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Editorial

Fine Chemicals from Natural Sources with Potential Application in the Cosmetic/Pharmaceutical Industry–Volume 2. Green Technologies Shaping the Future of Cosmetics and Pharmaceuticals

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The evolution of naturally originated fine chemicals within the cosmetic and pharmaceutical sectors is currently marked by a strategic shift from petrochemical feedstocks toward a sustainable, bio-based circular economy. This Special Issue, "Fine Chemicals from Natural Sources with Potential Application in the Cosmetic/Pharmaceutical Industry–Volume 2", captures a critical stage where green chemistry, digital innovation, and advanced biotechnology converge to redefine active ingredient design. This Special Issue features 21 peer-reviewed contributions which analyze modern trends in cosmetic and pharmaceutical chemistry, focusing on obtaining high-quality substances from renewable natural sources and presenting the evolution of the industry toward green chemistry by using biotechnology, precision fermentation, and artificial intelligence to design safe and long-lasting ingredients. Together, the collection emphasizes the importance of a circular economy and environmentally friendly extraction methods that replace petroleum-derived raw materials. It also indicates that technological innovation and sustainable development in the field of fine chemicals are crucial to the future of modern skincare formulations.

Modern cosmetic science is undergoing a pivotal transformation, shifting away from an exclusive focus on formulation esthetics and market trends toward rigorous scientific validation, sustainability imperatives, and technological integration. Recent progress has been defined by the replacement of synthetic, non-biodegradable components with high-performance natural alternatives. For example, the cosmetic industry is constantly accelerating in the replacement of plastic microbeads with biodegradable algae-derived polysaccharides, such as sodium alginate, and bacterial polyesters like polyhydroxyalkanoates (PHAs), which offer effective exfoliation without environmental toxicity. These materials not only match the functional performance of synthetic exfoliants but also offer improved safety profiles and environmental compatibility. Current studies confirm that such biopolymers can be engineered for controlled degradation rates and tailored mechanical properties, enabling their integration into a wide range of formulations from scrubs to encapsulation matrices (1). One of the most compelling developments highlighted across recent literature is the emergence of sustainable nanomaterials derived from agro-industrial waste streams. Silica nanoparticles (SiNPs), traditionally synthesized through energy-intensive and chemically demanding processes, can now be produced via green synthesis routes using precursors such as rice husks and sugarcane bagasse. Such bio-derived nanocarriers demonstrate enhanced biocompatibility and tunable porosity, enabling efficient encapsulation and controlled release of active compounds, which is essential for next-generation cosmetic products (2). Another domain that has witnessed

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significant progress is transdermal drug delivery systems (TDDS). The implementation of advanced, vesicular carriers, such as ethosomes, niosomes, and transferosomes, has significantly improved the penetration of sensitive antioxidants like rutin and coenzyme Q10 by overcoming the stratum corneum barrier. Recent clinical and preclinical studies suggest that these ultra-deformable systems are particularly vital for post-oncologic skin regeneration, where compromised barrier functions require specialized nanocarriers to deliver mitochondria-protective actives into deep cutaneous layers (3,4).

Despite these advances, the field has faced persistent challenges that have limited the translation of fine chemicals from natural sources into industrial practice. Variability in phytochemical composition, mostly driven by geographic origin, cultivation conditions, and extraction methods, still remains a major barrier to reproducibility and regulatory approval (5). Additionally, comprehensive toxicological evaluation of many plant-derived materials (PDMs) is still lacking, particularly with respect to chronic exposure and interactions with complex biological systems (6).

The following Special Issue has made substantial progress in addressing these limitations. Several studies have moved beyond ethnopharmacological claims to provide robust analytical and mechanistic validation of traditional materials. For instance, the characterization of Multani Mitti has revealed significant inhibitory activity against enzymes such as hyaluronidase and tyrosinase, positioning it as a credible anti-aging and depigmenting agent (7). Similarly, the identification of novel bioactives serving as tyrosinase inhibitors, including α-onocerin from *Lycopodiastrum casuarinoides*, demonstrates the untapped potential of underexplored botanical sources (8). Equally noteworthy is the exploration of synergistic systems that combine natural compounds from diverse origins. The integration of bee venom components with plant extracts such as *Ficus carica* exemplifies a multi-target strategy aimed at enhancing skin regeneration while minimizing adverse effects (9). The potential of fine chemicals from natural sources as alternatives or complements to conventional treatments is also emphasized, especially in the context of antibacterial and antifungal properties against skin pathogens. However, the need for further research and standardization to ensure their effectiveness and safety is also clearly stated (10–12). At the same time, the development of vegan and ethically compliant alternatives, such as plant-cell-derived polydeoxyribonucleotide (PDRN) and exosome-like vesicles, addresses growing consumer and regulatory demands for animal-free innovation. These systems have shown promising results in wound healing, inflammation modulation, and barrier repair (6). The issue also highlights emerging mechanistic insights that expand the functional scope of cosmetic actives. For example, the ability of blackberry (*Rubus fruticosus*) fruit extract to stimulate adipogenic pathways introduces new possibilities for non-invasive volume restoration strategies, potentially complementing or replacing traditional lipofilling procedures (13).

Looking forward, the translation of these scientific advances into scalable industrial solutions will require coordinated efforts across multiple disciplines. Standardization remains a top priority. The identification of validated marker compounds will be essential to ensure batch consistency and reproducible efficacy. In this context, analytical techniques coupled with chemometric modeling are expected to play a central role. The integration of artificial intelligence (AI) and machine learning (ML) represents another transformative opportunity. Predictive models can now assess molecular stability, permeability, and toxicity at early stages of development, significantly reducing reliance on animal testing and accelerating innovation pipelines. When combined with high-throughput screening and in silico toxicology, these tools offer a pathway toward more efficient and ethical product development.

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Biotechnological approaches, particularly precision fermentation and metabolic engineering, are also poised to reshape the supply chain of natural actives in the cosmetic and pharmaceutical products. Engineered microbial systems, such as bacteria and yeast, enable the production of high-purity bioidentical compounds of agricultural variability. This not only enhances sustainability but also ensures scalability and cost-effectiveness. In addition, hybrid conversion technologies that integrate chemical catalysis with enzymatic processes are emerging as powerful platforms for producing novel bio-based ingredients, including sustainable surfactants, emollients and UV filters [1–6]. Such approaches maximize resource efficiency while minimizing environmental impact.

Another area of growing importance is the interaction between cosmetic ingredients and the skin microbiome. Increasing evidence suggests that formulation components can influence microbial diversity and function [7]. Therefore, future research must adopt a systems-level perspective to ensure that new products support, rather than disrupt, the delicate ecological balance of the skin. Finally, the long-term safety of nanomaterials and advanced delivery systems remains an open question. While short-term studies indicate favorable safety profiles, there is a pressing need for chronic toxicological assessments that consider repeated exposure, systemic absorption, and cumulative effects [8]. Similarly, the stability of emerging systems such as exosomes under real-world storage conditions must be addressed to enable reliable commercialization.

In conclusion, this Special Issue marks an important step toward a more mature, evidence-based, and sustainable cosmetic science model. The convergence of green chemistry, biotechnology, and digital innovation is redefining what is possible in the design of cosmetic ingredients and formulations. By addressing remaining knowledge gaps and embracing interdisciplinary collaboration, the cosmetics and pharmaceutical industries are well positioned to deliver safe, effective, and ethically responsible solutions. Fine chemicals from natural sources, once limited by variability and skepticism, are now emerging as robust and reliable components of advanced cosmetic and pharmaceutics systems, playing a central role in the future of human health and skin care.

Conflicts of Interest: The authors declare no conflicts of interest.

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