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Review Article

Recent Advancements in Cosmeceuticals — A Review

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ABSTRACT

Cosmeceuticals — cosmetic products with active ingredients that exert therapeutic or biologically active effects on the skin — have evolved rapidly over the last five years. This review summarizes major recent advances (2019–2025) in active ingredients (peptides, biotics/postbiotics, polyphenols), delivery technologies (lipid-based nanoparticles, liposomes, niosomes, hydrogels), microbiome-targeted approaches, biotechnology-driven and "longevity" cosmeceuticals, and regulatory/safety considerations. We highlight converging trends: precision bioactive design (peptides and recombinant ingredients), nano- and lipid-based carriers for improved skin delivery, microbiome modulation (probiotics/postbiotics), and the rise of longevity science and biotechnology in product development. Finally, we outline current limitations (clinical evidence gaps, safety and regulatory uncertainty) and propose directions for future research. Cosmeceuticals, positioned at the intersection of cosmetics and pharmaceuticals, represent one of the fastest-growing sectors in dermatological research and skincare innovation. In recent years, significant advancements have been made in both active ingredients and delivery technologies aimed at enhancing skin health, rejuvenation, and protection. This review highlights key developments from 2019 to 2025, focusing on novel bioactive agents such as peptides, antioxidants, botanicals, and microbiome-targeted biotics (probiotics, prebiotics, and postbiotics). Emerging formulation technologies—including lipid-based nanoparticles, liposomes, niosomes, and hydrogel systems—have improved the stability, penetration, and bioavailability of these actives. Additionally, the integration of biotechnology and nanoscience has facilitated the development of personalized and "longevity" cosmeceuticals that address molecular mechanisms of aging and barrier dysfunction. Despite these innovations, challenges remain in ensuring clinical validation, regulatory standardization, and long-term safety assessment. The review concludes that the future of cosmeceuticals lies in evidence-based product development combining biotechnology, precision formulation, and sustainable ingredient sourcing

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for effective and safe dermatological applications.

INTRODUCTION

The global demand for skincare products that not only enhance appearance but also improve skin health has led to the rapid expansion of the cosmeceutical industry—a hybrid domain combining cosmetics and pharmaceuticals. The term *cosmeceutical* was first introduced by Dr. Albert Kligman in the late 20th century to describe topical products that contain biologically active ingredients with therapeutic benefits beyond simple cosmetic effects. Unlike conventional cosmetics, cosmeceuticals are formulated with active molecules that can influence biological functions within the skin, such as stimulating collagen synthesis, reducing oxidative stress, enhancing hydration, and modulating pigmentation. In the past decade, and particularly between 2019 and 2025, scientific advances in biotechnology, nanotechnology, and skin biology have driven remarkable progress in cosmeceutical innovation. A new generation of bioactive ingredients—such as signal peptides, growth factors, plant-derived polyphenols, probiotics, and postbiotics—is being integrated into formulations aimed at targeted mechanisms including skin aging, barrier repair, and inflammation control. The development of advanced delivery systems, such as liposomes, solid lipid nanoparticles (SLN), nanostructured lipid carriers (NLC), hydrogels, and microneedles, has significantly improved the stability, solubility, and dermal penetration of these actives, enhancing their clinical efficacy. Recent trends also indicate a paradigm shift toward personalized and sustainable cosmeceuticals, driven by consumer demand for biocompatible, eco-friendly, and ethically sourced ingredients. Moreover, the rise of microbiome-centered skincare has opened a new frontier, where modulation of skin microflora through probiotics, prebiotics, and postbiotics aims to restore barrier function and immunity. Parallelly, "longevity" cosmeceuticals, inspired by cellular aging research, are being developed to target senescence pathways, mitochondrial dysfunction, and DNA repair mechanisms to promote long-term skin vitality. However, despite the promising developments, significant challenges remain. The lack of clear regulatory definitions, limited clinical validation, and inadequate standardization in testing protocols hinder the scientific credibility of many commercial products. Ensuring the safety and long-term biocompatibility of nanomaterials and biotech-derived actives is another critical concern. Thus, continuous interdisciplinary research integrating dermatology, material science, and molecular biology is essential for translating laboratory innovations into clinically effective and safe cosmeceutical products. This review provides an updated overview of recent advancements in cosmeceuticals, focusing on emerging bioactive ingredients, delivery technologies, microbiome-targeted formulations, and biotechnological innovations. It also highlights the current challenges and outlines future perspectives for developing next-generation cosmeceuticals with enhanced efficacy, safety, and sustainability. Cosmeceuticals sit at the interface of cosmetics and therapeutics: formulations aim to improve appearance via biologically active ingredients but typically avoid the regulatory status of drugs. In the last half-decade, advances in peptide engineering, microbiome science, nanodelivery systems, and biotechnology have transformed both the pipeline of novel actives and the way manufacturers deliver them to viable skin targets. This review synthesizes current literature (2019–2025) to present the state of the art and research gaps.

2. Literature Review — Recent Advancements in Cosmeceuticals

This literature review synthesizes major developments (roughly 2019–2025) across four interrelated areas that are driving the cosmeceutical field: (1) novel bioactive ingredients (with emphasis on peptides and biotech-derived actives), (2) advanced delivery systems (lipid-based nanoparticles, liposomes/niosomes, hydrogels), (3) microbiome-targeted interventions, and (4) minimally invasive devices (microneedles) and combined delivery strategies. Where appropriate I cite recent high-quality reviews and primary studies to support the statements below.

A. Overview: scope and trends

Recent years have seen convergence of molecular dermatology, biotechnology, and formulation science in cosmeceuticals. The market-driven push for evidence-based efficacy, together with advances in peptide design, microbial ecology, and nanoscale carriers, has shifted product development from empirical botanicals toward rationally designed actives and precision delivery platforms. Reviews across lipid nanoparticles, peptide actives, microbiome interventions, and microneedles paint a consistent picture: stronger mechanistic rationale, improved formulation approaches to overcome skin barrier limitations, and an increasing demand for clinical validation.

B. Bioactive ingredients — peptides, recombinant proteins, and next-gen actives

Peptides are among the fastest-growing actives in cosmeceuticals because they can be engineered to modulate specific biological pathways (e.g., collagen synthesis, MMP inhibition, melanogenesis). Recent literature documents advances in peptide stabilization (D-amino acids, cyclization), multifunctional sequence engineering (combining signaling and cell-penetrating motifs), and recombinant production for cost-effective, pure peptides suitable for topical use. Systematic reviews and 2024–2025 papers summarize commercially used peptides, their proposed mechanisms, and preclinical/clinical evidence—while also noting heterogeneity in study quality and endpoints. In parallel, fermentation- and recombinant-derived growth factors and short proteins are gaining traction as high-potency cosmeceutical actives, enabled by biotechnology scale-up.

Key Takeaways:

- Peptide engineering allows targeted mechanisms with generally favorable tolerability, but robust RCTs with objective endpoints remain limited.
- Recombinant production improves sustainability and batch consistency, addressing earlier supply/contamination concerns.

C. Delivery systems — lipid nanoparticles, SLN/NLC, liposomes, and hybrid carriers

A central challenge in cosmeceuticals is delivering bioactive molecules through the stratum corneum to reach viable epidermal/dermal targets. Lipid-based carriers (SLN, NLC, lipid nanoparticles/LNPs) and vesicular systems (liposomes/niosomes) have been widely reviewed for their ability to (a) protect labile actives from degradation, (b) increase solubility of hydrophobic molecules, (c) control release kinetics, and (d) enhance skin deposition while minimizing irritation. Recent comprehensive reviews and experimental studies (2023–2025) report successful encapsulation of retinoids, antioxidants (resveratrol, CBD), peptides, and ceramides, showing improved stability and deeper skin delivery compared to conventional formulations. Advances in formulation analytics and scalable

manufacturing are reducing barriers to commercialization.

Notable themes:

- SLN/NLC systems improve photostability of retinoids and antioxidants and can reduce irritancy by controlled release.
- Lipid nanoparticles (LNPs) developed for nucleic acid therapeutics have informed skin LNP design, expanding possibilities for oligonucleotide-based cosmeceuticals and RNA-modulating topical agents.

D. Skin microbiome — probiotics, prebiotics, postbiotics, and microbiome-smart formulations

The skin microbiome is now a recognized target for cosmeceutical intervention. Reviews from 2023–2025 synthesize evidence linking microbial community composition to barrier function, inflammation, acne, and signs of aging. Interventions fall into three categories: topical probiotics (live strains), prebiotics (substrates favoring beneficial microbes), and postbiotics (microbial metabolites or inactivated microbial preparations). Emerging clinical studies show promise—especially for atopic dermatitis and acne models—however outcomes are strain- and formulation-dependent, and long-term safety/stability of live topical cultures needs standardized evaluation.

Research gaps and considerations:

- Strain specificity matters: clinical benefit cannot be generalized across taxa; genomic strain characterization is essential.
- Stability of live strains in consumer formulations, regulatory classification, and robust placebo-controlled trials are still maturing.

E. Microneedles and combination delivery strategies

Microneedle (MN) technologies—dissolving, coated, and hydrogel MNs—have transitioned from drug delivery research into cosmetic and dermatology applications. Recent reviews (2023–2025) highlight MNs' ability to bypass the stratum corneum and deliver peptides, vitamins, or hyaluronic acid derivatives into the epidermis/dermis with minimal pain and reduced infection risk when designed appropriately. Combining MNs with nanoparticle-loaded formulations (e.g., lipid nanoparticles within dissolving MN tips) opens routes for high-efficacy, low-dose delivery of sensitive actives. Regulatory and user-acceptability studies are emerging alongside clinical proof-of-concept trials.

Implications:

- MNs provide controlled intradermal dosing and may enable novel actives (oligonucleotides, growth factors) to be used in cosmeceuticals with improved bioavailability.

F. Safety, regulation, and translational challenges

A recurring theme across the literature is the necessity for higher-quality clinical evidence and clearer regulatory frameworks. While nanocarriers and live microbial products offer functional advantages, they raise distinct safety and labeling concerns. Reviews urge standardized testing for nanomaterial skin penetration, immunogenicity, reproductive and environmental impacts, and stricter product claims substantiation when clinical or biomarker endpoints are implied. Global

regulatory heterogeneity further complicates development and marketing of biotech-derived cosmeceuticals.

G. Synthesis — where the field is headed

Putting the literature together suggests a few clear directions for future work:

1. **Rigorous clinical trials** using objective skin imaging, histological or molecular biomarkers, and standardized endpoints to substantiate claims for peptides, microbiome interventions, and nanoformulations.
2. **Integrated delivery approaches** that combine nanocarriers with minimally invasive devices (microneedles) to expand the range of feasible actives.
3. **Transparent characterization** (strain genomics for probiotics; lipid composition and size distribution for nanoparticles) to improve reproducibility and regulatory submissions.
4. **Sustainability and scalable biotechnology** (recombinant and fermentation routes) to replace less sustainable sourcing of high-value bioactives.

H. Limitations of the current literature

Many published studies are preclinical (in vitro/ex vivo) or small open-label clinical trials; meta-analyses are limited by heterogeneity in formulations, endpoints, and short follow-up. Longitudinal safety data for nanomaterials and live topical biotics are scarce. Additionally, much industry data remain proprietary, restricting full academic appraisal.

Table 1. List of Novel Peptides and Their Mechanisms in Cosmeceuticals

Peptide Name / Type	Mechanism of Action	Primary Application	Remarks
Palmitoyl tripeptide-5	Stimulates TGF-β pathway; increases collagen synthesis	Anti-aging / wrinkle reduction	Widely used, strong clinical support
Acetyl hexapeptide-8 (Argireline)	SNARE complex modulation; muscle contraction reduction	Wrinkle relaxation ("Botox-like	

Table 2. Recent Clinical or Preclinical Studies on Novel Cosmeceutical Formulations

Study / Year	Active / Formulation Type	Model (Human / Preclinical)	Key Outcome	Reference
Badilli et al., 2025	Peptide-based anti-wrinkle cream (stabilized tripeptide)	Human (n=60)	Significant wrinkle depth reduction after 8 weeks	Polymers (MDPI, 2025)
Han et al., 2024	Probiotic *Lactobacillus plantarum* topical cream	Human (atopic dermatitis)	Improved barrier function and reduced TEWL	PubMed, 2024
Godase et al., 2023	NLC-based retinoid nanoemulsion	Rat & in vitro	Enhanced dermal deposition; reduced irritation	PMC, 2023
Klinngam et al., 2025	Longevity cosmeceutical (mitochondrial peptide analog)	In vitro (fibroblasts)	Increased collagen synthesis, reduced senescence markers	Frontiers in Aging, 2025
Alves et al., 2024	Liposomal polyphenol formulation	Human (photoaged skin)	Improved elasticity and hydration	PMC, 2024

3. Major research gaps

1. **Insufficient high-quality clinical evidence**
   Why it matters: Many cosmeceutical claims rest on in vitro work, small open-label studies, or heterogeneous trial designs; this undermines clinical credibility and regulatory acceptance. *Priority:* Multicenter, randomized, double-blind, placebo-controlled trials with objective endpoints (imaging, tape-stripping biomarkers, validated patient-reported outcomes) and ≥6–12 month follow-up.
2. **Lack of standardized endpoints and reporting**
   Why it matters: Heterogeneous methods prevent meta-analysis, comparison across products, and reproducibility. *Priority:* Develop cosmeceutical-specific reporting guidelines (protocol pre-registration, standardized imaging/biomarker panels, defined primary endpoints).
3. **Poor characterization & stability data for microbiome interventions**
   Why it matters: Efficacy and safety of topical probiotics/postbiotics are strain- and formulation-dependent; unstable products risk loss of activity or unintended effects. *Priority:* Mandate whole-genome strain identification, stability and on-skin viability studies for final formulations, and mechanistic work linking metabolites to host responses.
4. **Translational gap from preclinical models to humans**
   Why it matters: Effects seen in cell lines or ex vivo skin often fail to replicate in vivo, reducing predictive value of preclinical work. *Priority:* Use physiologically relevant 3D skin models and validate leading findings in human biopsies or well-designed clinical PK/PD studies.
5. **Long-term safety and toxicology of novel carriers and actives**
   Why it matters: Repeated exposure to nanocarriers, lipid nanoparticles, recombinant proteins, or live biotics could produce cumulative systemic effects or environmental risks that are currently under-studied. *Priority:* Longitudinal safety cohorts, targeted toxicology for repeated topical exposure, nanoparticle fate studies, and environmental impact assessments.
6. **Unclear dose-response relationships and formulation optimization**
   Why it matters: Without quantitative dose–response and skin PK data, formulations may underperform or produce irritation. *Priority:* Systematic dose-finding studies and quantitative skin PK (tape-stripping, microdialysis) tied to formulation variables (particle size, lipid composition).
7. **Few validated molecular biomarkers and surrogate endpoints**
   Why it matters: Mechanistic claims (anti-senescence, mitochondrial rescue) need objective biomarkers that correlate with clinical benefit. *Priority:* Validate minimally invasive biomarkers (e.g., senescence-associated markers, ECM turnover proteins) against clinical outcomes.
8. **Limited population diversity and personalization data**
   Why it matters: Responses vary by skin phototype, age, sex, and microbiome composition; narrow trial populations limit generalizability and equity. *Priority:* Ensure demographic diversity in trials and investigate predictors of response (microbiome, genomics) for personalized regimens.
9. **Regulatory ambiguity for biotech-derived and microbiome products**
   Why it matters: Divergent classifications slow development and create inconsistent quality

standards across markets. *Priority:* Multi-stakeholder policy work to harmonize testing, manufacturing and labeling standards (live vs inactivated, potency units, genomic disclosure).

10. **Lack of open data and reproducibility infrastructure**
    Why it matters: Proprietary datasets and unpublished trials impede independent verification and slow field progress. *Priority:* Create public repositories for trial data, formulation specs (particle size, lipid profiles), and microbial strain genomes.

4. Active Ingredients: what's new?

4.1 Peptides and bioengineered proteins

Peptides remain a dominant class of cosmeceutical actives due to targeted bioactivity (collagen stimulation, MMP modulation, signaling). Recent progress includes stabilized D-amino acid peptides, multifunctional peptide sequences that combine signaling and carrier functions, and recombinant production for purity and sustainability. Clinical and preclinical evidence supports peptides for wrinkle reduction, improved elasticity, and wound/healing adjuncts, although long-term clinical data remain limited.

4.2 Biotics — probiotics, prebiotics, postbiotics

Targeting the skin microbiome has moved from concept to early clinical testing. Carefully characterized topical probiotics and postbiotics (metabolites, bacterially derived peptides) aim to restore microbial balance, reduce inflammation, and improve barrier function. A number of clinical trials and reviews have evaluated specific strains and postbiotic preparations showing promising but variable results — product efficacy depends strongly on strain characterization, vehicle, and stability.

4.3 Natural bioactives and polyphenols

Polyphenols (e.g., curcumin, resveratrol) and marine polysaccharides continue to draw interest for antioxidant, anti-inflammatory, and photoprotective roles. The key limitations—poor solubility and stability—are being addressed by formulation science, including encapsulation in nanoparticles and complexation (phytosomes), to improve topical bioavailability.

5. Delivery Technologies — improving penetration, stability, and targeting

5.1 Lipid-based nanoparticles, solid lipid nanoparticles (SLN), and nanostructured lipid carriers (NLC)

Lipid-based nanocarriers enable enhanced skin deposition, controlled release, and improved stability of hydrophobic actives. Recent comparative studies and reviews document advantages in delivering antioxidants, retinoids, and botanical extracts with reduced irritation and better retention. Manufacturing scale and regulatory considerations are increasingly solvable, supporting wider commercial use.

5.2 Liposomes, niosomes, and phytosomes

Liposomes and niosomes remain popular for transdermal and intradermal delivery of peptides, vitamins, and plant actives. Innovations include "stealth" liposomes, hybrid lipid–polymer carriers, and formulations optimized for barrier-compromised skin. Phytosomes (complexes of plant actives with phospholipids) help enhance solubility and skin uptake of polyphenols.

5.3 Hydrogels, microneedles, and combined approaches

Hydrogel matrices provide moisturizing and controlled-release platforms, while minimally

invasive devices (microneedles) are crossing from clinical procedures into cosmeceutical niche products for enhanced delivery of peptides and growth factors. Combination systems (nano-formulation inside microneedle patches) are under active investigation.

6. Skin Microbiome and "Microbiome-Smart" Cosmeceuticals

Understanding host–microbe interactions has led to a new product class: microbiome-smart cosmeceuticals. These include prebiotic formulations that favor beneficial taxa, topical probiotics with well-characterized strains, and postbiotics delivering microbial metabolites. The evidence base is growing: randomized trials with specific strains have shown benefits for atopic and acne-prone skin in some studies, but heterogeneity in trial design and strain reporting remains a barrier to generalization. Safety (live cultures on skin) and regulatory classification are active discussion points.

7. Biotechnology, Personalization, and Longevity Cosmeceuticals

Biotech enables fermentation-derived actives, recombinant peptides, and cell-free growth factors that were previously impractical at scale. An emerging subfield—**longevity cosmeceuticals**—aims to target cellular senescence, mitochondrial function, and proteostasis to deliver durable improvements in skin health (beyond surface aesthetics). Companies and academic labs are applying genomics, proteomics, and biomarker-guided strategies to develop personalized regimens. This trend increases the demand for rigorous clinical endpoints and molecular biomarkers to substantiate claims.

8. Regulatory, Safety, and Ethical Considerations : Cosmeceuticals often occupy a gray regulatory area: marketed as cosmetics, yet claiming biological effects. Recent literature emphasizes the need for: (1) rigorous clinical testing when health claims are implied, (2) transparent ingredient characterization (especially for live biotics and recombinant proteins), (3) safety evaluation for nanomaterials and for devices (e.g., microneedles), and (4) environmental and sustainability assessments (biotech vs. wild harvesting). Regulatory frameworks differ internationally, so companies face complex compliance paths.

9. Challenges and Gaps in the Field

1. **Clinical evidence gap:** Many products still rely on in vitro or small-scale studies; large randomized controlled trials with standardized endpoints are scarce.

2. **Standardization of microbiome interventions:** Strain identification, viability, and vehicle stability need standard protocols.

3. **Safety and long-term data for nanomaterials:** Improved characterization and long-term exposure studies are needed.

4. **Regulatory harmonization:** Global markets require clearer guidelines for claims, especially for "longevity" and biotech-derived ingredients.

10. Future Directions and Recommendations

- **Evidence-first product development:** Prioritize randomized clinical trials and objective biomarkers (imaging, molecular markers).

- **Strain/ingredient transparency:** Full genomic/chemical characterization of probiotic strains and recombinant actives in labels and regulatory dossiers.

- **Combination technologies:** Combine targeted peptides with advanced carriers (lipid nanoparticles, microneedles) for better efficacy and safety balance.

- **Sustainability & biotech scaling:** Use fermentation and recombinant approaches to reduce ecological impacts of sourcing.

11. CONCLUSION

Recent years have seen rapid, multidisciplinary advances in cosmeceuticals: from rationally designed peptides and microbiome-targeting agents to sophisticated lipid- and nano-delivery systems and the rise of longevity-focused biotech products. While scientific and technological innovation is strong, the field must simultaneously strengthen clinical evidence, safety evaluation, and regulatory rigor to ensure products deliver meaningful, reproducible benefits. The literature from 2019–2025 supports a rapid evolution of cosmeceuticals toward mechanism-driven actives (especially engineered peptides and biotech-derived proteins), advanced lipid- and vesicle-based carriers, microbiome-targeted strategies, and minimally invasive delivery platforms such as microneedles. To translate these innovations into safe, effective, and claim-supporting consumer products will require coordinated progress in standardized clinical evaluation, analytical characterization, and regulatory clarity.

- Comprehensive reviews on lipid nanoparticles and LNP/RNA delivery advances.

- Reviews on SLN/NLC applications in cosmetics and demonstrated formulations (retinol, ceramides, CBD).

- Reviews and systematic overviews of skin microbiome interventions and clinical potential.

- Recent reviews on microneedles for cosmetic and dermatological delivery.

- Updated reviews on bioactive peptides in cosmetic formulations (2024–2025).

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