

**3.17. Micellar Nanoparticles.** Micellar nanoparticle-based emulsions offer a multipurpose and useful platform for incorporating a varied range of lipophilic ingredients, showing varied beneficial physicochemical characteristics in cosmetic products. Micellar nanoparticles have premium encapsulation efficiencies and low manufacturing costs, which makes them superior to other nanocarriers.[18] Typically, these are added to cleaners for efficient removal of oily dirts from the surface of the skin with no harm to the barrier integrities. Besides being effective cleansers, micellar nanosized particles are mandatory in the transdermal drug delivery sector. These nanoemulsions are successfully used for systemic drug delivery by means of topical application. Large amounts of the drug are allowable to permeate though the skin obtaining similar outcomes as those attained from transdermal drug delivery routes, thus making micellar nanoparticle formulations highly acceptable to consumers.[5]

## 4. MAJOR CLASSES OF NANOCOSMETICS

**4.1. Moisturizing Creams.** Nanosized particles are being lately added to many cosmetics' products to satisfy several needs and perform certain functions. Stratum corneum is the major barrier of human skin and leads water to evaporate easily from the skin causing dryness and dehydration. Skin dehydration could be avoided by means of applying moisturizers. Moisturizers produce a fine film of humectant that maintains moisture to the skin and gives it a better appearance, making it look fresh, supple, and smooth.[15] In addition to aiding for a better look, moisturizes have medicinal benefits as well, for instance, ailments of atopic pruritus and dermatitis are controlled and sometimes even stopped when the skin is hydrated well using moisturizers.[15] Cosmetics' sectors have lately been using nanoliposomes for delivering cosmetics' active constitutes (e.g., vitamin E, retinol, calcium, etc.) to enhance their solubility besides adding beauty/shimmer to the skin.[5] Nevertheless, nanostructured lipid carriers/solid lipid nanoparticles are more innovative nanosized materials having proven enhanced deliveries and higher stabilities than nanosized liposomes that have been previously solely used. When these are added to moisturizers, they provide a more controlled occlusion and higher bioavailability of the enclosed active ingredient, thus providing a superior hydration to the skin.[5] Last, but not least, gold nanoparticles are also added to some types of moisturizers. These formulations were reported to provide antioxidant, healing, and antibacterial properties.[15]

**4.2. UV Filters and Sunscreens.** Sunscreen formulations are universally used as a protection means of the human skin against the adverse consequences of UV rays.[24] Titanium oxide and zinc oxide are the major UV filters that are being added in their nanoforms to sunscreen formulations. These are the most efficient mineral-based active ingredient that are approved worldwide and were proven to effectively protect the skin from damage due to the sun's rays.[24] While some organic chemicals substitutes are being lately experimented with to be used for the same regard, titanium oxide and zinc oxide are still the best to protect against the UV harmful rays. Both minerals form barriers on the outer layer of the skin which reflect the UVA/UVB detrimental rays and also avoid their permeation to the skin layers.[24] Another advantage of using sunscreens containing titanium oxide and zinc oxide nanoparticles is avoiding some of the drawbacks of traditional sunscreen formulations, e.g., leaving a chalky white layer on the skin.[15] Conversely, sunscreens entailing titanium oxide and zinc oxide nanomaterials are less greasy, translucent, and not smelly and possess an augmented beautifying effect.[15]

**4.3. Antiaging Products.** Skin aging is a normal process and occurs in several ways, like dryness, wrinkles, thinning, decrease of elasticity, existence of dark acnes, alteration of the surface line isotropy, etc. Besides the normal aging process, air pollution, stress, UV rays, drinking/washing with contaminated water, and illness/ailments cause early aging of the skin.[53] Collagen is a protein that serves as the lead building blocks of the skin and is vital for the skin's rejuvenation/wrinkle reversal effects. Collagen is what gives our skin a youthful look and its quantity drops with aging.[15] Cosmetics were developed to satisfy the skin's need for the lost collagen. These are aimed for antiwrinkle, lifting, and whitening purposes.[53] Antiaging creams are the chief class of cosmetics in the market presently incorporating the use of nanotechnology. To be specific, addition of retinol to creams can elevate the epidermal water content, cell renewal, and epidermal hyperplasia, besides augmenting collagen's production.[53] An antiwrinkle cream was developed containing retinol nanosomes which was proven to reduces wrinkles to a great extent.[15] Additionally, retinol encapsulated in nanosomes was proven to interfere with melanogenesis and prevent matrices' metalloproteinases, which were responsible for collagen's reduction. Last, but not least, clinical benefits of retinol encapsulated in nanosomes include the lightening of lentigines.[15]

**4.4. Hair Care.** Nanocosmetics have been lately added to several hair products, such as hair growth repair products, shampoos, conditioners, hair leave-in products, styling sprays/gels, dyes, etc. A big quantity of the active ingredients can reach the hair follicles efficiently due to the intrinsic properties and small sizes of nanoparticles.[54] Innovative nanocarriers (e.g., nanospheres, niosomes, liposomes, etc.), being added to diverse hair products have the ability of renovating impaired cuticles and fixing the texture/gloss of damaged hair.[54] Considering shampoos specifically, nanoparticles added to shampoo formulations have the ability to seal moisture on the cuticles through enhancing the contact duration with the scalp and hair follicles. In addition, conditioners containing nanocosmetics provide shine, softness, and gloss to the hair; besides that, they enhance hair anti-tangling.[54]

**4.5. Skin Cleansers, Disinfectants, Soaps, and Antiseptics.** Human skin is naturally protected by a hydrolipid coat which contains discharges from the sebaceous glands and from the apocrine sweat glands as well. Besides providing a natural protection against microbial/pathogenic organisms, this thin film unfortunately attracts dust, dirt, and impurities.[15] Continuous cleaning of the skin is mandatory to remove dirt to maintain the skin as healthy and bright. Cleansing is also needed for bacterial removal from the skin's surface, the pathogenic organism being naturally attained by the application of medications, makeup, and other cosmetic products.[15] Certain nanoparticles are being integrated into cleansers, disinfectants, and antiseptics for a better cleansing performance. For instance, silver nanoparticles have a broad-range of antibactericidal activities and accordingly are extensively applied as a skin disinfectant. Precisely, Evolut hand sanitizers include silver nanoparticles in their formulations. This product has been proven to be a highly effective disinfectant. It is also recognized to be hypoallergenic and produces immunity against airborne germs.[5]

**4.6. Lip Products.** Lipsticks, lip balms, and lip glosses are applied as coatings mainly for beautifying reasons. Lip care and beatifying products may nowadays include nanosized materials for many purposes.[15] For instance, nanoparticles are added to lip care products to achieve soft and sooth lips by means of preventing trans-epidermal water loss from the surface of lips.[15] Besides, maintaining the smoothness of lips, lipstick products entailing nanoparticles provide excessive luster/shine to the lips' appearance owing to their very trivial sizes, thus improving the aesthetic appearance.[5] Lip sticks, prepared using gold or silver nanoparticles specifically, exhibit a wide range of colors, and the color is maintained for long durations after application. Lastly, silica nanoparticles added to lipsticks advance the homogeneous distribution of pigments throughout the formulation and avoid the pigments from moving to the lips' fine line.[15]

**4.7. Nail Polish.** Nail polishes entailing nanoparticles in their formulations possess several advantages over the conventional nail polishes. For instance, nail polishes consisting of nanoparticles have the ability to dry to a very hard state, besides that those develop firmness, durability, damage resistance, and stability to the applied polishes.[15] A novel approach, which possesses a huge potential in the cosmetics sector, is the integration of nanosized inorganic materials displaying antifungal activities in nail polish formulations for treating fungal toe nail infections. The types of nanoparticles that were proven successful for this regard are silver and metal oxide nanoparticles.[15] Last, but not least, nail polishes having nanoparticles resist scratching as their elasticity gives an ease of application without cracking.[15]

## 5. SUSTAINABILITY AND GREEN COSMETICS

There is currently an increasing awareness toward alleviating pollution. The globe is shifting toward adapting green ecological ideologies that are grounded to three pillars, namely, recycle, reduce, and reuse.[55] Currently, several cosmetic companies are striving toward developing products that are entirely composed of environmentally friendly, biocompatible, and biodegradable raw materials.[56] The advantages of novel nanosized particles are many, including their highly porous structure, augmented drug loading, and high mechanical strength, along with showing biocompatibility that makes them appropriate candidates of the novel trend of green

## Table 2. Natural Ingredients Used for Preparing Nanocosmetics

| Natural Source | Delivery System | Nanoformulation Benefits or Functions | Ref |
|---|---|---|---|
| Vegetable/Seed Oils and Fats | | | |
| Almond oil | Nanostructured lipid carriers | Sun screen formulations | 79 |
| Castor oil | Nanoencapsulation | Development of beneficial topical products | 80 |
| Cocoa butter | Solid-lipid nanoparticles | $\beta$-Carotene delivery | 68 |
| | Solid-lipid nanoparticles | Efficient antiaging effects | 81 |
| | Solid-lipid/liquid–liquid nanoparticles | Stability of $\beta$-carotene | 82 |
| Coconut oil | Nanoemulsion | Production of haircare treatment products | 83 |
| Coffee oil | Pickering emulsions | Sun screen formulations | 84 |
| Grape seed oil | Nanoencapsulation | Effective antioxidant | 85 |
| | Microemulsion | Topical cosmetic products | 86 |
| Jojoba oil | Nanolipidgels | Emollients and moisturizers | 87 |
| | Microemulsion | Solubilization of lycopene | 88 |
| Linseed oil | Nanoemulsion | Transdermal application | 89 |
| Olive oil | Lipid nanoparticles | Antioxidant agent | 90 |
| | Nanoemulsion | Lipstick base | 91 |
| | Nanoemulsion | Analgesic and anti-inflammatory effects | 92 |
| | Nanoencapsulation | Cutaneous applications for skin protection | 93 |
| | Microemulsion | Antioxidant and skin moisturizer | 94 |
| | Liposomes, ethosomes, and transferosomes | Boosting skin hydration level and sebum content | 95 |
| Palm oil | Nanoemulsion | Vitamin E encapsulation | 96 |
| | Nanoemulsion | Efficient antiaging effects | 97 |
| Pomegranate seed oil | Nanostructured lipid carriers | Efficient antioxidant effects | 98 |
| | Nanostructured lipid carriers | Photoprotection activity against UV rays | 99 |
| | Nanostructured lipid carriers | Sun screen formulations | 100 |
| Pumpkin oil | Nanostructured lipid carriers | Development of biocosmetic products | 101 |
| Rapeseed oil | Nanoemulsion | Development of cosmetic matrix with multiple ingredients | 102 |
| Rice bran oil | Nanostructured lipid carriers | Photoprotective cosmetics/minimal synthetic UV filters | 103 |
| | Nanoemulsion | Antiaging skin care | 104 |
| Rosehip oil | Nanostructured lipid carriers | Development of antiacne topical products | 78 |
| Sesame oil | Nanostructured lipid carriers | Photoprotection with antioxidant activity | 105, 106 |
| Shea butter | Solid-lipid nanoparticle | Curcumin delivery | 107, 108 |
| Soybean oil | Nanoemulsion | Mouth freshener | 109 |
| | Nanostructured lipid carriers | Increasing the bioavailability of bioactive compounds | 110 |
| Sunflower oil | Microemulsion | Microencapsulation of antioxidant extracts | 111 |
| | Nanoemulsion | Nanoencapsulation of antibacterial compounds | 112 |
| | Nanostructured lipid carriers | Production of safe biocosmetics | 113 |
| Essential Oils | | | |
| Bergamot | Nanoencapsulation | Antibacterial and antimicrobial properties | 114 |
| Carvacrol | Microemulsion | Antimicrobial agent for moisturizing creams | 115 |
| Citral | Nanoencapsulation | Antimicrobial agent in several cosmetic formulations | 116 |
| Clove | Microemulsion | Antimicrobial agent | 117 |
| | Solid-lipid nanoparticles | Antibacterial and antioxidant agent | 118 |
| Coriander | Nanoemulsion | Antiwrinkle activities | 119 |
| Cumin | Nanoemulsion | Antioxidant agent | 120 |
| Green tea | Nanoencapsulation | Antioxidant and antimicrobial properties | 121 |
| Holey basil | Nanoemulsion | Efficient antiacne agent | 122 |
| Lemongrass | Nanoemulsion | Antioxidant agent | 123 |
| Lemon myrtle oil | Nanoemulsion | Antimicrobial agent | 124 |
| Marijuana | Nanoencapsulation | Antioxidant agent | 125 |
| Nam nam | Nanoencapsulation | Antioxidant and antimicrobial properties | 126 |
| Oregano | Nanoencapsulation | Antibacterial agent | 127 |
| | Nanoemulsion | Antimicrobial agent | 128 |
| | Nanoemulsion | Antiacne agent | 129 |
| Peppermint | Nanoemulsion | Antimicrobial wound healing | 130 |
| Preciosa | Nanoemulsion | Healing of infected wounds | 131 |
| Tea tree | Nanoencapsulation | Antifungal agent for nails | 132 |
| | Nanoencapsulation | Beneficial face creams | 77 |
| Thyme | Nanoemulsion | Antibacterial agent | 133 |
| | Nanoemulsion | Antifungal agent for infected areas | 134 |
| Thymol | Solid-lipid nanoparticles | Antimicrobial agent in cosmetics lotions | 135 |

Table 2. continued

| Natural Source | Delivery System | Nanoformulation Benefits or Functions | Ref |
|---|---|---|---|
| Plants | | | |
| *Abutilon indicum* | Metal nanoparticles | Photocatalytic properties | 136 |
| *Achyrocline satureioides* | Nanoemulsion | Boosting of active ingredients' absorption on skin | 137 |
| *Adhatoda vasica* | Nanoemulsion | Cold cream formulations | 138 |
| *Aloe vera* | Nanoencapsulation | Enhancement of proliferation and collagen synthesis | 139 |
| | Microemulsion | Optimizing hair growth | 140 |
| | Liposomes | Antiaging and regeneration of skin creams | 141 |
| | Solid-lipid nanoparticles | Highly photoprotective sunscreen creams | 142 |
| *Ananas comosus* | Nanoemulsion | Topical creams | 143 |
| *Apium graviolens* | Microemulsion | Optimizing hair growth | 140 |
| *Armoracia rusticana* | Liposomes | Antioxidant agent | 144 |
| *Bixa orellana* | Polymeric nanoparticles | Sun screen formulations | 145 |
| *Brassica nigra* | Phytosomes | Wound healing formulations | 146 |
| *Brassica oleraceae* | Nanoencapsulation | Gels that protect against UV radiations | 147 |
| *Calendula officinalis* | Nanostructured lipid carriers | Remission of inflammatory acne lesion | 148 |
| *Camellia sinensis* | Polymeric nanoparticles | Enhancing the bioactivity of ingredients | 149 |
| | Ethosomes | Antioxidant agent | 150 |
| *Carthamus tinctorius* | Nanostructured lipid carriers | Diverse cosmetic formulations | 151 |
| *Centella asiatica* | Nanoencapsulation | Enhance skin protection activity | 152 |
| | Nanoemulsion | Cellulite reduction | 153 |
| *Centaurea pumilio* | Solid-lipid nanoparticles | Combating dark spots | 154 |
| *Citrus auranticum* | Nanoencapsulation | Antioxidant and antiaging creams | 155 |
| *Citrus sinensis* | Nanoemulsion | Antiaging cream/increasing elastin and collagen in skin | 156 |
| *Coleus forskohlii* | Solid-lipid nanoparticles | Wound healing and collagen deposition | 157 |
| | Solid-lipid nanoparticles | Antibacterial agent | 158 |
| *Curcuma longa* | Nanoemulsion | Improvement in skin hydration and sebum content | 159 |
| | Nanoencapsulation | Gels for elevation of skin hydration | 160 |
| | Transfersomes | Facial antiwrinkle cream | 161 |
| *Daucus carota* | Nanostructured lipid carriers | Antiacne cream | 162 |
| *Fraxinus angustifolia* | Nanoencapsulation | Healing of infected wounds | 163 |
| *Garcinia mangostana* | Polymeric nanoparticles | Antiacne agent | 164 |
| *Hedera helix* | Solid-lipid nanoparticles | Sun screen fillers | 165 |
| *Hibiscus sabdariffa* | Liposomes | Improving dermal penetration | 166 |
| *Iresine herbstii* | Solid-lipid nanoparticles | Antibacterial and antioxidant agent | 167 |
| *Labisia pumila* | Liposomes | Antiaging creams | 168 |
| *Lavandula* | Nanoencapsulation | Creams with antiaging properties | 169 |
| *Matricaria recutita* | Nanofibers | Skin-protective activities | 170 |
| *Mirabilis jalapa* | Bimetallic nanoparticles | Antibacterial agent | 171 |
| *Morinda lucida* | Solid-lipid nanoparticles | Transdermal transporter for plastic surgeries | 172 |
| *Nerium oleander* | Niosomes | Antioxidant agent | 173 |
| *Ocimum sanctum* | Nanostructured lipid carriers | Topical antiaging cream | 174 |
| *Olea europaea* | Nanoencapsulation | Diverse cosmetic formulations | 175 |
| *Opuntia ficus-indica* | Nanoemulsion | Moisturizers and emollients | 176 |
| *Orthosiphon Stamineus* | Solid-lipid nanoparticles | Antioxidant agent | 177 |
| *Oryza sativa* | Niosomes | Antiaging creams | 178 |
| *Oxytropis falcata Bunge* | Liposomes | Gels with wound healing and anti-inflammatory properties | 179 |
| *Panax ginseng* | Metal nanoparticles | Moisture retention capabilities and whitening effects | 180 |
| | Metal nanoparticles | Protective skin formulation | 181 |
| *Phyllanthus urinaria* | Nanoemulsion | Topical antiaging cream | 182 |
| *Phragmites communis* | Solid-lipid nanoparticles | Moisturizing agent | 183 |
| *Polygonum aviculare* | Solid-lipid nanoparticles | Transdermal delivery of antiaging therapeutics | 184 |
| *Poria cocos* | Cubosomes | Hair-growth promoting properties | 185 |
| *Prosopis juliflora* | Solid-lipid nanoparticles | Wound healing potential | 186 |
| *Pueraria mirifica* | Niosomes | Expands the lobules and alveoli of the breasts | 187 |
| | Solid-lipid nanoparticles | Hair growth promotion | 188 |
| *Punica granatum* | Solid-lipid nanoparticles | Improving sun protection factor in sunscreen creams | 189 |
| *Tamarindus indica* | Polymeric nanoparticles | Improvement of skin properties | 190 |
| *Theobroma cacao* | Nanoencapsulation | Face serum with antioxidant properties | 191 |
| *Urtica dioica* | Solid-lipid nanoparticles | Strengthens hair follicles/improves scalp circulation | 187 |
| *Vellozia squamata* | Nanoemulsion | Antioxidant agent | 192 |
| *Woodfordia fruticosa* | Solid-lipid nanoparticles | Wound healing potential | 193 |

cosmetics.[56] Along the trend of "going organic" in most industrial sectors these days, e.g., organic fruits and organic clothes; the same is being mirrored in the cosmetics sector. The rising awareness of consumers in using organic sustainable products has urged the cosmetics industry to make products formed from natural sources, while ensuring that the industrial steps used pose no/or minimal harm to the environment.[56] Marketing trends are presently shifting toward natural cosmetics that contribute to a healthier lifestyle. Researchers are investigating novel ways and routes for sustainable nanosized particles production, aiming for reducing the environmental risks which might be correlated to the traditional physiochemical production techniques.[56]

Novel oligosaccharide-based nanosized materials are currently being investigated as green nanocarriers that could be used for producing innovative smart cosmetics. Some of these biocompatible and eco-friendly natural materials are chitin, nanofibrils, nanolignin, nanocellulose, pullulan, and chitosan.[57] Bilal et al.[33] have developed a novel eco-friendly hair dye consisting of nanoparticles. They joined chitosan and graphene nanoparticles for the preparation of the colored nanoformulations which showed no environmental hazards. Further development in this area was performed by utilizing silica halloysite clay nanotubes which were integrated via eco-friendly peptide molecules. This nanoformulation has also shown a huge potential in the development of a novel biodegradable and biocompatible hair products.[57] Likewise, various environmentally friendly bridgeable biopolyesters, e.g., polyhydroxyalkanoates and polylactic acid, are currently under investigation for being used in certain cosmetics in their nanoforms. These might be potentially marketed as green cosmetic product.[58] Additionally, nanocosmetics incorporating ingredients extracted from natural resources, including plants and others, are likewise in need for the production of sustainable cosmetics and are elaborately discussed in the subsequent section.[59] Essential oils, for instance, are volatile oils consisting of low molecular weight compounds. Fragrances of essential oils impact the overall value of cosmetics. In that context essential oils are being exploited as eco-friendly and biodegradable nanoformulations in cosmetics.[59] Sugumar et al.[60] formulated essential oils into nanoparticles. They developed a nanoemulgel via preparing oil-in-water nanoemulsions comprising mangosteen extract aiming to deliver its antibacterial, antioxidant, antiviral, and antitumoral bioactivities. Mangosteen essential oil also has regenerative and emollient characteristics which makes it optimum for formulations to treat damaged skin. The nanoemulgel with mangosteen micelles was reported to penetrate the skin layer efficiently, delivering 95% of the mangosteen content, besides possessing no harm to the environment. Additionally, $CeO_2$ nanosized crystals were biosynthesized by utilizing *Hoodia gordonii* natural extracts to be added as additives to sunscreen formulation. The nanocrystals revealed an extraordinary UV selectivity and a remarkable photostability; in addition to being biosynthesized thus posing no harm to the eco-system.[61] Furthermore, an extract of Namibian red ochre was used as a natural ingredient in a nanoformulation that was added to skin beauty and protective creams. The natural-based biocompatible nanocosmetics product exhibited an extraordinary UV filtration, besides having substantial IR reflectivity abilities.[62] Lignin is the second most abundant organic compound found in plants and is known for its antioxidant potency and UV protection capabilities. In one of the research works, environmentally friendly sunscreens where prepared after changing modified kraft lignin to nanosized particles to enhance its properties. The nanoformulation significantly enhanced the UV absorption capabilities of sunscreens. To be precise, sunscreens consisting of the modified nanosized kraft lignin showed lower UV transmittance (0.5−3.8%) when compared with the commercial sunscreen formulations.[63]

## 6. NATURAL INGREDIENTS IN NANOCOSMETICS

Being inspired by the global sustainability move and the urge to reduce the carbon footprint, consumers are nowadays demanding natural healthy products prepared by environmentally friendly manufacturing processes. Many botanical products can be used as cosmetics ingredients, and these are abundant in polyphenols, vitamins, antioxidants, essential oils, minerals, proteins, and terpenoids.[2] Botanicals support the health and integrity of the skin, hair, and nails. These are the largest group of cosmetics additives found in the market these days because of the rising consumer interest in natural products. Many plants that formed the base of medicinal treatments of ancient civilizations are still used nowadays in cleansers/moisturizers and in many other skin care products. The cosmetics industry is investigating these compounds' biological effects in order to develop eco-friendly cosmetic products. Indeed, a rising number and types of cosmetic formulations constitute plant and vegetable extracts which are typically used in regular human nutrition as nutritious food. Novel botanical skin care treatments are emerging, giving dermatologists the challenge of understanding the science behind these cosmetics. Thus, dermatologists should have a working knowledge of these botanicals to provide optimal medical care.[64]

**6.1. Vegetable Oils and Fats.** Vegetable oils and fats are a class of the most significant natural ingredients applied in the production of cosmetics (Table 2). Both have different physical states at room temperature where oils are in a liquid state whereas fats are in a solid state.[65] Vegetable oils are usually constituted mainly by triacylglycerols and smaller amounts of monoacyl- and diacylglycerols. They also contain phytosterols, fat-soluble vitamins, alcohols, free fatty acids, polyphenols, terpenes, etc.[66]

Fatty acids, specifically, are useful for the maintenance of stratum corneum integrity. This is particularly relevant for some inflammatory/skin ailments such as dermatitis, psoriasis, and eczema where the chief resolution is replenishing the intracellular lipids to restore the stratum corneum using lotions and creams. Vegetable oils, containing fatty acids, increase the moisturization and softness of the skin; besides, it is useful for the epidermis structure recovery.[65] Linoleic and $\alpha$-linolenic acids are the most beneficial fatty acids for maintaining the structure of the skin. Linoleic acid is also essential for the integrity of the cutaneous barrier as it prevents the loss of water. Additionally, it forms a part of the ceramide-1 structure, which is principal for stratum corneum organization and also for producing arachidonic acid (i.e., a significant mediator that is involved in synthesizing proinflammatory eicosanoids). Moreover, $\alpha$-linolenic acid is important for immune response in the epidermis and also for producing docosahexaenoic/eicosapentaenoic acids (i.e., these produce anti-inflammatory eicosanoids).[65]

Vegetable oils are abundant in polyphenols which possess antioxidant activities. According to the different chemical compositions, polyphenols are classified into four major

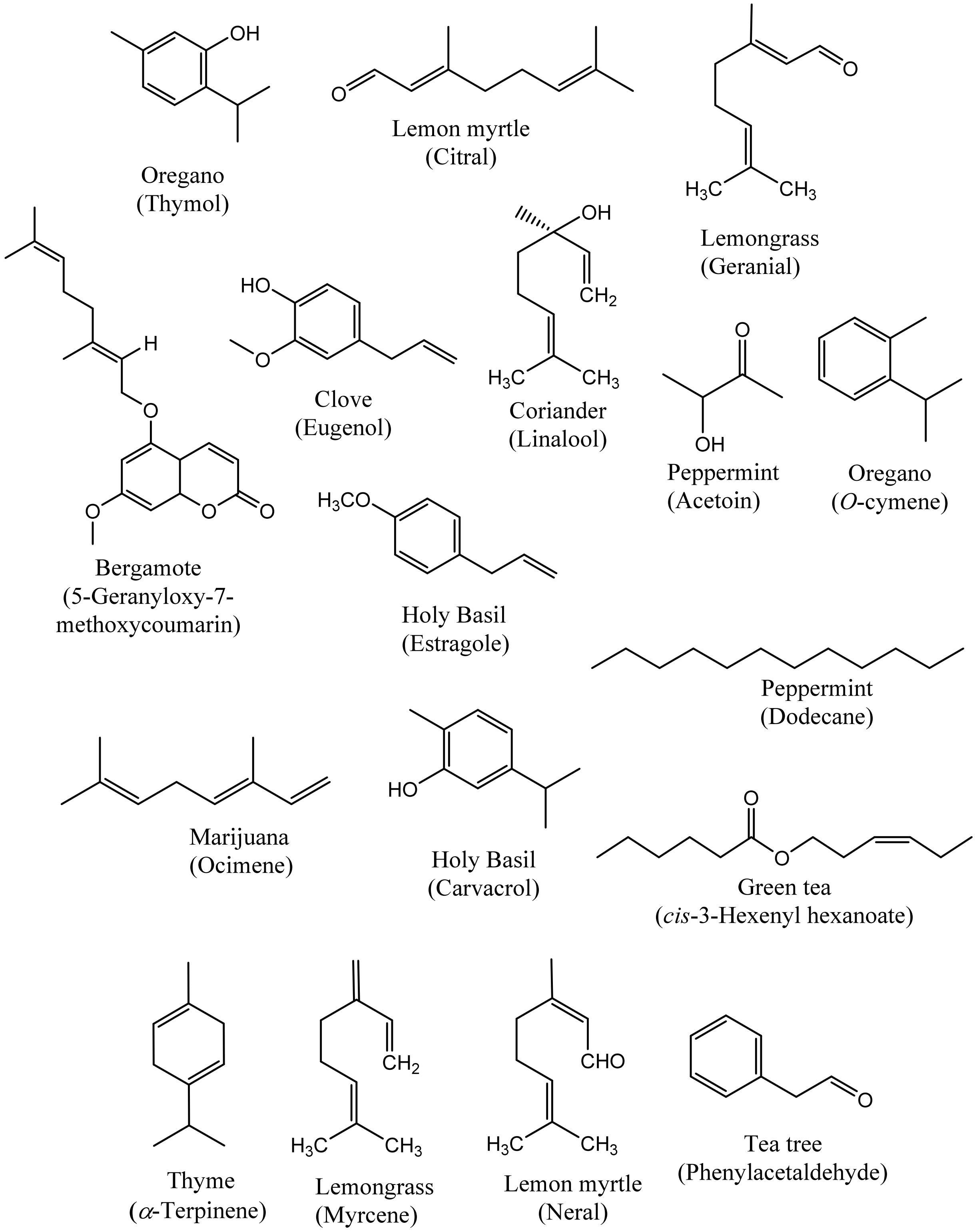


**Figure 3.** Chemical structures of selected main ingredients of essential oils used in nanocosmetics.

groups, i.e., phenolic acids, flavonoids, stilbenes, and lignans. Polyphenols chelate metal ions, which are key in generating reactive oxygen species, and by scavenging the free radicals, therefore counteracting lipid peroxidation, cell death, oxidative stresses, DNA damages, etc.[12] Another benefit of polyphenols is its photoprotection activity for the skin, and it is also capable of preventing photocarcinogenesis. Besides, polyphenols are antiallergy agents having the ability of influencing multiple biological pathways and immune cell functions involved in allergic immune response. Polyphenols also possess anti-immunomodulatory and anti-inflammatory properties. Last but not least, these are capable of promoting DNA repair and can also act as chemopreventive agents.[65]

Vegetable oils are applied as vehicles for dispersing active ingredients which are used for preparing emulsions. These are also are applied as the liquid lipid for the formulation of nanostructured lipid carrier matrices. The inner phase of those nanocarriers comprises a combination of both solid lipids and liquid composing a formulation having low-ordered internal assembly if compared with the solid-lipid nanoparticles.[67]

Fats, on the other hand, have high quantities of saturated fatty acids when compared to vegetable oils. Although most fats are derived from animals, yet some are extracted from plants, e.g., shea butter, cocoa butter, palm oil, etc.[68] Shea butter is derived from kernels of *Vitellaria paradoxa*, and it mainly comprises triglycerides of palmitic, stearic, oleic, and linolenic fatty acids. Shea butter also has phenols, tocopherol, sterols, and triterpenes, which possess antioxidant and anti-inflammatory charactertics.[69] Also, it has refatting properties and water-binding activities, which enable water retention on skin for prolonged durations. Shea butter is also a great ingredient for skin/hair formulations owning to its emollient properties. Last but not least, it promotes the inactivation of proteases which is important in the degradation of collagen/elastases and can absorb UV radiation; thus, it is highly beneficial for both sunscreen and antiaging creams.[69]

Cocoa butter is a raw fat extracted from cocoa beans of *Theobroma cacao*. Cocoa butter is a good source of antioxidants because it is rich in phenols (e.g., epigallocatechin, epicatechin, anthocyanins, flavanones, etc.) whose beneficial effects on skin's tonus and elasticity is scientifically proven. It consists of the beneficial vitamin E, sterols, triglycerides, and many fatty acids (for example, oleic, linoleic, stearic, and palmitic acids). It has emollient characteristics conferring firmness to the skin. Accordingly, cocoa butter is used in several cosmetic products, for instance, softening feet and hand lotions, lip glosses and balms, moisturizer creams for diverse skin types, etc.[70] Palm oil is also a natural raw material which is derived from the mesocarp of palm tree, namely, *Elais guineensis*. Palm oil is composed of around 40−60% saturated fatty acids, palmitic acid being the most significant fatty acids (36−56%). It also has a high content of oleic acid (29−44%), sterols, carotenoids, tocopherols, and aliphatic alcohols.[71]

Fats are applied for preparing nanostructured lipid carriers and solid-lipid nanoparticles. Both types of nanoparticle carriers have a nanosize. When these are applied on the skin, the systems get directly in contact with stratum corneum, permitting a release of active ingredients efficiently to the epidermis. Furthermore, the lipid content of these colloidal systems permits the composition of films having an occlusive effect on the surface of the skin, consequently lessening the trans-epidermal loss of water.[71]

### 6.2. Essential Oils.

Essential oils are volatile/aromatic liquids derived from a variety of plants' parts, including barks, leaves, flowers, buds, stems, twigs, fruits, seeds, roots, etc.[72] Examples of essential oils include tea tree, lemongrass, clove, preciosa, holy basil, coriander, ylang ylang, thyme, peppermint, rosemary, nam nam, marijuana, oregano, frankincense, pachouli, geranium, tangerine, cedarwood, rosemary, lavender, etc. (Table 2). Figure 3 represents the chemical structures of some of the previously used essential oils in cosmetics through applying nanotechnology. These natural oils are employed extensively in the cosmetics sector worldwide, and these are primarily applied for their pleasant and distinctive aroma. They have broad medicinal values as antioxidant, antibacterial, anti-inflammatory, and antifungal agents. Essential oils have the ability to heal damaged skin and provide deep nourishment. For instance, lavender and tea tree essential oils have anti-inflammatory properties that reduce irritation and inflammation linked to certain skin conditions, e.g., acne, eczema, and psoriasis. In addition, frankincense and patchouli essential oils alleviate wrinkles, hence improving skin's appearance.[72] Essential oils cannot be applied topically due to their high volatility and also there is a big probability that some of their ingredients can react allergically with the skin; accordingly they should be diluted with carrier oils such as olive, neem, avocado, castor, coconut, and sunflowers oils. Furthermore, stability problems also emerge when using these oils in their raw forms.[73] Also, the unsaturated carbon chains of certain ingredients of essential oils are prone to oxidation after exposure to light and heat. Besides, terpenoids and sesquiterpenes found in many essential oils have demonstrated a strong allergenic potency upon oxidation.[74] Moreover, the low solubility of essential oils in water restricts their miscibility in biological fluids, resulting in low bioavailability of their useful/natural chemical compounds.[73] While emulsion systems, such as lotions, ointments, and creams, have been used in the past to deliver essential oils, formulation scientists are now concentrating on utilizing cutting-edge nanotechnologies that can improve the product's functionality. The ideal solution would be to encapsulate essential oils in nanodelivery systems, which would help preserve an oil's integrity. The oil can then be released gradually in small amounts, allowing the essential oils to stay on skin for prolonged durations of time while promoting an improved biological activity of its beneficial ingredients.[73]

### 6.3. Plants.

Throughout human evolution, people have been using plants as herbal medicines.[15] It started when people first learned to select certain natural plants as food sources aiming to treat illnesses. For instance, over 800 medicinal plants, including aloe vera, garlic, juniper, retem, cannabis, castor bean, and mandrake root were widely used in ancient Egyptian civilization. Various cultures within Europe, comprising the Celts, Greeks, Romans, and Nordic communities, likewise applied herbal medicine as a major constituent of their therapeutic traditions.[75] Throughout the centuries, scientists have been impressed by the vast diversity of physicochemical and biological properties found in natural plant species. Plants are rich in vitamins, antioxidants, proteins, etc. These elements can work synergistically, providing several health benefits for skin. Most plant extracts exhibit antioxidant activity which fight free radicals. These free radicals can damage cells and contribute to signs of aging. Other plant species can help treat skin discoloration issues by inhibiting tyrosinase enzyme. Another advantage of plants is their antimicrobial properties which makes them fight off harmful microorganisms, including certain bacteria that can cause skin infections.[75] Accordingly, understanding the plants' chemical structures and their widely used applications is becoming a priority for the scientific communities across all scientific domains.[76] Numerous research teams have examined the biological activity of plants with an emphasis on how these plants could aid in the cosmetics industry.[64] Plant extracts possess poor solubility and low stability when used in their raw forms. Vehicles are therefore important to control the proper absorption and the biological response while simultaneously increasing the solubility of the active ingredient. Also, vesicles can minimize the degradation procedure, reduce any toxicity, and mask any unpleasant flavor.[11] The majority of biologically active ingredients found in plant extracts, including tannins, terpenoids, and flavonoids, have high molecular sizes, making them unable to cross lipid membranes, which reduces their

**Table 3. Environmental Impact of Nanoparticles**

| Nanomaterial | Environmental Risks | Reasons/Effects | Ref |
|---|---|---|---|
| Carbon nanoparticles | - Cytotoxicity in humans' cells and other mammals as well | - Altering the biogeochemical cycles of many nutrients<br>- Ruining the nutrient's natural balance<br>- Disturbing the microbes' metabolic activities | 194 |
| Silver nanoparticles | - Toxicity risks in the aquatic environment<br>- Absorbed by soil | - Causing oxidative stress<br>- Increasing the activities of antioxidant enzymes<br>- Ruining cell membranes | 200, 201 |
| Titanium dioxide nanoparticles | - Releasing the toxic titanium dioxide in water<br>- Damaging the aquatic life with a chronic exposure | - Influencing of either water bodies composition or UV rays | 5, 202 |
| Zinc oxide nanoparticles | - Toxic to plants and seaweeds<br>- Support seed germination | - Impeding metabolic pathways disturbing growth/functions of cells | 203 |
| Carbon black | - Toxic to animals | - Showing oxidative stress<br>- Harming organ development and body weight | 204 |
| Polystyrene and fullerene nanoparticles | - Toxic effect under biotic conditions | - Inducing oxidative stress<br>- Harming plants following their absorption and translocation | 203 |

bioavailability and effectiveness. This barrier has been attempted to be avoided by a number of nanotechnological techniques, including liposomes, solid-lipid nanoparticles, polymeric nanoparticles, nanoencapsulation, and nanoemulsions. These techniques enable the use of ingredients with unlike characteristics in the same formulation and can also alter an ingredient's behavior and properties in a biological environment.[77] Not only can the new delivery systems boost the potency of active ingredients but they can also bring back in other ingredients that were eliminated from the formulation because they were not useful. This approach is made even more appealing by the possibility of improving new substances before they are put on the market. Examples of these improvements include reducing side effects, improving efficacy and selectivity, guarding against thermal or photodegradation, and controlling the release of active constituents.[78] The utilization of nanotechnology in conjunction with plant extracts to produce cosmetics has been extensively documented (Table 2). This is due to the potential for nanostructured systems to augment the beneficial effects of raw plant extracts, facilitate the prolonged release of active ingredients, minimize certain adverse effects, and enhance their activity.[11]

## 7. ENVIRONMENTAL IMPACT OF NANOPARTICLES

Being vital in several biological/chemical procedures, nanoparticles can unfavorably possess harmful environmental influences.[194] The influences of nanomaterials on the environment rely on their isolation/segregation procedures in air, water, and soil and on how they are handled and used in the laboratory/factory.[195] The influences of nanoparticles also rely on their mobility and stability. Nanomaterials can trigger cell impairments by various mechanisms, including oxidative stress, autophagy, bioaccumulation, reactive oxygen species development, or lysosomal disfunctions, etc.[195] Due to the distinctive physical/chemical characteristics of nanosized particles, these may effortlessly pass into extremely minute spaces and can accordingly interfere with biochemical reactions in biological systems in an adverse way.[196] Table 3 compiles some environmental impacts of nanoparticles.

Throughout any manufacturing steps that incorporate the usage of nanoparticles, the nanomaterials may intentionally or accidentally be discharged into the air, causing pollution and health hazards. For instance, titanium dioxide nanoparticles that are applied for pollutants decomposition and for disinfection reasons, may possess a harmful impact on the photochemical reactions of the atmosphere.[197] Nanoparticles may also be discarded in water bodies (e.g., rivers and streams) and in the soil, producing adverse environmental hazards. Nanoparticles with antibacterial characteristics may hinder the beneficial activities of microorganisms in water treatment plants causing malfunctions in water recycling systems.[194] Also, titanium dioxide nanoparticles diminish the usefulness of microbes with minimal exposure durations; thus, if these nanoparticles end up in sewage treatment plants, they might interfere with the organisms which deliver essential roles to the environment.[5] Likewise, titanium dioxide nanoparticles, a chief ingredient in sunscreens, are discharged in huge amounts in water bodies, producing harm to aquatic life.[197] Additionally, nanomaterials entailing carbon display cytotoxic effects in humans through accumulating in certain organs (e.g., lungs, kidneys, liver, etc.). At elevated concentrations, these interfere with the metabolic activities of certain microbes through disturbing the nutrients' biogeochemical cycle and by disturbing the nutrients' natural balance.[197]

Metal nanosized particles can stimulate detrimental cellular reactions and generate toxicity to human cells.[194] Titanium, polystyrene, and fullerene nanoparticles were found to induce oxidative stress as these possess extra toxicity under biotic compared to abiotic conditions.[198] Carbon containing nanoparticles, e.g., carbon fullerenes, also affect all plant species adversely following their absorption and translocation, generating adverse effects on the botanical environment. In addition, silica, silver, and zinc oxide nanoparticles, absorbed by plants, trees, and seaweeds, cause toxicity to the soil and aquatic enjoinment besides these also hinder seed germination.[198] It is imperative to know the main causes/sources and the environmental pathways of the nanomaterials for an accurate environmental risk assessment. However, there have been no precise guidelines accessible until nowadays to accurately measure these effects.[199] A lot of research work is required to estimate the interactions between nanomaterials with the ecosystem and the biological systems. Furthermore, extensive research must be done to understand the absorption,

Table 4. Impact of Nanoparticles on Human Health

| Nanomaterial | Dosage | Exposure Time | Observed Effect(s) | Ref |
|---|---|---|---|---|
| Silver nanoparticles | 125−200 mg/mL | 24 days | ○ Oxidative damage | 210 |
| | | | ○ Upregulated stress | |
| | 125−500 μg/kg | 1−28 days | ○ Pulmonary inflammation, granuloma formation | 211 |
| Zinc oxide nanoparticles | 600 mg/kg, 1 g/kg | 5 days | ○ Increased serum inflammatory cytokines | 212 |
| | | | ○ Damaged DNA | |
| | | | ○ Increased calcium concentrations in heart | |
| | 0.2−0.4 mg/mL | 1, 24, and 72 h and 7 days | ○ Increased reactive oxygen species levels | 213 |
| | | | ○ Increased oxidative stress in lungs | |
| | 133.3, 200, and 300 mg/kg | 10 days | ○ Elevated maternal fetal transfer for pollutants and aggravated embryotoxicity | 214 |
| Gold nanoparticles | 3 μg/mouse | 1−60 days | ○ Major harms on the genes of cell cycle, lipid metabolism, defense response, circadian rhythm, detoxification | 215 |
| | 20 μg/m$^3$ | 90 days | ○ Accumulation of gold in kidneys and lungs | 216 |
| Titanium oxide nanoparticles | 106, 108, and 1010 s/cm$^2$ | 4 h and 5 days | ○ Damage intestinal epithelial cells | 217 |
| | | | ○ Reduced surface area for nutrient absorption | |
| | 0, 10, 50, and 200 mg/kg | 30 days | ○ Damaged cardiac muscle | 218 |
| | 62, 125, and 255 mg/kg | 30 days | ○ Impaired liver function | 219 |
| | | | ○ Lowered body weight | |
| | | | ○ Augmented coefficients of kidney, liver, spleen, thymus | |
| | 0.1 and 50 mg/kg | 30 and 90 days | ○ Elevated diastolic blood pressure | 220 |
| | | | ○ Reduced heart rate | |
| | | | ○ Injured cardiac function | |
| | 1, 5, and 10 μM/well | 8 and 24 h | ○ Elevated Bradykinin and ATP | 221 |
| | 200 μg/m$^3$ | 21−23 days | ○ Elevated ATP in bronchoalveolar lavage fluid | |
| Silicon dioxide nanoparticles | 8 mg/kg | 60 days | ○ Deposition in hippocampus and in medial prefrontal cortex | 222 |
| | | | ○ Elevated phosphorylation and neuroinflammation | |
| Carbon-based nanomaterials | 0.5 and 2.5 mg/m$^3$ | 90 days | ○ Multifocal granulomatous | 223 |
| | | | ○ Intra-alveolar lipoproteinosis | |
| | | | ○ Inflammation of lungs | |
| | | | ○ Increased neutrophilic and histiocytic inflammations | |
| | 20 mg/kg | 10 days | ○ Stimulated maternal weight gain | 224 |
| | | | ○ Induced abortion | |
| Carbon black | 0.018, 0.054, and 0.162 mg | 28 days | ○ DNA strand break down in lung epithelial cells and bronchoalveolar lavage | 204 |
| | | | ○ Elevated plasma low density lipoprotein | |
| | | | ○ Elevated hepatic cholesterol | |

distribution, and secretion of nanosized particles in living organisms.[199]

## 8. HEALTH RISKS ASSOCIATED WITH NANOCOSMETICS

Some types of nanoparticles cause severe health impacts on humans because of their possible toxicities. The level of harm that the nanoparticles may cause depends on their quantity, shape, method of administration, surface structure, solubility surface charge, chemical composition, duration of contact, etc.[11] Table 4 compiles several studies talking about the influences of nanoparticles on human health and wellbeing. Owing to their minute sizes and unique shapes, nanosized particles can easily move around inside the human body. Nanoparticles could also easily cross membranes, entering cells, tissues, and organs and causing cell damage.[205] Nanoparticles have large surface-area-to-volume proportions; accordingly, the chemical reactivities and biological activities are usually greater at the nanoscale as compared to the larger particles. Experiencing higher chemical reactivities, nanomaterials produce elevated amounts of detrimental reactive oxygen species, i.e., free radicals.[11]

Nanoparticles may induce an endocrine disruption and immunological effects. These may also stimulate toxicities in different human organs and systems, e.g., pulmonary, musculoskeletal, cardiovascular, neurological, respiratory, reticuloendothelial, and circulatory systems.[206] Nanosized particles pass to the body mainly through three routes, viz., by ingestion, via inhalation, and through topical application. Inhalation is the major way of exposure to nanomaterials. For example, during the production of nanocosmetics, workers and chemists may get exposed to nanoparticles and breathe them in, influencing their heath adversely. Furthermore, people may inhale nanoparticles by applying cosmetic products containing those. For instance, applying sunscreen sprays containing titanium dioxide nanoparticles may cause their inhalation followed by entering the nasal nerves, reaching the cerebrum, and then entering the bloodstream, thus triggering possible adverse health effects.[206] Moreover, the ingestion of nanoparticles may accidentally occur through their transfer from hands to mouth. These nanomaterials might get absorbed by the human body after ingestion and enter the tissues/organs, initiating adverse health hazards.[206] Topical application might also cause detrimental health effects. Sunscreens' nanoparticles can enter the bloodstream via injured skin, producing severe harm.[206] Figure 4 shows several diseases associated with the exposure of nanoparticles. Nanosized particles could harm the DNA leading to initiation of malignant tumors. Also, nanomaterials are minute and can penetrate inside cells, but these are adequately big enough to modify the normal functions of cells. Owning to their small sizes, these can be hardly separated via conventional separation methods and can come by the malignant cells causing substantial damage.[207] Nanomaterials can enter the placenta, endometrium, and yolk sac of pregnant women, causing irritation and oxidative stress. This might lead to fetal deformities, placental damage, neurotoxicity, delayed neonatal development, reproductive dysfunction in infants, etc. Lastly, nanosized particles can stimulate the production of cytokine in pregnant females that might enter the fetus resulting in bad growth of the brain of the fetus.[208]

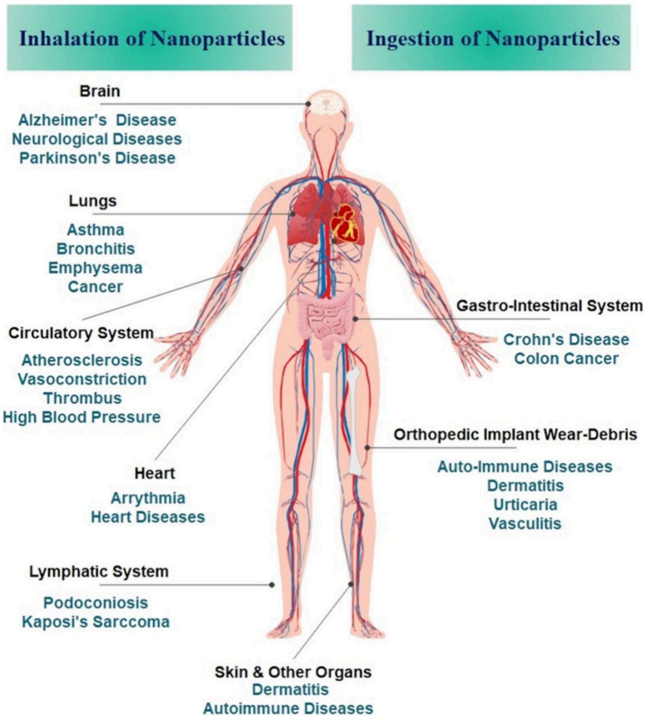


**Figure 4.** Health risks associated with certain types of nanocosmetics. Adapted with permission from ref 209. Copyright 2021 MDPI.

## 9. COSMETICS REGULATIONS

Cosmetics in the United States of America are accepted by the United States Food and Drug Administration; besides, these are monitored by the Food Drug and Cosmetic Act. Cosmetics do not require premarket approval, excluding those containing dyes.[3] However, the manufacturers and distributors of a cosmetic product have to follow a Voluntary Cosmetic Registration Program which provides information to the United States Food and Drug Administration about the cosmetics and their production, dispersal, and activity. Manufacturers must prepare a Cosmetic's Product Ingredient Statement that is specific to each cosmetic product prepared for commercialization.[225] The Personal Product Act 2013 enables the United States Food and Drug Administration to ensure that the cosmetic products are totally safe, containing no toxic ingredients.[5] The United States Food and Drug Administration founded a nanotechnology department responsible for managing all nanoparticle-based cosmetics in 2006 to monitor and even advance the safety and efficiency of nanosized patricles.[225] During 2014, the United States Food and Drug Administration acknowledged three main rules regarding the nanoparticles' safety, two of which are related to the cosmetics' products.[225] The first rule elucidates the assurance of the formulations integrating nanomaterials, while the second rule focuses specifically on the safety of nanoparticles in the cosmetic products.[225] Moreover, the Food and Drug Administration is not obliged to reveal the exact list of nanosized particles added in the cosmetic formulations on the labels and frequently update the producers about nanoparticles associated risks for a continual enhancement of the safety of cosmetics.[225]

The European Medicines Evaluation Agency is a regulatory agency responsible for cosmetic products in Europe. This regulatory agency lies under the control of the Council Directive 76/768/EEC, and it mainly covers the associated safety with the usage of cosmetics besides recording the allowable colorants. The safety of cosmetic products is managed by European Regulation 1223/2009.[5] These regulations provide a robust, globally accepted system that establishes the product's safety by bearing in mind the most novel scientific data, comprising the possible application of nanoparticles. A product safety report must be prepared before being released in the market. Frank unwanted effects must be conveyed to public government agencies that will then collect interrelated data from the health experts/clients and should be informing the other European Union Member States.[225] Dyes, preservatives, and UV protectants entailing nanoparticles must be accepted. The formulations comprising nanoparticles should go through an intricate examination under the supervision of European Union authorities. European Commission Regulation No. 1907/2006 controls the nanosized particles in the European Union. According to the European Union guidelines, the safety outline, the data of the item describing the adverse effects, and the toxicity must be provided a half-year before the market approval of the nanomaterial-based product. It necessitates a premarket approval for the nanoparticles-based cosmetics, dyes, antiaging creams, and sunscreen products.[5]

## 10. CONCLUSIONS

The cosmetics sector is growing rapidly with products developed by both major and local companies worldwide. Currently, nanotechnology symbolizes the central technology of the 21st century, proposing exceptional novelties in research works and businesses. Nanotechnology is a revolutionizing field that is being widely applied in the fields of cosmetics, biomedical/medicinal applications, dermatology, etc. Introducing novel developments and new active ingredients delivery systems lead the cosmetics sector to be more prevalent with an elevated market share. Nowadays, cosmetics are key to our daily routines and the application of nanotechnology in cosmetics sectors has further improved its acceptance among consumers universally. Currently, novel biodegradable nanocarriers, like ethosomes, niosomes, cubosomes, solid lipid nanoparticles, and liposomes, are applied to formulate diverse cosmetics with superior properties. Nanocosmetics can deliver nanoformulations through the human skin via different routes imparting many applications/uses, e.g., moisturization, sun protection, wrinkle lessening, etc. While these nanomaterials are attaining extraordinary market value and consumer interest, there is great concern regarding their toxicity and safety in humans, calling for more careful research and investigations.

## AUTHOR INFORMATION

### Corresponding Author

**Hassan Mohamed El-Said Azzazy** – *Department of Chemistry, School of Sciences & Engineering, The American University in Cairo, AUC Avenue, New Cairo 11835, Egypt; Department of Nanobiophotonics, Leibniz Institute of Photonic Technology, Jena 07745,, Germany;* orcid.org/0000-0003-2047-4222; Phone: +202 2615 2559; Email: hazzazy@aucegypt.edu

### Authors

**Yasmin R. Maghraby** – *Department of Chemistry, School of Sciences & Engineering, The American University in Cairo, AUC Avenue, New Cairo 11835, Egypt;* orcid.org/0000-0003-1152-4777

**Ahmed H. Ibrahim** – *Department of Chemistry, School of Sciences & Engineering, The American University in Cairo, AUC Avenue, New Cairo 11835, Egypt; Center for Materials Science, Zewail City of Science and Technology, 12578 Giza, Egypt*

**Rehan M. El-Shabasy** – *Department of Chemistry, School of Sciences & Engineering, The American University in Cairo, AUC Avenue, New Cairo 11835, Egypt; Chemistry Department, Faculty of Science, Menoufia University, 32512 Shebin El-Kom, Egypt*

Complete contact information is available at:
https://pubs.acs.org/10.1021/acsomega.4c00062

### Author Contributions

The work presented here was a collaboration of all authors.

### Notes

The authors declare no competing financial interest.

## ACKNOWLEDGMENTS

This work was funded by a grant from the American University in Cairo to H.M.E.-S.A.

## REFERENCES

(1) Parish, L. C.; Crissey, J. T. Cosmetics: A Historical Review. *Clin. Dermatol.* **1988**, *6* (3), 1–4.

(2) Bom, S.; Jorge, J.; Ribeiro, H. M.; Marto, J. A Step Forward on Sustainability in the Cosmetics Industry: A Review. *J. Clean Prod.* **2019**, *225*, 270–290.

(3) K, D.; Tripathy, S.; Dureja, H. Cosmetics: Regulatory Scenario in USA, EU and India. *J. Pharma. Technol. Res. Mang.* **2015**, *3* (2), 127–139.

(4) Maghraby, Y. R.; El-Shabasy, R. M.; Ibrahim, A. H.; Azzazy, H. M. E. S. Enzyme Immobilization Technologies and Industrial Applications. *ACS Omega* **2023**, *8* (6), 5184–5196.

(5) Gupta, V.; Mohapatra, S.; Mishra, H.; Farooq, U.; Kumar, K.; Ansari, M. J.; Aldawsari, M. F.; Alalaiwe, A. S.; Mirza, M. A.; Iqbal, Z. Nanotechnology in Cosmetics and Cosmeceuticals—A Review of Latest Advancements. *Gels* **2022**, *8* (3), 173.

(6) Das, P.; Das, M. K. Production and Physicochemical Characterization of Nanocosmeceuticals. *Nanocosmeceuticals* **2022**, 95–138.

(7) Kaul, S.; Gulati, N.; Verma, D.; Mukherjee, S.; Nagaich, U. Role of Nanotechnology in Cosmeceuticals: A Review of Recent Advances. *J. Pharm.* **2018**, *2018*, 3420204.

(8) Fytianos, G.; Rahdar, A.; Kyzas, G. Z. Nanomaterials in Cosmetics: Recent Updates. *Nanomaterials* **2020**, *10* (5), 979.

(9) Ekpa, D.; Uwah, T. O.; Udofa, E.; Akpabio, A. E. Nanotechnology in Cosmetics: Basics, Current Trends and Safety Concerns-A Review. *Adv. Nanopart.* **2020**, *9*, 1–22.

(10) Chaudhri, S. K.; Jain, N. K. History of Cosmetics. *Asian J. Pharma.* **2009**, *9*, 164–167.

(11) Sharma, P. K.; Dorlikar, S.; Rawat, P.; Malik, V.; Vats, N.; Sharma, M.; Rhyee, J. S.; Kaushik, A. K. Nanotechnology and Its Application: A Review. *Nanotechol. Cancer Manag.* **2021**, 1–33.

(12) Maghraby, Y. R.; Farag, M. A.; G Kontominas, M.; Shakour, Z. T.; Ramadan, A. R. Nanoencapsulated Extract of a Red Seaweed (*Rhodophyta*) Species as a Promising Source of Natural Antioxidants. *ACS Omega* **2022**, *7* (8), 6539–6548.

(13) Momoh, M. A.; Kenechukwu, F. C.; Attama, A. A. Formulation and Evaluation of Novel Solid Lipid Microparticles as a Sustained Release System for the Delivery of Metformin Hydrochloride. *Drug Delivery* **2013**, *20* (3–4), 102–111.

(14) Khan, S.; Jain, P.; Jain, S.; Jain, R.; Bhargava, S.; Jain, A. Topical Delivery of Erythromycin Through Cubosomes For Acne. *Pharm. Nanotechnol.* **2018**, *6*, 38–47.

(15) Lohani, A.; Verma, A.; Joshi, H.; Yadav, N.; Karki, N. Nanotechnology-Based Cosmeceuticals. *Dermatol* **2014**, *2014*, 1–14.

(16) Sankar, V.; Wilson, V.; Siram, K.; Karuppaiah, A.; Hariharan, S.; Justin, A. Topical Delivery of Drugs Using Ethosomes: A Review. *Indian Drugs* **2019**, *56* (8), 7–20.

(17) Husokawa, M.; Nogi, k. Development of Functional Skincare Cosmetics Using Biodegradable PLGA Nnospheres. *Nanopart. Technol. Handbook* **2008**, 501–506.

(18) Sonneville-Aubrun, O.; Simonnet, J. T.; L'Alloret, F. Nanoemulsions: A New Vehicle for Skincare Products. *Adv. Colloid Interface Sci.* **2004**, *108–109*, 145–149.

(19) Lee, H. S.; Byun, S. H.; Cho, S. W.; Yang, B. E. Past, Present, and Future of Regeneration Therapy in Oral and Periodontal Tissue: A Review. *Appl. Sci.* **2019**, *9* (6), 1046.

(20) Sankhyan, A.; Pawar, P. Recent Trends in Niosome as Vesicular Drug Delivery System. *J. Appl. Pharm. Sci.* **2012**, *2* (6), 20–32.

(21) Alaqad, K.; Saleh, T. A. Gold and Silver Nanoparticles: Synthesis Methods, Characterization Routes and Applications towards Drugs. *J. Environ. Anal. Toxicol.* **2016**, *6* (4), 1000384.

(22) Bakry, R.; Vallant, R. M.; Najam-Ul-Haq, M.; Rainer, M.; Szabo, Z.; Huck, C. W.; Bonn, G. K. Medicinal Applications of Fullerenes. *Int. J. Nanomed.* **2007**, *2* (4), 639–649.

(23) Wong-Ekkabut, J.; Baoukina, S.; Triampo, W.; Tang, I-M.; Tieleman, D. P.; Monticelli, L. Computer Simulation Study of Fullerene Translocation through Lipid Membranes. *Nat. Nanotehcnol.* **2008**, *3*, 363–368.

(24) Smijs, T. G.; Pavel, S. Titanium Dioxide and Zinc Oxide Nanoparticles in Sunscreens: Focus on Their Safety and Effectiveness. *Sci. Appl.* **2011**, *4*, 95−112.

(25) Mohammed, Y. H.; Holmes, A.; Haridass, I. N.; Sanchez, W. Y.; Studier, H.; Grice, J. E.; Benson, H. A. E.; Roberts, M. S. Support for the Safe Use of Zinc Oxide Nanoparticle Sunscreens: Lack of Skin Penetration or Cellular Toxicity after Repeated Application in Volunteers. *J. Investigative Dermatol.* **2019**, *139* (2), 308−315.

(26) Kokura, S.; Handa, O.; Takagi, T.; Ishikawa, T.; Naito, Y.; Yoshikawa, T. Silver Nanoparticles as a Safe Preservative for Use in Cosmetics. *Nanomedicine* **2010**, *6* (4), 570−574.

(27) Irshad, A.; Zahid, M.; Husnain, T.; Rao, A. Q.; Sarwar, N.; Hussain, I. A Proactive Model on Innovative Biomedical Applications of Gold Nanoparticles. *Appl. Nanosci.* **2020**, *10*, 2453−2465.

(28) Park, Y. H.; Kim, J. N.; Jeong, S. H.; Choi, J. E.; Lee, S. H.; Choi, B. H.; Lee, J. P.; Sohn, K. H.; Park, K. L.; Kim, M. K.; Son, S. W. Assessment of Dermal Toxicity of Nanosilica Using Cultured Keratinocytes, a Human Skin Equivalent Model and an *in Vivo* Model. *Toxicology* **2010**, *267* (1−3), 178−181.

(29) Sahu, D.; Kannan, G. M.; Vijayaraghavan, R. Carbon Black Particle Exhibits Size Dependent Toxicity in Human Monocytes. *Int. J. Inflam.* **2014**, *2014*, 827019.

(30) Yücel, Ç.; Şeker Karatoprak, G.; Değim, İ. T. Anti-Aging Formulation of Rosmarinic Acid-Loaded Ethosomes and Liposomes. *J. Microencapsu.l* **2019**, *36* (2), 180−191.

(31) Verma, P.; Pathak, K. Therapeutic and Cosmeceutical Potential of Ethosomes: An Overview. *J. Advanc. Pharma. Technol. Res.* **2010**, *1*, 274−282.

(32) Hirlekar, R.; Yamaga, M.; Garse, H.; Vij, M.; Kadam, V. Carbon Nanotubes and Its Applications: A Review. *Asian J. Pharma. Clin. Res.* **2009**, *2*, 17−27.

(33) Bilal, M.; Iqbal, H. M. N. New Insights on Unique Features and Role of Nanostructured Materials in Cosmetics. *Cosmetics* **2020**, *7* (2), 24.

(34) Coelho, C. C.; Grenho, L.; Gomes, P. S.; Quadros, P. A.; Fernandes, M. H. Nano-Hydroxyapatite in Oral Care Cosmetics: Characterization and Cytotoxicity Assessment. *Sci. Rep.* **2019**, *9*, 11050.

(35) Bernauer, U. Opinion of the Scientific Committee on Consumer Safety (SCCS) - Revision of the Opinion on Hydroxyapatite (Nano) in Cosmetic Products. *Reg. Toxicol. Pharm.* **2018**, *98*, 274−275.

(36) Couteau, C.; Paparis, E.; Chauvet, C.; Coiffard, L. Tris-Biphenyl Triazine, a New Ultraviolet Filter Studied in Terms of Photoprotective Efficacy. *Int. J. Pharm.* **2015**, *487* (1−2), 120−123.

(37) Cusan, C.; Da Ros, T.; Spalluto, G.; Foley, S.; Janot, J. M.; Seta, P.; Larroque, C.; Tomasini, M. C.; Antonelli, T.; Ferraro, L.; Prato, M. A New Multi-Charged C60 Derivative: Synthesis and Biological Properties. *Eur. J. Org. Chem.* **2002**, *2002*, 2928−2934.

(38) Kato, S.; Aoshima, H.; Saitoh, Y.; Miwa, N. Fullerene-C60/Liposome Complex: Defensive Effects against UVA-Induced Damages in Skin Structure, Nucleus and Collagen Type I/IV Fibrils, and the Permeability into Human Skin Tissue. *J. Photochem. Photobiol., B* **2010**, *98* (1), 99−105.

(39) Xu, X.; Costa, A. P.; Khan, M. A.; Burgess, D. J. Application of Quality by Design to Formulation and Processing of Protein Liposomes. *Int. J. Pharm.* **2012**, *434* (1−2), 349−359.

(40) Joseph, J.; Vedha Hari, B. N.; Ramya Devi, D. Experimental Optimization of Lornoxicam Liposomes for Sustained Topical Delivery. *Euro. J. Pharm. Sci.* **2018**, *112*, 38−51.

(41) Han, S. B.; Won, B.; Yang, S.; Kim, D. H. Asterias Pectinifera Derived Collagen Peptide-Encapsulating Elastic Nanoliposomes for the Cosmetic Application. *J. Ind. Eng. Chem.* **2021**, *98*, 289−297.

(42) Montenegro, L.; Lai, F.; Offerta, A.; Sarpietro, M. G.; Micicchè, L.; Maccioni, A. M.; Valenti, D.; Fadda, A. M. From Nanoemulsions to Nanostructured Lipid Carriers: A Relevant Development in Dermal Delivery of Drugs and Cosmetics. *J. Drug Delivery Sci. Technol.* **2016**, *32*, 100−112.

(43) Müller, R. H.; Petersen, R. D.; Hommoss, A.; Pardeike, J. Nanostructured Lipid Carriers (NLC) in Cosmetic Dermal Products. *Adv. Drug Delivery Rev.* **2007**, *59* (6), 522−530.

(44) Lee, Y. J.; Nam, G. W. Cosmetics Sunscreen Boosting Effect by Solid Lipid Nanoparticles-Loaded Fucoxanthin Formulation. *Cosmetics* **2020**, *7* (1), 14.

(45) Wissing, S. A.; Müller, R. H. A Novel Sunscreen System Based on Tocopherol Acetate Incorporated into Solid Lipid Nanoparticles. *Int. J. Cosmet. Sci.* **2001**, *23* (4), 233−43.

(46) Wissing, S. A.; Müller, R. H. Cosmetic Applications for Solid Lipid Nanoparticles (SLN). *Int. J. Pharm.* **2003**, *254* (1), 65−68.

(47) Hosseinkhani, B.; Callewaert, C.; Vanbeveren, N.; Boon, N. Novel Biocompatible Nanocapsules for Slow Release of Fragrances on the Human Skin. *N Biotechnol.* **2015**, *32* (1), 40−46.

(48) El-Komy, M.; Shalaby, S.; Hegazy, R.; Abdel Hay, R.; Sherif, S.; Bendas, E. Assessment of Cubosomal Alpha Lipoic Acid Gel Efficacy for the Aging Face: A Single-Blinded, Placebo-Controlled, Right-Left Comparative Clinical Study. *J. Cosmet. Dermatol.* **2017**, *16* (3), 358−363.

(49) Tadros, T.; Izquierdo, P.; Esquena, J.; Solans, C. Formation and Stability of Nano-Emulsions. *Adv. Colloid Interface Sci.* **2004**, *108−109*, 303−318.

(50) Ribeiro, R.; Barreto, S.; Ostrosky, E.; Rocha-Filho, P.; Verissimo, L.; Ferrari, M. Production and Characterization of Cosmetic Nanoemulsions Containing *Opuntia Ficus-Indica* (L.) Mill Extract as Moisturizing Agent. *Molecules* **2015**, *20*, 2492−2509.

(51) Musazzi, U. M.; Franzè, S.; Minghetti, P.; Casiraghi, A. Emulsion versus Nanoemulsion: How Much Is the Formulative Shift Critical for a Cosmetic Product? *Drug Delivery Transl. Res.* **2018**, *8* (2), 414−421.

(52) Van Tran, V.; Loi Nguyen, T.; Moon, J. Y.; Lee, Y. C. Core-Shell Materials, Lipid Particles and Nanoemulsions, for Delivery of Active Anti-Oxidants in Cosmetics Applications: Challenges and Development Strategies. *Chem. Eng. J.* **2019**, *368*, 88−114.

(53) Sorg, O.; Antille, C.; Kaya, G.; Saurat, J.-H. Dermatologic Therapy Retinoids in Cosmeceuticals. *Dermatol. Ther.* **2006**, *19*, 289−296.

(54) Rosen, J.; Landriscina, A.; Friedman, A. J. Nanotechnology-Based Cosmetics for Hair Care. *Cosmetics* **2015**, *2*, 211−224.

(55) Al Jahdaly, B. A.; Maghraby, Y. R.; Ibrahim, A. H.; Shouier, K. R.; Alturki, A. M.; El-Shabasy, R. M. Role of Green Chemistry in Sustainable Corrosion Inhibition: A Review on Recent Developments. *Mater. Today Sust.* **2022**, *20*, 100242.

(56) Fonseca-Santos, B.; Correa, M. A.; Chorilli, M. Sustainability, Natural and Organic Cosmetics: Consumer, Products, Efficacy, Toxicological and Regulatory Considerations. *Braz. J. Pharm. Sci.* **2015**, *51* (1), 17−26.

(57) Dubey, S. K.; Dey, A.; Singhvi, G.; Pandey, M. M.; Singh, V.; Kesharwani, P. Emerging Trends of Nanotechnology in Advanced Cosmetics. *Coll. Surf. B* **2022**, *214*, 112440.

(58) Morganti, P.; Chen, H. D.; Morganti, G. Nanocosmetics: Future Perspective. *Nanocosmetics* **2020**, 455−481.

(59) Sharmeen, J. B.; Mahomoodally, F. M.; Zengin, G.; Maggi, F. Essential Oils as Natural Sources of Fragrance Compounds for Cosmetics and Cosmeceuticals. *Molecules* **2021**, *26*, 666.

(60) Sugumar, S.; Mukherjee, A.; Chandrasekaran, N. Nanoemulsion Formation and Characterization by Spontaneous Emulsification: Investigation of Its Antibacterial Effects on Listeria Monocytogenes. *Asian J. Pharm.* **2015**, *9* (1), 23−28.

(61) Ditlopo, N.; Sintwa, N.; Khamlich, S.; Manikandan, E.; Gnanasekaran, K.; Henini, M.; Gibaud, A.; Krief, A.; Maaza, M. From Khoi-San Indigenous Knowledge to Bioengineered $CeO_2$ Nanocrystals to Exceptional UV-Blocking Green Nanocosmetics. *Sci. Rep.* **2022**, *12* (1), 3468.

(62) Havenga, D.; Akoba, R.; Menzi, L.; Azizi, S.; Sackey, J.; Swanepoel, N.; Gibaud, A.; Maaza, M. From Himba Indigenous Knowledge to Engineered $Fe_2O_3$ UV-Blocking Green Nanocosmetics. *Sci. Rep.* **2022**, *12* (1), 2259.

(63) DiNardo, J. C.; Downs, C. A. Dermatological and Environmental Toxicological Impact of the Sunscreen Ingredient Oxybenzone/Benzophenone-3. *J. Cosm. Dermatol.* **2018**, *17*, 15−19.

(64) Ribeiro, A.; Estanqueiro, M.; Oliveira, M.; Sousa Lobo, J. Main Benefits and Applicability of Plant Extracts in Skin Care Products. *Cosmetics* **2015**, *2*, 48−65.

(65) Fagionato Masiero, J.; Barbosa, E. J.; de Oliveira Macedo, L.; de Souza, A.; Nishitani Yukuyama, M.; Arantes, G. J.; Bou-Chacra, N. A. Vegetable Oils in Pharmaceutical and Cosmetic Lipid-Based Nanocarriers Preparations. *Ind. Crops Prod.* **2021**, *170*, 113838.

(66) Maghraby, Y. R.; Farag, M. A.; Ramadan, A. R. Protective Action of *Jania Rubens* Nanoencapsulated Algal Extract in Controlling Vegetable Oils' Rancidity. *ACS Omega* **2021**, *6* (8), 5642−5652.

(67) Pivetta, T. P.; Simões, S.; Araújo, M. M.; Carvalho, T.; Arruda, C.; Marcato, P. D. Development of Nanoparticles from Natural Lipids for Topical Delivery of Thymol: Investigation of Its Anti-Inflammatory Properties. *Colloids Surf. B Biointerfaces* **2018**, *164*, 281−290.

(68) Salminen, H.; Stübler, A. S.; Weiss, J. Preparation, Characterization, and Physical Stability of Cocoa Butter and Tristearin Nanoparticles Containing $\beta$-Carotene. *Euro. Food Res. Technol.* **2020**, *246* (3), 599−608.

(69) Honfo, F. G.; Akissoe, N.; Linnemann, A. R.; Soumanou, M.; Van Boekel, M. A. J. S. Nutritional Composition of Shea Products and Chemical Properties of Shea Butter: A Review. *Crit. Rev. Food Sci. Nutr.* **2014**, *54* (5), 673−686.

(70) Jahurul, M.H.A.; Zaidul, I.S.M.; Norulaini, N.A.N.; Sahena, F.; Jinap, S.; Azmir, J.; Sharif, K.M.; Omar, A.K. M. Cocoa Butter Fats and Possibilities of Substitution in Food Products Concerning Cocoa Varieties, Alternative Sources, Extraction Methods, Composition, and Characteristics. *J. Food. Eng.* **2013**, *117* (4), 467−476.

(71) Mancini, A.; Imperlini, E.; Nigro, E.; Montagnese, C.; Daniele, A.; Orrù, S.; Buono, P. Biological and Nutritional Properties of Palm Oil and Palmitic Acid: Effects on Health. *Molecules* **2015**, *20*, 17339−17361.

(72) Bakkali, F.; Averbeck, S.; Averbeck, D.; Idaomar, M. Biological Effects of Essential Oils - A Review. *Food Chem. Toxicol.* **2008**, *46* (2), 446−475.

(73) Carvalho, I. T.; Estevinho, B. N.; Santos, L. Application of Microencapsulated Essential Oils in Cosmetic and Personal Healthcare Products - A Review. *Int. J. Cosm. Sci.* **2016**, *38*, 109−119.

(74) Abelan, U. S.; de Oliveira, A. C.; Cacoci, É. S. P.; Martins, T. E. A.; Giacon, V. M.; Velasco, M. V. R.; Lima, C. R. R. de C. Potential Use of Essential Oils in Cosmetic and Dermatological Hair Products: A Review. *J. Cosm. Dermatol.* **2022**, *21*, 1407−1418.

(75) Maghraby, Y. R.; Labib, R. M.; Sobeh, M.; Farag, M. A. Gingerols and Shogaols: A Multi-Faceted Review of their Extraction, Formulation, and Analysis in Drugs and Biofluids to Maximize their Nutraceutical and Pharmaceutical Applications. *Food Chem.* **2023**, *20*, 100947.

(76) Sakna, S. T.; Maghraby, Y. R.; Abdelfattah, M. S.; Farag, M. A. Phytochemical Diversity and Pharmacological Effects of Triterpenes from Genus Ziziphus: A Comprehensive Review. *Phytoch. Rev.* **2023**, *22*, 1611−1636.

(77) Kalouta, K.; Eleni, P.; Boukouvalas, C.; Vassilatou, K.; Krokida, M. Dynamic Mechanical Analysis of Novel Cosmeceutical Facial Creams Containing Nano-Encapsulated Natural Plant and Fruit Extracts. *J. Cosmet. Dermatol.* **2020**, *19* (5), 1146−1154.

(78) Lacatusu, I.; Istrati, D.; Bordei, N.; Popescu, M.; Seciu, A. M.; Panteli, L. M.; Badea, N. Synergism of Plant Extract and Vegetable Oils-Based Lipid Nanocarriers: Emerging Trends in Development of Advanced Cosmetic Prototype Products. *Mater. Sci. Eng., C* **2020**, *108*, 110412.

(79) Dario, M. F.; Oliveira, F. F.; Marins, D. S. S.; Baby, A. R.; Velasco, M. V. R.; Löbenberg, R.; Bou-Chacra, N. A. Synergistic Photoprotective Activity of Nanocarrier Containing Oil of *Acrocomia Aculeata*. *Ind. Crops Prod.* **2018**, *112*, 305−312.

(80) Rocha-Filho, P. A.; Ferrari, M.; Maruno, M.; Souza, O.; Gumiero, V. *In Vitro* and *in Vivo* Evaluation of Nanoemulsion Containing Vegetable Extracts. *Cosmetics* **2017**, *4* (3), 32.

(81) Salem, M. A.; Manaa, E. G.; Osama, N.; Aborehab, N. M.; Ragab, M. F.; Haggag, Y. A.; Ibrahim, M. T.; Hamdan, D. I. Coriander (*Coriandrum Sativum L.)* Essential Oil and Oil-Loaded Nano-Formulations as an Anti-Aging Potentiality via TGF$\beta$/SMAD Pathway. *Sci. Rep.* **2022**, *12* (1), 6578.

(82) Qian, C.; Decker, E. A.; Xiao, H.; McClements, D. J. Impact of Lipid Nanoparticle Physical State on Particle Aggregation and $\beta$-Carotene Degradation: Potential Limitations of Solid Lipid Nanoparticles. *Food Res. Int.* **2013**, *52* (1), 342−349.

(83) Tamashiro, F. L.; Yukuyama, M. N.; Velasco, M. V. R.; De Araújo, G. L. B.; Bou-Chacra, N. A. Nanoemulsions Containing Plant Oils: How Do They Influence Hair Treatment? *Int. J. Cosmet. Sci.* **2021**, *43* (2), 136−143.

(84) Marto, J.; Gouveia, L. F.; Gonçalves, L.; Chiari-Andréo, B. G.; Isaac, V.; Pinto, P.; Oliveira, E.; Almeida, A. J.; Ribeiro, H. M. Design of Novel Starch-Based Pickering Emulsions as Platforms for Skin Photoprotection. *J. Photochem. Photobiol., B* **2016**, *162*, 56−64.

(85) Coradini, K.; Lima, F. O.; Oliveira, C. M.; Chaves, P. S.; Athayde, M. L.; Carvalho, L. M.; Beck, R. C. R. Co-Encapsulation of Resveratrol and Curcumin in Lipid-Core Nanocapsules Improves their *in Vitro* Antioxidant Effects. *Europ. J. Pharm. Biopharm.* **2014**, *88* (1), 178−185.

(86) Scomoroscenco, C.; Cinteza, L. O.; Teodorescu, M.; Gifu, I. C.; Ianchis, R.; Nistor, C. L.; Petcu, C.; Ninciuleanu, C. M.; Alexandrescu, E.; Mihaescu, C. I. Vegetable Oil-Based Microemulsion with Dermato-Cosmetic Applocations. *Sci. Bull. Ser. B* **2020**, *82* (2), 27−38.

(87) Estanqueiro, M.; Conceição, J.; Amaral, M. H.; Sousa Lobo, J. M. Characterization, Sensorial Evaluation and Moisturizing Efficacy of Nanolipidgel Formulations. *Int. J. Cosmet. Sci.* **2014**, *36* (2), 159−166.

(88) Garti, N.; Shevachman, M.; Shani, A. Solubilization of Lycopene in Jojoba Oil Microemulsion. *J. Am. Oil Chem. Soc.* **2004**, *81* (9), 873−877.

(89) Kumar, D.; Ali, J.; Baboota, S. Omega 3 Fatty Acid-Enriched Nanoemulsion of Thiocolchicoside for Transdermal Delivery: Formulation, Characterization and Absorption Studies. *Drug Delivery* **2016**, *23* (2), 591−600.

(90) Lacatusu, I.; Badea, N.; Murariu, A.; Nichita, C.; Bojin, D.; Meghea, A. Antioxidant Capacity of Lipid Nanoparticles Loaded with Rosemary Extract. *Mol. Crys. Liq. Cryst.* **2010**, *523*, 260−272.

(91) Munawiroh, S. Z.; Nabila, A. N.; Chabib, L. Development of Water in Olive Oil (W/O) Nanoemulsions as Lipstick Base Formulation. *Int. J. Pharm. Med. Biolog. Sci.* **2017**, *6* (2), 37−42.

(92) Ghiasi, Z.; Esmaeli, F.; Aghajani, M.; Ghazi-Khansari, M.; Faramarzi, M. A.; Amani, A. Enhancing Analgesic and Anti-Inflammatory Effects of Capsaicin When Loaded into Olive Oil Nanoemulsion: An *in Vivo* Study. *Int. J. Pharm.* **2019**, *559*, 341−347.

(93) Contri, R. V.; Ribeiro, K. L. F.; Fiel, L. A.; Pohlmann, A. R.; Guterres, S. S. Vegetable Oils as Core of Cationic Polymeric Nanocapsules: Influence on the Physicochemical Properties. *J. Exp. Nanosci.* **2013**, *8* (7−8), 913−924.

(94) Chaiyana, W.; Leelapornpisid, P.; Phongpradist, R.; Kiattisin, K. Enhancement of Antioxidant and Skin Moisturizing Effects of Olive Oil by Incorporation into Microemulsions. *Nanomater. Nanotechnol.* **2016**, *6*, 184798041666948.

(95) Kaur, C. D.; Saraf, S. Topical Vesicular Formulations of Curcuma Longa Extract on Recuperating the Ultraviolet Radiation-Damaged Skin. *J. Cosmet. Dermatol.* **2011**, *10* (4), 260−265.

(96) Teo, B. S. X.; Basri, M.; Zakaria, M. R. S.; Salleh, A. B.; Rahman, R. N. Z. R. A.; Rahman, M. B. A. A Potential Tocopherol Acetate Loaded Palm Oil Esters-in-Water Nanoemulsions for Nanocosmeceuticals. *J. Nanobiotechnol.* **2010**, *8*, 4.

(97) Mahdi, E. S.; Noor, A. M.; Sakeena, M. H.; Abdullah, G. Z.; Abdulkarim, M. F.; Sattar, M. A. Formulation and *in Vitro* Release Evaluation of Newly Synthesized Palm Kernel Oil Esters-Based Nanoemulsion Delivery System for 30% Ethanolic Dried Extract

Derived from Local Phyllanthus Urinaria for Skin Antiaging. *Int. J. Nanomedicine* **2011**, *6*, 2499−2512.

(98) Soleimanian, Y.; Goli, S. A. H.; Varshosaz, J.; Sahafi, S. M. Formulation and Characterization of Novel Nanostructured Lipid Carriers Made from Beeswax, Propolis Wax and Pomegranate Seed Oil. *Food Chem.* **2018**, *244*, 83−92.

(99) Badea, G.; Lăcătuşu, I.; Badea, N.; Ott, C.; Meghea, A. Use of Various Vegetable Oils in Designing Photoprotective Nanostructured Formulations for UV Protection and Antioxidant Activity. *Ind. Crops Prod.* **2015**, *67*, 18−24.

(100) Niculae, G.; Lacatusu, I.; Badea, N.; Meghea, A.; Stan, R. Influence of Vegetable Oil on the Synthesis of Bioactive Nanocarriers with Broad Spectrum Photoprotection. *Cent. Euro. J. Chem.* **2014**, *12*, 837−850.

(101) Lacatusu, I.; Niculae, G.; Badea, N.; Stan, R.; Popa, O.; Oprea, O.; Meghea, A. Design of Soft Lipid Nanocarriers Based on Bioactive Vegetable Oils with Multiple Health Benefits. *Chem. Eng. J.* **2014**, *246*, 311−321.

(102) Kabri, T. H.; Arab-Tehrany, E.; Belhaj, N.; Linder, M. Physico-Chemical Characterization of Nano-Emulsions in Cosmetic Matrix Enriched on Omega-3. *J. Nanobiotechnology* **2011**, *9*, 41.

(103) Niculae, G.; Lacatusu, I.; Badea, N.; Stan, R.; Vasile, B. S.; Meghea, A. Rice Bran and Raspberry Seed Oil-Based Nanocarriers with Self-Antioxidative Properties as Safe Photoprotective Formulations. *Photochem. Photobiol. Sci.* **2014**, *13* (4), 703−716.

(104) Bernardi, D. S.; Pereira, T. A.; Maciel, N. R.; Bortoloto, J.; Viera, G. S.; Oliveira, G. C.; Rocha-Filho, P. A. Formation and Stability of Oil-in-Water Nanoemulsions Containing Rice Bran Oil: In Vitro and in Vivo Assessments. *J. Nanobiotechnol.* **2011**, *9*, 44.

(105) Puglia, C.; Lauro, M. R.; Offerta, A.; Crascì, L.; Micicchè, L.; Panico, A. M.; Bonina, F.; Puglisi, G. Nanostructured Lipid Carriers (NLC) as Vehicles for Topical Administration of Sesamol: In Vitro Percutaneous Absorption Study and Evaluation of Antioxidant Activity. *Planta Med.* **2017**, *83* (5), 398−404.

(106) Chen, J.; Wei, N.; Lopez-Garcia, M.; Ambrose, D.; Lee, J.; Annelin, C.; Peterson, T. Development and Evaluation of Resveratrol, Vitamin E, and Epigallocatechin Gallate Loaded Lipid Nanoparticles for Skin Care Applications. *Euro. J. Pharma. Biopharmaceutics* **2017**, *117*, 286−291.

(107) Ali, H.; Kim, K. W.; Bang, S. G.; Chae, H. B.; Shin, S. W.; Park, C. W. Numerical Analysis to Improve the Ballistic Trajectory of an Air-Based Material Density Separator System. *Appl. Sci.* **2018**, *8* (3), 359.

(108) Hajj Ali, H.; Michaux, F.; Bouelet Ntsama, I. S.; Durand, P.; Jasniewski, J.; Linder, M. Shea Butter Solid Nanoparticles for Curcumin Encapsulation: Influence of Nanoparticles Size on Drug Loading. *Euro. J. Lipis Sci. Technol.* **2016**, *118*, 1168−1178.

(109) Delfanian, M.; Razavi, S. M. A.; Haddad Khodaparast, M. H.; Esmaeilzadeh Kenari, R.; Golmohammadzadeh, S. Influence of Main Emulsion Components on the Physicochemical and Functional Properties of W/O/W Nano-Emulsion: Effect of Polyphenols, Hi-Cap, Basil Seed Gum, Soy and Whey Protein Isolates. *Food Res. Inter.* **2018**, *108*, 136−143.

(110) Selvaraj, K.; Yoo, B. K. Curcumin-Loaded Nanostructured Lipid Carrier Modified with Partially Hydrolyzed Ginsenoside. *AAPS PharmSciTech* **2019**, *20* (6), 252.

(111) Batra, G.; Gortzi, O.; Lalas, S. I.; Galidi, A.; Alibade, A.; Nanos, G. D. Enhanced Antioxidant Activity of Capsicum Annuum l. And Moringa Oleifera l. Extracts after Encapsulation in Microemulsions Enhanced. *Chem. Eng.* **2017**, *1* (2), 15.

(112) Sampaio, C. I.; Bourbon, A. I.; Gonçalves, C.; Pastrana, L. M.; Dias, A. M.; Cerqueira, M. A. Low Energy Nanoemulsions as Carriers of Thyme and Lemon Balm Essential Oils. *LWT* **2022**, *154*, 112748.

(113) Pinto, F.; de Barros, D. P. C.; Fonseca, L. P. Design of Multifunctional Nanostructured Lipid Carriers Enriched with α-Tocopherol Using Vegetable Oils. *Ind. Crops Prod.* **2018**, *118*, 149−159.

(114) Froiio, F.; Ginot, L.; Paolino, D.; Lebaz, N.; Bentaher, A.; Fessi, H.; Elaissari, A. Essential Oils-Loaded Polymer Particles: Preparation, Characterization and Antimicrobial Property. *Polymers* **2019**, *11* (6), 1017.

(115) Mondéjar-López, M.; López-Jimenez, A. J.; García Martínez, J. C.; Ahrazem, O.; Gómez-Gómez, L.; Niza, E. Comparative Evaluation of Carvacrol and Eugenol Chitosan Nanoparticles as Eco-Friendly Preservative Agents in Cosmetics. *Int. J. Biol. Macromol.* **2022**, *206*, 288−297.

(116) Lu, W. C.; Huang, D. W.; Wang, C. C. R.; Yeh, C. H.; Tsai, J. C.; Huang, Y. T.; Li, P. H. Preparation, Characterization, and Antimicrobial Activity of Nanoemulsions Incorporating Citral Essential Oil. *J. Food Drug Anal.* **2018**, *26* (1), 82−89.

(117) Hamed, S. F.; Sadek, Z.; Edris, A. Antioxidant and Antimicrobial Activities of Clove Bud Essential Oil and Eugenol Nanoparticles in Alcohol-Free Microemulsion. *J. Oleo. Sci.* **2012**, *61*, 641−648.

(118) Hadidi, M.; Pouramin, S.; Adinepour, F.; Haghani, S.; Jafari, S. M. Chitosan Nanoparticles Loaded with Clove Essential Oil: Characterization, Antioxidant and Antibacterial Activities. *Carbohydr. Polym.* **2020**, *236*, 116075.

(119) Salem, M. A.; Manaa, E. G.; Osama, N.; Aborehab, N. M.; Ragab, M. F.; Haggag, Y. A.; Ibrahim, M. T.; Hamdan, D. I. Coriander (*Coriandrum Sativum L.)* Essential Oil and Oil-Loaded Nano-Formulations as an Anti-Aging Potentiality via TGF*β*/SMAD Pathway. *Sci. Rep.* **2022**, *12* (1), 6578.

(120) Mostafa, D. M.; Kassem, A. A.; Asfour, M. H.; Al Okbi, S. Y.; Mohamed, D. A.; Hamed, T. E. S. Transdermal Cumin Essential Oil Nanoemulsions with Potent Antioxidant and Hepatoprotective Activities: *In-Vitro* and *in-Vivo* Evaluation. *J. Mol. Liq.* **2015**, *212*, 6−15.

(121) Shetta, A.; Kegere, J.; Mamdouh, W. Comparative Study of Encapsulated Peppermint and Green Tea Essential Oils in Chitosan Nanoparticles: Encapsulation, Thermal Stability, in-Vitro Release, Antioxidant and Antibacterial Activities. *Int. J. Biol. Macromol.* **2019**, *126*, 731−742.

(122) Viyoch, J.; Pisutthanan, N.; Faikreua, A.; Nupangta, K.; Wangtorpol, K.; Ngokkuen, J. Evaluation of in Vitro Antimicrobial Activity of Thai Basil Oils and Their Micro-Emulsion Formulas against Propionibacterium Acnes. *Int. J. Cosmet. Sci.* **2006**, *28* (2), 125−133.

(123) Seibert, J. B.; Rodrigues, I. V.; Carneiro, S. P.; Amparo, T. R.; Lanza, J. S.; Frézard, F. J. G.; de Souza, G. H. B.; Santos, O. D. H. d. Seasonality Study of Essential Oil from Leaves of Cymbopogon Densiflorus and Nanoemulsion Development with Antioxidant Activity. *Flavour Fragr. J.* **2019**, *34* (1), 5−14.

(124) Buranasuksombat, U.; Kwon, Y. J.; Turner, M.; Bhandari, B. Influence of Emulsion Droplet Size on Antimicrobial Properties. *Food Sci. Biotechnol.* **2011**, *20* (3), 793−800.

(125) Hadidi, M.; Rostamabadi, H.; Moreno, A.; Jafari, S. M. Nanoencapsulation of Essential Oils from Industrial Hemp (*Cannabis Sativa L.)* by-Products into Alfalfa Protein Nanoparticles. *Food Chem.* **2022**, *386*, 132765.

(126) Samling, B. A.; Assim, Z.; Tong, W. Y.; Leong, C. R.; Rashid, S. A.; Nik Mohamed Kamal, N. N. S.; Muhamad, M.; Tan, W. N. *Cynometra Cauliflora* Essential Oils Loaded-Chitosan Nanoparticles: Evaluations of Their Antioxidant, Antimicrobial and Cytotoxic Activities. *Int. J. Biol. Macromol.* **2022**, *210*, 742−751.

(127) Granata, G.; Stracquadanio, S.; Leonardi, M.; Napoli, E.; Consoli, G. M. L.; Cafiso, V.; Stefani, S.; Geraci, C. Essential Oils Encapsulated in Polymer-Based Nanocapsules as Potential Candidates for Application in Food Preservation. *Food Chem.* **2018**, *269*, 286−292.

(128) Ali, H.; Al-Khalifa, A. R.; Aouf, A.; Boukhebti, H.; Farouk, A. Effect of Nanoencapsulation on Volatile Constituents, and Antioxidant and Anticancer Activities of Algerian Origanum *Glandulosum Desf.* Essential Oil. *Sci. Rep.* **2020**, *10* (1), 2812.

(129) Taleb, M. H.; Abdeltawab, N. F.; Shamma, R. N.; Abdelgayed, S. S.; Mohamed, S. S.; Farag, M. A.; Ramadan, M. A. *Origanum Vulgare L.* Essential Oil as a Potential Anti-Acne Topical Nanoemulsion—in Vitro and in Vivo Study. *Molecules* **2018**, *23* (9), 2164.

(130) Ghodrati, M.; Farahpour, M. R.; Hamishehkar, H. Encapsulation of Peppermint Essential Oil in Nanostructured Lipid Carriers: In-Vitro Antibacterial Activity and Accelerative Effect on Infected Wound Healing. *Colloids Surf. A Physicochem. Eng. Asp.* **2019**, *564*, 161−169.

(131) Kreutz, T.; Carneiro, S. B.; Soares, K. D.; Limberger, R. P.; Apel, M. A.; Veiga-Junior, V. F.; Koester, L. S. *Aniba Canelilla* (Kunth) Mez Essential Oil-Loaded Nanoemulsion: Improved Stability of the Main Constituents and in Vitro Antichemotactic Activity. *Ind. Crops Prod.* **2021**, *171*, 113949.

(132) Flores, F. C.; de Lima, J. A.; Ribeiro, R. F.; Alves, S. H.; Rolim, C. M. B.; Beck, R. C. R.; da Silva, C. B. Antifungal Activity of Nanocapsule Suspensions Containing Tea Tree Oil on the Growth of Trichophyton Rubrum. *Mycopathologia* **2013**, *175* (3−4), 281−286.

(133) Moradi, S.; Barati, A. Essential Oils Nanoemulsions: Preparation, Characterization and Study of Antibacterial Activity against Escherichia Coli. *Int. J. Nanosci. Nanotechnol.* **2019**, *15*, 199−210.

(134) Moazeni, M.; Davari, A.; Shabanzadeh, S.; Akhtari, J.; Saeedi, M.; Mortyeza-Semnani, K.; Abastabar, M.; Nabili, M.; Moghadam, F. H.; Roohi, B.; Kelidari, H.; Nokhodchi, A. *In Vitro* Antifungal Activity of Thymus Vulgaris Essential Oil Nanoemulsion. *J. Herb. Med.* **2021**, *28*, 100452.

(135) Wattanasatcha, A.; Rengpipat, S.; Wanichwecharungruang, S. Thymol Nanospheres as an Effective Anti-Bacterial Agent. *Int. J. Pharm.* **2012**, *434* (1−2), 360−365.

(136) Khan, S. A.; Noreen, F.; Kanwal, S.; Iqbal, A.; Hussain, G. Green Synthesis of ZnO and Cu-Doped ZnO Nanoparticles from Leaf Extracts of *Abutilon Indicum, Clerodendrum Infortunatum, Clerodendrum Inerme* and Investigation of Their Biological and Photocatalytic Activities. *Mater. Sci. Eng., C* **2018**, *82*, 46−59.

(137) Zorzi, G. K.; Caregnato, F.; Moreira, J. C. F.; Teixeira, H. F.; Carvalho, E. L. S. Antioxidant Effect of Nanoemulsions Containing Extract of *Achyrocline Satureioides* (Lam) D.C.—Asteraceae. *AAPS Pharm. Sci. Technol.* **2016**, *17* (4), 844−850.

(138) S., S.; H., L. J. K.; K., R.; M., S. Antimicrobial and Antioxidant Potentials of Biosynthesized Colloidal Zinc Oxide Nanoparticles for a Fortified Cold Cream Formulation: A Potent Nanocosmeceutical Application. *Mater. Sci. Eng., C* **2017**, *79*, 581−589.

(139) Takahashi, M.; Kitamoto, D.; Asikin, Y.; Takara, K.; Wada, K. Liposomes Encapsulating Aloe vera Leaf Gel Extract Significantly Enhance Proliferation and Collagen Synthesis in Human Skin Cell Lines. *J. Oleo Sci.* **2009**, *58*, 643−650.

(140) Sofia Pamudji, J.; Suciati, T.; Yulinah Sukandar, E.; Fidriani, I. Microemulsion formulation of Aloe vera gel and Apium graveolens ethanol extract for optimizing hair growth promotion. *Asian J. Pharm. Clin. Res.* **2015**, *8* (4), 319−323.

(141) Takahashi, M.; Kitamoto, D.; Asikin, Y.; Takara, K.; Wada, K. Encapsulating Aloe vera Extract Significantly Enhance Proliferation in Human Skin Cell Lines. *J. Oleo Sci.* **2009**, *58* (12), 643−650.

(142) Rodrigues, L. R.; Jose, J. Exploring the Photo Protective Potential of Solid Lipid Nanoparticle-Based Sunscreen Cream Containing Aloe Vera. *Environ. Sci. Pollution Res.* **2020**, *27* (17), 20876−20888.

(143) Yahya, N. A.; Abdul Wahab, R.; Attan, N.; Abdul Hamid, M.; Mohamed Noor, N.; Kobun, R. *Ananas Comosus* Peels Extract as a New Natural Cosmetic Ingredient: Oil-in-Water (O/W) Topical Nano Cream Stability and Safety Evaluation. *Evidence-Based Complementary Altern. Med.* **2022**, *2022*, 2915644.

(144) Pavaloiu, R. D.; Sha At, F.; Bubueanu, C.; Hlevca, C.; Nechifor, G. Design and Evaluation of a Delivery System Based on Liposomes for Armoracia rusticana Extract. *Rev. Chim.* **2019**, *70* (7), 2347−2349.

(145) Ntohogian, S.; Gavriliadou, V.; Christodoulou, E.; Nanaki, S.; Lykidou, S.; Naidis, P.; Mischopoulou, L.; Barmpalexis, P.; Nikolaidis, N.; Bikiaris, D. N. Chitosan Nanoparticles with Encapsulated Natural and Uf-Purified Annatto and Saffron for the Preparation of UV Protective Cosmetic Emulsions. *Molecules* **2018**, *23* (9), 2107.

(146) Mazumder, A.; Dwivedi, A.; Du Preez, J. L.; Du Plessis, J. In Vitro Wound Healing and Cytotoxic Effects of Sinigrin-Phytosome Complex. *Int. J. Pharm.* **2016**, *498* (1−2), 283−293.

(147) Khan, P.; Akhtar, N. Phytochemical Investigations and Development of Ethosomal Gel with *Brassica Oleraceae L.* (Brassicaceae) Extract: An Innovative Nano Approach towards Cosmetic and Pharmaceutical Industry. *Ind. Crops Prod.* **2022**, *183*, 114905.

(148) Lacatusu, I.; Istrati, D.; Bordei, N.; Popescu, M.; Seciu, A. M.; Panteli, L. M.; Badea, N. Synergism of Plant Extract and Vegetable Oils-Based Lipid Nanocarriers: Emerging Trends in Development of Advanced Cosmetic Prototype Products. *Mater. Sci. Eng., C* **2020**, *108*, 110412.

(149) Sanna, V.; Lubinu, G.; Madau, P.; Pala, N.; Nurra, S.; Mariani, A.; Sechi, M. Polymeric Nanoparticles Encapsulating White Tea Extract for Nutraceutical Application. *J. Agric. Food Chem.* **2015**, *63* (7), 2026−2032.

(150) Ramadon, D.; Wirarti, G. A.; Anwar, E. Novel Transdermal Ethosomal Gel Containing Green Tea (*Camellia Sinensis L. Kuntze*) Leaves Extract: Formulation and *in Vitro* Penetration Study. *J. Young Pharm.* **2017**, *9* (3), 336−340.

(151) Kumar, N.; Tharatha, S.; Chaiyasut, C. Development and Validation of Simple Isocratic High Performance Liquid Chromatography-Ultraviolet (HPLCUV) Method for Determination of Safflower Yellow in *Carthamus Tinctorius* (L.)-Loaded Nanostructured Lipid Carriers. *Afr. J. Pharm. Pharmacol.* **2011**, *5* (20), 2335−2341.

(152) Kwon, M. C.; Choi, W. Y.; Seo, Y. C.; Kim, J. S.; Yoon, C. S.; Lim, H. W.; Kim, H. S.; Ahn, J.; Lee, H. Y. Enhancement of the Skin-Protective Activities of *Centella Asiatica L.* Urban by a Nano-Encapsulation Process. *J. Biotechnol.* **2012**, *157* (1), 100−106.

(153) Rodrigues Ueoka, A.; Pedriali Moraes, C. Development and Stability Evaluation of Liquid Crystal-Based Formulations Containing Glycolic Plant Extracts and Nano-Actives. *Cosmetics* **2018**, *5* (2), 25.

(154) Mostafa, E.; Fayed, M. A. A.; Radwan, R. A.; Bakr, R. O. Centaurea Pumilio L. Extract and Nanoparticles: A Candidate for Healthy Skin. *Colloids Surf. B Biointerfaces.* **2019**, *182*, 110350.

(155) Damle, M.; Mallya, R. Development and Evaluation of a Novel Delivery System Containing Phytophospholipid Complex for Skin Aging. *AAPS Pharm. Sci. Technol.* **2016**, *17* (3), 607−617.

(156) Amer, R. I.; Ezzat, S. M.; Aborehab, N. M.; Ragab, M. F.; Mohamed, D.; Hashad, A.; Attia, D.; Salama, M. M.; El Bishbishy, M. H. Downregulation of MMP1 Expression Mediates the Anti-Aging Activity of *Citrus Sinensis* Peel Extract Nanoformulation in UV Induced Photoaging in Mice. *Biomed. Pharm.acother.* **2021**, *138*, 111537.

(157) Naraginti, S.; Kumari, P. L.; Das, R. K.; Sivakumar, A.; Patil, S. H.; Andhalkar, V. V. Amelioration of Excision Wounds by Topical Application of Green Synthesized, Formulated Silver and Gold Nanoparticles in Albino Wistar Rats. *Mater. Sci. Eng., C* **2016**, *62*, 293−300.

(158) Dhayalan, M.; Denison, M. I. J.; Ayyar, M.; Gandhi, N. N.; Krishnan, K.; Abdulhadi, B. Biogenic Synthesis, Characterization of Gold and Silver Nanoparticles from Coleus Forskohlii and Their Clinical Importance. *J. Photochem. Photobiol., B* **2018**, *183*, 251−257.

(159) Kaur, C. D.; Saraf, S. Topical Vesicular Formulations of *Curcuma Longa* Extract on Recuperating the Ultraviolet Radiation-Damaged Skin. *J. Cosmet. Dermatol.* **2011**, *10* (4), 260−265.

(160) Nešić, I.; Savić, V.; Kolarević, A. Investigation of Efficacy of Anti-Aging Liposomal Intimate Gel: An *in Vivo* Long-Term Study. *Acta Facul. Med.* **2020**, *37* (1), 48−56.

(161) Saraf, S.; Jeswani, G.; Kaur, C. D.; Saraf, S. Development of Novel Cosmetic Cream with *Curcuma Longa* Extract Loaded Transfersomes for Anti-Wrinkle Effect. *Afr. J. Pharm. Pharmacol.* **2011**, *5* (8), 1054−1062.

(162) Lacatusu, I.; Istrati, D.; Bordei, N.; Popescu, M.; Seciu, A. M.; Panteli, L. M.; Badea, N. Synergism of Plant Extract and Vegetable Oils-Based Lipid Nanocarriers: Emerging Trends in Development of Advanced Cosmetic Prototype Products. *Mater. Sci. Eng., C* **2020**, *108*, 110412.

(163) Moulaoui, K.; Caddeo, C.; Manca, M. L.; Castangia, I.; Valenti, D.; Escribano, E.; Atmani, D.; Fadda, A. M.; Manconi, M. Identification and Nanoentrapment of Polyphenolic Phytocomplex from *Fraxinus Angustifolia*: *In Vitro* and *in Vivo* Wound Healing Potential. *Eur. J. Med. Chem.* **2015**, *89*, 179−188.

(164) Pan-In, P.; Wongsomboon, A.; Kokpol, C.; Chaichanawongsaroj, S.; Wanichwecharungruang, S. Depositing α-Mangostin Nanoparticles to Sebaceous Gland Area for Acne Treatment. *J. Pharmacol. Sci.* **2015**, *129* (4), 226−232.

(165) Burris, J. N.; Lenaghan, S. C.; Zhang, M.; Stewart, C. N. Nanoparticle Biofabrication Using English Ivy (Hedera Helix). *J. Nanobiotechnol.* **2012**, *10*, 41.

(166) Pinsuwan, S.; Amnuaikit Phd, T.; Ungphaiboon Phd, S.; Itharat Phd, A. Liposome-Containing *Hibiscus Sabdariffa Calyx* Extract Formulations with Increased Antioxidant Activity, Improved Dermal Penetration and Reduced Dermal Toxicity. *J. Med. Assoc. Thai.* **2010**, *93*, S216−S226.

(167) Dipankar, C.; Murugan, S. The Green Synthesis, Characterization and Evaluation of the Biological Activities of Silver Nanoparticles Synthesized from *Iresine Herbstii* Leaf Aqueous Extracts. *Colloids Surf. B Biointer.* **2012**, *98*, 112−119.

(168) Roslan, N. Z. I.; Abdul Ghani, S. M.; Yusof, N. B.; Abd. Aziz, A. Liposome as transdermal carrier for labisia pumila and ficus deltoidea water extracts. *J. Teknol.***2017**, *79*, 7. DOI: 10.11113/jt.v79.10205

(169) Pereira, F.; Baptista, R.; Ladeiras, D.; Madureira, A. M.; Teixeira, G.; Rosado, C.; Fernandes, A. S.; Ascensão, L.; Silva, C. O.; Reis, C. P.; Rijo, P. Production and Characterization of Nanoparticles Containing Methanol Extracts of Portuguese Lavenders. *Measurement* **2015**, *74*, 170−177.

(170) Motealleh, B.; Zahedi, P.; Rezaeian, I.; Moghimi, M.; Abdolghaffari, A. H.; Zarandi, M. A. Morphology, Drug Release, Antibacterial, Cell Proliferation, and Histology Studies of Chamomile-Loaded Wound Dressing Mats Based on Electrospun Nanofibrous Poly(ε-Caprolactone)/Polystyrene Blends. *J. Biomed. Mater. Res. B Appl. Biomater.* **2014**, *102* (5), 977−987.

(171) Sumbal; Nadeem, A.; Naz, S.; Ali, J. S.; Mannan, A.; Zia, M. Synthesis, Characterization and Biological Activities of Monometallic and Bimetallic Nanoparticles Using *Mirabilis Jalapa* Leaf Extract. *Biotechnol. Rep.* **2019**, *22*, e00338.

(172) Lin, Q.; Hong, X.; Zhang, D.; Jin, H. Biosynthesis of Size-Controlled Gold Nanoparticles Using M. Lucida Leaf Extract and Their Penetration Studies on Human Skin for Plastic Surgery Applications. *J. Photochem. Photobiol., B* **2019**, *199*, 111591.

(173) Gunes, A.; Guler, E.; Un, R. N.; Demir, B.; Barlas, F. B.; Yavuz, M.; Coskunol, H.; Timur, S. Niosomes of *Nerium Oleander* Extracts: *In Vitro* Assessment of Bioactive Nanovesicular Structures. *J. Drug Delivery Sci. Technol.* **2017**, *37*, 158−165.

(174) Chaiyana, W.; Anuchapreeda, S.; Somwongin, S.; Marsup, P.; Lee, K. H.; Lin, W. C.; Lue, S. C. Dermal Delivery Enhancement of Natural Anti-Ageing Compounds from Ocimum sanctum Linn. Estract by Nanostructured Lipid Carriers. *Pharmaceutics* **2020**, *12* (4), 309.

(175) Kesente, M.; Kavetsou, E.; Roussaki, M.; Blidi, S.; Loupassaki, S.; Chanioti, S.; Siamandoura, P.; Stamatogianni, C.; Philippou, E.; Papaspyrides, C.; Vouyiouka, S.; Detsi, A. Encapsulation of Olive Leaves Extracts in Biodegradable PLA Nanoparticles for Use in Cosmetic Formulation. *Bioengineering* **2017**, *4* (3), 75.

(176) Ribeiro, R.; Barreto, S.; Ostrosky, E.; Rocha-Filho, P.; Verissimo, L.; Ferrari, M. Production and Characterization of Cosmetic Nanoemulsions Containing *Opuntia Ficus-Indica* (L.) Mill Extract as Moisturizing Agent. *Molecules* **2015**, *20* (2), 2492−2509.

(177) Aisha, A. F. A.; Majid, A. M. S. A.; Ismail, Z. Preparation and Characterization of Nano Liposomes of *Orthosiphon Stamineus* Ethanolic Extract in Soybean Phospholipids. *BMC Biotechnol.* **2014**, *14*, 23.

(178) Manosroi, J.; Chankhampan, C.; Kitdamrongtham, W.; Zhang, J.; Abe, M.; Akihisa, T.; Manosroi, W.; Manosroi, A. In Vivo Anti-Ageing Activity of Cream Containing Niosomes Loaded with Purple Glutinous Rice (*Oryza Sativa Linn.*) Extract. *Int. J. Cosmet. Sci.* **2020**, *42* (6), 622−631.

(179) Zeng, Q.; Cai, X.; Cao, Y.; Zhou, C.; Yu, L.; Chen, J. Preparation, Characterization, and Pharmacodynamic Study on Deep Second Degree Burns of Total Flavonoids Composite Phospholipids Liposome Gel of *Oxytropis Falcata* Bunge. *Drug Dev. Ind. Pharm.* **2020**, *46* (12), 2000−2009.

(180) Jiménez-Pérez, Z. E.; Singh, P.; Kim, Y. J.; Mathiyalagan, R.; Kim, D. H.; Lee, M. H.; Yang, D. C. Applications of Panax Ginseng Leaves-Mediated Gold Nanoparticles in Cosmetics Relation to Antioxidant, Moisture Retention, and Whitening Effect on B16BL6 Cells. *J. Ginseng Res.* **2018**, *42* (3), 327−333.

(181) Jiménez Pérez, Z. E.; Mathiyalagan, R.; Markus, J.; Kim, Y. J.; Kang, H. M.; Abbai, R.; Seo, K. H.; Wang, D.; Soshnikova, V.; Yang, D. C. Ginseng-Berry-Mediated Gold and Silver Nanoparticle Synthesis and Evaluation of Their in Vitro Antioxidant, Antimicrobial, and Cytotoxicity Effects on Human Dermal Fibroblast and Murine Melanoma Skin Cell Lines. *Int. J. Nanomedicine* **2017**, *12*, 709−723.

(182) Mahdi, E. S.; Noor, A. M.; Sakeena, M. H.; Abdullah, G. Z.; Abdulkarim, M. F.; Sattar, M. A. Formulation and in Vitro Release Evaluation of Newly Synthesized Palm Kernel Oil Esters-Based Nanoemulsion Delivery System for 30% Ethanolic Dried Extract Derived from Local *Phyllanthus Urinaria* for Skin Antiaging. *Int. J. Nanomedicine* **2011**, *6*, 2499−2512.

(183) Barua, S.; Kim, H.; Hong, S. C.; Yoo, S. Y.; Shin, D.; Lee, C. L.; Na, S. J.; Kim, Y. H.; Jo, K.; Yun, G.; Kim, J. H.; Sohn, U. D.; Lee, J. Moisturizing Effect of Serine-Loaded Solid Lipid Nanoparticles and Polysaccharide-Rich Extract of Root *Phragmites Communis* Incorporated in Hydrogel Bases. *Arch. Pharm. Res.* **2017**, *40* (2), 250−257.

(184) Kwon, S. S.; Kim, S. Y.; Kong, B. J.; Kim, K. J.; Noh, G. Y.; Im, N. R.; Lim, J. W.; Ha, J. H.; Kim, J.; Park, S. N. Cell Penetrating Peptide Conjugated Liposomes as Transdermal Delivery System of *Polygonum Aviculare* L. Extract. *Int. J. Pharm.* **2015**, *483* (1−2), 26−37.

(185) Seo, S. R.; Kang, G.; Ha, J. W.; Kim, J. C. *In Vivo* Hair Growth-Promoting Efficacies of Herbal Extracts and Their Cubosomal Suspensions. *J. Indust. Eng. Chem.* **2013**, *19* (4), 1331−1339.

(186) Arya, G.; Kumari, R. M.; Sharma, N.; Gupta, N.; Kumar, A.; Chatterjee, S.; Nimesh, S. Catalytic, Antibacterial and Antibiofilm Efficacy of Biosynthesised Silver Nanoparticles Using *Prosopis Juliflora* Leaf Extract along with Their Wound Healing Potential. *J. Photochem. Photobiol., B* **2019**, *190*, 50−58.

(187) Mamillapalli, V.; Atmakuri, A. M.; Khantamneni, P. Nanoparticles for Herbal Extracts. *Asian J. Pharm.* **2016**, *10* (2), S54−S60.

(188) Tansathien, K.; Nuntharatanapon, N.; Jaewjira, S.; Pizon, J. R. L.; Opanasopit, P.; Rangsimawong, W. Solid Lipid Nanoparticles Containing *Pueraria Mirifica* Ethanolic Extract for Hair Growth Promotion. *Eng. Mater.* **2019**, *819*, 175−180.

(189) Gubitosa, J.; Rizzi, V.; Lopedota, A.; Fini, P.; Laurenzana, A.; Fibbi, G.; Fanelli, F.; Petrella, A.; Laquintana, V.; Denora, N.; Comparelli, R.; Cosma, P. One Pot Environmental Friendly Synthesis of Gold Nanoparticles Using *Punica Granatum* Juice: A Novel Antioxidant Agent for Future Dermatological and Cosmetic Applications. *J. Colloid Interface Sci.* **2018**, *521*, 50−61.

(190) Phetdee, M.; Polnok, A.; Viyoch, J. Development of Chitosan-Coated Liposomes for Sustained Delivery of Tamarind Fruit Pulp's Extract to the Skin. *Int. J. Cosmet. Sci.* **2008**, *30* (4), 285−295.

(191) Priani, S. E.; Aprilia, S.; Aryani, R.; Purwanti, L. Antioxidant and Tyrosinase Inhibitory Activity of Face Serum Containing Cocoa Pod Husk Phytosome (*Theobroma Cacao* L.). *J. Appl. Pharm. Sci.* **2019**, *9* (10), 110−115.

(192) Quintão, F. J. O.; Tavares, R. S. N.; Vieira-Filho, S. A.; Souza, G. H. B.; Santos, O. D. H. Hydroalcoholic Extracts of Vellozia Squamata: Study of Its Nanoemulsions for Pharmaceutical or Cosmetic Applications. *Rev. Bras. Farmacognosia* **2013**, *23* (1), 101−107.

(193) Raghuwanshi, N.; Kumari, P.; Srivastava, A. K.; Vashisth, P.; Yadav, T. C.; Prasad, R.; Pruthi, V. Synergistic Effects of *Woodfordia*

*Fruticosa* Gold Nanoparticles in Preventing Microbial Adhesion and Accelerating Wound Healing in Wistar Albino Rats *in Vivo*. *Mater. Sci. Eng., C* **2017**, *80*, 252−262.

(194) Khan, I.; Saeed, K.; Khan, I. Nanoparticles: Properties, Applications and Toxicities. *Arab. J. Chem.* **2019**, *12* (7), 908−931.

(195) Stern, S. T.; Adiseshaiah, P. P.; Crist, R. M. Autophagy and Lysosomal Dysfunction as Emerging Mechanisms of Nanomaterial Toxicity. *Part. Fibre Toxicol.* **2012**, *9*, 20.

(196) Joseph, T. M. Toxic Effects of Nanoparticles from Environment and Indoor/Outdoor Workplaces. *Int. J. Curr. Res. Rev.* **2021**, *13* (16), 1−2.

(197) Hund-Rinke, K.; Simon, M. Ecotoxic Effect of Photocatalytic Active Nanoparticles ($TiO_2$) on Algae and Daphnids. *Environ. Sci. Pollut. Res.* **2006**, *13*, 225−232.

(198) Xia, T.; Kovochich, M.; Brant, J.; Hotze, M.; Sempf, J.; Oberley, T.; Sioutas, C.; Yeh, J. I.; Wiesner, M. R.; Nel, A. E. Comparison of the Abilities of Ambient and Manufactured Nanoparticles to Induce Cellular Toxicity According to an Oxidative Stress Paradigm. *Nano Lett.* **2006**, *6*, 1794−1807.

(199) Dunphy Guzmán, K.; Taylor, M.; Banfield, J. Environmental Risks of Nanotechnology: National Nanotechnology Initiative Funding, 2000−2004. *Environ. Sci. Technol.* **2006**, *40* (5), 1401−1407.

(200) Choi, Y.; Kim, H. A.; Kim, K. W.; Lee, B. T. Comparative Toxicity of Silver Nanoparticles and Silver Ions to Escherichia Coli. *J. Environ. Sci.* **2018**, *66*, 50−60.

(201) Zhao, Z.; Xu, L.; Wang, Y.; Li, B.; Zhang, W.; Li, X. Toxicity Mechanism of Silver Nanoparticles *to Chlamydomonas Reinhardtii*: Photosynthesis, Oxidative Stress, Membrane Permeability, and Ultrastructure Analysis. *Environ. Sci. Pollution Res.* **2021**, *28* (12), 15032−15042.

(202) Simon, M. Effect of Photocatalytic Active Nanoparticles on Algae and Daphnids. *J. Occup. Environ. Hyg.* **2008**, *5*, 239−249.

(203) Kaul, S.; Gulati, N.; Verma, D.; Mukherjee, S.; Nagaich, U. Role of Nanotechnology in Cosmeceuticals: A Review of Recent Advances. *J. Pharm.* **2018**, *2018*, 3420204.

(204) Bourdon, J. A.; Halappanavar, S.; Saber, A. T.; Jacobsen, N. R.; Williams, A.; Wallin, H.; Vogel, U.; Yauk, C. L. Hepatic and Pulmonary Toxicogenomic Profiles in Mice Intratracheally Instilled with Carbon Black Nanoparticles Reveal Pulmonary Inflammation, Acute Phase Response, and Alterations in Lipid Homeostasis. *Toxicol. Sci.* **2012**, *127* (2), 474−484.

(205) Li, N.; Sioutas, C.; Cho, A.; Schmitz, D.; Misra, C.; Sempf, J.; et al. Ultrafine Particulate Pollutants Induce Oxidative Stress and Mitochondrial Damage. *Environ. Health Perspect.* **2003**, *111* (4), 455−460.

(206) Schulte, P.; Geraci, C.; Zumwalde, R.; Hoover, M.; Kuempel, E. Occupational Risk Management of Engineered Nanoparticles. *J. Occup. Environ. Hyg.* **2008**, *5*, 239−249.

(207) Wani, M. Y.; Hashim, M. A.; Nabi, F.; Malik, M. A. Nanotoxicity: Dimensional and Morphological Concerns. *Adv. Phys. Chem.* **2011**, *2011*, 450912.

(208) Li, Y.; Zhang, Y.; Yan, B. Nanotoxicity Overview: Nano-Threat to Susceptible Populations. *Int. J. Mol. Sci.* **2014**, *15*, 3671−3697.

(209) Barhoum, A.; Garcia-Betancourt, M. L.; Jeevanandam, J.; Hussien, E. A.; Mekkawy, S. A.; Mostafa, M.; Omran, M. M.; S. Abdalla, M.; Bechelany, M. Review on Natural, Incidental, Bioinspired, and Engineered Nanomaterials: History, Definitions, Classifications, Synthesis, Properties, Market, Toxicities, Risks, and Regulations. *Nanomaterials* **2022**, *12* (2), 177.

(210) Xin, L.; Wang, J.; Wu, Y.; Guo, S.; Tong, J. Increased Oxidative Stress and Activated Heat Shock Proteins in Human Cell Lines by Silver Nanoparticles. *Hum. Exp. Toxicol.* **2015**, *34* (3), 315−323.

(211) Genter, M. B.; Newman, N. C.; Shertzer, H. G.; Ali, S. F.; Bolon, B. Distribution and Systemic Effects of Intranasally Administered 25 Nm Silver Nanoparticles in Adult Mice. *Toxicol. Pathol.* **2012**, *40* (7), 1004−1013.

(212) Baky, N.A.; Faddah, L.; Al-Rasheed, N.; Al-Rasheed, N.; Fatani, A. Induction of Inflammation, DNA Damage and Apoptosis in Rat Heart after Oral Exposure to Zinc Oxide Nanoparticles and the Cardioprotective Role of $\alpha$-Lipoic Acid and Vitamin E. *Drug Res.* **2013**, *63* (5), 228−236.

(213) Horie, M.; Kato, H.; Endoh, S.; Fujita, K.; Komaba, L. K.; Nishio, K.; Nakamura, A.; Miyauchi, A.; Yamamoto, K.; Kinugasa, S.; Hagihara, Y.; Yoshida, Y.; Iwahashi, H. Cellular Effects of Industrial Metal Nanoparticles and Hydrophilic Carbon Black Dispersion. *J. Toxicol. Sci.* **2014**, *39* (6), 897−907.

(214) Teng, C.; Jia, J.; Wang, Z.; Yan, B. Oral Co-Exposures to Zinc Oxide Nanoparticles and $CdCl_2$ Induced Maternal-Fetal Pollutant Transfer and Embryotoxicity by Damaging Placental Barriers. *Ecotoxicol. Environ. Saf.* **2020**, *189*, 109956.

(215) Balasubramanian, S. K.; Jittiwat, J.; Manikandan, J.; Ong, C. N.; Yu, L. E.; Ong, W. Y. Biodistribution of Gold Nanoparticles and Gene Expression Changes in the Liver and Spleen after Intravenous Administration in Rats. *Biomaterials* **2010**, *31* (8), 2034−2042.

(216) Sung, J. H.; Ji, J. H.; Park, J. D.; Song, M. Y.; Song, K. S.; Ryu, H. R.; Yoon, J. U.; Jeon, K. S.; Jeong, J.; Han, B. S.; Chung, Y. H.; Chang, H. K.; Lee, J. H.; Kim, D. W.; Kelman, B. J.; Yu, I. J. Subchronic Inhalation Toxicity of Gold Nanoparticles. *Part. Fibre. Toxicol.* **2011**, *8*, 16.

(217) Guo, Z.; Martucci, N. J.; Moreno-Olivas, F.; Tako, E.; Mahler, G. J. Titanium Dioxide Nanoparticle Ingestion Alters Nutrient Absorption in an *in Vitro* Model of the Small Intestine. *NanoImpact.* **2017**, *5*, 70−82.

(218) Wang, Y.; Chen, Z.; Ba, T.; Pu, J.; Chen, T.; Song, Y.; Gu, Y.; Qian, Q.; Xu, Y.; Xiang, K.; Wang, H.; Jia, G. Susceptibility of Young and Adult Rats to the Oral Toxicity of Titanium Dioxide Nanoparticles. *Small* **2013**, *9* (9−10), 1742−1752.

(219) Duan, Y.; Liu, J.; Ma, L.; Li, N.; Liu, H.; Wang, J.; Zheng, L.; Liu, C.; Wang, X.; Zhao, X.; Yan, J.; Wang, S.; Wang, H.; Zhang, X.; Hong, F. Toxicological Characteristics of Nanoparticulate Anatase Titanium Dioxide in Mice. *Biomaterials* **2010**, *31* (5), 894−899.

(220) Chen, Z.; Wang, Y.; Wang, X.; Zhuo, L.; Chen, S.; Tang, S.; Zhao, L.; Luan, X.; Jia, G. Effect of Titanium Dioxide Nanoparticles on Glucose Homeostasis after Oral Administration. *J. Appl. Toxicol.* **2018**, *38* (6), 810−823.

(221) Kim, B. G.; Park, M. K.; Lee, P. H.; Lee, S. H.; Hong, J.; Aung, M. M. M.; Moe, K. T.; Han, N. Y.; Jang, A.-S. Effects of Nanoparticles on Neuroinflammation in a Mouse Model of Asthma. *Respir. Physiol. Neurobiol.* **2020**, *271*, 103292.

(222) You, R.; Ho, Y. S.; Hung, C. L.; Liu, Y.; Huang, C.; Chan, H. N.; Ho, S. L.; Lui, S. Y.; Li, H. W.; Chang, R. Silica Nanoparticles Induce Neurodegeneration-like Changes in Behavior, Neuropathology, and Affect Synapse through MAPK Activation. *Part. Fibre. Toxicol.* **2018**, *15* (1), 28.

(223) Ma-Hock, L.; Treumann, S.; Strauss, V.; Brill, S.; Luizi, F.; Mertler, M.; Wiench, K.; Gamer, A. O.; van Ravenzwaay, B.; Landsiedel, R. Inhalation Toxicity of Multiwall Carbon Nanotubes in Rats Exposed for 3 Months. *Toxicol. Sci.* **2009**, *112* (2), 468−481.

(224) Qi, W.; Bi, J.; Zhang, X.; Wang, J.; Wang, J.; Liu, P.; Li, Z.; Wu, W. Damaging Effects of Multi-Walled Carbon Nanotubes on Pregnant Mice with Different Pregnancy Times. *Sci. Rep.* **2014**, *4*, 4352.

(225) Dhapte-Pawar, V.; Kadam, S.; Saptarsi, S.; Kenjale, P. P. Nanocosmeceuticals: Facets and Aspects. *Fut. Sci. OA* **2020**, *6* (10), FSO613.