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Applications of Nanotechnology in Advanced Cosmeceuticals

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Abstract

Nanotechnology is the study and manipulation of atoms and molecules on the nanoscale, which is approximately 80,000 times smaller than the width of a human hair. By 2015, the global market for products incorporating nanomaterials is projected to reach $2.6 trillion. This field showcases significant progress in research and development by improving product performance and introducing innovative solutions. The usage of cosmetics has increased significantly throughout time, and they are thought to be the personal care product category with the quickest rate of growth. There are still concerns about the potential risks that nanoparticles may have to human health, which may go unnoticed due to their low toxicity, despite the rapid advancement of nanotechnology. Cutting-edge nanocarriers like liposomes, niosomes, microemulsions, nanoemulsions, solid lipid nanoparticles, nanostructured lipid carriers, and nanospheres have revolutionized drug delivery, replacing conventional methods with more efficient and effective alternatives. Nanoparticles have improved features, such as color, transparency, solubility, and other attributes, which is why nanotechnology has become so prevalent in the cosmetic sectors. Better known as UV filters, they offer superior UV absorption, which is why sunscreen formulations employ them widely over the globe without leaving an unwanted white film on users' skin. This page addresses the many applications, advantages, and kinds of nanomaterials as well as the potential and challenges of nanotechnology and how it applies to the cosmetics sector. Examining the pros and cons of nanotechnology.

Keywords: Cosmeceutical, Nanotechnology, Nanomaterials, Nanometals, Health risks

INTRODUCTION

Nanotechnology is thought to be the most significant technological advancement of the twenty-first century and has great potential to benefit the cosmetics sector. Nanotechnology is a compound phrase consisting of the Greek term "nano," which meaning dwarf, plus the word "technology." The creation and modification of particles ranging from 1 to 100 nanometers in size are considered the foundation of nanotechnology, blending both science and technology [1, 2]. Since 1959, nanotechnology has become more and more prevalent in a variety of sectors, including engineering, physics, chemistry, biology, and science. It has also been present in the cosmetics, health, and dermal preparation industries for almost 40 years. The Egyptians, Greeks, and Romans documented the usage of nanotechnology around 4000 BC, and they used this technique to prepare hair dye [3]. According to the Food and Drug Administration (FDA), cosmetics are products designed to be applied to the human body or specific areas to cleanse, enhance beauty, boost attractiveness, or change appearance [4]. A large variety of personal care items fall under the

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category of cosmetics. Cosmetics can be divided into two categories based on the parts of the body on which they are applied: 1) skin-care cosmetics (such as moisturizing and cleansing agents) 2) hair-care products (such as shampoos, colorants, and styling agents). 3) Face-care items, such as foundations, powders, lipsticks, and mascara 4) nail care items, such as paint removers and nail disappear, 5) Fragrance items and 6) UV light screening products, such sunscreens. In the professional skin care industry, the term "cosmeceutical" refers to a product that, like a drug, has measurable biological accomplishment in the skin but is regulated as a cosmetic because it makes appearance-related claims and is used to treat conditions like wrinkles, photoaging, hyperpigmentation, and hair damage [5, 6]. "The European Union Cosmetics Directive (EUCD) defines cosmetics as substances or formulations intended for application on external parts of the body – such as the skin, hair, nails, lips, and external genital areas – or on the teeth and oral mucous membranes." Their primary purpose is to cleanse, perfume, enhance appearance, correct body odor, or protect and maintain skin health [7]. Cosmeceuticals, on the other hand, are specialized formulations that, when used alongside regular cosmetics, provide therapeutic benefits due to their active ingredients. These products help address various skin and hair concerns, including wrinkles, photoaging, dry skin, hyperpigmentation, light spots, and damaged hair [8, 9].

HISTORY

Previous research on cosmeceutical products has shown promising growth trends for the coming years. Projections suggest that the global cosmeceutical market could reach $31.84 billion by 2016, growing at a compound annual rate of 7.7%. Several Asian countries, including China, India, and Japan, are expected to attract major industry players due to their significant potential in the global market. Japan, in particular, has already built a strong reputation in the international cosmetics industry and continues to expand its presence in the cosmeceutical sector [10].

In 2006, leading cosmetics brand Estée Lauder entered the nanotechnology market by incorporating "nanoparticles" into its products. Meanwhile, L'Oréal, the world's largest cosmetics company, has patented the use of various "nanosome particles" and is investing nearly $600 million of its $17 billion revenue into nanotechnology patents. It currently ranks sixth among U.S. holders of nanotech patents [11].

Consumer attitudes toward cosmetics are evolving, with a growing emphasis on personal care. Women, especially professionals with higher incomes, are particularly drawn to high-end skincare products that offer benefits like anti-aging, multifunctionality, and skin brightening. Additionally, men are increasingly viewing personal grooming as an essential part of their routine rather than a luxury [12].

Nanotechnology has played a role in the cosmetics industry for nearly four decades, continuously driving innovation and enhancing product performance.

Front-Running Brands of Nanocosmetic

It has been discovered through numerous surveys that nearly every significant cosmetic industry uses nanotechnology in their diverse products.

Nano-Variegation in Cosmetics

Mineral-Based Cosmetic Ingredients with Nano-Sized Dimensions

The efficiency of certain mineral-based cosmetics, such sunscreens, is dependent on the size of the particles in the product [13, 14].

Other Nano-Sized Materials Employed in Cosmetics

Skin Care

Cosmeceutical skincare products play a crucial role in protecting the skin from free radical damage and stimulating collagen production, which enhances skin texture and overall function. By maintaining the structural integrity of keratin, they help promote healthier skin [15].

In sunscreen formulations, zinc oxide and titanium dioxide nanoparticles are highly effective. These advanced formulations penetrate deep into the skin, offering better protection while being less greasy, less pungent, and more transparent compared to traditional sunscreens (Figure 1) [16].

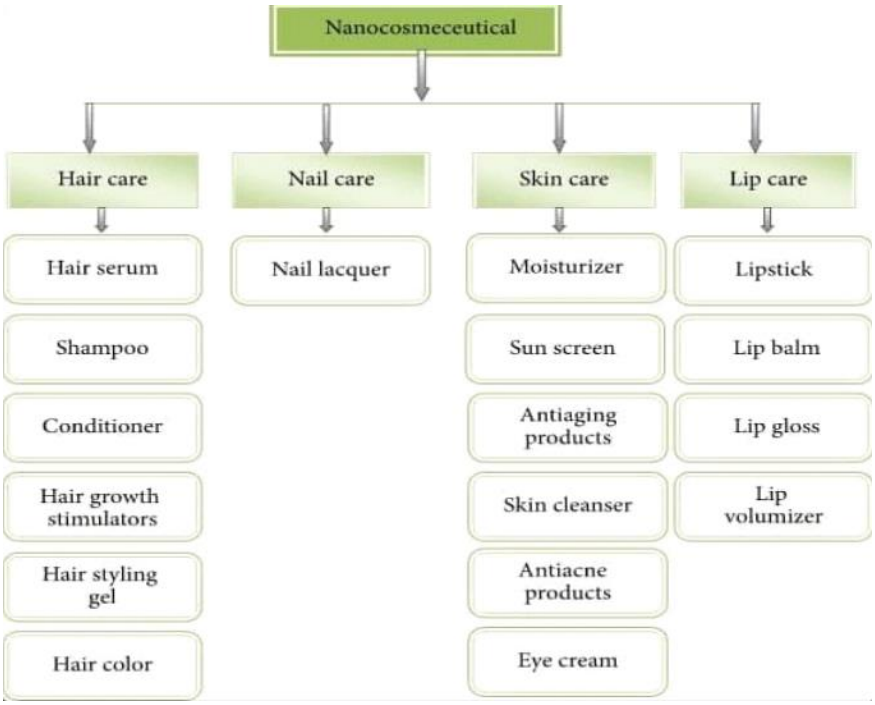

Figure 1. Major Classes of Nanocosmeceuticals.

For long-lasting hydration, nanoemulsions, solid lipid nanoparticles (SLNs), liposomes, and niosomes are widely used in moisturizers. These technologies form a thin layer of humectants that retain moisture for extended periods, ensuring prolonged skin hydration and improved skin health [16].

- *Hair care:* The products offered by hair nanocosmeceuticals include shampoos, conditioning agents, colorants, hair growth enhancers, and styling aids. concentrating on the hair shaft, follicle, and Characteristics that are unique and intrinsic allow for higher concentrations of the active ingredient. Size of nanoparticles [17]. Conditioning agents for nanocosmeceuticals help to provide softness, luster, silkiness, and gloss to hair while also enhancing hair disentanglement [18].
- *Lips care:* Lip gloss, lip balm, lip volumizer, and lipstick are examples of nanocosmeceuticals lip care products. A range of nanoparticles can be added to lip gloss and lipstick to lessen trans epidermal water loss and soften the color transfer [19].
- *Nail care:* When compared to conventional nail care products, nanocosmeceuticals-based products are superior [18].

TYPES OF NANOMATERIALS IN COSMETIC

Various nanoparticles are utilized in the preparation of cosmeceuticals and cosmetics:

1. *Titanium Dioxide and Zinc Oxide:* Sunscreens are helpful in protecting the skin from UVB, UVA-2, and UVA-1 rays of solar radiation [20, 21]. Given its transparency compared to its original hue, titanium dioxide (TiO2) is arguably the most widely used and effective inorganic nanoparticle for sunscreens. It also has a greater sun protection factor (SPF) at the nanoscale, making it more effective and producing a superior restorative effect. Due to its high surface area to volume ratio in the nano range, TiO2 possesses these characteristics [22].
2. *Gold and Silver Nanoparticles:* Both antibacterial and antifungal effects are shown by gold and silver nanoparticles [23]. The Egyptians thought that gold enhanced the flexibility and composition of their skin. Gold is currently used in a variety of skincare products, including

lotions, salves, and treatments. Generally speaking, gold used in skincare products is referred to as colloidal gold or, more accurately, nanogold if its size falls between 5 and 400 nm. Depending on the size and overall surface area, its hue can range from red to purple [19, 24]. A variety of bacteria can be effectively inhibited by silver nanoparticles. In various formulations, the use of silver and silver-based combinations can be employed to regulate the growth of bacteria [25].

3. *Silica (SiO2):* Nanosilica is used in cosmetic products to make them more appropriate, smoother on the surface, and longer lasting [26]. Silica nanoparticles can encapsulate hydrophilic and lipophilic substances and are present as nanodispersions with a size range of 5 to 100 nm [27]. A wide variety of leave-on and wash-off cosmetic products for the hair, skin, lips, face, and nails contain these nanoparticles, and it is anticipated that the amount of silica nanoparticles in cosmetic products will continue to grow [28].
4. *Nano-Hydroxyapatite:* Cosmetic products produced specifically for oral preparations used to cure excessive dental sensitivity and polish remineralization of the teeth contain nano-hydroxyapatite [29].
5. *Bucky Balls (Buckminsterfullerene/C60):* Fullerene, also referred to as "buckyballs" or buckminsterfullerene, is a three-dimensional spherical compound consisting of an odd number of carbon atoms in its carbon ring [30].
6. *Carbon Black:* Carbon black, or CI 77266, is widely used as a colorant in cosmetic treatments for the eyes and skin and is recognized as an important component in cosmetic formulations. Its use as a colorant at a maximum proportion of 10% and in its nano structure form have been permitted by the EU [31].
7. *Nano-Organic (Tris-Biphenyl Triazine):* Tris-biphenyl triazine is a recently developed, potent, and photostable filter that is mostly utilized in sunscreen formulas [32].

TYPES OF NANOMATERIAL USED IN COSMETIC

- *Liposomes:* Liposomes are widely used in cosmeceutical formulations due to their unique structure and effectiveness. These vesicles have a water-based core enclosed by one or more layers of hydrophobic lipids, forming a protective barrier [33]. Liposomes are ideal for cosmetic delivery applications because their lipid bilayer can fuse with other bilayers, such the cell membrane, which increases release of its contents [18].
- *Niosomes:* composed of cholesterol and non-ionic surfactants, niosomes are tiny lamellar structures [34]. Surfactants are highly stable chemically therefore they don't require special handling during preparation, storage, or purity concerns. It is quite simple to design and modify the hydrophilic surfaces since they have advantageous functional groups. Anti-aging cream has niosomes in it [19].
- *Solid Lipid Nanoparticles:* These consist of a single shell layer with an oily or lipoidal core. The drug matrix contains solid lipids or mixtures of lipids that are dissolved or dispersed within the solid core matrix. Liquid lipids are substituted with solid lipids or a combination of solid lipids that remain stable at both room and body temperature. These formulations are further stabilized using surfactants or polymers to enhance their effectiveness and durability [3].
- *Nanostructured Lipid Carriers (NLC):* Lipid nanoparticles of the second generation are regarded as nanostructured lipid carriers. The delivery method referred to as nanostructured lipid carriers (NLC) is made up of partially crystalline lipid particles that range in size from 100 nm to 200 nm and are distributed in an aqueous phase containing an emulsifier [35]. NLC is mostly composed of lipids, water, and emulsifier. Particle sizes range from 10 to 1000 nm. It can be used topically, intravenously, orally, or through the eyes [36].
- *Nanoemulsions:* Nanoemulsions are oil-in-water (o/w) emulsions with droplet sizes typically ranging between 50 and 1000 nanometers. These formulations offer enhanced stability, improved absorption, and better delivery of active ingredients in various cosmetic and pharmaceutical applications. The nanoparticles (NPs) can have two different forms: oil-in-oil and water-in-oil, where the particle's center is made of either water or oil. By combining an aqueous phase and a water-immiscible oil phase under high shear stress, or by using a widely accessible mechanical extrusion process, these emulsions can be readily made in huge quantities [37].

- *Gold Nanoparticles:* Depending on the use, gold nanoparticles can be employed in a variety of sizes and forms to provide different functional modifications. The shapes that are employed are nanocubes, nanospheres, nanorods, nanosheets, nanoshells, and nanotriangles, among others, and the sizes are usually between 5 and 400 nm [38]. A variety of structures, including nanospheres, nanoshells, clusters, rods, stars, cubes, branching, and triangles, are displayed by them. Resonance frequency of gold nanoparticles is highly dependent on shape, size, dielectric characteristics, and environment.
- *Nanosphere:* The spherical particles with a core-shell structure are called nanospheres. The diameter of the size varies from 10 to 200 nm. The medication is encapsulated, dissolved, linked, or trapped in the polymer matrix of nanospheres, shielding it from enzymatic and chemical breakdown. The medication is evenly and physically distributed throughout the polymer matrix structure. The nanospheres may have an amorphous or crystalline structure [39].
- *Dendrimers:* The Greek terms "Dendron," which means tree, and "Meros," which means portion, are the sources of the English word "dendrimer." Dendrimers are multivalent nanoparticles with a micellar nanostructure, globular, highly branching, unimolecular, and multivalent properties [40]. They can be multifunctionalized in a large number of external groupings. They are frequently polymers, and because of their stability, they help move active ingredients through the skin. Resveratrol has been found to have antioxidant and anti-aging properties. increased overall solubility and skin penetration, which in turn encouraged the scale-up [16].
- *Cubosomes:* Cubosomes are bicontinuous cubic liquid phases that produce a highly packed structure by enclosing two distinct water regions that are separated by bilayers regulated by surfactants and wrapped into a three-dimensional, periodic, and minimum surface [41]. Cubosomes are available at nearly any dilution level, have a huge surface area, and low viscosity. They are able to transport both hydrophilic and hydrophobic molecules and have a good thermal stability [42].

Carbon Nanotubes

Carbon nanotubes (CNTs) are considered one of the most groundbreaking innovations in nanotechnology. Structurally, they can be visualized as rolled-up graphene sheets with SP2 hybridization. These seamless, hollow cylindrical fibers are rolled at specific "chiral" angles, giving them unique properties.

The walls of carbon nanotubes consist of graphene, a hexagonal carbon lattice. When individual nanotubes naturally align, they form "ropes" held together by pi-stacking interactions. Their diameters typically range from 0.7 to 50 nanometers, while their lengths extend to several tens of microns [43, 44].

- *Polymersomes:* Polymersomes are artificial vesicles made of self-assembling block copolymer amphiphiles that surround a core aqueous cavity. They can be employed for both lipophilic and hydrophilic medicines because of their hydrophilic inner core and lipophilic bilayer, and their hydrophobic core creates an environment that is friendly to proteins [45].

BLACK-BOX WARNINGS FOR NANOCOSMETICS – HOW AND WHY?

Many risks have been discovered for both persons and the environment as a result of nanoparticles. The characteristics of nanomaterials – their smaller size, chemical makeup, surface structure, solubility, form, and aggregation – have an impact on their toxicity.

One of the defining characteristics of nanoparticles is their incredibly small size. This feature significantly alters their physicochemical properties compared to larger particles, enhancing their ability to be absorbed and interact with biological tissues. Their nanoscale dimensions allow for easier penetration through the skin or inhalation into the respiratory system, where they can then travel and distribute to various organs. These unique properties make nanoparticles highly effective for applications in medicine, skincare, and drug delivery [46, 47].

- *Surface area of nanoparticles:* Particles become more reactive as their surface area grows with decreasing particle size. Because they have a high surface area-to-mass ratio, which gives them greater area per unit weight for chemical reactions, nanomaterials are also very reactive [48].

Shape of Nanoparticles

Nanoparticles can be engineered in various shapes, including spheres, tubes, and sheets. Their shape plays a crucial role in determining their interaction with biological systems and may influence potential health risks. Different nanoparticle structures can affect how they are absorbed, distributed, and processed within the body, making their shape an important factor in safety assessments and biomedical applications [49].

RISK

Occupational Risks of Nanoparticles

When nanomaterials or goods containing them are being produced, used, disposed of, or recycled, workers may unintentionally come into contact with them Workers involved in cleaning, maintaining, and managing research, production, and handling facilities may come into contact with various chemicals during these processes. Proper safety measures are essential to minimize exposure and ensure a safe working environment [50].

Environmental Risks of Nanoparticles

Nanomaterials released into the air, water, or soil during manufacturing, use, or disposal can pose environmental risks. Research suggests that these particles, when reaching municipal sewage treatment plants, may disrupt bacterial populations that play a crucial role in wastewater treatment [51].

Route and Extent of Exposure

- *Inhalation:* According to the National Institute for Occupational Health and Safety, inhalation is the most common way people are exposed to airborne nanoparticles. Consumers may unknowingly inhale these particles, leading to potential respiratory exposure. Studies on the toxicity of inhaled silicon dioxide have shown that particles measuring 10 nanometers or smaller cause a lower toxicological response compared to those ranging from 1 to 5 nanometers [52].
- *Ingestion:* Studies show that while nanomaterials are rapidly eliminated from the body after ingestion, occasionally a tiny amount may find its way to the organs. Research conducted on pig skin shows that some nanoparticles can penetrate the skin's layers during a 24-hour period [53]. When mice were given oral doses of zinc oxide nanoparticles with sizes ranging from 20 nm to 120 nm, the spleen, heart, liver, bones, and pancreas were the organs that were targeted. Copper nanoparticles are present in a number of commercially available goods, including cosmetics [52].

Dermal Exposure to Nanoparticles

Nanoparticles can penetrate the skin through three main pathways: transcellular, transfollicular, and intracellular. Research indicates that smaller particles, particularly those under 10 nanometers (nm), tend to cause more damage compared to larger particles over 30 nm, which penetrate deeper into the skin.

Additionally, any disruption in the skin barrier – such as cuts, scrapes, or conditions, like dermatitis – can increase the likelihood of nanoparticles entering the body. Studies have linked nanoparticles smaller than 10 nm to conditions, like chronic erythema, edema, and eschar formation, highlighting their potential impact on skin health [54].

CONCLUSIONS

The cosmeceutical industry is expanding daily due to the extremely varied cosmeceutical market, which sources its products from both large and small manufacturers as well as local businesses worldwide. One of the major technological advances of the twenty-first century is nanotechnology,

which has fantastic prospects for both industry and research. The product's stability, safety, effectiveness, and visual appeal can all be improved with nanotechnology, which will ultimately increase customer compliance. It is important to manufacture and handle nanoproducts in a way that enhances their values while also addressing consumer and environmental health.

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