Available online on 15.06.2026 at http://ajprd.com

Asian Journal of Pharmaceutical Research and Development

Open Access to Pharmaceutical and Medical Research



Open Access Review Article

# Nano cosmeceuticals: Emerging Advances, Therapeutic Benefits, Safety Concerns, and Regulatory Perspectives

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## A B S T R A C T

Nanotechnology has revolutionized cosmetic and cosmeceutical formulations by enabling the development of advanced delivery systems with improved efficacy, stability, and consumer acceptance. Nano cosmetics and nano cosmeceuticals are increasingly used in products for skin, hair, nails, lips, and oral care, offering advantages such as enhanced penetration, targeted delivery, and better performance compared to conventional formulations. As a result, many traditional cosmetic products are being replaced by nano-based alternatives. However, concerns regarding the safety of nanomaterials, including increased skin penetration, potential toxicity, and environmental impact, have prompted the need for thorough evaluation and regulation. This review highlights the major nanotechnology-based delivery systems used in cosmetics, discusses recent patents, and examines their benefits and potential risks. It also provides an overview of the regulatory landscape governing cosmeceuticals, with a comparative analysis of regulations in India, Europe, and the United States. The review aims to support informed development, regulation, and responsible use of nano-enabled cosmetic products.

**Keywords:** Nanotechnology, nanomaterials, cosmetics, cosmeceuticals, nano cosmetics, nano cosmeceuticals, patents, regulation, toxicity, health risks.

**A R T I C L E I N F O:** Received 15 Jan. 2026; Review Complete 26 April, 2026; Accepted 19 May. 2026; Available online 15 June. 2026

**Cite this article as:**

Patel RN, Parmar VN, Pandya BD, Shah KP, Saluja AK, Diwakar SA, Nano cosmeceuticals: Emerging Advances, Therapeutic Benefits, Safety Concerns, and Regulatory Perspectives, Asian Journal of Pharmaceutical Research and Development. 2026; 14(3):-462-470, DOI: http://dx.doi.org/10.22270/ajprd.v14i3.1815

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## INTRODUCTION

Nanotechnology and nano-based delivery systems represent advanced scientific disciplines focused on the design, characterization, fabrication, and application of materials at the nanoscale (1–100nm).Recognized as a revolutionary technological advancement, nanotechnology has been extensively explored in the fields of cosmetics and cosmeceuticals.The incorporation of nanoscale materials into cosmetic science has led to significant innovations, contributing to increased global consumer demand. Nanomaterials offer distinct advantages over conventional cosmetic ingredients, primarily due to their unique physicochemical properties. Their integration has also played a vital role in the expansion of both pharmaceutical and cosmetic markets worldwide. In 2019, the global nanomaterials market was valued at approximately USD 8.5 billion and is projected to grow at a compound annual growth rate of over 13% between 2020 and 2027.[1, 3, 10, 11, 21, 23]

Cosmetics are among the oldest preparations used by humans, traditionally intended for beautification and rejuvenation purposes. They are typically applied externally and may be formulated using natural or synthetic substances.According to the United States Food and Drug Administration (USFDA), cosmetics are products intended for cleansing, beautifying, enhancing attractiveness, or alteringappearance without influencing the structure or function of the body. While the term "cosmeceutical" is widely used within the cosmetic industry to describe products that offer therapeutic benefits, it lacks formal recognition under the Federal Food, Drug, and Cosmetic Act. Similarly, regulatory definitions vary globally, with the European Union Cosmetics Directive and the Indian Drugs and Cosmetics Act providing comprehensive descriptions of cosmetic products. [21, 29, 30]

Cosmeceuticals occupy an intermediate position between pharmaceuticals and conventional cosmetics, as they contain biologically active ingredients that exert measurable therapeutic effects upon topical application. These products are designed to address conditions such as skin aging, hyperpigmentation, dryness, hair damage, and photoaging. Due to their dual cosmetic and therapeutic functions, cosmeceuticals represent one of the fastest-growing segments of the personal care industry, driving increased interest in nano cosmeceutical research and development.[7, 21, 23]

The application of nanotechnology in cosmeceuticals enables manipulation of materials at the molecular level, resulting in enhanced bioavailability, prolonged action, improved stability, and superior aesthetic properties. Nanoparticles offer a high surface-to-volume ratio, facilitating efficient interaction with biological systems without altering the inherent properties of the active ingredients. Cosmetic manufacturers utilize nanoscale ingredients to enhance UV protection, skin penetration, color uniformity, fragrance release, anti-aging effects, and product durability. However, despite their advantages, nano-based formulations present challenges related to toxicity, stability, scalability, and cost. The increased reactivity and bioavailability of nanoparticles raise safety concerns, particularly regarding systemic absorption and dose-dependent toxicity. Consequently, extensive safety assessments and regulatory oversight are essential to ensure consumer protection.[5, 13, 16, 19, 29]

The nanoparticles and nano delivery systems employed in cosmetic and cosmeceutical formulations, emphasizing their benefits, limitations, and associated patents. It also addresses potential health and environmental risks while evaluating existing regulatory frameworks.The objective is to provide a comprehensive understanding of nano cosmetics and nano cosmeceuticals and to guide future research, regulation, and responsible consumer use. [1, 22, 31]

## NANOMATERIALS USED IN COSMETIC PRODUCTS:

Nanomaterials are characterized by at least one dimension within the nanoscale range and possess physicochemical properties distinct from their bulk counterparts. Their extensive use in the cosmetic industry is attributed to enhanced surface area, improved bioavailability, increased transparency, and prolonged product action. Compared to microscale formulations, nanocosmetics demonstrate superior performance; however, careful consideration of concentration is essential to minimize toxicity. A wide range of nanomaterialsincluding inorganic particles, organic nanoparticles, and carbon-based materialsare incorporated into cosmetic and cosmeceutical products.[1, 8, 11, 13]

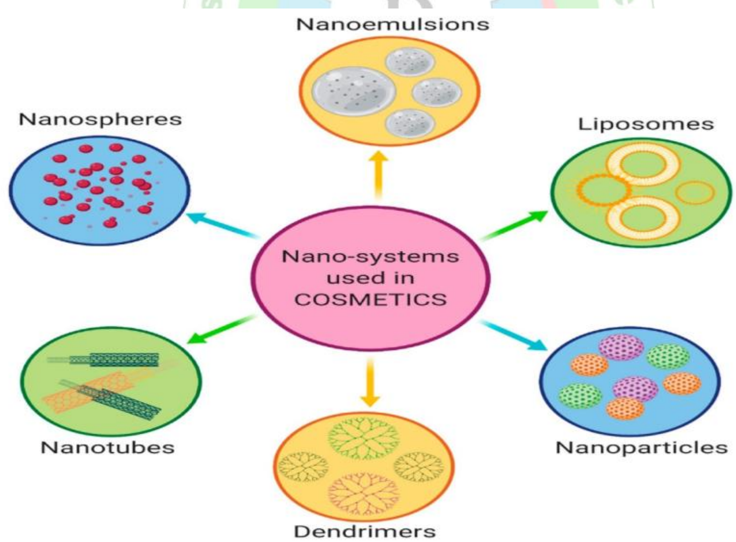


**Figure 1:** Nanotechnology-Based Delivery Systems in Cosmetics

**Inorganic Nanoparticles:**Inorganic nanoparticles such as titanium dioxide, zinc oxide, gold, silver, silica, and hydroxyapatite are widely used due to their stability, biocompatibility, and functional versatility.These materials contribute to UV protection, antimicrobial activity, pigmentation, remineralization, and aestheticenhancement.[14, 16, 18]

**Organic Nanomaterials:**Nano-organic compounds such as tris-biphenyl triazine serve as highly photostable UV filters, offering broad-spectrum protection and improved formulation stability.[23]

**Carbon-Based Nanomaterials:**Fullerenes (buckyballs) are valued for their exceptional antioxidant activity and are commonly employed in anti-aging formulations to mitigate oxidative stress and UV-induced skin damage.[11]

**Miscellaneous Nanomaterials:**Biodegradable nanoparticles derived from chitosan, lipids, and polymers are gaining attention due to their safety and moisturizing properties, particularly in skin hydration and barrier repair.[5]

## NANO-DRUG DELIVERY SYSTEMS IN COSMETICS:

Advancements in nanotechnology have led to the development of innovative delivery systems such as liposomes, ethosomes, solid lipid nanoparticles, nanostructured lipid carriers, nanocapsules,dendrimers, nanocrystals, cubosomes, nanoemulsions, and micellar nanoparticles. These systems enhance solubility, penetration, stability, and controlled release of active ingredients, thereby improving cosmetic efficacy and consumer experience.[3, 5, 15]

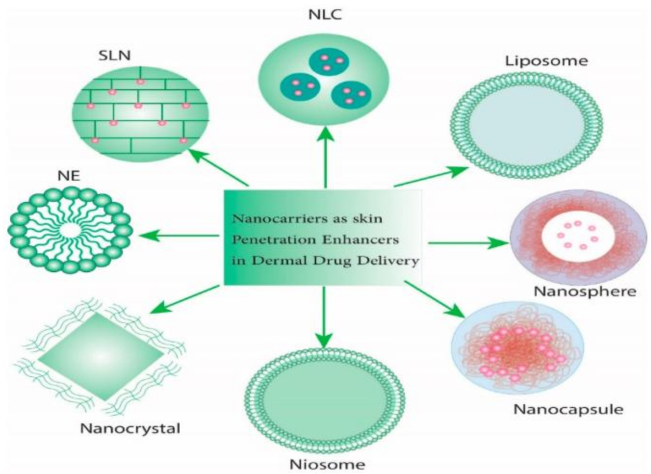


**Figure 2:** Classification of Cosmetic Nano-Delivery Systems

### Health Risks Associated With Nano Cosmeceuticals:

Despite their benefits, nanoparticles pose potential health risks due to their small size, enhanced reactivity, and ability to penetrate biological barriers.Toxicity is influenced by factors such as particle size, surface charge, chemical composition, exposure route, and duration. Nanoparticles may induce oxidative stress, inflammation, DNA damage, and systemic toxicity, raising concerns regarding inhalation, ingestion, dermal exposure, and reproductive safety.[13, 19, 26]

### Environmental Risks Of Nanoparticles:

Nanomaterials may adversely impact ecosystems by entering air, water, and soil during manufacturing, usage, and disposal. Their persistence and bioaccumulation can disrupt microbial activity, aquatic life, plant growth, and nutrient cycles.Sustainable manufacturing practices, green nanotechnology, and effective waste management strategies are essential to mitigate environmental hazards.[19, 24, 31]

### Regulatory Guidelines For Cosmetics And Cosmeceuticals:

Given the rapid expansion of the global cosmetic market, stringent regulatory frameworks arenecessary to ensure product safety.Regulatory approaches vary across regions, with India, Europe, and the United States adopting distinct guidelines for cosmetic and nanocosmetic products. Continuous evaluation, harmonization of standards, and post-marketing surveillance are critical for safeguarding public health.[29, 30]

## FACTORS RESPONSIBLE FOR NANO COSMECEUTICAL FORMULATIONS:

**Extensive Use of Nanotechnology in Cosmetics**:A rapid increase in the incorporation of nanotechnology into cosmetic and cosmeceutical products.Nanomaterials are widely used to enhance product efficacy, stability, Product stability, aesthetic appeal, skin penetration, targeted delivery, shelf life, UV protection, controlled release, and overall consumer appeal.Nano-enabled formulations demonstrate clear superiority over conventional cosmetics in terms of performance and consumer satisfaction.[1, 2, 3,5, 16]

**Functional Advantages of Nanomaterials:**The key advantages of nanomaterials include increased surface area leading to better interaction with skin, enhanced solubility of poorly soluble actives, controlled and sustained release, improved UV protection, reduced dosage requirements, inorganic nanoparticles such as titanium dioxide and zinc oxide provide transparent yet effective sun protection, while lipid-based nanocarriers enhance hydration and anti-aging effects.

**Effectiveness of Nano-Drug Delivery Systems:**Nanocarriers significantly improve the delivery efficiency of bioactive compounds.Liposomes, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), and nanoemulsions demonstrateenhanced penetration through the stratum corneum without immediate systemic toxicity.However, penetration depth and accumulation depend on particle size, surface charge, composition, exposure duration.[5,13]

**Safety and Toxicological Concerns:**The review consistently emphasizes that small particle size and high surface reactivity, while beneficial for therapeutic and cosmetic efficacy, also raise significant safety concerns such as, oxidative stress, inflammation, cellular damage, DNA interaction, potential systemic absorption. Long-term exposure data remain insufficient, making nanotoxicology a critical research priority.[13, 19]

**Environmental Impact:** Nanoparticles released into ecosystems may disrupt aquatic life, affect microbial populations, accumulate in food chains, alter soil and water chemistry.

**Regulatory Inconsistencies:** Regulatory frameworks differ significantly across regions such as, EU enforces stricterlabelling requirements towards nano cosmeceuticals, US regulations are less nano-specific, Indian regulations are evolving but lack detailed nano-guidelines. This inconsistency creates challenges for global commercialization and consumer safety assurance.

## APPLICATIONS OF NANOTECHNOLOGY IN COSMETIC AND COSMECEUTICAL PRODUCTS:

**Skin Care Applications:** One of the most significant findings of the review is the dominant role of nanotechnology in skincare formulations. Nanoparticles are extensively used to enhance moisturization, skin repair, anti-aging effects, pigmentation control, and photoprotection.Nano-based systems improve the delivery of active compounds such as vitamins, antioxidants, peptides, ceramides, and botanical extracts by increasing penetration through the stratum corneum, protecting active ingredients from degradation, and enabling sustained and controlled release.Lipid-based nanocarriers, such as liposomes and nanostructured lipid carriers, closely resemble natural skin lipids, making them particularly effective in restoring the skin barrier and improving hydration. These systems also reduce irritation by allowing lower concentrations of active ingredients to achieve the same therapeutic effect.Increasing penetration through the stratum corneum, Protecting actives from degradation.[5, 9, 10, 12, 14, 58]

**Hair Care Applications:** There are increasing use of nanotechnology in hair care products, including shampoos, conditioners, serums, and anti-dandruff formulations.Nanoparticles improve product performance by enhancing scalp penetration, increasing retention of active ingredients, and providing targeted delivery to hair follicles.Penetration into hair shafts, Repair of damaged cuticles, Deposition of conditioning agents, Nanocarriers help deliver antifungal agents, proteins, and oils more effectively, enhancing hair strength, shine, and smoothness while reducing breakage.[16, 17, 18]

**Nail, Lip, and Oral Care Products:** Nanotechnology also plays a significant role in nail, lip, and oral care formulations. It enhances product performance by improving adhesion, increasing durability, enabling deeper penetration of active ingredients, and providing antimicrobial protection, Nail-strengthening formulations, Lip products with enhanced color stability and hydration, Oral care products such as toothpaste and mouthwashes. Nanohydroxyapatite is widely used in oral care for enamel remineralization, while nano-sized pigments improve color uniformity and durability in lip cosmetics.[20, 21, 22]

## PERFORMANCE ADVANTAGES OBSERVED IN NANO COSMECEUTICALS:

There are several performance-related advantages consistently reported across studies as per following: [6, 7, 9, 11, 12, 15]

**Improved Bioavailability:** Nanoparticles increase the effective concentration of active ingredients at the target site without increasing the overall dosage.

**Enhanced Product Stability:** Encapsulation protects bioactive compounds from oxidation, photodegradation, and hydrolysis, thereby improving formulation stability.

**Aesthetic Superiority:** Nano-sized particles reduce grittiness, surface whiteness, and uneven texture, particularly in sunscreens and color cosmetics.

**Prolonged Activity:** Controlled-release systems extend the duration of action, reducing the need for frequent application.

These advantages collectively explain the rapid transition from conventional cosmetic formulations to nano-enabled products.

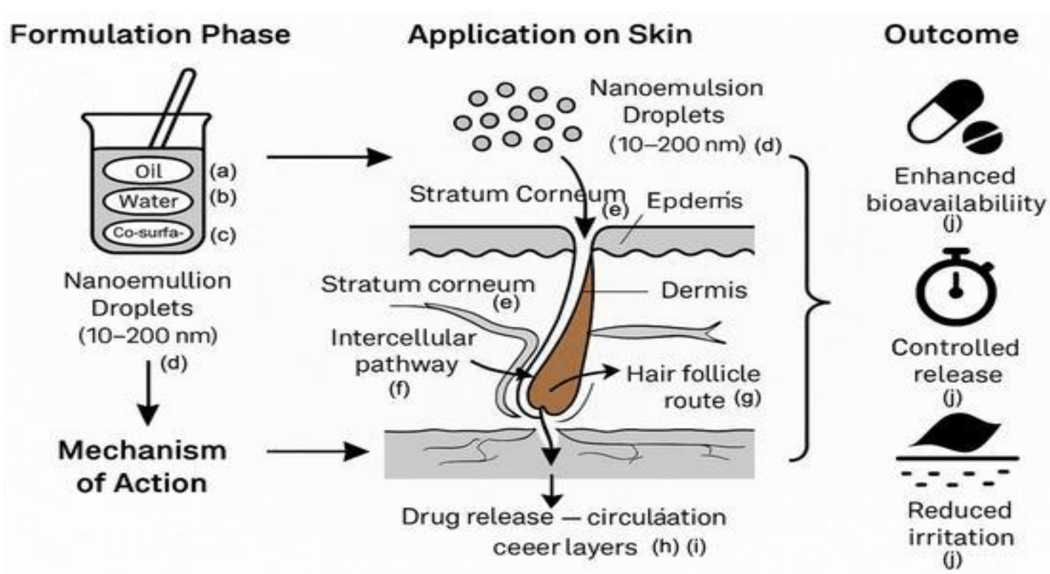


**Figure 3:** Mechanism of Nanoemulsion-Mediated Skin Delivery

## NANOTOXICOLOGY AND HEALTH RISK OBSERVATIONS:

Despite demonstrated benefits, the review emphasizes that nanotoxicological concerns remain inadequately resolved. Nanoparticles may induce oxidative stress, inflammatory responses, cellular damage, and potential systemic toxicity depending on their size, surface characteristics, chemical composition, and exposure route.[13, 14, 19]

**Dermal Penetration Risks:**Nanoparticles may penetrate deeper skin layers, particularly when: skin barrier is damaged, Particle size is <100 nm, surface charge favours penetration, repeated exposure occurs, although intact skin offers some protection, long-term accumulation and systemic absorption remain concerns.

**Cellular and Molecular Toxicity:**Experimental studies cited in the review suggest that some nanoparticles can generate reactive oxygen species (ROS), induce inflammation, cause mitochondrial dysfunction, interact with DNA and proteins, metal oxide nanoparticles, in particular, have been associated with oxidative stress under certain conditions.

**Inhalation and Accidental Exposure:**Spray-based cosmetics pose inhalation risks, especially for nanoparticles that may reach the lungs and enter systemic circulation. The review highlights the lack of long-term inhalation studies in cosmetic contexts.

## ENVIRONMENTAL IMPACT AND ECOTOXICOLOGICAL FINDINGS:

**Routes of Environmental Release:**Nanoparticles can enter ecosystems through manufacturing waste, product wash-off, improper disposal, ecological effects, studies indicate potential, Toxicity to aquatic organisms, bioaccumulation in food chains, disruption of microbial ecosystems. The persistence of nanoparticles raises concerns regarding long-term environmental consequences.

## PATENT ANALYSIS AND INDUSTRIAL TRENDS

**Patent analysis reveals:**Rapid growth in nano-enabled cosmetic formulations**,** strong industrial interest in lipid-based carriers**,** focus on sunscreens, anti-aging, and skin-lightening products**.** Patents demonstrate the commercial viability and innovation-driven nature of nanocosmetics, bridging academic research and market application.

## REGULATORY FRAMEWORK – THE COMPARATIVE ANALYSIS:

**European Union:**The European Union has one of the most advanced and comprehensive regulatory frameworks for cosmetics and nanocosmetics. It requires mandatory safety assessment of all cosmetic ingredients, specific notification of nanomaterials used in formulations, and labelling requirements indicating the presence of nano-ingredients.Additionally, manufacturers must submit detailed product information files and comply with stringent pre-market safety evaluations under EU cosmetic regulations.Safety assessment of nanomaterials, Mandatory labelling of nano-ingredients, Pre-market notification. [23, 24]

**United States:**In the United States, cosmetics are regulated differently from drugs under federal law. Unlike pharmaceuticals, cosmetic products and their ingredients do not require pre-market approval by the regulatory authority, except for color additives. Manufacturers are responsible for ensuring product safety prior to marketing, and regulatory action is generally taken post-marketing if safety concerns arise.[2526] Although nanomaterials are not governed by a separate regulatory category, authorities have issued guidance documents encouraging safety evaluation and transparency in the use of nanotechnology in cosmetic products.No nano-specific cosmetic law, Responsibility largely placed on manufacturers, Limited mandatory safety testing. [25, 26, 27]

**India:**In India, cosmetic products are regulated under the Drugs and Cosmetics Act and associated rules; however, specific provisions addressing nanomaterials remain limited and are still evolving. While general safety and labelling requirements apply to cosmetic products, there is currently no dedicated regulatory framework exclusively governing nanocosmetics.Regulatory authorities are increasingly recognizing the need for updated guidelines, standardized safety evaluation protocols, and harmonization with international regulatory practices to address emerging challenges associated with nano-based formulations.Governed by the Drugs and Cosmetics Act, Limited nano-specific guidance, Growing need for regulatory clarity. [28, 29]

**Regulatory Gaps Identified:**There are several regulatory gaps in the governance of nanocosmetics and nanocosmeceuticals.These include the absence of universally accepted definitions of nanomaterials, lack of standardized testing protocols for nano-specific toxicity assessment, insufficient long-term safety data, and limited post-marketing surveillance mechanisms. Additionally, inconsistencies between regional regulatory frameworks create challenges in global harmonization and cross-border commercialization of nano-enabled cosmetic products.Lack of harmonized global standards, inconsistent labelling requirements, insufficient long-term safety data.[30, 31]

## FUTURE PERSPECTIVES IN NANOCOSMETICS AND NANOCOSMECEUTICALS:

The nanotechnology in cosmetics remains an evolving and rapidly expanding field with substantial opportunities for scientific advancement, industrial innovation, and regulatory refinement.Emerging research is expected to focus on the development of safer, biodegradable, and environmentally sustainable nanomaterials, along with advanced delivery systems that optimize efficacy while minimizing systemic exposure.Although current applications demonstrate promising outcomes in product performance and consumer satisfaction, future investigations must prioritize long-termtoxicological studies, standardized safety assessment models, and ethical commercialization practices to ensure responsible and sustainable growth of the nanocosmetic industry.[32, 33]

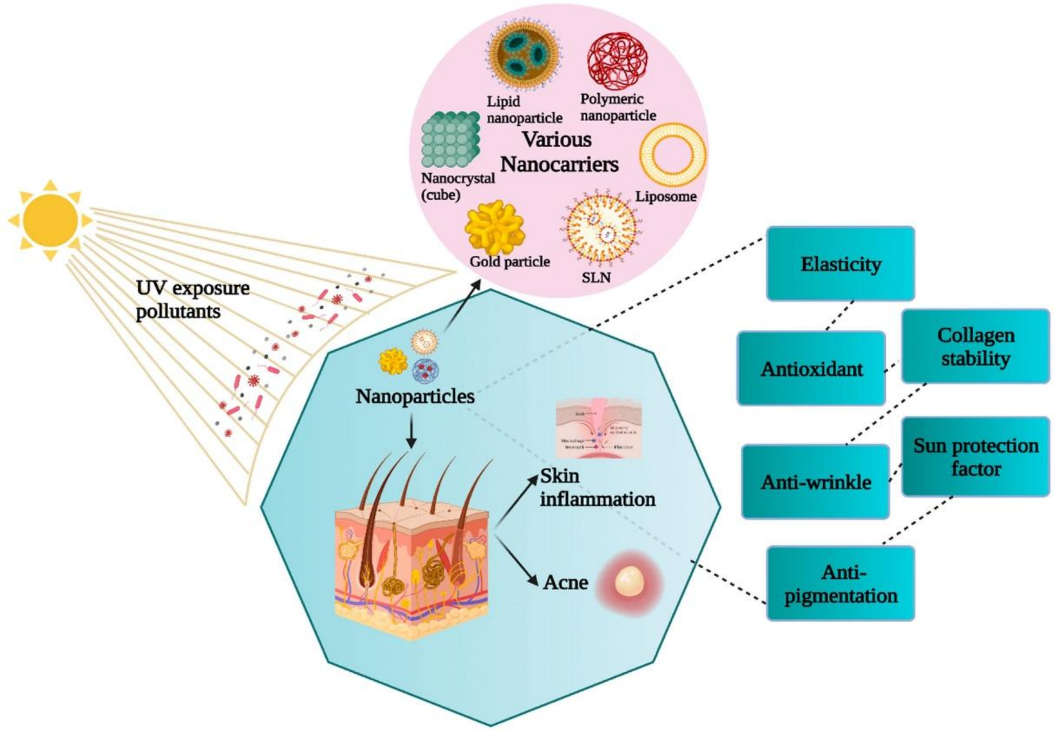


**Figure 4: Nano-Carriers for Skin Protection and Cosmeceutical Benefits**

**Advancements in Nanomaterial Design:** Future developments are expected to focus on the design of safer, biodegradable, and biocompatible nanomaterials with improved functional performance. Research is likely to emphasize surface modification techniques, green synthesis approaches, and stimulus-responsive nanocarriers that enhance targeted delivery while minimizing toxicity. The advancements in precision engineering at the nanoscale may enable the customization of particles with controlled size, charge, and release characteristics, thereby improving both efficacy and safety profiles in cosmetic and cosmeceutical applications.Biodegradable and biocompatible nanomaterials, naturally derived lipid and polymer-based nanoparticles, reduction of persistent inorganic nanomaterials. Green nanotechnology approaches, such as plant-based synthesis and eco-friendly fabrication methods, are likely to gain importance due to increasing environmental concerns.[34, 35]

**Smart and Responsive Nanocarriers:**Emerging nanocarriers are being designed to respond to specific physiological and environmental stimuli such as pH changes, temperature variations, light exposure, enzymatic activity, and oxidative stress conditions. These smart delivery systems enable targeted release of active ingredients only under desired conditions, thereby enhancing therapeutic precision while minimizing unnecessary exposure and potential adverse effects. Such responsive nanocarriers represent a significant advancement toward personalized and adaptive cosmetic formulations with improved efficacy andsafety profiles. The pH changes, temperature variations, enzymatic activity, UV exposure. Such stimuli-responsive systems may allow controlled activation of cosmetic ingredients only at the target site, reducing systemic exposure and improving safety profiles.[36, 37]

**Personalized and Precision Cosmeceuticals:** Nanotechnology may enable the development of personalized cosmetic formulations based on individual skin type, genetic profile, microbiome composition, age, and environmental exposure.Advanced nano-delivery platforms can be tailored to address specific dermatological needs, allowing precise targetingof active ingredients for conditions such as hyperpigmentation, acne, photoaging, and barrier dysfunction. The integration of nanotechnology with artificial intelligence and diagnostic tools may further facilitate customized product design, improve treatment outcomes while minimize adverse reactions.Skin type, genetic predisposition environmental exposure lifestyle factors. Integration with artificial intelligence, skin diagnostics, and wearable sensors may allow individualized nanocosmeceutical therapies, marking a shift toward precision cosmetic science.[38, 39]

**Integration with biotechnology:** There is an increasing convergence of nanotechnology with biotechnology, peptide engineering, stem cell research, and microbiome-based cosmetic science. This interdisciplinary integration is anticipated to support the development of advanced bioactive formulations withenhanced regenerative and therapeutic potential.By incorporating nanocarrier systems, bio-functional ingredients such as peptides, growth factors, and probiotic components can be delivered more effectively while maintaining their structural stability and biological activity.Such convergence represents a significant step toward scientifically engineered, high-performance cosmeceuticals with improved precision, efficacy, and safety, biotechnology, peptide engineering, stem cell research, microbiome-based cosmetics. Nanocarriers can enhance delivery of bioactive peptides, growth factors, and probiotics while preserving their stability and activity.[42, 43]

**RESEARCH GAPS IDENTIFIED:** Despite extensive research, the review clearly identifies several critical gaps that must be addressed to ensure responsible and sustainable progress in nanocosmetics and nanocosmeceuticals. Although numerous studies demonstrate enhanced efficacy and formulation advantages, long-term toxicological data and standardized safety evaluation models remain limited.There is a need for comprehensive in-vivo studies, improved characterization techniques, harmonized international regulatory standards, and robust post-marketing surveillance systems. Furthermore, insufficient understanding of chronic exposure effects, bioaccumulation potential, and environmental persistence highlights the necessity for multidisciplinary research integrating nanotoxicology, environmental science, and regulatory science.[44, 45]

**Long-Term Human Safety Data:** Most available studies are short-term, use in-vitro or animal models**,** lack chronic exposure evaluation. There is a pressing need forlong-term dermal exposure studies**,** human-relevant models, post-marketing surveillance data.

**Standardized Toxicological Protocols:** Current toxicity studies vary widely in test modelsdoses, exposure routes, endpoints measured**.** The absence of standardized nanotoxicology protocols limits comparability and regulatory decision- making.

**Environmental Risk Assessment Models:** Existing environmental studiesFocus on isolated ecosystems do not reflect real-life exposure scenarios; rarely assess cumulative or synergistic effects. Comprehensive life-cycle assessments of nanocosmetics are needed to evaluate their true environmental footprint.

**Regulatory Science Gaps:** Regulatory systems lag behind technological innovation due to insufficient nano-specific definitions, limited expertise in regulatory agencies, lack of global harmonization. This gap creates uncertainty for manufacturers and potential risks for consumers.

## POLICY AND REGULATORY RECOMMENDATIONS:

Based on the findings of the review, several policy-level recommendations are proposed to strengthen the safe development and commercialization of nanocosmetics and nanocosmeceuticals. The need for clear and universally accepted definitions of nanomaterials, along with nano- specific regulatory frameworks that distinguish them from conventional cosmetic ingredients.It further recommends mandatory pre-market safety evaluation of nano-ingredients, standardized toxicological testing protocols, transparent labelling requirements, and strengthened post-marketing surveillance systems. International harmonization of regulatory guidelines is also highlighted as essential to facilitate global trade while ensuring consumer safety and environmental protection.[46, 47]

**Development of Nano-Specific Cosmetic Regulations:** Regulatory authorities should clearly define nanomaterials in cosmetic legislation, mandate nano-specific safety assessments, require pre-market approval for high-risk nanomaterials.

**Mandatory Labelling and Transparency:** Consumers should be informed about presence of nanomaterials, type and function of nanoparticles, potential risks and benefits. Transparent labelling promotes informed consumer choice and builds public trust.

**Strengthening Post-Marketing Surveillance:** Post-marketing systems should monitor adverse skin reactions, long-term health effects, environmental contamination, data collected should guide regulatory updates and product reformulation.

**International Regulatory Harmonization:**Global collaboration is essential to establish unified safety standards, avoid regulatory loopholes, facilitate safe international trade organizations such as WHO, OECD, and ISO can play key roles in developing harmonized nano- guidelines.

## ETHICAL AND SOCIETAL CONSIDERATIONS:

The importance of ethical responsibility in the development and commercialization of nanocosmetic products.As nanotechnology advances rapidly, manufacturers and researchers must ensure transparency, consumer awareness, and informed consent regarding the inclusion of nano-ingredients in cosmetic formulations.Ethical considerations include accurate product labelling, responsible marketing claims, equitable access to safe products, and proactive disclosure of potential risks. The scientific innovation must be accompanied by accountability, public engagement, and adherence to principles of sustainability and long-term safety to maintain consumer trust and societal acceptance.[48, 49]

**Consumer Safety and Informed Consent:** Consumers often remain unaware of nanotechnology use in cosmetics. Ethical marketing must ensure accurate claims, evidence-based benefits, and disclosure of uncertainties.

**Sustainability and Environmental Responsibility:** Manufacturers should adopt eco-friendly synthesis, waste minimization strategies, sustainable packaging. Nanotechnology must align with global sustainability goals.

**Responsible Innovation:** Innovation should proceed alongside, rigorous scientific validation, regulatory compliance, social responsibility.

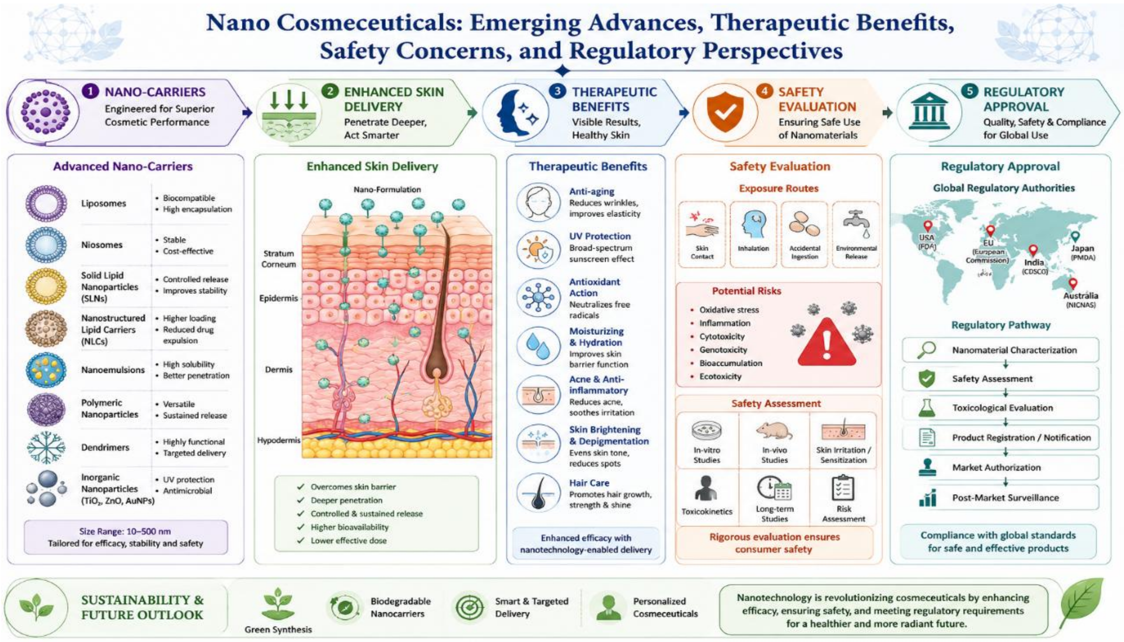


**Figure 5: Nano-cosmeceuticals: Delivery, Benefits, Safety and Regulation**

## CONCLUSION:

The nanotechnology has emerged as a transformative force in the cosmetic and cosmeceutical industry, offering advanced solutions for formulation challenges, enhanced delivery of bioactive ingredients, and superior product performance. Nanomaterials and nanocarrier systems have enabled improved bioavailability, prolonged efficacy, aesthetic refinement, and targeted action across a wide range of cosmetic applications, including skincare, hair care, oral care, and personal hygiene products. However, the review also underscores that the very properties that make nanoparticles effective small size, high surface area, and enhanced reactivity also raise valid safety and environmental concerns. Current scientific evidence, while promising, remains insufficient to fully assess the long- term implications of chronic exposure to nano cosmeceuticals in humans and ecosystems. The authors conclude that the future success of nano cosmetics depends not solely on technological innovation, but on a balanced, precautionary, and ethically grounded approach that integrates scientific rigor, regulatory oversight, environmental stewardship, and consumer awareness. Addressing existing research gaps, establishing standardized safety protocols, and harmonizing global regulations are essential steps toward sustainable advancement. In conclusion, nanotechnology holds immense potential to redefine cosmetic science, but its responsible application requires collaborative efforts among researchers, industry stakeholders, regulatory bodies, and consumers. With thoughtful governance and continued research, nano cosmeceuticals can evolve into safe, effective, and sustainable components of modern personal care.

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