# Advanced nanocarrier-based strategies for enhancing herbal actives in cosmetic and cosmeceutical applications

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The integration of herbal extracts into cosmetic and cosmeceutical products has obtained considerable interest due to their broad spectrum of bioactivities, including antioxidant, anti-inflammatory, anti-aging, and antimicrobial effects. However, the therapeutic potential of many phytoconstituents is often limited by their poor aqueous solubility, low skin permeability, chemical instability, and rapid degradation under environmental conditions. To overcome these challenges, advanced delivery systems such as microemulsions, liposomes, cubosomes, and various nanoscale carriers have been developed to enhance stability, bioavailability, and targeted delivery of herbal actives. Additionally, other nanocarriers such as solid lipid nanoparticles, phytosomes, ethosomes, and dendrimers have shown promise in modulating drug release kinetics, enhancing skin penetration, and reducing systemic toxicity, thereby driving research into more efficient delivery technologies for plant-derived actives. Bridging the gap between traditional herbal remedies and modern pharmaceutical innovation is key to unlocking the full potential of cosmeceutical formulations. This review highlights the technological advancements and applications of nanostructured delivery systems in optimizing the efficacy of herbal-based cosmetics, providing a promising approach for next-generation phytocosmeceuticals with improved performance and consumer compliance.

**Keywords:** Herbal extracts, cosmetic and cosmeceutical products, and advanced delivery systems

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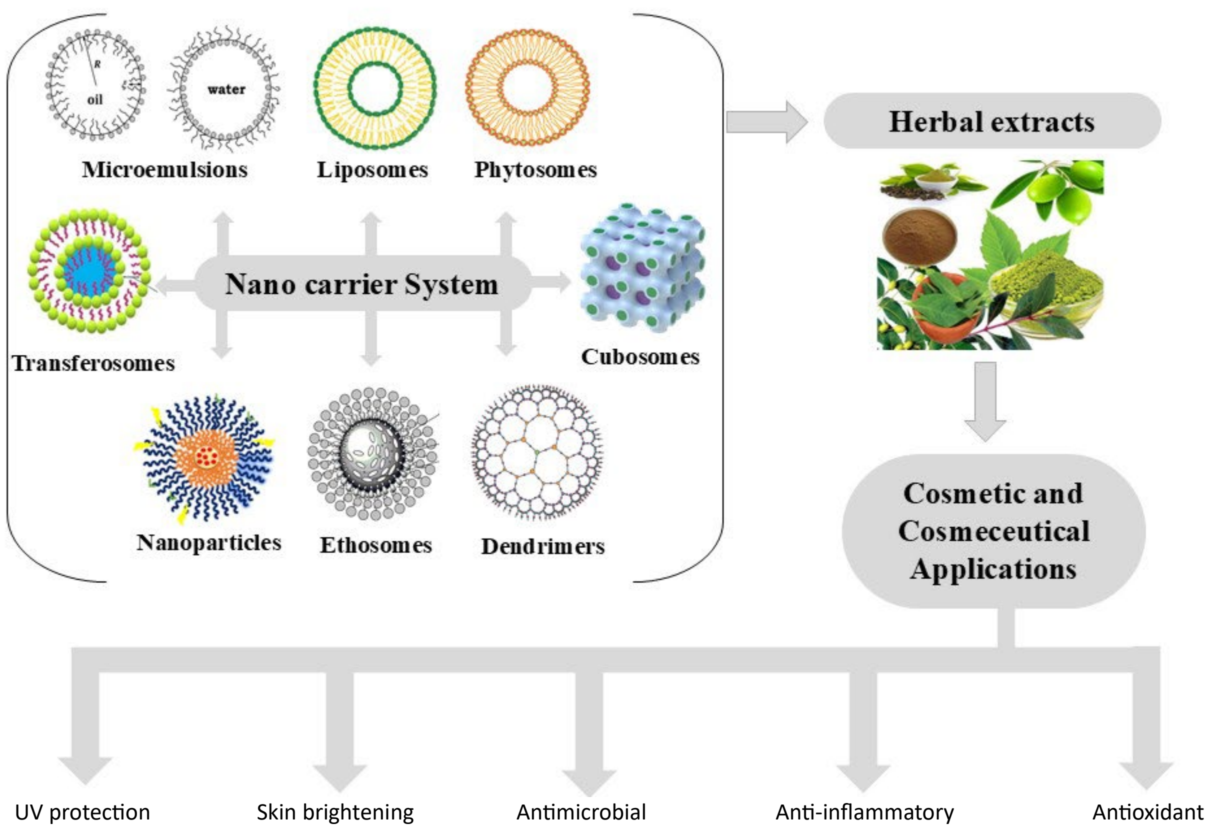
## Graphical Abstract



## INTRODUCTION

Cosmetics are defined as products intended to be applied externally to the human body for cleansing, beautifying, promoting attractiveness, or altering appearance without affecting the body's structure or functions [1]. This definition, as outlined by regulatory authorities such as the U.S. Food and Drug Administration (FDA) and the European Commission, includes a wide range of products such as skin creams, lipsticks, shampoos, deodorants, and perfumes [2]. On the other hand, cosmeceuticals represent a hybrid category that bridges the gap between cosmetics and pharmaceuticals [3]. The term "cosmeceutical" refers to topical formulations that, while marketed as cosmetics, contain biologically active ingredients claiming therapeutic or drug-like benefits on skin health and function, such as anti-aging, pigmentation correction, or acne reduction [4]. Although they are not officially recognized as a separate category by most regulatory bodies, cosmeceuticals are distinguished from conventional cosmetics by their active compounds and functional skin benefits, although without undergoing the rigorous clinical trials required for pharmaceuticals. This developing classification reflects the increasing consumer demand for products that offer both aesthetic enhancement and physiological benefits, thus driving innovation at the intersection of dermatology and cosmetic science [5].

Herbs have played a fundamental role in cosmetic formulations throughout history, and their significance continues to expand in modern cosmetology due to their natural origin, pharmacological activities, and broad spectrum of applications [6]. Herbal extracts are widely incorporated into cosmetic products for their antioxidant, anti-inflammatory, antimicrobial, anti-aging, moisturizing, and skin-brightening properties [7]. Many plant-derived compounds, such as flavonoids, phenolic acids, tannins, alkaloids, saponins, and essential oils, exert beneficial effects on the skin and hair. For example, Aloe vera is valued for its soothing, hydrating, and wound-healing effects, while Chamomile (*Matricaria chamomilla*) is included for its anti-inflammatory and calming properties [8]. Green tea (*Camellia sinensis*) is rich in polyphenols that help neutralize free radicals and protect against photoaging [9]. Turmeric (*Curcuma longa*) offers anti-inflammatory and antimicrobial activities, making it useful in acne and pigmentation control [10]. In addition to their bioactivity, herbal ingredients are also favoured for being biodegradable and generally well-tolerated, making them ideal for use in products targeting sensitive skin and consumers seeking "clean," "green," or "organic" cosmetic alternatives [11].

### Applications of herbal extracts in cosmetic products

Botanical extracts exhibit multifunctional properties that make them valuable components in cosmetic formulations [12]. Their wide-ranging activities, such as photoprotective, antiaging, moisturizing, antioxidant, astringent, anti-irritant, and antimicrobial effects, are often interconnected (Figure 1) [13]. Skin exposure to ultraviolet (UV) radiation and environmental pollutants leads to the formation of reactive oxygen species (ROS), which can induce oxidative stress by damaging cellular DNA, proteins, and lipids [14,15]. This oxidative burden impairs the skin's intrinsic antioxidant defense mechanisms, disrupting cellular homeostasis and accelerating the process of photoaging [16,17]. Long-term consequences include the degradation of collagen and elastin, resulting in visible signs of aging such as wrinkles, fine lines, loss of skin elasticity, surface roughness, and pigmentation disorders [18–20]. Herbal extracts help counteract these effects by modulating oxidative pathways and enhancing the skin's defense systems [21]. Many plant-derived compounds, including polyphenols, flavonoids, and carotenoids, have demonstrated the ability to scavenge free radicals, reduce inflammation, and modulate signalling pathways involved in skin aging [22,23]. Additionally, their moisturizing and soothing properties contribute to the restoration of the skin barrier function. As a result, botanical extracts confer healing, rejuvenating, and protective effects, making them ideal agents in formulations aimed at preventing or treating photoaging and maintaining overall skin health [24]. Details of actions and examples of herbal constituents are presented in Table 1.

### Advanced Delivery Strategies for Herbal Actives in Cosmeceuticals

Conventional cosmetic formulations often suffer from limited skin affinity and transdermal penetration, which restricts their functional efficacy as cosmeceutical agents [25]. To overcome these limitations, recent advancements in drug delivery technologies, particularly in nanotechnology, have provided promising platforms for enhancing the cutaneous delivery of bioactive phytoconstituents and botanical extracts with poor solubility, low permeability, or chemical instability [26,27].

Nanocarriers such as liposomes, niosomes, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), ethosomes, and nanoemulsions have demonstrated superior capabilities in improving dermal and transdermal bioavailability, protecting labile compounds, and enabling controlled or sustained release profiles [28,29]. These systems also enhance the aesthetic attributes (e.g., spreadability, skin feel) and therapeutic effectiveness of herbal-based formulations, while promoting prolonged interaction with the target site. The selection of an appropriate delivery system for herbal cosmeceuticals is governed by various factors, including the intended pharmacological action (localized and systemic), the physicochemical characteristics of the active ingredient (hydrophilicity/lipophilicity), carrier surface charge and permeability, and biocompatibility and biodegradability of the materials [30,31]. Additionally, consideration must be given to immunogenicity, toxicity [32], desired particle size, and the targeted release kinetics [33]. In this respect, the newer approaches developed are discussed here (Figure 2).

**Microemulsions**

Microemulsions are thermodynamically stable colloidal systems capable of encapsulating lipophilic and amphiphilic bioactive compounds, including lipids, antioxidants, antimicrobials, flavor agents, and vitamins [34]. Their unique nanoscale droplet size and interfacial architecture enhance solubilization and improve the chemical stability of incorporated actives [35]. For example, an oil-in-water (O/W) microemulsion system developed with lecithin and alkyl glucoside, both mild, skin-compatible surfactants, has been proposed as an effective delivery vehicle for naturally derived skin-lightening agents such as arbutin and kojic acid, demonstrating improved stability compared to aqueous formulations [36].

Additionally, microemulsions composed of lipid-based phases, surfactant blends, and polar solvents have been utilized to deliver octyl methoxycinnamate, a common UV filter [37], in conjunction with soya lecithin to confer water resistance in sunscreen formulations [38]. Comparative studies have demonstrated the successful formulation of various O/W and W/O microemulsions, as well as multiple emulsions, employing non-ionic and non-methoxylated surfactants with high dermal tolerability. These systems not only preserve the functional integrity of labile compounds, such as ascorbic acid, but also enhance their skin permeability, stability, and aesthetic compatibility in cosmetic applications [39]. Numerous researchers have investigated the application of microemulsions as delivery systems for herbal actives in cosmeceuticals, highlighting their potential to enhance skin penetration, stability, and therapeutic efficacy of botanical compounds.

Firstly, Leanpolchareanchai and Teeranachaideekul [40] investigated the topical application of microemulsions (MEs) for the delivery of herbal substances, focusing on their anti-inflammatory properties. The study demonstrated that MEs loaded with herbal actives did not exacerbate skin irritation compared to unencapsulated herbal substances. In some cases, the incorporation of herbal compounds into MEs was shown to mitigate the skin irritation typically associated with these substances. Moreover, MEs enhanced the therapeutic efficacy of herbal agents, particularly their anti-inflammatory activity, due to improved skin penetration and controlled release. These findings support the potential of MEs as effective colloidal carriers for the topical delivery of herbal actives in cosmeceutical and dermatological applications [40].

Another study, Maneewattanapinyo [41], investigated the solubility profiles of Thai herbal extracts in various oils, surfactants, and co-surfactants to identify suitable components for the formulation of microemulsion systems. Based on the solubility data, the optimal oil phase, surfactant, and co-surfactant were selected to construct pseudo-ternary phase diagrams. This approach facilitated the development of novel microemulsion systems designed specifically for the incorporation of Thai herbal extracts, aiming to enhance their applicability in herbal cosmetic formulations [41]. Additionally**,** Kurup and Joshi [42] developed a microemulsion-based herbal formulation incorporating petroleum ether extracts of Hibiscus rosa-sinensis and Murraya koenigii in a 1:1 ratio, aiming to evaluate its safety and therapeutic efficacy in controlling hair loss. The formulation demonstrated promising drug release profiles, with in vitro and ex vivo release rates of 81.31% and 85.64%, respectively. In vivo assessments confirmed the non-irritant nature of the formulation and revealed superior anti-hair loss activity compared to the standard treatment. These findings highlight the potential of microemulsion systems as effective carriers for herbal actives in hair loss management [42].

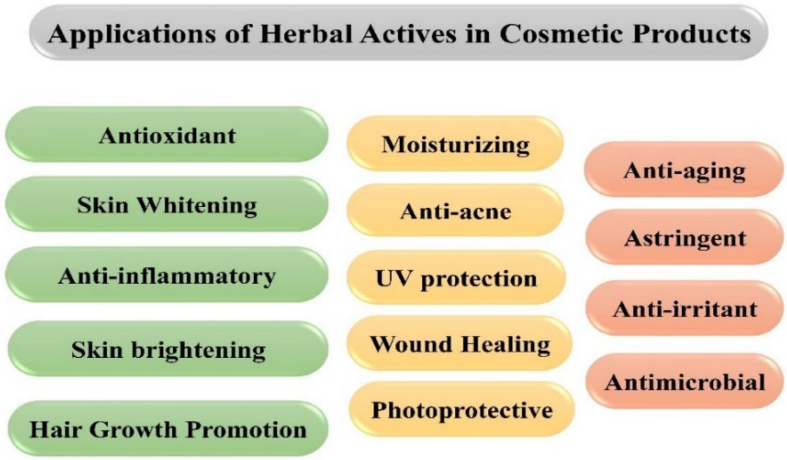



**Figure 1.** Applications of herbal extracts in cosmetics and cosmeceutical products.

**Table 1.** Applications of herbal extracts with actions.

| Applications | Herbal Ingredients | Action | References |
|---|---|---|---|
| Antioxidant & Photoprotective | Vitamin C, Vitamin E, Tea polyphenols, Curcumin, Silymarin, Resveratrol, Ginkgo, Genistein, Pomegranate extract | Neutralize free radicals; reduce erythema, DNA damage, sunburn, and immunosuppression caused by UV exposure. | [132,133] |
| Anti-aging | Pycnogenol, Centella asiatica, Boswellia, Oleanolic acid, Tetrahydrocurcuminoids | Stimulate collagen synthesis and skin repair; restore elasticity; normalize age-related immune and enzymatic imbalances. | [134] |
| Moisturizing | Retinoids, Alpha-hydroxy acids, Fruit acids, Soy extract, Black cohosh, Aloe vera, Calendula | Induce cytokinin release; soften the stratum corneum; fill intercellular spaces; reduce fine lines. | [135,136] |
| Astringent | Arnica, Cucumber | Tighten pores; cool and refresh skin; reduce sebum secretion and balance skin pH. | [137] |
| Anti-irritant & Anti-inflammatory | Coriander seed oil, Bisabolol | Inhibit histamine release; relieve skin irritation and inflammation. | [133] |
| Skin Whitening | Kojic acid, Arbutin, Licorice root extract | Inhibit tyrosinase enzyme; reduce melanin synthesis; lighten hyperpigmented areas. | [138,139] |
| Anti-acne | Tea tree oil, Neem extract, Basil, Green tea | Antimicrobial against *P. acnes*; reduces inflammation; regulates sebum production. | [140] |
| Hair Growth Promotion | Thuja orientalis, Polygonum multiflorum, Hibiscus, Murraya koenigii | Stimulate hair follicle activity; improve hair density and growth cycle regulation. | [141,142] |
| Wound Healing | Aloe vera, Centella asiatica, Calendula, Chamomile | Promote fibroblast proliferation, collagen synthesis, and epithelial regeneration. | [143–146] |

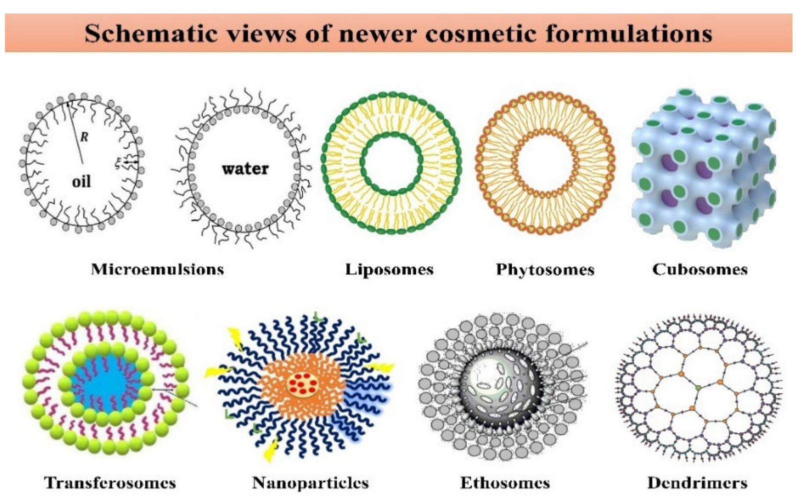



**Figure 2.** Schematic views of newer cosmetic formulations.

Besides, Choedchutirakul *et al .* [43] successfully developed and optimized a microemulsion (ME) system incorporating an herbal remedy extract known as Kae-Lom-Pid. The optimized ME formulation consisted of 4–5% isopropyl myristate, 35–45% S-mix (surfactant/co-surfactant mixture), and 46–58% water. Stability studies confirmed that the ME maintained consistent physical characteristics, including low viscosity and stable pH, particle size, polydispersity index, and zeta potential after undergoing nine heating–cooling cycles. Furthermore, the ME demonstrated a sustained release profile for rhinacanthin-C, with a gradual increase in release from 10.34% ± 0.03% at 0.5 hours to 20.21% ± 0.11% at 8 hours. These findings suggest that Kae-Lom-Pid is well-suited for incorporation into microemulsion systems and holds promise for future pharmaceutical and cosmeceutical applications [43]. Finally, Rangsimawong *et al .* [44] developed microemulsions (MEs) and microemulgels (MGs) to enhance the transdermal delivery of Kaempferia parviflora (KP) extract. The optimized ME system consisted of 5 wt% oleic acid, 20 wt% Tween 20, 40 wt% propylene glycol (PG), and 35 wt% water. Incorporation of KP extract into this system was successful. Among the various formulations tested, the ME containing 10 wt% limonene (ME-L10%) demonstrated the highest transdermal flux of total methoxyflavones. In contrast, the MG and MG-L10% formulations exhibited lower methoxyflavone flux compared to their ME counterparts. These findings indicate that ME formulations, particularly those containing limonene as a permeation enhancer, are more effective in promoting the dermal delivery of KP-derived methoxyflavones than microemulgel-based systems [44].

**Liposomes**

Liposomes are spherical vesicular systems composed of one or more phospholipid bilayers capable of encapsulating both hydrophilic and lipophilic bioactive agents [45]. Hydrophilic compounds are isolated within the aqueous core, while amphiphilic and lipophilic substances, including oil-soluble UV filters, are incorporated into the lipid bilayer [46]. In addition to their role as delivery vehicles, empty liposomes are also employed in cosmetic formulations due to their inherent ability to enhance skin hydration [47]. These vesicles can be unilamellar or multilamellar and range in size from approximately 20 nanometers to several hundred micrometers [48]. The surface charge of the polar lipids used in liposome formation facilitates the encapsulation of charged water-soluble ionic species within the vesicle. Liposomal systems composed of natural phospholipids assist in restoring the skin's barrier function, maintaining hydration, and enabling the sustained release of active ingredients, thereby promoting prolonged cosmetic efficacy [49]. Comparative *in vivo* evaluations of liposome formulations prepared from egg-derived and soy-derived phospholipids have demonstrated that egg phospholipid-based liposomes significantly enhance skin hydration, showing a 1.5-fold increase in water content ($p < 0.05$) [50]. Furthermore, liposomes preferentially localize encapsulated actives within the epidermal and dermal layers, while limiting their systemic permeation [51]. This localization supports targeted delivery and enhances the residence time of active ingredients on the stratum corneum, a desirable attribute for topical applications such as sunscreens. The encapsulation also contributes to water resistance, minimizing wash-off during use [52]. Numerous researchers have investigated the application of liposomes as delivery systems for herbal actives in cosmeceutical formulations.

Firstly, Zhang *et al* [53] developed a novel multifunctional hydrogel formulation, ginseng extract liposome-loaded hybrid hydrogel (GS-LPs@Hy), designed for enhanced skin protection and care. Hydrogel dressings are known for their continuous moisturizing ability, excellent permeability, antibacterial activity, and high biocompatibility, making them promising materials for dermal applications. Ginseng extract, a natural herbal component, possesses multiple beneficial skin-related properties, including antioxidant, anti-inflammatory, brightening, and anti-aging effects. By encapsulating ginseng extract in liposomes and incorporating them into a hybrid hydrogel matrix, the formulation aims to improve the delivery and stability of the active compounds, thereby enhancing their effectiveness in skin protection and rejuvenation. This integrated delivery system demonstrates a synergistic approach, combining the advantages of both liposomal encapsulation and hydrogel matrices to promote sustained release, improved skin absorption, and enhanced therapeutic outcomes [53].

Another study, Saraf *et al* . [54], investigated the impact of incorporating Rosmarinus officinalis (rosemary) extract into a liposomal delivery system on its skin permeation characteristics under in vitro conditions, in comparison to the conventional extract formulation without a delivery system. The study aimed to assess whether the liposomal system significantly enhanced the rate and extent of dermal absorption. The findings revealed that the liposome-encapsulated rosemary extract exhibited a markedly superior skin permeation profile, achieving a high in vitro release rate within 160 minutes, with evidence of rapid absorption occurring within just a few minutes. These results underscore the potential of liposomal carriers to significantly enhance the transdermal delivery efficiency of herbal actives, offering improved therapeutic performance over conventional topical preparations [54].

According to the study by Gyamera and Kim [55], liposomal formulations have been employed in the treatment of dermatological disorders by incorporating both synthetic and herbal agents. This dual approach aims to enhance therapeutic efficacy while minimizing side effects typically associated with synthetic drugs. In their work, antioxidants from green tea leaves and Roselle calyces were encapsulated into cholesterol-based liposomes using the reverse-phase evaporation technique. The formulation process involved various molar ratios of lecithin, Tween 80, and cholesterol, which were systematically analyzed. The yield and total phenolic content (TPC) of the water extracts from green tea leaves (GTLW) and powdered leaves (GTPW) were found to be 30.35 ± 0.90% (TPC: 325.13 ± 1.04 mg GAE/g) and 27.83 ± 1.38% (TPC: 272.65 ± 0.15 mg GAE/g), respectively. For Roselle calyces, the water extracts (GHFW) and powder extracts (GHPW) yielded 52.42 ± 3.23% and 51.49 ± 1.30%, with TPC values of 37.82 ± 0.21 mg GAE/g and 50.00 ± 0.11 mg GAE/g, respectively. In solvent mixtures combining water and organic phases, the green tea leaf extract (GTLWC) and powdered extract (GTPWC) showed slightly lower yields (19.22 ± 1.20% and 19.42 ± 2.28%) with TPCs of 246.67 ± 0.17 mg GAE/g and 180.16 ± 0.81 mg GAE/g. Roselle calyces extracted under similar conditions yielded 52.42 ± 3.23% (GHFWC) and 56.06 ± 1.90% (GHPWC), with respective TPCs of 37.82 ± 0.21 and 38.52 ± 0.34 mg GAE/g. These results support the effectiveness of liposomal systems in encapsulating and preserving the antioxidant content of herbal extracts for cosmeceutical applications [55].

**Phytosomes**

Phytosomes are novel lipid-compatible molecular complexes in which standardized herbal extracts or purified phytoconstituents are complexed with phospholipids, typically phosphatidylcholine, to enhance bioavailability and improve dermal absorption. These complexes possess amphiphilic properties, enabling the enhanced permeation of phytoconstituents through the stratum corneum [56]. The lipidic nature of phytosomes facilitates their integration into the skin's lipid matrix, resulting in improved deposition and therapeutic activity at the targeted site. The phytosome technology enhances the efficacy of bioactive herbal compounds by increasing their solubility, permeability, and cellular uptake, leading to greater tissue distribution [57]. When applied topically, these systems deliver the active constituents directly to the affected site, optimizing pharmacodynamic responses such as hydration, enzymatic balance, and collagen support. Phytosomes have demonstrated superior skin-specific performance compared to conventional liposomal carriers, attributed to their structural affinity with skin lipids [58].

Several phytosome formulations have been successfully developed using botanical extracts, including Ginkgo biloba, grape seed, *Silybum marianum* (milk thistle), green tea, hawthorn, and ginseng [59]. Notably, Ginkgo biloba terpene phytosomes have exhibited significant efficacy in mitigating dermal hypersensitivity responses, while silymarin phytosomes have shown a more than sixfold increase in antioxidant activity compared to the free compound [60]. This enhancement is primarily due to the formation of stable chemical bonds between the phospholipid and phytoconstituent, which confer both improved pharmacokinetics and chemical stability [61]. Phosphatidylcholine, apart from acting as a carrier, contributes to skin health by serving as a structural component of cell membranes. The high biocompatibility and functional benefits of phytosomes position them as promising delivery systems for cosmeceutical and dermatological applications [62,63]. Numerous researchers have investigated the application of phytosomes as delivery systems for herbal actives in cosmeceutical formulations. According to Surini *et al* . [64], grape seed extract (GSE) is rich in phenolic compounds known for their potent antioxidant properties. However, the hydrophilic nature of these phenolics limits their ability to effectively penetrate the skin barrier. To address this challenge, the researchers developed a phytosome-based serum formulation of GSE. The study concluded that incorporating GSE into phytosomes significantly enhanced the dermal penetration of total phenolic compounds when delivered in a serum dosage form, thus improving its potential efficacy in topical antioxidant and cosmetic applications [64].

According to Shree *et al* . [65], herbal cosmeceuticals represent a rapidly evolving segment within the personal care industry, with increasing consumer demand over time. Despite their growing popularity, conventional Phyto-based formulations often suffer from limited skin penetration and instability of active compounds, which compromise their therapeutic efficacy. Nanotechnology has emerged as a promising tool to overcome these limitations by enhancing the stability and delivery of herbal actives. The application of nanoscale delivery systems in cosmeceutical formulation facilitates prolonged and targeted release of plant-derived bioactive compounds, thereby improving their effectiveness in skin-related therapies. This advancement highlights the critical role of nanotechnology in modernizing herbal cosmeceuticals and elevating their performance in dermatological care [65].

**Transferosomes**

Transferosomes are lipid vesicles specifically engineered for non-occlusive topical application, facilitating efficient transdermal delivery. These vesicles possess high elasticity and adaptability, enabling them to traverse the intercellular lipid lamellae of the stratum corneum [66]. Their penetration capability is largely driven by the hydration gradient and osmotic pressure across the skin barrier. Due to their deformable nature, transferosomes can deliver a broad spectrum of bioactive agents, including small molecules, peptides, proteins, and nutraceuticals into and across the skin [67]. They provide localized delivery of nutrients and therapeutic agents, thus contributing to the maintenance and restoration of physiological skin functions. It can encapsulate and transport both hydrophilic and lipophilic compounds, regardless of molecular size, enhancing their dermal bioavailability [68,69]. Upon application, these vesicles merge with the skin’s lipid matrix, facilitating efficient deposition of the encapsulated actives in deeper skin layers, making them promising carriers for both cosmetic and pharmaceutical dermatological formulations [70]. Numerous researchers have investigated the application of Transferosomes as delivery systems for herbal actives in cosmeceutical formulations. This study, Saraf *et al* . [54] developed a stable nano-transpersonal cream aimed at addressing morphological skin defects and enhancing dermal penetration for an anti-wrinkle effect. The formulation involved Soxhlet extraction of Curcuma longa using absolute ethanol and 85% ethanol as solvents. Transferosomes were prepared through the conventional rotary evaporation method. Key formulation parameters were systematically optimized, including the lecithin-to-surfactant ratio, type of surfactant (Tween 20 or Tween 80), and the influence of extraction solvent (95% vs. 85% ethanol). The resulting transferosome cream demonstrated potential for deep dermal delivery and improved cosmetic performance for anti-aging applications [54].

Another study, Wongrakpanich *et al* . [71] investigated the potential of Phyllanthus emblica Linn. (PE) as a hair growth-promoting agent through targeted delivery using transfersomes. Dried PE fruit powder was extracted with two solvent systems—water and 30% ethanol before lyophilization. The ethanolic extract exhibited superior antioxidant activity and total phenolic content compared to the aqueous extract; however, it also showed higher cytotoxicity. Consequently, the aqueous extract was selected for further formulation. Ultra-performance liquid chromatography (UPLC) analysis identified gallic acid as the major bioactive constituent. PE-loaded transfersomes demonstrated promise as an effective carrier system for targeted delivery to hair follicles, offering a novel strategy for enhancing hair growth [71]. Furthermore, Retnaningtyas *et al* . [72] formulated a dual nanocarrier system comprising Centella asiatica transfersomes (CA-TF) and Bergamot essential oil nanoemulsions (BEO-NE), incorporated into a gel for topical application. The objective was to investigate their potential synergistic anti-photoaging and UVB-protective effects. The physicochemical characteristics of nanocarriers were thoroughly evaluated, revealing a monodisperse size distribution with an average particle diameter of $9.64 \pm 0.35$ nm and a zeta potential of $-39.86 \pm 1.33$ mV, indicating good colloidal stability. In vivo studies using BALB/c mice exposed to UVB radiation (840 mJ/cm$^2$) for two weeks assessed the biological efficacy of the combined nanocarrier gel. The findings support the potential of this combinatorial nanocarrier system for enhanced photoprotection and anti-aging skin therapy [72]. Additionally, Chamsai *et al* . [73] investigated the development of a topical formulation incorporating radish sprout extract (R) into transfersomes for potential anti-aging and skin-whitening applications. Radish sprouts are rich in bioactive constituents, notably phenolic compounds and ascorbic acid, known for their inhibitory effect on tyrosinase, the rate-limiting enzyme in melanogenesis. Given the role of UV radiation inducing hyperpigmentation and dermal damage, the

R-loaded transfersomes were integrated into a sunscreen-based emulgel to enhance skin protection. The resulting transferosomal formulation exhibited spherical nanovesicles with a negative surface charge, indicating good colloidal stability. Functional assays demonstrated a significant reduction in both tyrosinase activity and melanin synthesis. Additionally, cytotoxicity testing confirmed that the formulations were safe for skin cells at low concentrations. These findings suggest that R-loaded transfersomes offer a promising platform for multifunctional cosmetic products targeting pigmentation and photoaging [73].

**Nanoparticles**

Nanoparticles offer substantial advantages in dermal applications due to their excellent physicochemical stability and strong affinity for the stratum corneum, resulting in enhanced cutaneous bioavailability of encapsulated actives [74–76]. Formulations incorporating nanoparticles loaded with lipophilic vitamins, such as derivatives of vitamins A and E, have demonstrated superior skin hydration compared to control treatments. This increase in skin moisture is primarily attributed to the high water-retention capability of the phospholipid matrix composing the nanoparticles. Upon topical application, nanoparticles penetrate the superficial layers of the stratum corneum, where they integrate with endogenous skin lipids, facilitating localized release of active agents [77]. Their ultrafine size enables the formation of a continuous adhesive film on the skin surface, exerting an occlusive effect that further enhances the percutaneous absorption of the encapsulated compounds. Nanoparticles have been extensively utilized to deliver a wide array of bioactives, including vitamins, UV filters, fragrances, and essential oils [78].

These nanocarriers offer multiple benefits, such as stabilization of labile compounds, controlled release profiles, improved pigment dispersion, and enhanced skin hydration and protection through film-forming mechanisms [79]. Compared to conventional liposomal carriers, nanoparticles exhibit a higher loading capacity for lipophilic agents and improved formulation versatility, including low viscosity and non-greasy textures [80]. Solid lipid nanoparticles (SLNs) have emerged as promising excipients in cosmetic science, notably for their ability to enhance skin hydration and viscoelasticity [81]. Their high compatibility with conventional excipients allows for seamless integration into existing cosmetic products. For example, encapsulation of α-lipoic acid, an anti-aging compound susceptible to oxidative degradation and associated odor, in SLNs effectively stabilizes the active and mitigates sensory drawbacks [82]. Additionally, SLN-based sunscreens have demonstrated the potential to reduce the required concentration of molecular UV filters by approximately 50%, while maintaining comparable photoprotective efficacy relative to traditional emulsions [37,83]. Numerous researchers have investigated the application of nanoparticles as delivery systems for herbal actives in cosmeceutical formulations.

In this study, Pham *et al .* [84] explored the use of silk fibroin nanoparticles (SFNs) as a nanocarrier system to enhance the stability and delivery of phenolic compounds derived from guava (Psidium guajava L.) leaf ethanolic extract. Guava is rich in phenolic antioxidants, yet these bioactives are prone to degradation under environmental and physiological conditions such as heat, light, pH, oxidation, and enzymatic activity. To address this challenge, guava extract was obtained via maceration, yielding a total phenolic content of 312.6 mg GAE/g DPW and notable antioxidant activity ($IC_{50}$ = 5.397 ± 0.618 µg/mL). The extract was subsequently encapsulated into SFNs using the desolvation technique. The resulting nanoparticles exhibited favorable physicochemical characteristics, including a narrow size distribution (200–700 nm), spherical morphology, and a silk-II crystalline structure. The formulation achieved an encapsulation efficiency exceeding 70%, which was influenced by the fibroin content. Additionally, the SFNs provided a biphasic sustained release profile lasting up to 210 minutes. These findings support the potential of SFNs as a robust delivery platform to stabilize and prolong the antioxidant efficacy of guava-derived phenolics in cosmetic applications [84].

Another study, Haddada *et al .* [85] investigated the potential of *Hubertia ambavilla*, a medicinal plant endemic to Réunion Island, for the green synthesis of gold nanoparticles (AuNPs) intended for cosmetic applications. Traditionally recognized for its anti-inflammatory and wound-healing properties, *H. ambavilla* was utilized to extract polyphenolic compounds capable of simultaneously reducing gold salts and stabilizing the resulting nanoparticles. The biosynthesized AuNPs exhibited significant dermoprotective activity, antioxidant capacity, and free radical scavenging effects, highlighting their relevance as anti-aging cosmetic ingredients.

Importantly, these green-synthesized nanoparticles demonstrated biocompatibility, showing no cytotoxicity towards human dermal fibroblasts. Furthermore, they offered protection against UVA-induced damage in fibroblast and dermal cells. When compared to AuNPs synthesized via the classical Turkevich method, the *H. ambavilla*-mediated nanoparticles displayed superior biological activity, emphasizing the critical influence of plant-derived coatings on nanoparticle functionality. The classical Turkevich method is a widely used chemical technique for synthesizing gold nanoparticles, in which chloroauric acid ($HAuCl_4$) is reduced by sodium citrate in boiling aqueous solution. In this process, sodium citrate serves both as the reducing agent, converting $Au^{3+}$ ions into metallic gold, and as the stabilizing agent, preventing nanoparticle aggregation. The method typically produces uniform, spherical nanoparticles with controllable sizes by adjusting the citrate-to-gold ratio. While it is valued for its simplicity and reproducibility, the Turkevich method relies on chemical reagents, which may limit biocompatibility compared to green synthesis approaches that use plant-derived compounds as natural reducers and stabilizers. This study underscores the promise of phyto-mediated nanotechnology in developing safe and efficacious cosmetic formulations [85].

Besides, Jiménez-Pérez *et al .* [86] explored the green synthesis of gold nanoparticles (PgAuNPs) using Panax ginseng leaf extract, aiming to assess their potential as multifunctional cosmetic ingredients. The bioactive constituents in P. ginseng facilitated the reduction of metal ions and stabilization of the nanoparticles, yielding novel nanostructures with enhanced properties. The study evaluated the antioxidant activity, moisture retention capability, and skin-whitening potential of the synthesized PgAuNPs. Results demonstrated that these nanoparticles exhibited significant free radical scavenging activity, improved skin hydration, and inhibited melanin synthesis—key attributes desirable in cosmetic formulations. This investigation is the first to confirm the multifunctional benefits of P. ginseng leaf-mediated AuNPs in dermatological applications, suggesting their promise as value-added, bioactive components in next-generation skincare products [86].

Additionally, Lacatusu *et al .* [87] developed nanostructured herbal formulations incorporated into hydrogels (HGs) designed to enhance the transdermal absorption of bioactive compounds derived from selective plant extracts and vegetable oils. These nanostructured lipid carriers (NLCs), formulated with Carrot Extract (CE) and Marigold Extract (ME) using rosehip or black cumin oil as lipid matrices, demonstrated notable biocompatibility and stability. The hydrogel systems exhibited a synergistic therapeutic response characterized by potent antioxidant, anti-inflammatory, and anti-acne effects, without eliciting adverse side effects. The formulations showed strong capacity for scavenging both short- and long-lived free radicals, thereby highlighting their promise for topical dermatological and cosmeceutical applications [87].

Another study, Sallustio *et al .* [88], explored the extraction of bioactive compounds from rosehips and blackthorns using natural deep eutectic solvents (NaDES) and their subsequent encapsulation within chitosan nanoparticles for cosmetic use. The phenolic profiles of the extracts derived via ethanolic and NaDES extraction were analyzed using phytochemical assays. Chitosan nanoparticles were formulated with varying polymer concentrations and crosslinking agents, then assessed for their physicochemical properties. The study concluded that chitosan nanoparticles loaded with NaDES-based extracts represent a promising, eco-friendly antioxidant delivery system suitable for incorporation into cosmetic formulations [88].

**Cubosomes**

Cubosomes are nanostructured particles derived from bicontinuous cubic liquid crystalline phases. These systems comprise two distinct, non-intersecting aqueous channels separated by a lipid bilayer that adopts a periodic minimal surface with zero mean curvature [89]. This unique architecture results in an extensive internal surface area and a highly ordered, thermodynamically stable structure. In comparison to conventional liposomes, cubosomes possess a markedly higher bilayer surface area-to-particle volume ratio, enhancing their loading capacity for both hydrophilic and lipophilic agents. Their strong bioadhesive properties promote prolonged skin contact and improved retention of active ingredients, making them particularly suitable for dermal and transdermal cosmetic applications [90].

Owing to their structural versatility, cubosomes can encapsulate a broad range of cosmetic actives, including lipophilic, amphiphilic, and water-soluble compounds [91]. Their ability to provide controlled and sustained release of actives, combined with superior skin adherence and compatibility, positions them as an innovative platform for the delivery of functional ingredients in advanced cosmetic and personal care formulations [92]. Numerous researchers have investigated the application of cubasomes as delivery systems for herbal actives in cosmeceutical formulations.

In this study, Araujo *et al .* [93] presented a comprehensive review on the advancement of nano delivery systems tailored for the nanoencapsulation of plant extract-based cosmetics. These systems are designed to enhance skin penetration and ensure efficient release of active cosmetic agents. The review highlights a diverse array of nano-systems, including lipid-based nanoparticles, vesicular carriers, cubosomes, nanoemulsions, polymeric nanoparticles, nanofibers, and metal-based nanostructures such as silver, gold, and zinc oxide nanoparticles. Furthermore, the study emphasizes extract-based cosmeceuticals documented in the literature and elaborates on the key physicochemical characteristics of plant extract-loaded nano-systems. The authors underscore the potential of these nanotechnological strategies to revolutionize the cosmetics industry, offering innovative solutions in one of the most dynamic sectors of the global market [93].

Another study, Seo *et al .* [94] investigated the in vivo hair growth-promoting effects of six herbal extracts: Poria cocos, *Thuja orientalis, Espinosilla, Lycium chinense* Mill, *Coix lacryma-jobi*, and Polygonum multiflorum Thunberg formulated both in their pure form and incorporated into monoolein-based cubosomal suspensions. Hair regrowth was assessed on days 0, 10, 15, and 20 through visual observation and histological evaluation of hair follicles. Among the tested extracts, Thuja orientalis, Polygonum multiflorum, and Espinosilla demonstrated notable hair growth-promoting activity. Notably, cubosome-based formulations significantly enhanced the efficacy of these extracts. The cubosomal herbal systems showed comparable activity to a 2.4% minoxidil solution, a standard hair growth agent. These results suggest that cubosomes effectively improve the skin permeation and therapeutic performance of herbal actives, positioning them as promising nanocarriers for topical hair loss treatments [94].

Furthermore, Ahmad *et al .* [95] highlighted the complexities associated with cosmetic formulation, emphasizing that the efficacy of active ingredients is highly dependent on both the carrier system and the barrier properties of the skin. The epidermis, particularly the stratum corneum, presents the primary challenge for transdermal delivery, limiting the permeation of many bioactive compounds. Several formulation-related parameters, including particle size, viscosity, and the lipophilic/hydrophilic balance, significantly influence the extent of dermal absorption. Despite the widespread use of conventional creams and gels, their performance often remains suboptimal due to poor penetration and bioavailability [96]. This review focuses on advanced nanoscale delivery systems such as nanoemulsions, nanogels, liposomes, niosomes, dendrimers, cubasomes, and fullerenes, which have shown considerable promise in enhancing the delivery and efficacy of cosmetic agents by facilitating deeper skin penetration and improved controlled release profiles. These novel nanocarrier systems offer innovative solutions to overcome conventional limitations in dermal product performance [95].

Another study, Sharma *et al .* [97], described cubosomes as biocompatible, thermodynamically stable, and bioadhesive nanostructured drug delivery systems formed from specific ratios of amphiphilic lipids and surfactants. These self-assembled nanoparticles exhibit a liquid crystalline structure characterized by a three-dimensional bicontinuous lipid bilayer architecture, creating two distinct aqueous channels separated by lipid domains. This structural configuration imparts a honeycomb-like morphology, which has been confirmed by small-angle X-ray scattering (SAXS) and cryo-transmission electron microscopy (cryo-TEM), showing square and spherical particles within the nanometre range. Owing to their large internal surface area and dual aqueous-lipid regions, cubosomes are capable of encapsulating and delivering a wide spectrum of hydrophilic, hydrophobic, and amphiphilic bioactive agents, making them highly versatile for pharmaceutical and cosmeceutical applications [97].

Additionally, Otlatıcı *et al .* [98] emphasized that skin aging is an unavoidable biological phenomenon influenced predominantly by ultraviolet (UV) radiation, with additional contributing factors including nutritional deficiencies, dry skin, smoking, hormonal changes, and gravity. Skin aging is categorized into intrinsic aging (chronological) and extrinsic aging (photoaging). Clinically, aged skin presents with thinning of the dermis, loss of elasticity, hyperpigmented spots, wrinkles, and sagging. To mitigate these aging effects, numerous cosmeceutical interventions have been developed, incorporating bioactive compounds such as kinetin, retinoids, sun filters, and plant-derived ingredients (e.g., resveratrol, curcumin, and green tea polyphenols), as well as potent antioxidants like alpha-tocopherol (vitamin E), ascorbic acid (vitamin C), coenzyme Q10, and lipoic acid. Recent innovations have focused on enhancing the delivery and bioavailability of these agents through advanced nanoscale delivery systems, including vesicular carriers, polymeric and lipid-based nanoparticles, nanoemulsions, dendrimers, and fullerenes. These nanocarrier systems offer multiple advantages over traditional formulations, such as improved skin penetration, targeted delivery, controlled release, and increased stability of active ingredients. The review presents a comprehensive summary of current cosmeceutical strategies and nanotechnological approaches aimed at preventing or reversing the signs of skin aging [98].

**Ethosomes**

Ethosomes are novel lipid-based nanocarriers composed of phospholipids, high concentrations of ethanol (typically 20–45%), and water [99]. These flexible vesicles are specifically engineered to improve dermal delivery of active compounds, including various plant-derived phytoconstituents [100]. The inclusion of ethanol increases the fluidity of the lipid bilayer and enhances the permeability of the stratum corneum, thereby enabling deeper penetration of encapsulated herbal molecules into the skin. Herbal extracts often contain bioactive constituents with poor water solubility or limited skin absorption due to their high molecular weight or hydrophilicity. Ethosomes facilitate the transdermal and dermal delivery of such phytochemicals, including flavonoids, terpenoids, polyphenols, and alkaloids, by disrupting the ordered lipid structure of the skin's barrier [101]. This mechanism significantly enhances the bioavailability and therapeutic effect of herbal actives in cosmetic formulations. Another advantage of ethosomes is their ability to stabilize labile herbal constituents [27]. Many natural compounds are prone to oxidative degradation, photolysis, or hydrolysis when exposed to environmental stressors. Encapsulation within ethosomes protects these actives from degradation, prolongs shelf life, and ensures sustained release upon topical application. This is particularly beneficial for herbal ingredients such as curcumin, resveratrol, and silymarin, which are otherwise unstable in conventional formulations [102].

Ethosomal delivery systems also offer reduced skin irritation and improved compatibility with human skin [99]. The non-occlusive, deformable nature of ethosomes enables smooth application and uniform distribution without disrupting the skin's natural physiology. These characteristics make ethosomal formulations especially suitable for sensitive or allergy-prone skin [103]. They have been employed in various cosmetic applications, including anti-aging, depigmenting, antioxidant, and anti-inflammatory products [104]. For instance, ethosomal encapsulation has been reported to enhance the efficacy of kojic acid and arbutin in skin-lightening formulations, improve the anti-wrinkle effects of Centella asiatica, and promote the anti-acne activity of tea tree oil [105]. Moreover, the vesicular system allows for controlled and sustained release of herbal actives, reducing the frequency of application while maintaining prolonged efficacy [106]. Numerous researchers have investigated the application of ethosomes as delivery systems for herbal actives in cosmeceutical formulations.

Firstly, Madhunithya *et al.* [107] investigated the hair growth-promoting potential and dermal safety of Phyllanthus niruri leaves, Zingiber officinale rhizomes, and Croton tiglium Linné seed extracts when incorporated into ethosomal formulations. Extracts were prepared using petroleum ether and ethanol, followed by phytochemical screening, heavy metal analysis, sterility tests, and HPTLC profiling, which confirmed the presence of flavonoids and phenolic compounds in both extract types and their respective formulations. In vitro cytotoxicity assays using keratinocyte cell lines demonstrated that the combined pet. The ether extract formulation exhibited higher cytotoxicity ($IC_{50}$ = 43 µg/mL) compared to the ethanol-based formulations. Histological evaluations and hair follicle parameters (density, anagen/telogen ratio, and follicle count) revealed that pet. Ether extract of C. tiglium and combined pet. Ether extract-loaded ethosomes had superior efficacy in promoting hair growth relative to the combined ethanolic extract-loaded ethosomes. However, ethanolic formulations showed significantly greater dermal safety, with no signs of irritation observed during skin irritation tests. Histopathological assessment after 21 days of treatment confirmed normal epidermal architecture and active hair follicle presence in the groups treated with the combined ethanolic extract formulation [107].

Another study, Hyder *et al.* [108], explored the development of a herbal ethosomal gel containing *Glycyrrhiza glabra* methanolic extract for the treatment of acne vulgaris, offering an alternative to synthetic anti-acne agents that often cause undesirable side effects. The extract, rich in phytoconstituents with known antibacterial and antioxidant activity, was confirmed to contain glycyrrhizin using UV spectrophotometry. The ethosomal gels (EF1, EF2, EF3) were formulated using Carbopol® 940 as the gel base and subjected to a series of evaluations, including pH, viscosity, spreadability, texture profile, and thermal and chemical characterization using DSC and FT-IR. The in vitro drug release profile and antioxidant activity against Propionibacterium acne were assessed to confirm the formulation's therapeutic potential. To study skin permeation, the ethosomal gels were radiolabelled using two types of tracers: hydrophilic $^{99m}$Tc-DTPA and lipophilic $^{99m}$Tc-MIBI and evaluated through gamma scintigraphy. The hydrophilic tracer $^{99m}$Tc-DTPA showed significant permeation (1.3 µg/mg), indicating the gel's ability to penetrate the skin effectively and deliver the drug in a sustained manner, suitable for moderate to severe acne therapy [108]. Moreover, Jadaun and Rai [109] developed an ethosomal delivery system encapsulating kiwi extract for its potential anti-aging effects. The study focused on formulating and evaluating ethosomes loaded with kiwi and rosemary extracts to enhance dermal delivery and therapeutic efficacy. The ethosomal vesicles were designed to improve skin permeation, providing sustained release and maximizing the bioavailability of active phytoconstituents for cosmetic and dermatological applications [109].

Another study, Shegokar [110], highlights the integration of nanotechnology in the formulation of herbal-based cosmetic products. Historically, cosmetics have garnered attention across all age groups. While conventional cosmetics often rely on synthetic ingredients such as parabens, urea derivatives, petrolatum, and surfactants, herbal cosmetics incorporate bioactive phytoconstituents known for their therapeutic potential. Among nanocarriers, liposomes were the earliest and remain widely used in cosmetic applications. Nanotechnology enhances not only the formulation and stability of multicomponent herbal cosmetics but also their efficacy and targeted delivery. This approach holds promise for the future of natural herbal cosmetics, offering safer and more efficient alternatives to conventional synthetic formulations in the global beauty industry [110].

**Dendrimers**

Dendrimers are highly branched, monodisperse, nanoscale macromolecules with a well-defined three-dimensional architecture and numerous surface functional groups [111]. These unique structural features make dendrimers exceptionally suitable as carriers for herbal bioactives in cosmetic formulations, offering significant advantages in solubility enhancement, targeted delivery, and controlled release [112]. One of the primary challenges in incorporating herbal extracts into cosmetics is the poor aqueous solubility and instability of many phytochemicals, such as curcumin, resveratrol, and quercetin [113]. Dendrimers, particularly polyamidoamine (PAMAM) types, can encapsulate hydrophobic herbal molecules within their internal cavities or bind them to their surface via covalent or non-covalent interactions. This improves solubility, enhances dermal penetration, and protects the active constituents from premature degradation caused by environmental factors such as light, pH, or oxidative stress [114].

In herbal cosmeceuticals, dendrimers facilitate site-specific delivery of actives to targeted skin layers, thereby maximizing therapeutic efficacy while minimizing systemic absorption and potential toxicity [115]. Their multivalency enables conjugation with multiple herbal molecules, enhancing synergistic actions, for example, combining anti-inflammatory and antioxidant effects within one nanocarrier. Additionally, surface functionalization with natural ligands or moieties such as sugars, peptides, or vitamins can further enhance skin compatibility and reduce irritation [116]. Dendrimers also allow for controlled and sustained release of herbal compounds, which is essential in maintaining prolonged activity of bioactives on the skin surface. This property is particularly valuable in anti-aging, depigmenting, moisturizing, and photoprotective formulations [117]. For instance, dendrimer-based delivery of polyphenols or flavonoids can lead to more durable antioxidant effects, helping to combat oxidative stress-induced skin aging and pigmentation disorders [118]. In this study, Kumar *et al.* [119] emphasized that cosmeceutical treatments represent one of the most rapidly expanding segments within the personal care industry, addressing conditions such as skin aging, wrinkles, hair damage, and hyperpigmentation. To enhance the performance and consumer appeal of cosmetic products, both domestic and international brands are increasingly incorporating nanotechnology. This advancement offers innovative avenues for product development, allowing modifications at the molecular and atomic levels. Nanotechnology confers several benefits in the cosmeceutical field, including enhanced bioavailability of active agents, improved cutaneous penetration, controlled and sustained drug release, and targeted delivery. These attributes contribute to increased product efficacy and stability. Notably, micellar nanoparticles are emerging as a prominent nanocarrier system in cosmetic formulations, facilitating efficient percutaneous absorption due to their high surface area and ability to transport bioactive constituents [119].

Another study, Kaul *et al.* [120], reported that nanotechnology represents significant advancement in research and development within the cosmeceutical industry by enhancing product efficacy through innovative delivery strategies. Its integration addresses limitations associated with traditional cosmetic formulations, contributing to the rapid expansion of nanotechnology applications in cosmeceuticals, currently among the fastest-growing sectors in personal care. Nanocosmeceuticals have gained widespread usage for skin, hair, nail, and lip care, targeting dermatological conditions such as wrinkles, photoaging, hyperpigmentation, dandruff, and hair damage. Advanced nanocarriers, including liposomes, niosomes, nanoemulsions, microemulsions, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), and nanospheres, have largely replaced conventional delivery systems due to their improved skin penetration, controlled and sustained release, enhanced stability, site-specific targeting, and high entrapment efficiency. Nevertheless, the increased incorporation of nanoparticles raises toxicological concerns, as these particles may permeate the skin barrier and elicit systemic health effects. This review comprehensively explores the application of nanotechnology in cosmeceuticals, evaluating the benefits and limitations of various nano-systems, their commercial availability, associated toxicological risks, and current regulatory frameworks [120].

Furthermore, Sharma *et al.* [121] highlighted that the integration of novel drug delivery systems (NDDS) in herbal medicine significantly enhances therapeutic efficacy while reducing adverse effects. Although traditional herbal drug delivery systems have been historically employed for disease treatment and recovery, the emergence of allopathic and homeopathic medicines led to a decline in the perceived effectiveness and utilization of herbal therapeutics. However, modern advancements in drug delivery technologies have revitalized the potential of herbal formulations, enabling their application in the management of more complex and chronic diseases. Limitations such as inadequate standardization, inefficient extraction methods, difficulty in isolating individual active components, and the complexity of polyherbal mixtures have hindered the development of effective herbal medicines [121]. These challenges can be addressed through modern Phyto-pharmaceutical research, which provides improved pharmacokinetic profiles and a clearer understanding of mechanisms of action [121]. The applications of nanocarrier systems in cosmetics and cosmeceuticals are summarized in Table 2. A comparative overview of their advantages, limitations, and performance differences for delivering herbal actives in cosmetic and cosmeceutical formulations is presented in Table 3.

**Safety and Regulatory Aspects**

The integration of nanocarrier-based systems in cosmetic and cosmeceutical formulations introduces unique safety considerations that differ from those of conventional products. Due to their nanoscale dimensions, these carriers can penetrate deeper into the stratum corneum and, in certain cases, reach viable epidermal or dermal layers, raising concerns about systemic absorption, bioaccumulation, and long-term toxicological effects [122]. Key toxicological endpoints include cytotoxicity, oxidative stress induction, genotoxicity, and immunogenicity, which may be influenced by particle size, shape, surface charge, composition, and coating materials. Comprehensive safety assessment requires a multi-tiered approach combining in vitro assays (e.g., keratinocyte viability, ROS generation), ex vivo skin penetration studies, and in vivo dermal toxicity evaluations [123]. The lack of harmonized protocols for nanomaterial testing in cosmetics remains a critical challenge. From a regulatory standpoint, international frameworks vary considerably in their approach to nanotechnology in cosmetics:

- United States (FDA): Cosmetics are regulated under the Federal Food, Drug, and Cosmetic Act, with no specific nanotechnology law; however, the FDA encourages manufacturers to assess nanoscale materials for safety and to label ingredients accurately. While pre-market approval is not required for cosmetics (except for color additives), products must not be adulterated or misbranded [124].

**Table 2**. Applications of Nanocarrier System in the field of cosmetics and cosmeceuticals.

| Nanocarrier System | Cosmetic Role | Type of Herbal Agent | Reference |
|---|---|---|---|
| Microemulsions | Enhanced solubilization, stability, and skin permeation of herbal actives; used in sunscreens and anti-inflammatory cosmetics | General herbal actives (polyphenols, terpenoids) | [39] |
| Microemulsions | Optimized Thai herbal extract microemulsions via pseudoternary phase diagram for cosmetic use | Mixed Thai herbal extracts | [40] |
| Microemulsions | Herbal microemulsion for hair loss control; high in vitro/ex vivo release; non-irritant | Herbal blend for alopecia (e.g., plant polyphenols) | [41] |
| Microemulsions | Optimized Kae-Lom-Pid microemulsion; stable properties and sustained rhinacanthin-C release | Rhinacanthus nasutus extract (rhinacanthin C) | [42] |
| Microemulsions | Kaempferia parviflora microemulsions/microemulgels for enhanced transdermal flavone delivery | Kaempferia parviflora flavones | [43] |
| Liposomes | Ginseng-extract liposome hybrid hydrogel for moisturizing, permeability, antibacterial, and-aging skin care. | Panax ginseng extract (ginsenosides) | [52] |
| Liposomes | Rosemary-extract liposomes improved in vitro skin permeation vs. conventional formulations. | Rosmarinus officinalis extract | [53] |
| Liposomes | Review of herbal liposome use in cosmetics: antioxidant, anti-inflammatory, and acne prevention | Various herbal extracts | [147] |
| Liposomes | Green-tea/Roselle liposomal antioxidants for dermatological applications; phenolic content analysis | Camellia sinensis, Hibiscus sabdariffa | [54] |
| Phytosomes | Grape seed phytosome serum improved the dermal penetration of total phenolics. | Vitis vinifera seed extract | [63] |
| Phytosomes | Nanotechnology enhances herbal cosmeceuticals' delivery and stability | Various herbal actives | [64] |
| Transfersomes | Curcuma longa transfersomal cream for deep dermal anti-wrinkle effect | Turmeric (curcuminoids) | [53] |
| Transfersomes | Phyllanthus emblica transfersomes for hair-follicle targeting and hair growth. | Indian gooseberry (emblicanin) | [70] |
| Transfersomes | Centella asiatica transfersomes + bergamot NE gel for UV protection, anti-photaging | Centella asiatica, Citrus bergamia | [71] |
| Transfersomes | Radish sprout extract transfersomes in sunscreen emulgel for anti-aging & whitening. | Raphanus sativus sprouts | [72] |
| Nanoparticles | Silk-fibroin nanoparticles enhanced the stability and sustained release of guava phenolics. | Psidium guajava | [83] |
| Nanoparticles | Hubertia-mediated gold nanoparticles: antioxidant, dermoprotective, UVA protection | Hubertia ambavilla | [84] |
| Nanoparticles | Panax ginseng leaf gold nanoparticles: antioxidant, moistening, whitening cosmetic claims | Panax ginseng leaves | [85] |
| Nanoparticles | Carrot/Marigold NLC hydrogel: antioxidant, anti-inflammatory, anti-acne, high biocompatibility | Daucus carota, Calendula officinalis | [86] |
| Nanoparticles | Chitosan nanoparticles with rosehip/blackthorn NaDES extracts: green antioxidant cosmetics | Rosa canina, Prunus spinosa | [87] |
| Cubosomes | Review of nano-delivery systems; cubosomes highlighted for plant-extract cosmetics | Various herbal extracts | [92] |
| Cubosomes | Herbal cubosomal suspensions (e.g., Thuja orientalis) for hair growth comparable to minoxidil | Thuja orientalis | [93] |
| Cubosomes | Review emphasizes nanocarrier advances (incl. cubosomes) for overcoming skin barrier. | Various herbal actives | [94] |
| Cubosomes | Structural & functional characterization of cubosomes as biocompatible dermal carriers | General plant-derived actives | [120] |
| Cubosomes | Nanosystems (cubosomes, vesicles, etc.) reviewed for photoaging interventions | Various herbal extracts | [97] |
| Ethosomes | Enhanced follicular delivery and hair growth; assessed skin safety of *Phyllanthus niruri*, *Zingiber officinale*, and *C. tiglium* extracts | Phyllanthus niruri, Zingiber officinale, Croton tiglium | [106] |
| Ethosomes | Anti-acne therapy using *Glycyrrhiza glabra* extract; antibacterial and antioxidant effect; sustained drug delivery | Glycyrrhiza glabra | [107] |
| Ethosomes | Anti-aging potential using kiwi and rosemary extract; enhanced dermal delivery and sustained release. | Actinidia deliciosa, Rosmarinus officinalis | [108] |
| Dendrimers | General enhancement in bioavailability, sustained release, and penetration of cosmeceuticals; micellar nanoparticles in focus | Various herbal actives | [118] |
| Dendrimers | Broad review of nanotechnology in cosmeceuticals; improved penetration, targeting, stability; regulatory concerns | Various herbal extracts | [119] |

**Table 3**. Comparative summary of advantages, limitations, and performance differences of nanocarrier systems for herbal actives in cosmetic and cosmeceutical applications.

| Nanocarrier system | Advantages | Limitations | Performance differences | References |
|---|---|---|---|---|
| Liposomes | Biocompatible and biodegradable; encapsulate both hydrophilic and lipophilic actives; enhance skin hydration; targeted epidermal/dermal delivery | Prone to oxidation and hydrolysis of phospholipids; physical instability (fusion, leakage); high production cost | Moderate skin penetration; good for localized delivery; stability improved with antioxidants or polymer coating | [148] |
| Ethosomes | High ethanol content enhances penetration through the stratum corneum; suitable for both hydrophilic and lipophilic actives; good stability of certain phytoconstituents. | Ethanol may irritate sensitive skin; limited loading for highly hydrophilic compounds. | Superior transdermal delivery over liposomes; improved stability of unstable phytochemicals | [149] |
| Phytosomes | Strong phospholipid–phytoconstituent complexation improves solubility and bioavailability; high skin affinity; enhanced antioxidant activity. | Complex preparation; limited data for large-scale manufacturing; cost of high-purity phospholipids | Higher dermal deposition than conventional liposomes; excellent for polyphenolic compounds | [150] |
| Solid Lipid Nanoparticles (SLNs) | Excellent physicochemical stability; controlled release; occlusive film enhances hydration; compatible with cosmetic bases | Low loading capacity for hydrophilic actives; risk of polymorphic transitions during storage | High stability and skin adhesion; good UV filter carriers; lower drug expulsion than NLCs | [80] |
| Nanostructured Lipid Carriers (NLCs) | Higher loading capacity than SLNs; reduced drug expulsion; flexible release profiles; good stability | More complex formulation; potential lipid oxidation | Better active retention during storage; improved performance for lipophilic actives over SLNs | [151] |
| Cubosomes | High internal surface area; can encapsulate hydrophilic, lipophilic, and amphiphilic molecules; strong skin bioadhesion; sustained release. | Viscosity may limit spreadability; manufacturing complexity | Superior loading capacity compared to liposomes; prolonged skin residence time | [152] |
| Transfersomes | Highly deformable vesicles enable deep skin penetration; suitable for macromolecules and herbal extracts. | Stability issues due to surfactant content; possible irritation | Higher penetration depth and transdermal flux than liposomes/ethosomes | [65] |
| Dendrimers | Precisely defined nanoscale structure; multiple surface functional groups for ligand attachment; high loading capacity; controlled release | Potential cytotoxicity depending on generation and surface groups; synthesis cost | Enhanced solubility and penetration for poorly soluble phytoconstituents; tunable delivery profiles | [153] |

- European Union (EU): Under Regulation (EC) No 1223/2009, all nanomaterials used in cosmetics must be notified to the European Commission six months before market placement. The ingredient list must indicate nanoscale substances using the term "(nano)". A rigorous safety assessment, including particle characterization and toxicological data, is mandatory [125].
- ASEAN Cosmetic Directive (ACD): ASEAN member states follow harmonized guidelines requiring full ingredient disclosure, compliance with safety requirements, and prohibition of certain hazardous nanomaterials. While the ACD does not have a dedicated nanotechnology regulation, member states are adopting EU-aligned safety assessment approaches for nanocarrier-based products [126].
- Global regulatory convergence on definitions, testing protocols, and labelling requirements is essential to ensure both consumer safety and industry innovation. Establishing long-term dermal exposure databases, advancing non-animal alternative testing methods, and promoting transparent risk communication will be critical for the safe and sustainable integration of nanocarriers in herbal cosmetic and cosmeceutical products [127].

**Limitations**

Although advanced nanocarrier-based strategies markedly enhance the stability, penetration, and bio-efficacy of herbal actives in cosmetic and cosmeceutical formulations, several constraints limit their broader implementation. Many nanocarriers exhibit physicochemical instability, including aggregation, phase separation, which may alter particle size distribution and compromise functional performance during storage [128]. Compatibility between nanocarriers and complex semisolid or multiphase cosmetic matrices is not always assured, potentially leading to reduced encapsulation efficiency or premature active release. Scale-up from laboratory to industrial production remains challenging due to the need to maintain critical quality attributes such as particle morphology, zeta potential, and controlled release profiles [74,75,129,130]. Regulatory uncertainties arising from the absence of harmonized global standards for nanomaterials in cosmetics, further impede commercialization. Additionally, there is a paucity of long-term toxicological data assessing chronic dermal exposure, systemic absorption, and potential bioaccumulation [131]. The requirement for advanced analytical and characterization methodologies, such as atomic force microscopy and in vitro/in vivo penetration assays, increases development complexity and cost [132]. Overcoming these limitations is essential for the successful translation of nanocarrier technologies into clinically relevant and commercially sustainable phytocosmeceutical products.

**Future Perspectives**

The future of advanced nanocarrier-based delivery systems for herbal cosmetics and cosmeceuticals lies in bridging innovation with safety, scalability, and consumer trust. Continued exploration of biocompatible, biodegradable, and sustainably sourced nanomaterials, especially those derived from renewable plant resources, can enhance both environmental and skin safety profiles. Emerging approaches such as multifunctional and stimuli-responsive nanocarriers hold promise for delivering multiple herbal actives with synergistic effects, offering targeted action and controlled release in response to skin conditions or environmental triggers. Integrating artificial intelligence and computational modelling in formulation design may accelerate the optimization of carrier properties, stability, and release kinetics. Furthermore, large-scale clinical studies and harmonized regulatory frameworks are essential to validate efficacy, ensure safety, and facilitate global market adoption. Ultimately, advancing nanocarrier technologies with a focus on personalized skincare, sustainability, and transparent consumer communication will define the next generation of high-performance phytocosmeceuticals.

**CONCLUSION**

The integration of advanced nanocarrier-based delivery systems, including microemulsions, liposomes, cubosomes, and various nanoscale platforms, has significantly enhanced the efficacy, stability, and bioavailability of herbal bioactives in cosmetic and cosmeceutical formulations. These delivery systems not only overcome the inherent limitations of herbal extracts, such as poor solubility, instability, and limited skin penetration, but also facilitate targeted and sustained release, improving therapeutic outcomes. Emerging nanotechnologies offer multifunctional capabilities such as photoprotection, anti-aging, moisturizing, depigmenting, and anti-inflammatory effects through the enhanced localization of actives at desired skin layers. Continued interdisciplinary research and clinical validation are imperative for translating these innovations into safe, effective, and commercially viable phytocosmeceutical products. The future of herbal cosmetics lies in the rational design of nano-delivery systems that bridge traditional phytotherapy with modern dermatological science.

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