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SCOPE AND IMPORTANCE OF NANOTECHNOLOGY IN COSMECEUTICAL DEVELOPMENT

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Abstract
Nanotechnology has emerged as a transformative approach in the cosmeceutical industry, offering innovative solutions to overcome the limitations of conventional cosmetic formulations. The integration of nanoscale delivery systems has significantly the efficacy, stability, and safety of active cosmetic ingredients. This review enhanced analyses recent research on nanotechnology-based cosmeceuticals, focusing on widely used nanocarriers such as liposomes, Nano emulsions, Niosome, Nano capsules, solid lipid nanoparticles, nanostructure lipid carriers, and nanocrystals. These systems improve skin penetration, provide controlled and sustained release, enhance bioavailability of poorly soluble actives, and protect sensitive compounds such as vitamins, antioxidants, and UV filters from degradation. Nano cosmeceuticals have found extensive applications in skin, hair, nail, and lip care, particularly in anti-aging, photoprotection, moisturization, hyperpigmentation, and hair damage management. Despite their advantages, concerns regarding nanoparticle toxicity, skin permeation, long-term exposure, and environmental impact remain significant. Regulatory challenges and the lack of standardized safety assessment protocols further complicate their widespread adoption. Overall, nanotechnology presents substantial potential for advancing cosmeceutical performance, but balanced development supported by rigorous toxicological evaluation and regulatory frameworks is essential for safe and sustainable commercialization.

Keywords: *Nanotechnology, Cosmeceuticals, Controlled Release, Nano emulsions.*

INTRODUCTION

In the state-of-the-art science of nanotechnology, structures, devices, and systems are designed, characterized, manufactured, and used by changing their size and shape at the manometer scale, which spans the size range of 1 nanometer to 100 nanometers (nm), where 1 manometer is one billionth of a meter. Nanotechnology has been used in many scientific domains, such as electronics, medicine, and cosmetics, where it is currently referred to as nano cosmetics. The cosmetics industry is greatly impacted by nanotechnology because of the enhanced properties that nanoparticles attain, including color, transparency, and solubility. Among the various types of nanomaterials used in cosmetics are solid lipid nanoparticles, liposomes, fullerenes, and nanosomes [1]. In order to keep the skin hydrated, cosmeceuticals employ nanotechnology to extend the wear of moisturizers, sunscreens, antiaging creams, and perfumes. The cosmeceutical industry is expanding daily due to the market's diversity and the fact that products are produced by both big and small manufacturers as well as local companies across the globe. Therefore, cosmeceutical products based on nanotechnology must be developed and marketed with consideration for consumer health and the environment [2].The 1940 Drugs and Cosmetics Act and Regulations According to the 1945 definition, a cosmetic is "any article intended to be rubbed, poured, sprinkled or sprayed on, or introduced into, or otherwise applied to the human body or any part thereof for cleansing, beautifying, promoting attractiveness, or altering the appearance, and includes any article intended for use as a component of cosmetic. Despite their many advantages, they also have drawbacks in terms of cost, toxicity, scalability, stability, etc. Furthermore, there is ongoing debate regarding the toxicity and safety profiles of nanomaterials. Nanoparticles are better able to interact biologically with the microenvironment because of their small size, large surface area, and positive surface charge. However, they exhibit dose-dependent toxicity when administered through various routes. It is commonly known that dosage has a greater impact on an active ingredient's bioavailability than the active moiety's physicochemical characteristics.

Formulations containing therapeutically active ingredients are referred to as "cosmeceuticals." Damaged hair, wrinkles, photoaging, dry skin, light spots, and hyperpigmentation are just a few of the conditions that these products are used to treat. Their restorative effects on the skin and hair can be measured. Compared to other, larger objects, it has certain advantages. Better texture, increased stain resistance, better appearance, longer shelf life, and improved UV protection are some of the components. These nanoparticles are therefore frequently used in cosmetic and pharmaceutical products. Three industries have a big influence on the market: V-Liposomes, materials technology (displays and batteries), and manufacturing (coatings, composite for products like cars). Because they can transport active molecules into the deeper layers of the skin and even the systemic circulation, they can be used as a transdermal medication delivery mechanism (TDDS). In the cosmetics business, they are usually utilised for moisturising and anti-aging purposes. Ageing goals. Koci et al. conducted an experiment in which they examined the moisturising effects of marketed creams and nanoliposome creams containing skimmed donkey milk. They determined that deeper strata may be penetrated by the cream with nanoliposomes, resulting in an unreasonably high capacity for hydration and, as a result, it may have anti-aging properties well as the fields of medicine and biological sciences to many more advantages which give protection as well long life to the product increases such technology more in the cosmetic market rather than any other market. The nanoparticles are mostly used as UV filters [5]. Materials used in cosmetic products should be ensured that the creams or powders used for necessities like UV protection or anti-aging are easy to penetrate skin, should overcome the insolubility problem and protection of physical and chemical decomposition over a period of time [2]. The cosmeceutical products that are marketed by the companies are legally liable for the well-being and labelling of their product. A product that includes drugs and a cosmetic are referred as "cosmeceutical". It's a phrase used in the professional skin-care business to describe a substance that show quantifiable biological activity in the skin and it is declared as a cosmetic item due to its nature of improving skin. According to the FDA, cosmetics are particles that are meant to be applied to the skin or other areas for a variety of reasons, such as cleaning, beautifying, or changing appearance. In the cosmetics industry, cosmeceuticals are commonly defined as cosmetic products made of biologically active ingredients with therapeutic qualities that are used to treat a variety of dermatological conditions or to simply improve appearance. Between pharmaceuticals and cosmetics, the term "cosmeceuticals" refers to a market niche where products are infused with medicinal ingredients. In the cosmetic industry, smaller particles are more readily absorbed by the skin and can heal damage more quickly. From skin to body to hair and other new tropical treatments for skin conditions, the cosmeceutical industry is growing.expansion of the cosmeceutical industry is counted from skin to body to hair and other emerging tropical treatments for the improvement of skin conditions such as skin damage, hyperpigmentation photoaging, and hair damage have come into extensive profitable use. The global cosmetic industry has a lot of allegiance to Asian countries like Japan, China, and India which are expected to draw a lot of customers eventually. Nano cosmetics is promoted to make the fragrance last longer, sunscreen to protect the skin, antiaging therapies, and application of moisturizers to keep the skin hydrated. Usage of nanotubes biosomes, fullerene, nanocrystals, and dendrimers show excellent and primary benefits in cosmeceuticalmanufacturing. Through this nanomaterial, the biologically active ingredients are targeted to the intended place and released in a regulatory manner for long-lasting impact. Nano-emulsions which are colloidal particulate and have distinctive perceptible texture properties, nano-capsules which are utilized in skin care product, nano-pigments which are transparent and improve the efficiency of sunscreen products, and liposome formulations which consist of small vesicular system made of traditional cosmetic matter and also act as a shield in oxygen or light sensitive products some of the nanotechnology-based innovations. Usage of these carbon nanotubes Biosomes, fullerenes,nanocrystals, solid lipid nanoparticles and dendrimers show excellent and primary benefits in cosmeceuticals manufacturing. Nanoparticles are predominant in cosmeceutical industries due to its increased stability of cosmetic constituents (e.g., antioxidants, vitamins and unsaturated fatty acids) which are generally encapsulating within these nanoparticles; effective protection of the skin from harmful ultraviolet (UV) rays; visually attractive products(for example, smaller active mineral particles in mineral sunscreens allow them to be applied without leaving a visible white cast); Active chemicals are targeted to the intended place and released in a regulated manner for a long-lasting impact.

NANOPARTICLES

The Latin word nanus, which means small or dwarf, is the source of the English word nano. Particles in the nm range are called nanoparticles [2]. Nanoparticles are solid particles or particulate dispersions that range in size from 1 to 100 nm. The drug is attached to a matrix of nanoparticles, dissolved, trapped, or encapsulated. Depending on the preparation method, nanoparticles, nanospheres, or nano capsules can be created. Humans and various businesses have used particles in these size ranges for thousands of years; however, there has been a recent resurgence due to the ability to synthesize and manipulate such materials. Improvements in cosmetic science brought about by the incorporation of nanotechnology have raised global consumer demand. Nanomaterials are currently gaining

attention in this field because they offer more advantages than traditional cosmetics. Furthermore, the global market share of pharmaceuticals and cosmetics has increased dramatically due to the combination of nanomaterials [3].

Nanoparticles are of different shapes like Spherical, cylindrical, conical, and tubular, rod shape or irregular. Nanomaterials can be made by two different methods either by breaking down complex into simple or by combining small particles to form Nanoparticle. Nanoparticles are used in different fields such as fertilizers in Agriculture, as medical devices in medicine, also used in electronics

NANOMATERIALS USED IN COSMETICS

Materials with at least one dimension in the nano range and notably different physicochemical characteristics are called nanomaterials. For many years, the cosmetics industry has made extensive use of these materials. Nanomaterial-based cosmetics exhibit greater benefits than microscale cosmetics. These particles' efficient transportation, absorption, bioavailability, transparency, and long-lasting effects are all due to their large surface area. To avoid the related toxicity, the concentration should be taken into account. The various nanomaterials used in the cosmetics industry are described in the following table. Proportions of different inorganic nanoparticles in cosmetics formulation.

SKIN PENETRATION OF NANOPARTICLES

The main function of the skin is to shield the body from the environment; in reality, the stratum corneumprevents the body from being invaded by chemicals and biological agents. The three layers thatcomprise skin are the epidermis, dermis, and hypodermis. Its importance comes from the capillaryanastomoses in the dermis, which remove waste products from cell metabolism and foreign materials while simultaneously supplying the epidermis with nutrients and oxygen. The epidermis is the defense system. The skin is the body's biggest organ. The epidermis, dermis, and hypodermis are the three layers that make up human skin. Because of its lipophilicity among cells, the stratum corneum, the outermost layer of the epidermis, serves as the skin's external barrier. Molecules can move through the stratum corneum passively by appendageal, transcellular, and intercellular pathways. There are several cosmeceutical products on the market that include nanoparticles and are put all over the skin, which could offer risks if they are exposed to skin penetration.

Soluble biodegradable nanoparticles and insoluble nonbiodegradable nanoparticles are the two primary categories into which nanoparticles fall. Although cosmetics are designed to be applied to healthy skin, they are also applied to unhealthy skin. The skin may become injured in those kinds of situations. Numerous studies have demonstrated that the majority of items included in nanoparticles mostly enter through the skin pore openings and hair follicles located underneath the stratum corneum.

TYPES OF NANOMATERIAL USED IN COSMETIC

1.Liposomes

Liposomes are concentric bilayer vesicles in which a lipid bilayer made of synthetic or natural phospholipids that are GRAS (generally recognized as safe) products completely encloses the aqueous volume. Liposomes are ideal for cosmetic delivery applications because their lipid bilayer can fuse with other bilayers, like the cell membrane, which encourages the release of its contents [4]. Their simplicity in preparation and improved skin absorption of active substances. Because of their biodegradability and biocompatibility, they serve as a very versatile nanomaterial in the cosmetics sector. Because liposomes are difficult to remove, cosmetic solutions that contain them offer a longer skin-lasting effect. These are the top sources of bio membranes and cells. They can also be utilized to mend and distribute nutrients, as well as to give body wash, lipsticks, and antiperspirants nice scents. Making use of nanoliposomes Cosmetics promote skin hydration since the particles used in them are smaller. Skin that is smooth and elastic [5]. Liposomes Because they can transport active molecules into the deeper layers of the skin and even the systemic circulation, they can be used as a transdermal medication delivery mechanism (TDDS). In the cosmetics business, they are usually utilized for moisturizing and anti-aging purposes. Ageing goals. Kocis et al. conducted an experiment in which they examined the moisturizing effects of marketed creams and nanoliposome creams containing skimmed donkey milk. They found that the cream containing nanoliposomes may be able to enter deeper strata, giving it an excessively high capacity for hydration and possibly anti-aging effects. Positive and Negative aspects of Liposomes [6].

2.Niosome

Surfactant has a high degree of chemical stability, necessitating neither particular preparation nor storage conditions nor purity issues. Due to the presence of beneficial functional groups on the hydrophilic surfaces, surface development and modification are quite straight forward head Anti-aging cream contains Niosome.

3.Nanocapsule

The possible dermatological uses of these microscopic particles were investigated when the French company L'Oreal debuted the first cosmetic product based on Nano capsules in 1995. to make their cosmetics more effective. Nano capsules are microscopic particles with an oily or watery core surrounded by a polymeric shell. The usage of octyl nano capsules has been found to decrease the penetration of UV filters. contrasting standard methods with methoxycinnamate in pig skin [7]. These are utilized in beauty care solutions to shield

chemicals, mask offensive Odors, and lessen issues with ingredient compatibility. Polymeric Nano capsule suspensions can be applied directly to the skin or mixed to create semisolids that are utilized in systems and as transporters [8].

4. Nanosphere

With a core-shell structure, nanospheres are spherical particles. Its diameter varies from 10 to 200 nm. Because the medicine is trapped, dissolved, connected, or encapsulated in the polymer matrix of nanospheres, it is shielded from enzymatic and chemical destruction. Physically and uniformly, the medication is distributed throughout the polymer matrix. Biodegradable nanospheres and nonbiodegradable nanospheres are the two types of nanospheres [9].

Gelatine, modified starch, and albumin nanospheres are examples of biodegradable nanospheres; the sole authorized polymer is polylactic acid, which is an example of a nonbiodegradable nanosphere. Nanospheres are used in cosmetics and skin care products to more accurately and efficiently transport active chemicals into the deep layer of the skin and their therapeutic effects to the afflicted area. These little pieces contribute favourably to defense against actinic aging. The use of nanospheres is growing in the cosmetics industry, particularly in skin care products such moisturizers, anti-acne creams, and anti-wrinkle creams [10].

5. Dendrimers

Their exceptional adaptability is due to the production of dendrimers, which are three-dimensional nanostructured macromolecules with many branches. Dendrimers are micellar, unimolecular, monodisperse, and 20 nm in size. They have a distinct structure. a symmetrically branching structure that is clearly defined and has a high density of functional end groups around its edges. Their exterior groups are numerous and capable of multifunctional zed. They are frequently polymers, and because of their stability, they help move active ingredients through the skin. These ingredients can be used to make shampoo and deodorant compositions that work better. A dendrimer. Resveratrol's anti-aging and antioxidant qualities have been identified. increased overall solubility and skin penetration, which in turn triggered the scaleup [11].

6.Nanocrystals

Usually employed to administer poorly soluble medications, these clusters, which vary in size from 10 to 400 nm, are composed of thousands of molecules organized in a certain pattern. Bioactive compounds are primarily found in nanocrystals. substances and accelerate the rate at which they break down. The first commercially accessible formulation of "Judaical" featuring rutin-bearing nanocrystals was developed by Juvena and released in 2000. According to a study, rutin nanocrystals exhibited more bioactivity than regular rutin glycoside. They make it possible to pass through skin safely and effectively [12].

METHODS OF PREPARATION OF NANOPARTICLES

1. solvent evaporation method
1. 2.Emulsification/solvent diffusion
2. salting out method
3. Nanoprecipitation

TOXICITY OF NANOPARTICLES

Cosmeceutical products containing nanoparticles, when applied on the skin may give toxic effects after reaching the blood stream. Research upon toxicity showed that when TiO_2 nanoparticles are administered into a pregnant mouse, that are been transferred to its offspring and caused severe brain damage also reduction of sperm production in case of male offspring. Accidental inhalation and consumption of nanoparticles or its absorption through skin can cause severe skin and lung damage or organ damage. But silver nano particles are used as an antimicrobial agent. Silver concentration used are lethal for bacteria which is also lethal for keratinocytes and fibroblasts [13].

ADVANTAGES

- Targeted and Controlled Delivery: continuous release and targeting are made possible
- Increased Stability & Shelf Life: Nanoparticles improve the stability and shelf life of formulations [14]
- Better Fee, Texture, and Appearance: Nano cosmetics. offer a better finish and a smoother texture [15].
- TiO2 and ZnO NPs function as transparent UV filters, providing transparent UV protection without white cast.
- High Surface-Area Promotes Reactivity: Reactivity and interaction are enhanced by a higher surface-to-volume ratio.
- Improved Suspension & Stability: Nano emulsions increase stability and prevent settling[16]
- Benefits of Hydration and Moisturization: Nano emulsions enhance skin hydration and occlusion.

DISADVANTAGES

- Oxidative stress and DNA damage: Reactive oxygen species (ROS) produced by high surface reactivity can lead to inflammation and cellular damage.
- Deep tissue penetration: Nanoparticles have the ability to penetrate the epidermis, enter the bloodstream, and gather in important organs.
- Inhalation risks: Nanoparticles may reach the lungs through spray-based products, causing irritation or raising the risk of cancer.
- Environmental impact: Discharging wastewater can damage aquatic life, disturb ecosystems, and lead to food chain bioaccumulation [17].
- Toxicological concerns: Laboratory research suggests that there may be genotoxic, neurotoxic, and reproductive consequences.

- Regulatory gaps: Uncertainty regarding chronic exposure is increased by a lack of clear restrictions and inadequate long-term safety data.
- Occupational concerns: Prolonged exposure to manufacturing and handling operations can pose health risks to workers [18].

APPLICATIONS OF NANOPARTICLES IN COSMECEUTICALS

Nanoparticles are widely used in cosmeceutical and cosmetic formulations to increase the dispersion and efficacy of active ingredients. Their nanoscale size enables them to penetrate deeper layers of the skin, improving moisturization, anti-aging, and photoprotection. Liposomes, nano emulsions, and solid lipid nanoparticles are common nanoparticle systems that provide stable and controlled release of delicate compounds, like vitamins and UV filters. Their use enhances skin absorption and reduces the frequency of application [19].

List of Applications of Nanoparticles in Cosmetic and Cosmeceutical Preparations:

1. Sunscreens.
2. Moisturizers.
3. Skin Whitening Products.
4. Hair Care Products (Shampoos, Conditioners, Serums)
5. Perfumes & Fragrance Gels.
6. Face Masks and Serums
7. Anti-Aging Creams.
8. Acne Treatment Gels/Creams.
9. Makeup Products (Foundations, Creams).
10. Eye Creams & Serums.

LIMITATIONS

Notwithstanding its potential to improve the efficacy of cosmetics, nanotechnology has a number of drawbacks that prevent its broad and secure use.

1. Safety and Toxicity Issues: Nanoparticles have the ability to cross the epidermal barrier and potentially enter the bloodstream. Chronic consequences are still unclear, although long-term exposure may result in cytotoxicity, oxidative stress, inflammation, or DNA damage.

2. Lack of Long-Term Clinical Data: There is uncertainty surrounding long-term cosmetic use because most studies concentrate on short-term advantages and there are few long-term human safety studies.

3. Regulatory Difficulties: The regulations governing nano cosmetics are not universally standardized. Product approval is made more difficult by variations in definitions, safety assessment techniques, and labelling specifications.

4. Stability Issues: During storage, nanocarriers may aggregate, oxidize, or degrade, which could impact the effectiveness of the product and its shelf life.

5. High Production Cost: The synthesis, characterization, and quality control of nanomaterials necessitate sophisticated equipment and knowledgeable workers, which raises manufacturing prices.

6. Environmental Impact: When released into soil and water, nanoparticles have the potential to build up in ecosystems, endangering aquatic life and the equilibrium of the environment.

FUTURE DIRECTIONS

These days, these cosmetics are an essential part of everyday life, and the introduction of nanotechnology has increased their acceptability among consumers worldwide. People with larger market shares are increasingly interested in cosmeceuticals as a result of the introduction of fresh innovations and innovative systems. The industry's future will be significantly impacted by the technological advancements provided by omics science, which when combined with big data analysis and machine learning techniques, will enable us to more accurately assess the biological reactions to particular cosmetic formulations and bioactive compounds at the tissue and cellular level. Currently, nanotechnology is used in the production of cosmetics.

CONCLUSION

Nanotechnology is bringing big changes to cosmetics and skincare by making products more effective and enjoyable to use. Tiny nano-sized carriers help important ingredients reach deeper layers of the skin, leading to better hydration, stronger sun protection, anti-aging benefits, and improved acne care. They also give creams and lotions a smoother texture and lighter feel, which people appreciate. At the same time, there are concerns about safety, since nanoparticles can sometimes go too deep into the body, build up over time, or affect the environment. This is why proper safety checks and clear rules are so important. In the future, scientists are focusing on creating safe, eco-friendly materials so that nanotechnology can be trusted and used responsibly in beauty products.

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All authors are contributed equally.

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The authors have no conflicts of interest to declare.

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