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Nanotechnology in Cosmetics and Cosmeceuticals—A Review of Latest Advancements

Swati Gupta, Mr.Vishwanath Dubey
(B Pharm) (Assistant Professor), S.N College of Pharmacy

Abstract:
Nanotechnology has great potential to bring new ideas and improvements in how products are made and delivered. It is a fast-growing field used in both **medicine** and **diagnostics**. Recently, nanotechnology has also started to be used in **cosmetic products**, which is a new but very promising area of research.
Using nanotechnology in cosmetics helps solve many problems found in traditional cosmetic products and adds new useful features. These **nanocosmetics** and **nanocosmeceuticals** are now being developed for **skin, hair, nails, lips, and teeth**. The addition of tiny particles called **nanomaterials** has made these products more effective and increased customer satisfaction. As a result, many traditional cosmetics are being replaced by nanotechnology-based ones.
However, some studies have raised concerns about the **safety** of nanocosmeceuticals. Because nanoparticles can penetrate the skin, they might cause **toxic effects** or health problems.
This review discusses the different **nanotechnology-based methods** used to create cosmetics and cosmeceuticals, including related **patents**. It explains their **advantages**, as well as the possible **health and environmental risks**. The article also compares **regulations and guidelines** for these products in **India, Europe, and the USA**, as set by various health authorities.
In conclusion, the article provides an overview of **nanocosmetics and nanocosmeceuticals**, their **uses in the cosmetic industry**, and their possible **benefits and risks**. The goal is to help **consumers and regulators** better understand both the positive effects and potential dangers of long-term use, promoting the **safe and responsible use** of these products.

Keywords: nanotechnology, nanomaterial, cosmetics, cosmeceuticals, nanocosmetics, nanocosmeceuticals, patent, regulation, health hazards, toxicity

1. Introduction

Nanotechnology in Cosmetics and Cosmeceuticals

Nanotechnology and **nanodelivery systems** are new scientific areas that deal with creating and using materials and devices at a very tiny scale — between **1 and 100 nanometers**. This technology has brought major changes to many fields, including **cosmetics** and **cosmeceuticals** (cosmetic products with medical benefits).
Because nanotechnology improves how cosmetic products work, it has become very popular worldwide. **Nanomaterials** are now used widely in cosmetics because they provide better results than traditional ingredients. This has helped increase the global market for both cosmetics and pharmaceuticals. In **2019**, the global nanomaterials market was worth about **USD 8.5 billion** and is expected to grow by **13.1% every year** until 2027. Although gold and silver nanoparticles have been used in beauty products for years, their use has grown much more in recent times.

What Are Cosmetics and Cosmeceuticals?

Cosmetics are products people have used for centuries to improve their appearance. They can be made from natural or synthetic substances and are used externally on the body.

- The **U.S. Food and Drug Administration (USFDA)** defines cosmetics as products meant for **cleansing, beautifying, or changing appearance** without affecting body functions. (Soap is not included.)

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- The **European Union (EU)** defines cosmetics as substances used on the **skin, hair, nails, lips, and teeth** mainly to clean, perfume, change appearance, or protect the body.
- The **Indian Drugs and Cosmetics Act (1940)** has a similar definition, covering any product applied to the body to enhance beauty or appearance.

The term **"cosmeceutical"** is not officially recognized by the FDA — it's mainly used by the industry. It describes cosmetic products that contain **active ingredients** with **therapeutic (healing)** effects.

Cosmeceuticals work like a bridge between cosmetics and medicines. They are used for treating skin and hair problems such as **wrinkles, aging, dryness, pigmentation, and damaged hair**. This field is growing quickly and is now one of the fastest-expanding parts of the personal care industry.

Role of Nanotechnology

Nanotechnology allows scientists to **manipulate materials at the atomic level**, helping to create **nanocosmetics** and **nanocosmeceuticals**. These products have several benefits:

- Longer-lasting effects
- Better absorption and bioavailability
- Improved texture, appearance, and skin coverage
- Enhanced UV protection, fragrance release, and anti-aging effects

Nanoparticles are very small and have a large surface area, which helps them stay on the skin better and deliver ingredients more effectively. However, their **safety** and **toxicity** are still under study. In high doses, nanoparticles may enter the bloodstream and cause unwanted side effects. Therefore, more **clinical research** is needed to ensure they are safe for long-term use.

Nanomaterials Used in Cosmetics

Nanomaterials are particles with at least one dimension at the nanoscale (1–100 nm). They have unique chemical and physical properties that make cosmetics more effective. However, their concentration must be controlled to avoid toxicity.

Here are some **common nanomaterials** used in cosmetics:

Nanomaterial	Advantages	Disadvantages	Example Products
Titanium Dioxide (TiO_2) & Zinc Oxide (ZnO)	Provide UV protection, stable, safe	Can cause lung damage if inhaled	Sunscreens
Silica (SiO_2)	Cheap, increases product texture	Can cause lung irritation	Lipsticks, creams
Carbon Black	Adds color, stable, low cost	Can be toxic to cells	Mascara, facemasks
Gold & Silver Nanoparticles	Antibacterial, anti-aging	Harmful at high doses	Face masks, anti-aging creams
Nano-Hydroxyapatite	Repairs teeth, reduces sensitivity	Brittle	Toothpaste
Tris-Biphenyl Triazine (Nano-Organic Filter)	UV protection, photostable	Harmful to aquatic life	Sunscreens
Fullerenes (C60 "Buckyballs")	Strong antioxidants, anti-aging	Can damage brain tissue in large amounts	Face creams

Details of Major Nanomaterials

1. Titanium Dioxide (TiO_2) and Zinc Oxide (ZnO):

Used mainly in sunscreens to protect the skin from harmful **UV rays**. TiO_2 protects against UVB, while ZnO protects against UVA. When used as nanoparticles, they are transparent and more

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effective. However, inhaling them can be harmful, so they are safe only when applied to the skin.

2. Gold and Silver Nanoparticles:
These have **antibacterial and anti-aging** effects. Gold has been used since ancient Egypt for skin health. In modern times, it's used in creams and masks. Silver nanoparticles prevent bacterial growth, but their long-term safety is still unclear.

3. Silica (SiO_2):
Used in products like **lipsticks and face powders** to improve smoothness and color quality. It's cheap and effective, but its safety needs further study.

4. Carbon Black:
A black pigment used in **mascara and eyeliners**. Safe for use as long as it is not inhaled.

5. Nano-Hydroxyapatite:
Used in **toothpaste** to strengthen teeth and reduce sensitivity. Considered safe by the **USFDA**.

6. Tris-Biphenyl Triazine:
A **nano UV filter** used in sunscreens (like **TINOSORB® A2B**). It's effective and stable but can accumulate in tissues if overused.

7. Fullerenes (C60 or "Buckyballs"):
Powerful **antioxidants** that help reduce wrinkles and protect against sun damage. They are spherical carbon molecules but must be modified to dissolve properly in water.

Other Nanomaterials
Nanoparticles can be either:

- **Biodegradable:** Made from natural materials like **lipids or chitosan**.
- **Non-biodegradable:** Made from substances like **ZnO or silica**.

Chitin and chitosan nanoparticles, made from shellfish, are used in creams because they help retain skin moisture and prevent water loss.

3. Nano-Drug Delivery Systems Used in Cosmetics

Nanotechnology in Cosmetics (Simple Version)
In recent years, **nanotechnology** has created many new solutions in medicine and pharmacy. The same technology is now used in **cosmetics**, leading to new types of products called **nanocosmeceuticals** — cosmetics that contain tiny particles (nanomaterials) to improve skin and beauty treatments. Because these particles are very small, they have **unique properties** like better solubility, higher stability, transparency, and stronger chemical activity.
Different types of nanomaterials such as **liposomes, ethosomes, solid lipid nanoparticles (SLNs), nanocapsules, dendrimers, nanocrystals, cubosomes, and nanoemulsions** are now widely used in cosmetic industries to make products for **skin, hair, and body care**.

Common Nanoformulations in Cosmetics

Type	Benefits	Drawbacks	Example Product	Used For
Nanoliposomes	Biodegradable, safe, increase skin absorption	May cause immune response, less stable	*Capture Totale – Dior*	Moisturizer, anti-wrinkle cream
Niosomes	Better penetration, bioavailability	Costly, unstable	*Lancome® – L'Oréal*	Anti-aging cream
Ethosomes	Deep skin penetration	Low stability	*Supravir Cream – Trima, Israel*	Moisturizer
Sphingosomes	Repairs damaged skin	Expensive	*Noicellex – NTT, Israel*	Anti-cellulite cream
SLNs (Solid Lipid Nanoparticles)	Long action, safe	Short shelf life	*Chanel Allure*	Perfume, creams

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Type	Benefits	Drawbacks	Example Product	Used For
NLCs (Nanostructured Lipid Carriers)	Long shelf life	Short action	*Dr. Rimpler – Cutanova*	Face cream
Nanocapsules	Protect ingredients, control release	Requires extra purification	*Primordiale Intense – L'Oréal*	Anti-wrinkle, hair care
Dendrimers	Better stability, controlled release	Expensive, may be toxic	*Topical Resveratrol Formulation*	Sunscreen
Nanoemulsions	Transparent, stable	Difficult to make	*Vitalipid – Vitamins A, D, E, K*	Creams, lotions
Nanocrystals	Improve solubility	May clump together	*Nano Whitening Toothpaste – Whitewash*	Moisturizers, toothpaste

1. Nanoliposomes
Nanoliposomes are tiny vesicles made of **phospholipids** that can carry both water- and oil-based ingredients. They can enter deeper layers of the skin better than normal liposomes. They are safe, biodegradable, and improve **hydration**, **smoothness**, and **elasticity** of the skin.
They are used in **moisturizers, anti-aging creams, lipsticks, and perfumes**.
However, they can be unstable and have low drug loading. Studies have shown that nanoliposomes with collagen or natural extracts can help reduce wrinkles and improve skin moisture.

2. Ethosomes
Ethosomes are soft vesicles containing a **high amount of ethanol** and lipids. They can easily pass through the **outer skin barrier (stratum corneum)**, improving absorption of ingredients like **antioxidants, melatonin, salicylic acid**, and **whitening agents**.
Studies have shown that ethosomes help deliver ingredients like **niacinamide**, **phenylethyl resorcinol**, and **minoxidil** (used for hair growth) more effectively than traditional creams.

3. Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs)
SLNs and NLCs are made of solid or mixed lipids that can deliver active ingredients deep into the skin. They are **safe, biocompatible**, and used in **sunscreens, moisturizers, and anti-aging creams**.

- **SLNs** provide good UV protection and help repair skin barriers but have short shelf life.
- **NLCs** have higher drug-loading ability and longer shelf life.
  Studies show that SLNs containing **natural antioxidants** like **fucoxanthin** protect against UV damage and improve sunscreen efficiency.

4. Nanocapsules
Nanocapsules are **tiny polymer shells** that hold active ingredients inside. They protect the product, mask bad smells, and allow **slow release** of the active ingredient.
They are used in **perfumes, creams, and sunscreens**. Some nanocapsules release ingredients only when the skin is damaged or irritated, providing **targeted treatment**.
For example, nanocapsules containing **oxygen carriers or carrot oil** have shown to improve **anti-aging** and **sun protection** properties.

5. Dendrimers
Dendrimers are **tree-like molecules** with multiple branches. They are stable and can carry active substances deep into the skin.
They are used in **sunscreens, shampoos, and anti-**

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aging creams. Dendrimers with **resveratrol** (an antioxidant) help improve skin absorption and reduce aging effects.

6. Nanocrystals
Nanocrystals are clusters of molecules (10–400 nm) used to improve the solubility of ingredients that don't dissolve easily in water.
They increase the **bioavailability** and **skin absorption** of ingredients like **rutin** or **anti-pollution agents**, making them more effective.

7. Cubosomes
Cubosomes are cube-shaped particles made from surfactants and water. They are used in **skincare creams and deodorants**. They can absorb pollutants and stabilize emulsions.
For example, cubosomes containing **erythromycin** were found to be effective in treating **acne** and **aging skin**.

8. Nanoemulsions
Nanoemulsions are mixtures of oil and water at the nanoscale. They are **transparent, stable, and lightweight**, used in **lotions, sunscreens, and skin creams**.
They help increase the penetration of **oils, vitamins, and antioxidants**.
For example, **ellagic acid** and **Opuntia extract** nanoemulsions have shown better **skin whitening** and **hydration** effects.

9. Micellar Nanoparticles
Micellar nanoparticles are small carriers that can trap oily substances inside. They are mainly used in **cleansing products** like **micellar water and shampoos** because they remove oil and dirt without damaging the skin.
They are affordable and easy to make, and they have revolutionized **transdermal drug delivery**.

Health Risks of Nanocosmeceuticals
While nanotechnology offers many benefits, it also has **potential health risks** due to its **tiny particle size** and **high chemical activity**.

- Nanoparticles can **enter the body through the skin, lungs, or mouth**, and travel to vital organs like the **brain, heart, and liver**.
- They may produce **reactive oxygen species (ROS)**, leading to **oxidative stress**, **inflammation**, **DNA damage**, or even **cancer**.
- Inhalation of nanoparticles (for example, from **spray sunscreens**) can cause **lung problems** and allow particles to reach the brain.
- If swallowed accidentally, nanoparticles may accumulate in organs and cause side effects.
- Through **skin application**, some nanoparticles can enter deeper layers, especially if the skin is damaged.

Studies show that nanoparticles may cause **neurological, cardiovascular, and reproductive problems**. In pregnant women, they might **cross the placenta**, leading to **developmental issues** or **fetal toxicity**.
Because of these risks, it is important to conduct **more safety research** and use nanocosmetics **carefully and responsibly**.

5. Environmental Risks of Nanoparticles

Nanotechnology and the Environment
In modern times, **nanotechnology** is used to improve environmental quality—such as cleaning **air and water**, reducing **waste**, lowering **greenhouse gas emissions**, and decreasing the release of **harmful chemicals**.
However, nanotechnology can also have **negative effects on the environment**. Because nanoparticles are extremely small and have unique physical and chemical properties, they can move easily into tiny spaces and enter **living systems**. Once inside, they can cause **cell damage** through different mechanisms such as **bioaccumulation**, **oxidative stress**, or **cell dysfunction**.
The **impact of nanoparticles** depends on how they are used, how they move and settle in **air, water, or soil**, and how stable they are. Factors such as **temperature, pressure, chemical composition, and coatings** also affect their behavior. During **manufacturing**, nanoparticles may be released into the **environment**, contaminating air, water, and soil.
A study by the **US Government Accountability Office (GAO)** found that nanomaterials with

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antibacterial properties can harm helpful microbes in **water treatment plants**, affecting water purification. Another study by the **University of Toledo** showed that **titanium dioxide nanoparticles (nano-TiO_2)**, used in sunscreens and cleaning products, can reduce microbial activity within just one hour of exposure. This means that such particles could harm important microorganisms in sewage systems and should be used **carefully**.

Environmental Effects of Nanoparticles

Titanium dioxide (TiO_2) nanoparticles, used in many sunscreens, are often washed off into **oceans and rivers**. When their protective coatings break down under **sunlight or seawater**, toxic TiO_2 is released, harming **marine organisms** like algae and water fleas, and upsetting the **aquatic ecosystem**.

Carbon-based nanomaterials can also be dangerous. They may accumulate in organs like the **lungs and kidneys**, disturbing metabolism and nutrient cycles. Similarly, **metal nanoparticles** can bind to proteins and cause harmful **cell reactions**. Studies show that nanoparticles such as **titanium, polystyrene, and fullerenes** can create **oxidative stress**, making them more toxic in living conditions than in non-living systems.

Experiments on fish like **largemouth bass** showed that **fullerenes** can cause mild harm and even kill **water fleas** due to their **bactericidal effects**. Researchers at **Rice University** found that nanoparticles can attach to toxic chemicals (like cadmium or oil-based pollutants), allowing them to **transport contaminants** over long distances in **groundwater**.

Nanoparticles also harm **plants and algae** by entering their systems and disrupting growth, seed germination, and cell function. This contamination can move through the **food chain** and become **biomagnified**, affecting animals and humans over time.

Research and Risk Assessment

A workshop by the **National Science Foundation (NSF)** and the **US Environmental Protection Agency (EPA)** identified key risks of nanomaterials and emphasized the need to study:

- Their **toxicity** and **environmental exposure**
- How they can be **recycled** and made **sustainable**

At present, **little information** is available about the long-term environmental risks of nanomaterials. More studies are needed to understand their behavior, sources, and effects on plants and animals. Researchers are now measuring nanoparticle levels in **workplaces** to identify exposure risks for workers.

Eco-Friendly Solutions

To minimize harm, scientists are exploring:

- **Green manufacturing**: making nanoparticles using **less energy** and **non-toxic materials**
- **Coating or recycling** metal nanoparticles to prevent pollution
- **Bioremediation**: using **plants or fungi** to absorb nanoparticles from the environment

Raising **public awareness** about nanotoxicity and promoting **eco-friendly alternatives** are key steps toward environmental protection.

Regulatory Guidelines for Cosmetics and Cosmeceuticals

The **global cosmetic market** was worth **USD 532 billion in 2017** and is expected to reach **USD 805 billion by 2023**. Due to this fast growth, there is a need for **strict regulations** to ensure **consumer safety**.

1. Food and Drug Administration (FDA – USA)

The **FDA** provides guidance for companies on how to test the **safety of nanomaterials** in cosmetics. The document recommends checking:

- **Physical and chemical properties**
- **Particle size and impurities**
- **Skin and inhalation exposure**
- **Toxicity tests (both short- and long-term)**

Manufacturers are encouraged to meet with the FDA before launching nano-based cosmetics to ensure proper **testing and safety data**.

2. International Cooperation on Cosmetics Regulation (ICCR)

The ICCR brings together regulators and industry experts from several countries. Their report suggests:

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- The same **risk assessment process** used for normal chemicals can also be applied to **nanomaterials**
- Tests should examine how nanoparticles behave in the **body** (absorption, distribution, metabolism, excretion)
- **Formulation type** can change how toxic or absorbable a material becomes
- **Animal testing** is banned in the **EU**, so **alternative tests** must be used for nanomaterials

3. Scientific Committee on Consumer Safety (SCCS – EU)

The **SCCS** provides detailed guidance for nanomaterial safety in cosmetics.

Main Points:

- **Definition:** Materials between **1–100 nm** are considered nanomaterials.
- **Characterization:** Must analyze **particle size, solubility, and stability** using accurate tools like **electron microscopy**.
- **Exposure Assessment:** Study how nanoparticles may enter the body through **skin, lungs, or mouth**.
- **Hazard Identification:** Determine how they interact with **cells and biological membranes** and whether they cause **oxidative stress** or **inflammation**.
- **Safety Testing:** Since animal testing is banned, **alternative in vitro (lab-based)** methods are used to predict **real-life safety**.

4. Comparison of Cosmetic Regulations Across Countries

Country	Regulatory Body	Approval Needed	Label Language	Expiry Date Requirement	Notes
USA	USFDA	No premarket approval (except for color additives)	English	Not required	Manufacturer is responsible for safety
EU	EMEA	Not required, but product safety file must be maintained	Local language	Required if stability <30 months	Nanomaterials must be labeled as "(nano)"
India	CDSCO / BIS	License required under Drugs & Cosmetics Act	English	"Use before" date required	Safety records must be kept by the manufacturer

5. Country-Specific Rules

United States

Cosmetics in the U.S. are regulated by the **FDA** under the **Food, Drug, and Cosmetic Act (FDCA)**. Unlike drugs, cosmetics don't need FDA approval before being sold, except for **color additives**. Manufacturers are encouraged to use the **Voluntary Cosmetic Registration Program (VCRP)** to share product data with the FDA. Labels must be **accurate, clear, and in English**, showing ingredients, usage, and safety warnings.

The **FDA's Nanotechnology Team** (formed in 2006) regularly updates rules to ensure the safe use of nanoparticles in cosmetics.

European Union

In Europe, cosmetics are regulated by the **European Medicines Evaluation Agency (EMEA)** under **Regulation 1223/2009**.

Manufacturers must:

- Provide a **safety report** before marketing
- Notify the **EU Cosmetic Product Notification Portal (CPNP)**
- Label nano-ingredients clearly (e.g., *zinc oxide (nano)*)

Premarket approval is required for products using **nanomaterials**, such as **anti-aging creams, sunscreens, and colorants**.

India

In India, cosmetics are governed by the **Central Drugs Standard Control Organization (CDSCO)**

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under the **Drugs and Cosmetics Act (1940)** and **Rules (1945)**.
Labels must include:

- Manufacturer's name and address
- Ingredients and warnings
- Batch number ("B") and manufacturing license number ("M")

Small products (like small soaps or mini bottles) may be exempt from some labeling requirements. The **Government of India** has launched initiatives to promote **safe nanotechnology** research and **green innovation**, with oversight from agencies such as the **Department of Biotechnology** and **Indian Council of Medical Research**.

7. Conclusions and Future Direction

Nanotechnology is now seen as a **promising and revolutionary field** used in many areas like **cosmetics, skincare (cosmeceuticals), dermatology, and medicine**. New technologies and modern drug delivery systems have made cosmetics more advanced and popular, increasing their **market demand**. Today, cosmetics have become a **necessary part of daily life**, and the use of nanotechnology has made them even more effective and appealing to people worldwide.
However, there are growing concerns about the **possible toxic effects** of nanoparticles. Because these particles can **easily penetrate the skin**, they may cause **unwanted health problems** if not properly tested.
Different types of **nanocarriers** such as **liposomes, ethosomes, cubosomes, nanostructured lipid carriers (NLCs), solid lipid nanoparticles (SLNs), nanoemulsions, and niosomes** are now being used to make cosmetics work better. These nanosystems help carry active ingredients deep into the skin and perform many functions like **sun protection, moisturizing, and reducing wrinkles**.
Although products made with nanomaterials are becoming more common and profitable, there is still **a lot of debate about their safety**. More detailed **research and testing** are needed to ensure they are safe for humans and the environment.
Therefore, **cosmetic laws and regulations** should include clear lists of **safe ingredients** and highlight those that may cause **harmful environmental effects**. This will protect both **consumers and professionals** who use these products.
Before any nanocosmetic product is sold, **long-term safety and cancer risk studies** should be done. These products should be designed to **benefit the user's health** and not cause harm. **Clinical trials**, similar to those used for medicines, should also be conducted to confirm their safety.
In addition, there should be **strict rules** for the **manufacturing, storage, import, and sale** of cosmetics that contain nanoparticles. To make this possible, **researchers, governments, and international organizations** need to work together to create **global standards and regulations** for the safe use of nanotechnology in cosmetics.
Both **government and non-government organizations** should also focus on **educating the public**. They can do this through **seminars, videos, or online materials** that explain how to use nanocosmetics safely and wisely.
Finally, it is important to have **internationally harmonized regulations** to ensure **safety, effectiveness, and fair marketing practices**. This will help cosmetic companies follow consistent global standards and protect **consumers from potential risks**. By being aware and informed, **consumers can make better choices** when selecting nanotechnology-based cosmetic products.

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