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Application of Nanotechnology in Hydration, Antioxidant, and Photoprotection Skincare – A Review

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ABSTRACT

Purpose: To summarize the primary findings of novel nanotechnology applications in hydration skincare, antioxidant skincare, and photoprotection skincare.

Method: Review of all relevant publications from peer-reviewed and high-impact journals in narrative form that is mainly focused on nanotechnology and its application in cosmetics, particularly in nano-hydration skincare, nano-antioxidant skincare, and nano-sunscreens.

Results: Nano-hydration skincare, nano-antioxidant skincare, and nano-sunscreens have been found to have biodegradable nature, be easily eliminated in the body, have a wide range of biomedical applications which include antimicrobial and antioxidant, have low immunogenicity, high physicochemical stability, long-term stability of incorporated drug during storage, minimum surfactant concentration with maximum drug loading potential, have modulation of drug release pattern, specifically reach the affected organ or tissue, exhibit high antioxidative activity, exhibit no cytotoxicity in vitro or in vivo, have an appropriate administration route, and be easily excreted from the body.

Conclusion: Nanoparticles are widely regarded to increase the efficacy of cosmetic products in several ways, both as active components and carriers. Although extensive research has been conducted, nanotechnology in skincare can still be improved in the future through the rational design of nanotechnology materials and techniques based on an in-depth understanding of biological processes.

Keywords:nanotechnology, nanoparticle, nanomaterial, nano-hydration, nano-antioxidant, nano-sunscreens, skincare

1. Introduction

As the cosmetic industry continues to evolve and new production techniques are developed, nano-cosmeceuticals have emerged in which the products' active ingredients are formulated with nanotechnology or into nano-vehicles (Lohani et al., 2014). Azis et al. (2019) mentioned that the application of nanotechnology in cosmetic formulations is recognized as the most recent technology, and its potential in drug delivery systems is worth exploring.

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In synthesizing nanoparticles, five preparation techniques are employed. First, high-pressure homogenization is a viable approach that is scalable and commercially demonstrated. The second is hot homogenization, which is suitable for insoluble and lipophilic compounds when exposed to high temperatures for a brief time. Third, cold homogenization is appropriate for hydrophilic, thermolabile, and thermosensitive substances. Fourth, the microemulsion process requires low mechanical energy input. Lastly, ultrasonication is effective at a laboratory scale to reduce shear stress (Hameed et al., 2019).

Manufacturers in the cosmetic industry make use of nanomaterials primarily because of their miniscule size. The outermost layer of the human skin is mostly impermeable to exogenous substances because of the structure of the stratum corneum. As a result, most traditional pharmacological drugs cannot easily penetrate the skin's surface defenses. In contrast, nanoparticles, which measure from 1 to 100 nanometers, allow better penetration of skincare products because their small size permits them to have contact directly with the stratum corneum, thus increasing medication transfer through the skin (Bhatia et al., 2021; Sharma et al., 2018). The small size of nanoparticles' lipid vesicles also allows for easier skin absorption of bioactive components like liposomes, niosomes, micelles, and dendrimers, which are added to formulations (Ahmad et al., 2019; Bronaugh et al., 2015).

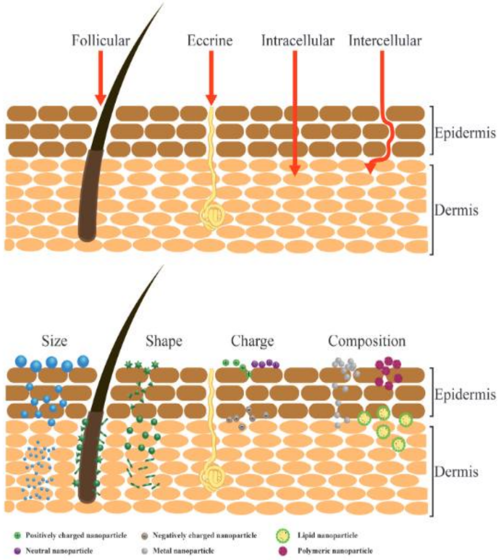

Fig. 1 - Different routes for nanoparticles to enter the skin and its dermal penetration. (a) Nanoparticles and drugs employ these pathways to penetrate deep skin layers.; (b) The effect of physicochemical properties of nanoparticles on their penetration into the epidermal and dermal layers of skin (Bhatia et al., 2021)

While the size of nanoparticles makes them useful in the cosmetics industry, they can also cause harm to consumers. Due to their nano-size, nanoparticles possess higher toxicity than micronized materials since they penetrate more tissues and cells and can easily be transported inside the body. Despite their small particle size, nanoparticles can interfere with normal cell functions. Moreover, nanoparticles and their interaction with the human body are harder to scrutinize using traditional methods (Gupta et al., 2022).

Several studies also show the risks brought by nanoparticles. When inhaled in high concentrations, zinc oxide and titanium dioxide nanoparticles have been found to be hazardous. Additionally, in-vitro results have shown neurotoxicity in the neural stem cells of a mouse (Shokri J., 2017). Additionally, spray-on sunscreens that contain nanoscale titanium dioxide may be inhaled, which may enter the brain and blood system through the nasal nerves and cause severe and fatal adverse effects (Raj et al., 2012). Meanwhile, silica, although possessing numerous benefits, is still questionable in terms of its safety and requires long-term trials to ensure its safety for use. Neonatal toxicity may happen when pregnant women are exposed to and negatively affected by the use of products with nanoparticles, which can permeate the uterus lining, amniotic sac, umbilical vesicle, and the fetus and eventually damage them (Gupta et al., 2022).

Because of nanomaterials' unpredictable behavior, crucial evaluative methods such as identification and characterization are needed to assess their safety for consumer use. In toxicological evaluations, the characterization of the nanomaterial needs to be carried out at the raw material stage, in the cosmetic formulation, and during exposure. The characterization data must identify the materials in accordance with Cosmetics Regulation (EC) No 1223/2009. Moreover, since particle size is the most critical factor, it must be measured more than once and be carried out using generally accepted techniques (Gupta et al., 2022). In addition, since specific nanomaterials have a higher bioavailability or toxicity, their potential skin absorption must also be considered when determining whether safety problems exist (Katz et al., 2015).

Since nanotechnology is a relatively recent innovation, further investigations on its safety, efficacy, and cost are required (Gupta et al., 2022).

Nevertheless, its application in cosmetics is undeniable and has been widely recognized. In this paper, the use of nanoparticles in nano-hydration skincare, nano-antioxidant skincare, and nano-sunscreens are emphasized and further discussed.

2. Methods

This article review utilizes recovered studies and peer-reviewed articles from the different journals in PubMed, ResearchGate, ScienceDirect, Elsevier, Springer Link, and Semantic Scholar. The Scientific Research Publishing, MDPO, Pharmacognosy Reviews, JPBS, Taylor and Francis Online, LJMU Research Online, RACGP, and JEADV were also selected for the search of the articles. The search for studies took place from April to May 2022.

The explored topics mainly focused on nanotechnology and its application in cosmetics, particularly in nano-hydration skincare, nano-antioxidant skincare, and nano-sunscreens. All of the articles were carefully reviewed and analyzed.

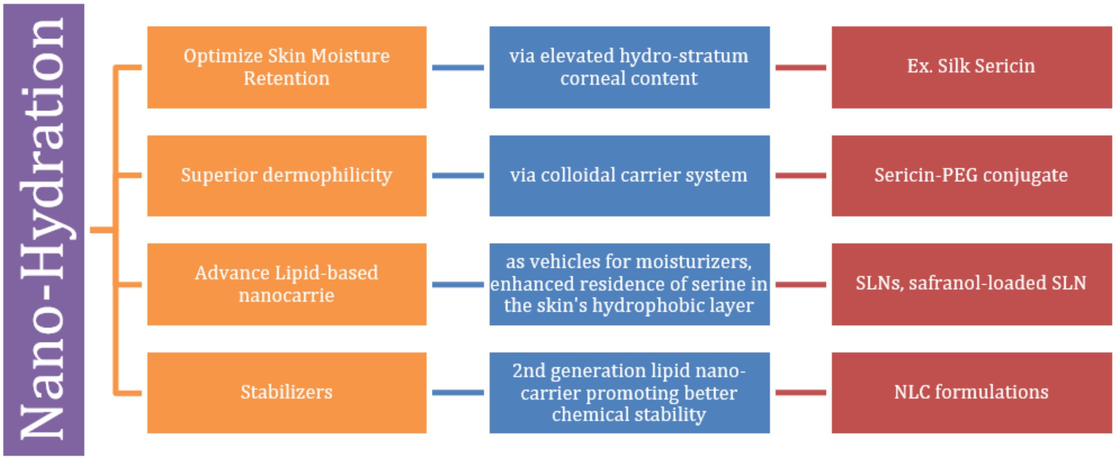

Fig. 2 - General matrix of nano-hydration in skincare

2.1. Nano-hydration skincare

Maintaining healthy skin requires optimal skin moisture. Thus, a moisturizer is a vital component of basic skincare. Moisturizers are designed to promote skin hydration and are usually applied topically or on the skin because their mechanism increases hydration in the stratum corneum (Hardwood et al., 2019; Sethi et al., 2016). The use of nanotechnology in delivering moisture within the skin is one of the innovations of the cosmetic industry, as traditional emollients cannot effectively deliver the active constituents onto the skin strata. Nanotechnology is essential in the interaction with the stratum corneum strata, particularly natural lipids, which have a high dermophilicity and hydration power (Muller et al., 2000). Nano-moisturizers as drug carrier systems are colloidal in nature (Sharma et al., 2018), intended for improving drug delivery while reducing toxicity. Such developments include sericin protein nanoparticles, solid lipid nanoparticles (SLN), and nanostructured lipid carriers (NLC), among others.

2.1.1 Sericin protein nanoparticle

Sericin is a silkworm cocoon protein extract composed mostly of glycine, serine, aspartic acid, and threonine. (Das et al., 2021). Silk sericin (SS) is a gum-like protein found in silk fibers surrounding fibroin (Vootla et al., 2015). Its chemical structure, which is high in serine (approximately 32%) and has a high amount of hydroxyl groups, determines its cosmetic action. Sericin may possess moisture-retaining properties; however, its usage in cosmetics is complicated due to its insolubility in organic solvents and instability in water (Cho et al., 2003). A chemical alteration has been created to introduce poly(ethylene glycol) (PEG) into proteins. PEG is amphiphilic, indicating it can be dissolved in both aqueous systems as well as on organic solvents. The sericin-PEG conjugate, with sericin and PEG as the hydrophobic and hydrophilic parts, was utilized to generate self-assembled polymeric nanoparticles. This revealed that the moisturizing effect of sericin-PEG nanoparticles is higher than sericin alone. The benefits of employing this on a sericin-PEG nanoparticle safety test include that no skin or eye discomfort was detected in the safety test (Es et al., 2003). Sericin protein nanoparticles are noted for their use in drug delivery systems because they are biodegradable, can be eliminated from the body, and have various applications in biomedicine (Das et al., 2021).

2.1.2 Solid lipid nanoparticles

Solid lipid nanoparticles (SLNs), the first successful lipid-based nanocarriers for skin delivery, are extensively studied and utilized by formulators worldwide and have emerged as versatile nano-sized drug carriers (Neseri et al., 2015). Depending on the synthesis technique, SLNs can be used for both hydrophilic and hydrophobic pharmaceuticals (Mukherjee et al., 2009). SLNs have also been studied as vehicles for moisturizers. Some substances have a high amount of natural moisturizing factor (NMF), serine, for instance. However, their hydrophilicity limits its passage through the stratum corneum barrier, so it could not effectively hydrate the skin. However, serine-loaded solid lipid nanoparticles showed an enhanced residence of serine in the skin by forming a thin hydrophobic layer, and thus, the influx of the active component in the deeper epidermis increases (Barua et al., 2017). Moreover, a moisturizing cream containing a ceramide SLN formulation has been studied, and its data showed that the use of this formulation for two weeks could significantly decrease the transepidermal water loss (TEWL) value, from 24.50 gr/m2/hour range (22.95-26.10) before treatment to 14.98 gr/m2/hour (13.55-16.95), in patients with eczema (Hartini et al., 2020). Additionally, a safranal-loaded SLN was studied for its moisturizing effects, and results showed that the application of the formulation enhanced skin hydration better than free SLN formulations. However, no significant changes were seen between loaded and unloaded SLN.. This indicates that skin hydration qualities were exclusively connected to SLN and not to safranal (Khameneh et al., 2015). It has been proven that formulations with SLNs can improve the effectiveness and increase the stability of moisturizing products. However, the amount of hydration of SLN depends on the particle size, lipid concentration, and crystallinity of lipids. As the lipid nanoparticles are applied to the skin, the surface area of the film layer formed will be dependent on the particle size. Smaller particle sizes will form a smaller air channel that will decrease the hydrodynamic evaporation of water, making the skin more hydrated (Sarhadi et al., 2020).

SLNs have numerous advantages, including ease of preparation, low cost, large-scale production, excellent physical stability, good release profile, chemical versatility, biocompatibility, and biodegradability (Mukherjee et al., 2009). Moreover, the production of lipid particles avoids the utilization of toxic additives such as organic solvents or toxic monomers. SLNs are stable against coalescences; however, drug content leakage, high water concentration, and insufficient drug loading may lead to some disadvantages of SLNs. Upon prolonged storage, solid lipid nanoparticles undergo polymeric transition where their polymeric form changes into a crystalline form without changing its internal structure. Furthermore, their perfect crystalline structure resulted in a low drug loading efficiency and the possibility of drug expulsion due to the crystallization process during the storage conditions (Deepa et al., 2020).

2.1.3 Nanostructured lipid carriers

Nanostructured lipid carriers (NLCs) are innovative formulations comprising physiological and biocompatible lipids, as well as surfactants and co-surfactants. It was found to be a viable alternative to first-generation nanoparticles as a second-generation lipid nanocarrier. (Chauhan et al., 2020). NLCs can enhance the chemical stability of actives, provide an occlusive effect to the skin and can therefore increase skin hydration, enhance the skin bioavailability of actives, and increase the physical stability of topical formulations (Choi et al., 2010). Moreover, Loo et al. (2013) claimed that NLC formulations showed a significantly increased skin hydration. Within the seven days of treatment conducted using an in vivo study, NLC with a high lipid concentration further enhanced skin hydration as skin occlusion is strongly dependent on the sample volume, particle size, lipid concentration, and crystallinity of lipids. In terms of trans-epidermal loss, the application of NLC to the skin helped limit water loss by absorbing more lipids into the intercellular space of the stratum corneum, forming a homogeneous compact layer on the skin surface, and preventing water from evaporating. Also, Loo et al. (2013) showed that NLC containing propylene glycol exhibited a highly significant difference in the reduction of trans-epidermal water loss as compared to the NLC without propylene glycol. Thus, NLCs, with the addition of occlusive agents such as propylene glycol, lecithin, high lipid content, and solid lipid content, can be promising systems for cosmetics since they have proven an effect on skin hydration and trans-epidermal water loss.

Additionally, NLC dispersions often have a low viscosity, which is undesirable for topical application since it reduces the time of permanence at the application site. To circumvent this, NLCs can be introduced into typical semi-solid systems (e.g., hydrogels), which can improve the consistency of final formulations as well as the nanoparticles' long-term stability (H. Muller et al., 2011). Thus, the presence of lipid nanoparticles, which have a skin-moisturizing impact when integrated into semi-solid formulations, could explain the considerable increase in skin hydration seen for the HG-NLC formulation. NLC shows great potential in skin hydration and has numerous advantages such as long-term stability of incorporated drug during storage, minimum surfactant concentration with maximum drug loading potential, and modulation of drug release pattern (Khan et al., 2015).

2.2. Nano-oxidant skincare

The skin has the capacity to protect itself against the harmful effects of both intrinsic and extrinsic determinants through an elaborate antioxidant defense system. However, as the skin ages, the free radical increases while the efficacy of natural endogenous defenses of the skin decreases. Moreover, the inability of the skin to compensate or fix the accumulative effects of free radical damage leads to oxidative stress (McDaniel et al., 2019).

Natural and synthetic substances having antioxidant activity may be effective at preventing and managing skin aging, as oxidative stress is one of the key mechanisms implicated in skin aging.According to Montenegro (2014), topical antioxidant supplementation is one of the most effective treatments for preventing or treating skin aging. An antioxidant is a substance that is stable enough to donate an electron to a free radical and eventually neutralize it, thus reducing its ability to damage. Cellular damage is inhibited primarily due to the ability of low molecular weight antioxidants to interact with free radicals and terminate the chain reaction before vital molecules are damaged (Lobo et al., 2010). Aside from interfering with intracellular signaling pathways implicated in skin damage, antioxidants also protect the skin against photodamage and prevent wrinkles and inflammation (Nguyen et al., 2012).

Although antioxidants have enormous potential for treating skin damage caused by oxidative stress, their pharmaceutical applicability, on the other hand, is severely limited due to their low bioavailability and biocompatibility. Hence, the establishment of skin delivery systems using nanotechnology would be most beneficial for antioxidant skin care products in the market (Montenegro, 2014). Several studies suggest that nano-antioxidants are more effective in rescuing oxidative stress-related illnesses as compared to antioxidant monomers. Additionally, they have the potential to outperform all other antioxidative therapy (Zhao et al., 2021).

Antioxidants can be encapsulated in nanomaterials or covalently bonded to them to generate nano-antioxidants. The encapsulation approach, the surface-functionalized method, and their combination are commonly used ways of making nano-antioxidants (Ray et al., 2018).

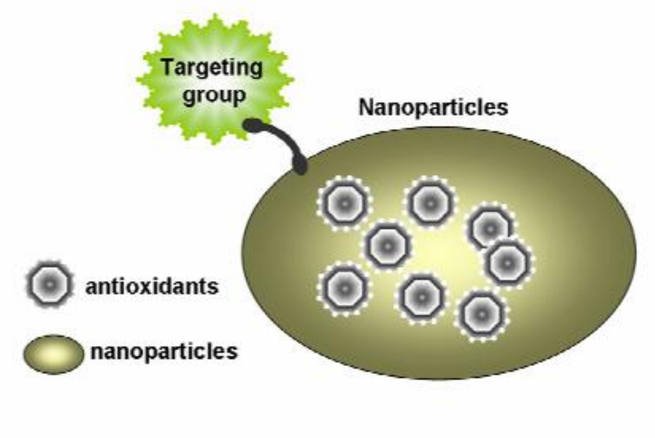

Fig. 3 - Illustration of ideal nano-antioxidants (Du et al., 2014)

According to Chen, C. et al. (2014), ideal nano-antioxidants have a targeting group that can specifically reach the affected organ or tissue, avoid the release of antioxidant monomers contained within nanocarriers during long-term circulation prior to reaching the target point, exhibit high antioxidative activity, exhibit no cytotoxicity in vitro or in vivo, have an appropriate administration route, and are easily excreted from the body. Although extensive research has been conducted on nano-antioxidants, the technology can still be improved in the future through the rational design of nanotechnology materials and techniques based on an in-depth understanding of biological processes (Du et al., 2014)

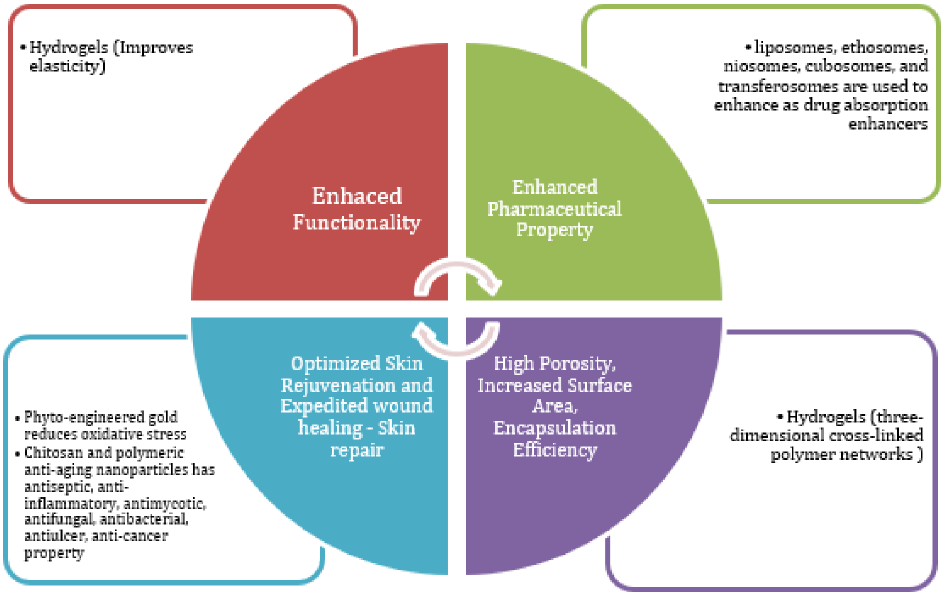

Fig. 4 – Matrix for antioxidants employing nanotechnology.

2.2.1 Nano-ingredients in skin rejuvenation

The use of nanotechnology exhibits great advantages in terms of skin rejuvenation, as well as wound healing and skin regeneration (Bellu et al., 2021). One nano-ingredient utilized in this application is nanofibers, which are long polymeric filaments with excellent characteristics such as high porosity, surface area, encapsulation efficiency, controllable morphology, and chemical and thermal stability (Vimala et al., 2021). Nanofibers such as polycaprolactone, polyethylene glycol, polylactic acid, polyvinyl pyrrolidone are often used as scaffolds for skin rejuvenation and regeneration.

Hydrogels, which are three-dimensional cross-linked polymer networks that absorb a considerable amount of water when placed in an aqueous solution, are also important materials in skin rejuvenating products. Hydrogels are soft, wet materials with characteristics of both solids and liquids, owing to the massive amount of free water and possibly soluble molecules that can seep in and out of the gels. Hydrogels that help provide elasticity to skin tissues include polysaccharides, hyaluronic acid, chitosan, polyvinyl alcohol, sodium alginate, cyclodextrin, polyacrylic acid, polyvinyl pyrrolidone, polyvinyl acetate, collagen, pectin, and chitin. Gold, silver, and other metals or metal oxides like hydrogel nanoparticles are considered one of the most effective tools specifically for skin and as an intervention for wound repair (Bashir et al., 2020).

Gold, silver, carbon, and polymers can also be manufactured as nanocrystals (Bashir et al., 2020). Compared to macrocrystals, nanocrystals offer a multifold increase in contact points to the skin or mucosal surface due to their higher surface area. This improves nanocrystal adherence to skin surfaces, allowing them to stay longer on the surface in touch (Shegokar, R., 2016).

2.2.2 Nano-ingredients in skin anti-aging

Organic and inorganic nanoparticles have been advantageous in anti-aging cosmetics as they improve the products' antioxidant properties, stability, and biocompatibility. For instance, liposomes, ethosomes, niosomes, cubosomes, transferosomes, and other lipid-based nanoparticles are used to enhance drug penetration through the skin. Solid lipid core nanoparticles (SLCN) make cosmetic products more effective because they increase active delivery of ingredients to the epidermis (Ferreira et al., 2021).

Nanoemulsions are also utilized in the prevention of skin aging and are powerful tools for delivering potent skin-protecting and rejuvenating plant-based extracts to the skin. They provide an effective and safe topical delivery system for skin improvement and regenerative therapy. Better permeation of the nanoemulsions' nano-sized particles through the stratum corneum increases the bioavailability of phytoanti-oxidants for molecular-level skin repair (Romes, Abdul Wahab, Abdul Hamid 2021).

Metallic nanoparticles have also sparked tremendous interest and substantial research efforts in biomedical evaluation and revaluation in recent decades due to their specific and innate chemical, biological, and physical properties. For instance, phytochemical-loaded silver and gold nanoparticles interfere with the skin degradation process as phytochemicals enable metallic nanoparticles to interact with collagenase and elastase, both of which are enzymes responsible for breaking down skin proteins (Burdusel et al., 2018). Silver nanoparticles also inhibit protein synthesis by destroying the cell membrane potential or inhibiting the binding of tRNA to the small subunit of the ribosome (Rónavári et al., 2021). On the other hand, phyto-engineered gold nanoparticles stop further injury from oxidative stress caused by reactive oxygen species (Ganesan et al., 2020). Meanwhile, palladium and platinum nanoparticles, especially when combined (PAPLAL), significantly reduce skin aging and thinning because they have strong catalytic activity (Shibuya et al., 2014). Lastly, cerium oxide nanoparticles have potent antioxidant and free radical scavenging properties and act similarly to the enzymes superoxide dismutase and catalase, which prevent damage to skin tissues (Li et al., 2019).

Lastly, polymeric anti-aging nanoparticles are more commonly used in cosmetics than synthetic polymeric nanoparticles since their efficacy in wrinkle reduction is proven by several studies. In addition, the antiseptic, anti-inflammatory, antimycotic, antifungal, antibacterial, antiulcer, anticancer, and immunomodulatory properties of the developed polymeric nanoparticles have also been established (An et al., 2022).

2.2.3 Nano-ingredients in skin repair

Antioxidants in a cosmetic formulation based on lipid nanoparticles are particularly efficient on sensitive and irritated skin and show tremendous potential in the treatment of skin illnesses such as atopic dermatitis and psoriasis. (Ahmad, 2021). Nanoparticles are useful for cell targeting and medication administration due to their physical features, and they have some of the most effective techniques in skin restoration interventions. One of these developments is the chitosan-silver nanoparticles. It revealed great antibacterial and antioxidant activity in vitro, as well as a high efficiency in avoiding oxidative damage (Hajji et al., 2019). Chitosan has shown a positive effect in accelerating the synthesis of collagen in the early phases of wound healing in dogs (Ueno et al., 1999). Moreover, Lu et al. (2017) revealed that silver nanoparticle-impregnated chitosan-L-glutamic acid sponge dressings promote wound repair by stimulating the growth of epidermal cells.

Furthermore, the substantial oxidative stress that arises throughout the recovery process often inhibits the healing of wounded tissues. Because of their high oxidative, anti-inflammatory, and anti-infective characteristics, topical antioxidants like curcumin may considerably shield tissues from oxidative damage and enhance tissue remodeling. (Akbik et al., 2014). A unique dual drug co-loaded in situ gel-forming nanoparticle/hydrogel system that operated as a supporting matrix for the regeneration tissue, as well as a sustained drug depot for EGF and Cur was developed, resulting in much faster wound healing. (Li et al., 2016). Metal-based NPs are used in wound healing because of their stability, antibacterial and antioxidant properties, and cellular interactions (Sharifiaghdam et al., 2022).

2.3. Nano-sunscreens

The sun is vital to sustaining life on Earth because it stimulates vitamin D-dependent and independent biological pathways, which have been linked to a variety of health advantages. According to Santos et al. (2022), vitamin D generation in the skin is connected to a lower risk of primary intestinal malignancies, type 2 diabetes, and bone disease. In addition, various conditions, such as atopic dermatitis, psoriasis, vitiligo, and cardiovascular problems, have been proven beneficial from other pathways, both the ultraviolet (UV)-related and vitamin D-independent. However, the negative consequences of sun exposure have been thoroughly documented in numerous literature. Sunburn, photocarcinogenesis, photo immunosuppression, and photoaging are all possible side effects of both acute and chronic UV exposure. Sun avoidance, seeking shade, wearing protective clothing, and applying sunscreen are all current photoprotection measures, but sunscreen application remains the most popular method of protection among the general public (Burnett & Wang, 2011). Similarly, Wang and Tooley (2011) name sunscreen as the most common type of photoprotection utilized by the general public. Since the early 1900s, these products have been created to counteract UV radiation’s harmful effects, thus protecting human skin (McSweeney, 2016).

The global cosmetic market has seen a considerable surge in sunscreen production and usage, particularly in recent decades (Schiavo et al., 2018). Traditional sunscreens were viscous formulations that did not integrate well into the skin and were cosmetically unpleasant before introducing nanosized particles. This was a consequence of titanium dioxide and zinc oxide, the two most frequently used components of sunscreen, having long been utilized for their capacity to filter ultraviolet (UV)A and UVB rays. To circumvent the issue of the unsightly white films produced by traditional sunscreens, manufacturers have recently begun to replace the bulk forms of titanium dioxide and zinc oxide with nanosized ones, thus creating a carrier that is less viscous, more transparent, and more rapidly blends in (Newman et al., 2009). Moreover, novel sunscreens filter UV rays with a combination of organic and inorganic chemicals (McSweeney, 2016). Inorganic-based sunscreens use mineral UV filters, which have long been considered safe and effective. Individuals who are prone to skin irritation favor them to sunscreens that contain organic UV filters like avobenzone and oxybenzone (Wang & Tooley, 2011). Sunscreens based on inorganic compounds also possess the benefit of avoiding common issues such as sensitization and skin irritation, while also boasting broad-spectrum protection, an inertness of components, and minimal penetration through the skin (Antoniou et al., 2008; Smijs& Pavel, 2011). Indeed, studies conducted on sunscreen formulations, including various types of nanoparticles, were shown to have higher ratings on Sun Protection Factor (SPF), a measurement of a sunscreen's efficacy, with one study even indicating that a 45% increase in SPF was achieved (Nikolić et al., 2011). A different study on solid lipid nanoparticles in which oxybenzone was incorporated reported that UVA protection and SPF values were more than quintupled, while also avoiding irritation of the skin (Sanad et al., 2010).

2.3.1 Titanium dioxide and zinc oxide in sunscreens

It is crucial to consider the physicochemical characteristics of titanium dioxide and zinc oxide nanoparticles when it pertains to their application in sunscreens. According to Smijs and Pavel (2011), rutile, anatase, and brookite are the three crystalline structures found in titanium dioxide, whereas the two primary crystalline forms of zinc oxide are naturally found in the earth’s crust are wurtzite and zinc-blende. Additionally, titanium dioxide is a semiconducting material with an electronic structure consisting of several bands, and orbitals separated by an energy bandgap in which no molecular orbitals exist, while zinc oxide is an n-type semiconductor with a broad bandgap.

The refractive indices in the UV and visible wavelength ranges are important optical features since the capacity of particles to attenuate UV light is determined by the surrounding medium in addition to size-related optical particle characteristics (Smijs& Pavel, 2011). Sun and Kwok (1999) discovered zinc oxide’s optical refractive indices using variable angle spectroscopic ellipsometry in the 375 to 900 nm range, with values between 2.3 and 2.0. Meanwhile, rutile polycrystalline and epitaxial films of titanium dioxide had an average refractive index (n) of 4.0, whereas anatase films had an average refractive index (n) of 3.6. The reason why titanium dioxide is so white, even compared to zinc oxide, is largely owing to its high refractive index. Additionally, titanium oxide is predominantly a UVB absorbing component, whereas zinc oxide is more effective in UVA absorption.

According to multiple studies, such as that of Gollavilli et al. (2020) and Nasir et al. (2014), titanium dioxide and zinc oxide are utilized in sunscreens since under normal circumstances, they are unable to penetrate the horny layer of the skin, in addition to their capability to protect from UV radiation. This is due to their clumping into larger particles, thereby preventing them from reaching cells and inducing toxic reactions or damage. However, their bigger particle size also resulted in a white-tinted, matte look after application, leading to the development of their nanoparticle forms. This brought about safety concerns because nano-sized particles are affected by sunray and UV ray exposure more than larger ones, leading to reactive oxygen species (ROS) and free radical formation (Gollavilli et al., 2020; Wang et al., 2011). It was discovered that titanium dioxide and zinc oxide showed photocatalytic properties, where harmful effects were probable (Bogdan et al., 2015).

Based on the study of Dr. Steven Wang and Dr. Ian Stooley (2011), ROS can damage the DNA, cause point mutations, single-strand breaks, and sister chromatid exchange, and can also damage proteins and lipids, resulting in permanent cell and tissue damage. However, it is stated in another study that the damage and skin toxicity was induced due to the application of the nanoparticles in vitro (outside the living body). This means that the test was done in a test tube or in cultured skin tissues, in contrast to the test being done in vivo (within the living body), which would not yield toxicity. Therefore, in addition to the requirement of the host body failing to neutralize the enzyme and small molecules, the damage is contingent on nanoparticle titanium dioxide and zinc oxide's ability to penetrate the skin (Nasir et al., 2014). Lastly, sunscreens containing zinc oxide claimed that they had properties of algae genotoxicity and the ability to inhibit algal growth. Still, the authors claimed that this phenomenon could be caused by the sunscreen as a whole, and not only because of the nanoparticles alone (Schiavo et al., 2018).

2.3.2 Chitosan in sunscreens

Chitosan is a β-(1-4)-linked, linear copolymer that is only naturally produced by Mucoraceae fungi and commercially manufactured by de-N-acetylating the natural polysaccharide chitin (Ntohogian et al., 2018). Due to several advantages, chitosan is widely utilized as a means to enhance skin permeability in drug delivery systems of the transdermal and topical routes by altering the structure of keratin. It also serves as a carrier in various oral, ocular, and gene delivery systems. The skin surface's negative charges readily absorb the chitosan, which then works as a cationic humectant in topical formulations and cosmetics, enhancing the stratum corneum's water content and increasing the cell membrane's fluidity. It also has antibacterial, antioxidant, anti-inflammatory, and UV-protecting effects, according to reports (Ta et al., 2022).

Meanwhile, a dye made from annatto, which belongs to the Bixaceae family, is a red-orange pigment derived from the seed coat that is utilized as a color in the culinary, cosmetic, and soap industries. The carotenoids included in annatto, bixin, and norbixin, are also potent antioxidants. On the other hand, saffron is made from the dried red/yellow stigmas of a flower known as Crocus sativus L. The pharmacological properties of the powdered stigma of saffron, such as antibacterial, antiseptic, anticonvulsant, antioxidant, and antifungal effects, have been reported by (Hosseini et al., 2018). Due to the desirable combination of antioxidant and pigmenting properties, several attempts to develop formulations of chitosan-based sunscreens through ionotropic gelation, including ultrafiltered annatto or saffron, have been made (Ntohogian et al., 2018). Results show that since these neat materials possess acceptable levels of toxicity, those in encapsulation as additives into chitosan nanoparticles are ensured to be safe for use in biomedicine. Moreover, good pH stability was observed in the preparation of nanoparticles and the usage of chitosan, which demonstrates that the integration of the sunscreening agents within a nanoparticle system based on chitosan leaves the resultant emulsion's pH stability unaffected (Ntohogian et al., 2018). The same study also indicates that such emulsions meet the recommended ratings in viscosity, color stability, and SPF evaluations.

According to Morsy et al. (2017), the development of a HAp-chitosan gel with nanosized particles grants protection from UV radiation. It also demonstrates potential as an antibacterial sunscreen due to its exhibiting of significant effects on the ultrastructure, growth, and activities of multi-drug resistant bacteria, an observation that is especially pertinent considering that acne, another common skin ailment aside from sunburn, is attributed to the activity of surface-dwelling bacteria. A similar study by Petrick et al. (2020), in which numerous multifunctional, chitosan/TiO2 nanocomposite-based creams were successfully synthesized, eradicated up to 99.7% of test sample Escherichia coli bacteria within 2 hours.

3.Conclusion

Incorporating nanotechnology into cosmetic formulations is the newest and most cutting-edge technology accessible. This study concentrates on the use of nanotechnology as active ingredients and as carriers in hydration, antioxidant, and photoprotection skincare. The enormous exterior structure of nanoparticles owing to their little stature is responsible for the cosmetic ingredients' systematic conveyance, permeability, and bioavailability, and in turn the product's incessant result. Nanotechnology's utilization in hydration skincare is among the innovations of the enterprise of skincare, as traditional emollients cannot effectively deliver the active constituents onto the skin strata. Nano-moisturizers as drug delivery methods are colloidal in nature designed to enhance medication distribution while lowering toxicity. Such developments include sericin protein nanoparticles, solid lipid nanoparticles (SLN), and nanostructured lipid carriers (NLC) among others. Nano-moisturizers have high dermophilicity and hydration power. Nano-antioxidants have already demonstrated their potency in treating diseases because they contain a targeting group that can specifically reach the affected organ or tissue and avoid the release of antioxidant monomers during long-term circulation. Antioxidant monomers contained within nanocarriers during long-term circulation prior to reaching the target point exhibit high antioxidative activity, exhibit no cytotoxicity in vitro or in vivo, have an appropriate administration route, and are easily excreted from the body. In nano-sunscreens, titanium dioxide and zinc oxide are utilized in sunscreens not only for their UV-protective capabilities but also because they are incapable of penetrating the stratum corneum. By changing the keratin structure, chitosan in sunscreens is additionally generally utilized as a skin porousness enhancer in skin and transdermal medication conveyance frameworks. It also has antibacterial, antioxidant, anti-inflammatory, and UV-protecting effects. Many studies on sunscreen containing various types of nanoparticles were shown to have higher ratings on SPF. Although extensive research has been conducted, nanotechnology in skincare can still be improved in the future through the rational design of nanotechnology materials and techniques based on an in-depth understanding of biological processes.

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REFERENCES

1. Ahmad, J. (2021). Lipid nanoparticles-based cosmetics with potential application in alleviating skin disorders. Cosmetics, 8(3), 84. https://doi.org/10.3390/cosmetics8030084

2. Ahmad, A., Aziz, Z., Chuo, S., Ibrahim, M., Khatoon, A., Nasir, H., Peng, W., Setapar, S., Umar, K., Yaqoob, A. (2019). Role of Nanotechnology for Design and Development of Cosmeceutical: Application in Makeup and Skin Care. Frontiers in Chemistry, 7(739), 1-15.

3. Akbik, D., Ghadiri, M., Chrzanowski, W., &Rohanizadeh, R. (2014). Curcumin as a wound healing agent. Life sciences, 116(1), 1-7.

4. An, J. Y., Kim, C., Park, N. R., Jung, H. S., Koo, T.-S., Yuk, S. H., Lee, E. H., & Cho, S. H. (2022). Clinical anti-aging efficacy of Propolis polymeric nanoparticles prepared by a temperature-induced phase transition method. Journal of Cosmetic Dermatology. https://doi.org/10.1111/jocd.14740

5. Antoniou, C., Kosmadaki, M. G., Stratigos, A. J., &Katsambas, A. D. (2008). Sunscreens–what's important to know. *Journal of the European academy of dermatology and venereology*, *22*(9), 1110-1119.

6. Aziz, Z., Mohd-Nasir, H., Ahmad, A., MohdSetapar, S. H., Peng, W. L., Chuo, S. C., Khatoon, A., Umar, K., Yaqoob, A. A., & Mohamad Ibrahim, M. N. (2019). Role of Nanotechnology for Design and Development of Cosmeceutical: Application in Makeup and Skin Care. Frontiers in chemistry, 7, 739. https://doi.org/10.3389/fchem.2019.00739

7. Barua, S., Kim, H., Hong, S. C., Yoo, S. Y., Shin, D., Lee, C. L., ... & Lee, J. (2017). Moisturizing effect of serine-loaded solid lipid nanoparticles and polysaccharide-rich extract of root Phragmites communis incorporated in hydrogel bases. Archives of pharmacal research, 40(2), 250-257.

8. Bashir, S., Hina, M., Iqbal, J., Rajpar, A. H., Mujtaba, M. A., Alghamdi, N. A., Wageh, S., Ramesh, K., & Ramesh, S. (2020). Fundamental Concepts of Hydrogels: Synthesis, Properties, and Their Applications. Polymers, 12(11), 2702. https://doi.org/10.3390/polym12112702

9. Bellu, E., Medici, S., Coradduzza, D., Cruciani, S., Amler, E., &Maioli, M. (2021). Nanomaterials in Skin Regeneration and Rejuvenation. International journal of molecular sciences, 22(13), 7095. https://doi.org/10.3390/ijms22137095

10. Bhatia, E., Kumari, D., Sharma, S., Ahamad, N., & Banerjee, R. (2021). Nanoparticle platforms for dermal antiaging technologies: Insights in cellular and Molecular Mechanisms. WIREs Nanomedicine and Nanobiotechnology, 14(2). https://doi.org/10.1002/wnan.1746

11. Bogdan, J., Jackowska-Tracz, A., Zarzyńska, J., &Pławińska-Czarnak, J. (2015). Chances and limitations of nanosized titanium dioxide practical application in view of its physicochemical properties. *Nanoscale research letters*, *10*(1), 1-10.

12. Boomi, P., Ganesan, R., Prabu Poorani, G., Jegatheeswaran, S., Balakumar, C., Gurumallesh Prabu, H., Anand, K., Marimuthu Prabhu, N., Jeyakanthan, J., & Saravanan, M. (2020). Phyto-engineered gold nanoparticles (AuNPs) with potential antibacterial, antioxidant, and wound healing activities under in vitro and in vivo conditions. International Journal of Nanomedicine, 15, 7553–7568. https://doi.org/10.2147/IJN.S257499

13. Bronaugh, R., Dewan, K., Katz, L. (2015). Nanotechnology in cosmetics. Food and Chemical Toxicology, 85, 127-137.

14. Burduşel, A.-C., Gherasim, O., Grumezescu, A. M., Mogoantă, L., Ficai, A., & Andronescu, E. (2018). Biomedical applications of silver nanoparticles: An up-to-date overview. Nanomaterials (Basel, Switzerland), 8(9), 681. https://doi.org/10.3390/nano8090681

15. Burnett, M. E., & Wang, S. Q. (2011). Current sunscreen controversies: a critical review. *Photodermatology, photoimmunology& photomedicine*, *27*(2), 58-67.

16. Chauhan, I., Yasir, M., Verma, M., & Singh, A. P. (2020). Nanostructured lipid carriers: A groundbreaking approach for transdermal drug delivery. Advanced pharmaceutical bulletin, 10(2), 150.

17. Cho, K. Y., Moon, J. Y., Lee, Y. W., Lee, K. G., Yeo, J. H., Kweon, H. Y., ... & Cho, C. S. (2003). Preparation of self-assembled silk sericin nanoparticles. International Journal of Biological Macromolecules, 32(1-2), 36-42.

18. Choi, W. S., Cho, H. I., Lee, H. Y., Lee, S. H., & Choi, Y. W. (2010). Enhanced occlusiveness of nanostructured lipid carrier (NLC)-based carbogel as a skin moisturizing vehicle. Journal of Pharmaceutical Investigation, 40(6), 373-378.

19. Das, G., Shin, H. S., Campos, E. V. R., Fraceto, L. F., del Pilar Rodriguez-Torres, M., Mariano, K. C. F., ... & Patra, J. K. (2021). Sericin based nanoformulations: A comprehensive review on molecular mechanisms of interaction with organisms to biological applications. Journal of Nanobiotechnology, 19(1), 1-22.

20. Deepa MK, Karthikeyan M*, Abhay AD, Shruti PC, Omkar SD, Satish RC. (2020). Comprehensive Review on Solid Lipid Nanoparticles. Ann Pharmacol Pharm; 5(4): 1190.

21. Du, L., Li , J., Chen, C., & Liu, Y. (2014). Nanocarrier: A potential tool for future antioxidant therapy .

22. Es, C., Sy, E., Kim, J. H., Kim, K. S., Kim, K. H., Lee, K. G., ... & CS, C. (2003). Synthesis, Characterization and Cosmetic Application of Self-Assembled Sericin-PEG Nanoparticle. In Proceedings of the SCSK Conference (pp. 501-519). Society of Cosmetic Scientists of Korea.

23. Ferreira, K. C. B., Valle, A. B. C. D. S., Paes, C. Q., Tavares, G. D., &Pittella, F. (2021). Nanostructured lipid carriers for the formulation of topical anti-inflammatory nanomedicines based on natural substances. Pharmaceutics, 13(9), 1454. https://doi.org/10.3390/pharmaceutics13091454

24. Gollavilli, H., Hegde, A. R., Managuli, R. S., Bhaskar, K. V., Dengale, S. J., Reddy, M. S., ... &Mutalik, S. (2020). Naringin nano-ethosomal novel sunscreen creams: Development and performance evaluation. *Colloids and Surfaces B: Biointerfaces*, *193*, 111122.

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

26. Hajji, S., Khedir, S. B., Hamza-Mnif, I., Hamdi, M., Jedidi, I., Kallel, R., Boufi, S., &Nasri, M. (2019). Biomedical potential of chitosan-silver nanoparticles with special reference to antioxidant, antibacterial, hemolytic and in vivo cutaneous wound healing effects. Biochimica et Biophysica Acta. General Subjects, 1863(1), 241–254. https://doi.org/10.1016/j.bbagen.2018.10.010

27. Hameed, A., Fatima, G. R., Malik, K., Muqadas, A., Fazal-ur-Rehman, M., (2019). Scope of nanotechnology in cosmetics: dermatology and skin care products. Journal of Medicinal and Chemical Sciences, 2(1), 9-16.

28. H. Muller, R., Shegokar, R., & M. Keck, C. (2011). 20 Years of Lipid Nanoparticles (SLN & NLC): Present State of Development & Industrial Applications. Current Drug Discovery Technologies, 8(3), 207–227. doi:10.2174/157016311796799062

29. Hartini, H., Vlorensia, H. A., Martinus, A. R., &Ikhtiari, R. (2020). The Effect of a Moisturizing Cream Containing Saccharide Isomerate and Ceramide on Reducing Transepidermal Water Loss in Eczema.

30. Harwood, A., Nassereddin, A., & Krishnamurthy, K. (2019). Moisturizers. In: StatPearls. StatPearls Publishing, Treasure Island (FL); PMID: 31424755.

31. Hosseini, A., Razavi, B. M., &Hosseinzadeh, H. (2018). Saffron (Crocus sativus) petal as a new pharmacological target: a review. *Iranian Journal of Basic Medical Sciences*, *21*(11), 1091–1099. https://doi.org/10.22038/IJBMS.2018.31243.7529.

32. Khameneh, B., Halimi, V., Jaafari, M. R., &Golmohammadzadeh, S. (2015). Safranal-loaded solid lipid nanoparticles: evaluation of sunscreen and moisturizing potential for topical applications. Iranian journal of basic medical sciences, 18(1), 58.

33. Khan, S., Baboota, S., Ali, J., Khan, S., Narang, R. S., & Narang, J. K. (2015). Nanostructured lipid carriers: an emerging platform for improving oral bioavailability of lipophilic drugs. International journal of pharmaceutical investigation, 5(4), 182.

34. Ray, L., & Gupta, K.C. (2018). Role of Nanotechnology in Skin Remedies.

35. Li, Y., Hou, X., Yang, C., Pang, Y., Li, X., Jiang, G., & Liu, Y. (2019). Photoprotection of Cerium Oxide Nanoparticles against UVA radiation-induced Senescence of Human Skin Fibroblasts due to their Antioxidant Properties. Scientific Reports, 9(1), 2595. https://doi.org/10.1038/s41598-019-39486-7

36. Li, X., Ye, X., Qi, J., Fan, R., Gao, X., Wu, Y., Zhou, L., Tong, A., & Guo, G. (2016). EGF and curcumin co-encapsulated nanoparticle/hydrogel system as potent skin regeneration agent. International Journal of Nanomedicine, 11, 3993–4009. https://doi.org/10.2147/IJN.S104350

37. Lobo, V., Patil, A., Phatak, A., & Chandra, N. (2010). Free radicals, antioxidants and functional foods: Impact on human health. Pharmacognosy Reviews, 4(8), 118. https://doi.org/10.4103/0973-7847.70902

38. Lohani, A., Verma, A., Joshi, H., Yadav, N., & Karki, N. (2014). Nanotechnology-Based Cosmeceuticals. ISRN Dermatology, 2014, 1–14. https://doi.org/10.1155/2014/843687

39. Lu, B., Lu, F., Zou, Y., Liu, J., Rong, B., Li, Z., ... & Lan, G. (2017). In situ reduction of silver nanoparticles by chitosan-l-glutamic acid/hyaluronic acid: Enhancing antimicrobial and wound-healing activity. Carbohydrate polymers, 173, 556-565.

40. Loo, C. H., Basri, M., Ismail, R., Lau, H. L. N., Tejo, B. A., Kanthimathi, M. S., ... & Choo, Y. M. (2013). Effect of compositions in nanostructured lipid carriers (NLC) on skin hydration and occlusion. International journal of nanomedicine, 8, 13.

41. McDaniel, D. H., Waugh, J. M., Jiang, L. I., Stephens, T. J., Yaroshinsky, A., Mazur, C., Wortzman, M., & Nelson, D. B. (2019). Evaluation of the Antioxidant Capacity and Protective Effects of a Comprehensive Topical Antioxidant Containing Water-soluble, Enzymatic, and Lipid-soluble Antioxidants. The Journal of clinical and aesthetic dermatology, 12(4), 46–53.

42. McSweeney, P. C. (2016). The safety of nanoparticles in sunscreens: An update for general practice. *Australian family physician*, *45*(6), 397-399.

43. Montenegro, L. (2014). Nanocarriers for skin delivery of cosmetic antioxidants [Ebook]. Journal of Pharmacy & Pharmacognosy Research. Retrieved 27 April 2022, from https://www.researchgate.net/publication/302190066_Nanocarriers_for_skin_delivery_of_cosmetic_antioxidants.

44. Morsy, R., Ali, S. S., & El-Shetehy, M. (2017). Development of hydroxyapatite-chitosan gel sunscreen combating clinical multidrug-resistant bacteria. J*ournal of Molecular Structure*, *1143*, 251–258. https://doi.org/10.1016/j.molstruc.2017.04.090

45. Mukherjee, S., Ray, S., & Thakur, R. S. (2009). Solid lipid nanoparticles: a modern formulation approach in drug delivery system. Indian journal of pharmaceutical sciences, 71(4), 349.

46. Müller, R. H., Mäder, K., &Gohla, S. (2000). Solid lipid nanoparticles (SLN) for controlled drug delivery–a review of the state of the art. European journal of pharmaceutics and biopharmaceutics, 50(1), 161-177.

47. Naseri, N., Valizadeh, H., &Zakeri-Milani, P. (2015). Solid lipid nanoparticles and nanostructured lipid carriers: structure, preparation and application. Advanced pharmaceutical bulletin, 5(3), 305.

48. Nasir, A., Wang, S., & Friedman, A. (2011). The emerging role of nanotechnology in sunscreens: an update. *Expert Review of Dermatology*, *6*(5), 437-439.

49. Newman, M. D., Stotland, M., & Ellis, J. I. (2009). The safety of nanosized particles in titanium dioxide–and zinc oxide–based sunscreens. *Journal of the American Academy of Dermatology*, *61*(4), 685-692.

50. Nguyen, G., & Torres, A. (2012). Systemic antioxidants and skin health. Journal of drugs in dermatology : JDD, 11(9), e1–e4.

51. Nikolić, S., Keck, C. M., Anselmi, C., & Müller, R. H. (2011). Skin photoprotection improvement: synergistic interaction between lipid nanoparticles and organic UV filters. *International journal of pharmaceutics*, *414*(1-2), 276-284.
52. Ntohogian, S., Gavriliadou, V., Christodoulou, E., Nanaki, S., Lykidou, S., Naidis, P., ... &Bikiaris, D. N. (2018). Chitosan nanoparticles with encapsulated natural and uf-purified annatto and saffron for the preparation of uv protective cosmetic emulsions. *Molecules*, *23*(9), 2107. https://doi.org/10.3390/molecules23092107
53. Petrick, J., Ibadurrohman, M., &Slamet. (2020, September). Synthesis of chitosan/TiO2 nanocomposite for antibacterial sunscreen application. In *AIP Conference Proceedings* (Vol. 2255, No. 1, p. 060020). AIP Publishing LLC.
54. Raj, S., Jose, S., Sumod, U. S., &Sabitha, M. (2012). Nanotechnology in cosmetics: Opportunities and challenges. Journal of pharmacy &bioallied sciences, 4(3), 186–193. https://doi.org/10.4103/0975-7406.99016

55. Ray, L., & Gupta, K. C. (2018). Role of Nanotechnology in Skin Remedies. Photocarcinogenesis& Photoprotection, 141–157.

https://doi.org/10.1007/978-981-10-5493-8_13

56. Romes, N. B., Abdul Wahab, R., & Abdul Hamid, M. (2021). The role of bioactive phytoconstituents-loaded nanoemulsions for skin improvement: a review. Biotechnology, Biotechnological Equipment, 35(1), 711–729. https://doi.org/10.1080/13102818.2021.1915869

57. Rónavári, A., Igaz, N., Adamecz, D. I., Szerencsés, B., Molnar, C., Kónya, Z., Pfeiffer, I., &Kiricsi, M. (2021). Green silver and gold nanoparticles: Biological synthesis approaches and potentials for biomedical applications. Molecules (Basel, Switzerland), 26(4), 844. https://doi.org/10.3390/molecules26040844

58. Salvioni, L., Morelli, L., Ochoa, E., Labra, M., Fiandra, L., Palugan, L., Prosperi, D., & Colombo, M. (2021). The emerging role of nanotechnology in skincare. Advances in Colloid and Interface Science, 293, 102437.

59. Sanad, R. A., Abdel Malak, N. S., El-Bayoomy, T. S., & Badawi, A. A. (2010). Preparation and characterization of oxybenzone-loaded solid lipid nanoparticles (SLNs) with enhanced safety and sunscreening efficacy: SPF and UVA-PF. *Drug DiscovTher*, *4*(6), 472-483.

60. Santos, A. C., Marto, J., Chá-Chá, R., Martins, A. M., Pereira-Silva, M., Ribeiro, H. M., &Veiga, F. (2022). Nanotechnology-based sunscreens—a review. *Materials Today Chemistry*, *23*, 100709.

61. Sarhadi, S., Gholizadeh, M., Moghadasian, T., &Golmohammadzadeh, S. (2020). Moisturizing effects of solid lipid nanoparticles (SLN) and nanostructured lipid carriers (NLC) using deionized and magnetized water by in vivo and in vitro methods. Iranian journal of basic medical sciences, 23(3), 337.

62. Schiavo, S., Oliviero, M., Philippe, A., & Manzo, S. (2018). Nanoparticles based sunscreens provoke adverse effects on marine microalgae Dunaliellatertiolecta. *Environmental Science: Nano*, *5*(12), 3011-3022.

63. Sethi, A., Kaur, T., Malhotra, S. K., & Gambhir, M. L. (2016). Moisturizers: the slippery road. Indian journal of dermatology, 61(3), 279.

64. Sharifiaghdam, M., Shaabani, E., Asghari, F., &Faridi-Majidi, R. (2022). Chitosan coated metallic nanoparticles with stability, antioxidant, and antibacterial properties: Potential for wound healing application. Journal of Applied Polymer Science, 139(10), 51766. https://doi.org/10.1002/app.51766

65. Sharma, N., Singh, S., Kanojia, N., Grewal, A. S., & Arora, S. (2018). Nanotechnology: a modern contraption in cosmetics and dermatology. Applied Clinical Research, Clinical Trials and Regulatory Affairs, 5(3), 147-158.

66. Shegokar, R. (2016). What nanocrystals can offer to cosmetic and dermal formulations. Nanobiomaterials in Galenic Formulations and Cosmetics, 69–91. https://doi.org/10.1016/b978-0-323-42868-2.00004-8

67. Shibuya, S., Ozawa, Y., Watanabe, K., Izuo, N., Toda, T., Yokote, K., & Shimizu, T. (2014). Palladium and platinum nanoparticles attenuate aging-like skin atrophy via antioxidant activity in mice. PloS One, 9(10), e109288. https://doi.org/10.1371/journal.pone.0109288

68. Smijs, T. G., & Pavel, S. (2011). Titanium dioxide and zinc oxide nanoparticles in sunscreens: focus on their safety and effectiveness. *Nanotechnology, science and applications*, *4*, 95–112. https://doi.org/10.2147/NSA.S19419

69. Sun, X. W., & Kwok, H. S. (1999). Optical properties of epitaxially grown zinc oxide films on sapphire by pulsed laser deposition. *Journal of applied physics*, *86*(1), 408-411.
70. Ta, Q., Ting, J., Harwood, S., Browning, N., Simm, A., Ross, K., ... & Al-Kassas, R. (2021). Chitosan nanoparticles for enhancing drugs and cosmetic components penetration through the skin. *European Journal of Pharmaceutical Sciences*, *160*, 105765.
71. Ueno, H., Yamada, H., Tanaka, I., Kaba, N., Matsuura, M., Okumura, M., ... &Fujinaga, T. (1999). Accelerating effects of chitosan for healing at early phase of experimental open wound in dogs. Biomaterials, 20(15), 1407-1414.

72. Vimala Bharathi, S. K., Murugesan, P., Moses, J. A., & Anandharamakrishnan, C. (2021). Recent trends in nanocomposite packaging materials. Innovative Food Processing Technologies, 731–755. https://doi.org/10.1016/b978-0-08-100596-5.23027-8

73. Vootla, S. K., Su, C. C., &Masanakatti, S. I. (2015). Self-assembled nanoparticles prepared from TasarAntherea mylitta silk sericin. In Biomedical Applications of Natural Proteins (pp. 65-77). Springer, New Delhi.

74. Wang, S. Q., & Tooley, I. R. (2011, December). Photoprotection in the era of nanotechnology. In *Seminars in cutaneous medicine and surgery* (Vol. 30, No. 4, pp. 210-213). WB Saunders.

75. Zhao, J., Wang, Y., Wang, W., Tian, Y., Gan, Z., Wang, Y., ... & Ma, G. (2021). In situ growth of nano-antioxidants on cellular vesicles for efficient reactive oxygen species elimination in acute inflammatory diseases. Nano Today, 40, 101282.