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HERBAL NANOCOSMECEUTICALS: THE ULTIMATE FUSION OF SCIENCE AND NATURE

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ABSTRACT

The integration of herbal extracts into nanotechnology-based skincare products has garnered considerable attention within the beauty and skin therapy realm. These formulations, interwines the benefits of herbs with advanced nanotechnology, and offer distinct advantages over traditional skincare items. They excel in delivering active ingredients precisely to target cells, thereby enhancing effectiveness and achieving targeted outcomes. Moreover, owing to their biodegradable properties, these nanocosmeceuticals pose lower toxicity risks and are environmentally friendlier compared to conventional skincare products. Additionally, leveraging nanotechnology enables the encapsulation and controlled release of herbal compounds, ensuring optimal skin absorption and maximizing therapeutic benefits. By harnessing natural elements like aloe vera, curcumin, vitamin E, and vitamin C herbal-based nanocosmeceuticals offer a wealth of bioactive ingredients for pioneering skincare treatments. These nanocosmeceuticals can be produced using plant extracts, which are then integrated into various delivery systems, such as Solid Lipid nanoparticles (SLNs), Nanostructured lipid carriers, Lipid-based nanocapsules, Nanoliposomes, Nanoniosomes, Fullerene, Carbon tubes, Cubosomes, Ethosomes. In summary, the evolution of herbal-based nanocosmeceuticals represents a promising frontier in the realm of beauty and skincare. These ground-breaking formulations have the potential to transform the skincare industry by offering more effective and sustainable solutions for individuals seeking natural and holistic approaches to beauty and skin care.

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Introduction

Skin-care products are in high demand all over the world as a result of expanding trends in the cosmetics industry and developments in global marketing [1]. The skin, being the largest organ in the human body, is also the most prominently exposed. It also acts as a shield, warding off a range of skin disorders and infections. Carbohydrates, amino acids, and lipids make up the skin. Sufficient sustenance is necessary to maintain the skin's glossy surface and lustrous nature [2]. The dermis, hypodermis, and epidermis are the three primary layers. Each layer contributes differently to the skin's overall ability to function. The internal organs, bones, muscles, and ligaments are all covered and shielded by the skin. The two primary forms of skin are glabrous and hairy skin. Skin plays a vital role in protecting the body from infections and dehydration. Water resistance, insulation, temperature regulation, senses, storage, and UV light-induced vitamin D production are some of its additional functions. It also helps with the absorption of different drugs and protects vitamin B folates. The creation of scar tissue is the skin's effort to mend from deep wounds. This is often drab and depigmented [3]. Herbs and other natural substances have antibacterial, nutritious, and antioxidant properties that make them useful for treating skin conditions. Antibiotic resistance and adverse effects in cutaneous infections are often caused by conventional medications such as antibiotics. By eliminating disease-causing microorganisms, natural products, and plant extracts accelerate the regeneration of skin, as they contain antibacterial and anti-inflammatory properties [1].

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The general public is becoming more and more enthusiastic about using herbal medications, which are thought to be "natural medicines" with fewer side effects and adverse drug responses than their synthetic equivalents [4]. Herbal medicine, often referred to as phytomedicine or botanical medicine, makes use of different parts of plants, such as foliage, bark, roots, flowers, berries, fruits, and seeds, which are meant for therapeutic reasons [5]. The term "Herbal Cosmetics" refers to products that are produced by utilizing a variety of approved cosmetic components as the foundations (base), then one or more herbal components are added to give specific cosmetic advantages solely. The finest aspect of herbal cosmetics is their pure herbal and shrub-based composition. The body is enriched with nutrients and other beneficial elements by the natural composition of the herbs, which has no negative effects on humans. The lack of adverse effects in herbal treatments is driving up demand for them [6].

Cosmeceuticals are products that blend cosmetic and pharmaceutical elements to provide health benefits alongside enhancing appearance. American dermatologist Albert Klingman helped popularize the idea of cosmeceuticals, which was initially developed by Raymond Reed, the founder of the Society of Cosmetic Chemists in the United States [7]. Kligman came up with the idea in 1984, combining medicine and beauty. Combining the phrases "cosmetic" and "pharmaceutical," the term "cosmeceutical" refers to a field that has both medicinal and cosmetic properties. Many cosmetic items aim to improve both appearance and health. For instance, shampoos primarily serve a cosmetic function by cleaning hair, while anti-dandruff shampoos are considered therapeutic. Sunscreen moisturizers and antiperspirant makeup deodorants are additional examples of products that combine cosmetic and medicinal properties [8]. The cosmeceutical sector is currently the fastest-growing segment in the personal care industry [9, 10]. Over the years, phytocompounds have been widely used in cosmeceuticals for their benefits in moisturizing, sun protection, anti-aging, and hair treatments. However, their application is often limited by their poor skin penetration and instability. Nanotechnology offers a solution, enhancing the stability and sustained release of these compounds in cosmetic products [11].

In recent years, there has been considerable advancement in the development of nanotechnology. Nanotechnology is presently employed in the cosmetics business under the wide umbrella of nanocosmetics, having been used in various study domains from electronics to health [12]. Within the grooming sector, cosmeceutical research is growing quickly and covering a wide variety of goods, from cosmetic treatments to skin and body care [9]. The global market is expected to grow at an 8.64% annual pace by 2027, which has led the cosmeceutical industries to develop products that are effective and make use of cutting-edge technology [13].

Nanotechnology in Cosmeceuticals

Since 1986, the nanotechnology market has grown, sparked by Christian Dior's development of the first cosmetic utilizing a liposome system and nanocarrier technology. It's projected to exceed a value of US$ 125 billion by 2024 [14].

In the creation of advanced and effective cosmeceuticals, nanotechnology plays a significant role. Within the cosmetics sector, there is a prevalent belief that smaller particles have a greater ability to penetrate the skin and facilitate quicker and more effective skin restoration [15]. The integration of nanotechnology into cosmeceuticals aims to extend the longevity of fragrances, enhance the protective capabilities of sunscreens, combat the signs of aging with anti-aging creams, and sustain skin hydration with moisturizers.

The main benefits of incorporating nanoparticles into cosmeceuticals include enhancing the stability of cosmetic components like vitamins, unsaturated fatty acids, and antioxidants through encapsulation within the nanoparticles. Nanoparticles also offer effective shielding of the skin from harmful ultraviolet (UV) rays. Additionally, they aid in crafting visually attractive products, like mineral-based sunscreens, where finer particles of active minerals allow for application without noticeable white residue. Moreover, nanoparticles enable precise delivery of active ingredients to designated locations, allowing for controlled release and extended efficacy [15]. **Figure 1** depicts the use of nanotechnology in developing herbal-based nanocosmeceuticals.

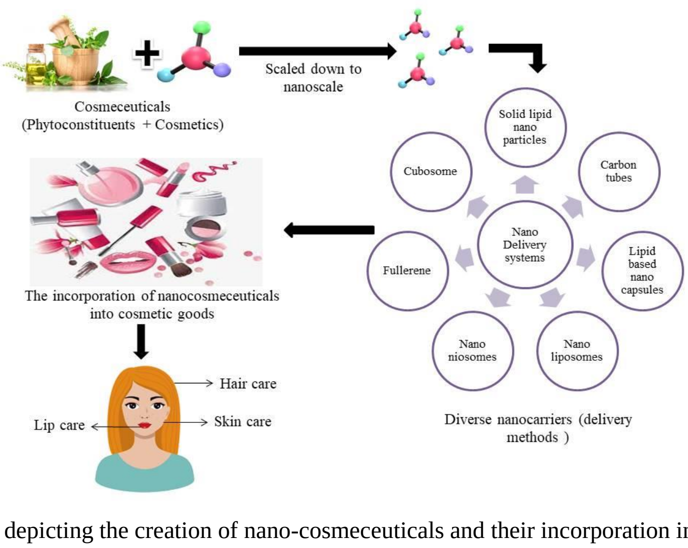

Figure 1. Graphic depicting the creation of nano-cosmeceuticals and their incorporation into cosmetic goods

Major Classes in Nanocosmeceuticals

One of the rapidly expanding sectors within the personal care market is cosmetics, which now incorporates numerous nano cosmeceuticals in products for hair, skin, lips, and nail care. **Figure 2** lists the main categories that comprise nanocosmeceuticals [14].

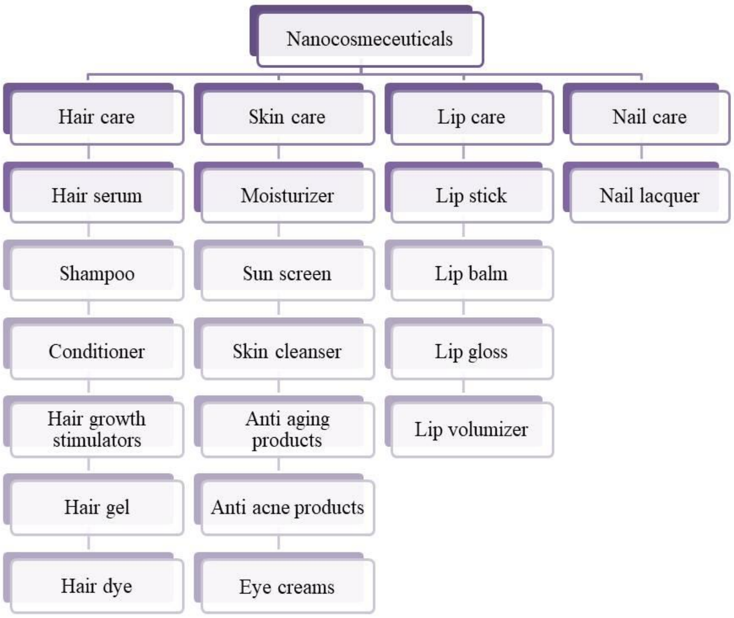

Figure 2. Categories of Nano-cosmeceuticals

Nanocosmeceutıcals Incorporatıng Phyto-Constıtuents for Skın Therapy

Nano Anti-Aging

Aging begins with changes in the structural integrity of exterior matrix proteins and decreased cell renewal, influenced by genetics, metabolism, lifestyle, and harmful metabolic byproducts. It leads to skin collagen alterations, reduced oil production, dryness, texture degradation, age spots, and laxity, ultimately causing wrinkles. Aging factors can be grouped into biological elements (genetics and metabolism), environmental influences (lifestyle choices like smoking and sun exposure), mechanical aging (muscle movements), and miscellaneous factors (nutrition, sleep, mental well-being) [9]. Various artificial and natural anti-aging creams, often using nanotechnology, are available for firming, moisturizing, and brightening the skin [13]. One notable formulation by Mohamed A. Salem uses lipid nanoparticles with coriander essential oil to enhance the stability and effectiveness of the oil in penetrating the skin. The anti-aging properties of coriander oil are attributed to its high concentration of oxygenated monoterpenes, particularly linalool (81.29%), which inhibits enzymes like hyaluronidase, tyrosinase, collagenase, and elastase that cause skin aging. Additionally, these formulations significantly reduce inflammation, mitigate UV-induced skin damage, and increase collagen production and protein expression involved in skin regeneration, contributing to the oil's anti-wrinkle and anti-aging effects [16].

Nano Moisturizers

The skin plays a crucial role in protecting the body from physical and chemical harm and preserving body fluids. The outermost layer, the stratum corneum (SC), consists of protein-rich corneocytes and lipid-filled intercellular spaces, responsible for maintaining skin hydration. This layer undergoes continuous renewal, repairing damage from daily wear and tear. Environmental factors and individual characteristics can contribute to skin abnormalities [9]. Moisturizers help prevent skin dehydration, promote skin health, and improve suppleness by maintaining moisture [13]. Nanotechnological approaches enhance the efficacy of moisturizers in preserving skin moisture [17]. A recent study developed a topical peel-off oil-in-water (O/W) nanoemulsion with Kojic monooleate, ensuring its therapeutic levels through controlled and sustained release. This nanoemulsion enhances the skin-lightening and anti-aging benefits of Kojic monooleate, increasing its bioavailability and effectiveness. In vivo evaluations showed significant improvements in skin moisture and hydration, with the nanoemulsion enhancing the skin's ability to retain moisture, reducing water loss, and strengthening the skin's natural barrier function. The peel-off feature also established a protective barrier on the skin, suggesting the nanoemulsion's effectiveness in treating dry skin and aging symptoms [18]. Another study demonstrated that a 1% turmeric rhizome extract moisturizing nanoemulgel significantly alleviates atopic dermatitis (AD)-like symptoms in a DNCB (2,4-Dinitrochlorobenzene)-induced mouse model. The nanoemulgel reduced key inflammatory cytokines (TSLP, IL-13, IL-17) and improved skin hydration and barrier function. Histopathological analysis showed reduced epidermal hyperplasia and eosinophil infiltration, highlighting turmeric extract's potential as a natural anti-inflammatory agent in moisturizers for managing AD. However, further research is needed to confirm its efficacy and safety in human AD patients [19].

Nano Skin Cleanser

Skin cleansers, available as soaps, creams, liquids, or gels are essential for maintaining skin health by regulating sebaceous gland functions [9]. These glands produce sebum, a lipid mixture that aids in photoprotection, antimicrobial activity, delivery of fat-soluble antioxidants, and inflammation regulation, contributing to skin homeostasis and moisture retention [20-22]. Sebum also helps in retaining skin surface moisture by forming a lipid film [23]. However, this film can attract unwanted microorganisms, leading to odor production when metabolized by sweat glands. Skin cleansing effectively removes surface bacteria, thus reducing odor formation [13]. Various skin cleansing products, from macro to nano sizes, include synthetic and natural ingredients, with ongoing research on phyto-based nano-compounds to enhance efficacy. Medicinal plants like Neem, Aloe vera, Tulsi, Amla, Manjistha, and Eucalyptus are popular in Ayurveda for their antioxidative, anti-inflammatory, rejuvenating, and antimicrobial properties [9]. Herbal skin cleansers offer benefits such as antioxidant effects, anti-inflammatory properties, moisturization, and control over sebum secretion [24]. Recent studies indicate that plant-based extracts in cleansers may reduce pore diameter and skin oiliness. Research demonstrates the efficacy of plant-derived compounds in purifying skin and addressing issues like acne [25]. For instance, nanosized liposomal lauric acid has demonstrated enhanced antimicrobial activity against acne-causing bacteria. Mixing lauric acid and curcumin within niosomes has demonstrated enhanced effectiveness in combating microbial infections associated with acne on the skin [9]. These findings suggest that phyto-based nanotechnologies can enhance the effectiveness of skin cleansers against skin diseases, opening avenues for the development of skin care products with enhanced cleansing properties derived from plant compounds [13].

Nano Sunscreens

The surge in melanoma cases has led to increased use of sun protection products to counter the harmful effects of ultraviolet (UV) rays [26]. Sunscreens containing mineral UV filters shield users from UV exposure, reducing risks of skin aging, skin cancers, and herpes labialis [27]. Commercial sunscreens, typically creams and lotions, incorporate synthetic compounds to create a barrier against UV rays, preventing deep penetration and associated irritation. However, synthetic sunscreens have drawbacks like chalky residue, greasiness, and odor, detracting from their appeal and potentially posing toxicity risks [28]. Natural phyto-based active ingredients, such as those derived from Schinus terebinthifolius Raddi or Brazilian Lippia species, offer promising alternatives with enhanced antioxidant and sun-blocking properties [29]. Incorporating these phyto-bioactive compounds into sunscreen formulations can bolster their efficacy, especially when delivered through nanotechnology systems [30, 31]. The researchers created and analyzed naringin-loaded ethosomes and added them to sunscreen lotions containing nano-ZnO and -TiO2. The skin retention, stability, and effective encapsulation of naringin were proven by the improved ethosomal formulation, whereas the sunscreen cream showed a high SPF of 21.21 and minimal naringin penetration throughout the skin. This formulation ensures better skin penetration and retention of naringin while providing efficient antioxidant, anti-aging, and UV protection. This combination of antioxidant advantages and efficient sun protection highlights the potential of naringin ethosomes to improve the effectiveness of sunscreens [32]. Similarly, the synthesis of lignin nanoparticles with improved antioxidant and UV shielding capabilities, as well as improved biocompatibility, biodegradability, and antibacterial characteristics, is made possible by nanotechnologies. Natural UV absorption by lignin in the UV-A and UV-B range provides a more environmentally responsible option than manufactured filters. The lignin market is expected to develop due to its applicability in a variety of sectors and the availability of affordable extraction techniques. This presents lignin as a viable alternative to petroleum-based chemicals used in sunscreen and cosmeceutical products [33].

Nano Hair Care

Hair care represents a highly promising sector within the cosmeceutical industry, as concerns about hair health and appearance cut across all age groups. Hair loss, a prevalent concern, can happen at any phase of life and is frequently associated with inflammation of the scalp and irregularities in growth, which differ from individual to individual. Hair-related difficulties like increased hair loss can notably affect a person’s self-esteem because of alterations in their physical appearance, especially when it results in the transformation of vellus follicles. To address these concerns, many hair care products utilize plant-derived compounds known for their bioactive properties [9]. In recent times, a study has examined how well vitamin E-loaded nanostructured lipid carriers (Vit E-NLCs) and NLCs themselves protected against UV and thermal treatment-induced hair damage and discoloration. Vit E-NLCs and NLCs both showed impressive effectiveness in maintaining the integrity and color of hair, while Vit E-NLCs had somewhat better photo-protective properties. According to these results, Vit E-NLCs and NLCs are viable substitutes for protecting hair from UV and heat exposure regularly, which might have positive effects on hair care products [34]. Minoxidil (MXD) formulations based on nanotechnology show potential in augmenting and improving the management of androgenetic alopecia (AGA). Potential advantages of these formulations include better medication administration, fewer side effects, and better therapeutic results. To define regulatory guidelines for manufacturing and toxicity evaluations, as well as to address important concerns including formulation stability, characterization, and safety profiles, more research is necessary [35].

Nano Nail Care

Nano nail care has emerged as a dynamic and pioneering sector within both the cosmetic and healthcare industries. These nano nail care particles, primarily synthesized, offer enhanced protection against nail infections and contribute to improved nail appearance and resilience in mammals. Natural pigments sourced from plants, such as carotene, chlorophyll, curcumin, lycopene, anthocyanin, and annatto, exhibit various therapeutic properties and vibrant colors [9]. In a recent study, nail penetration enhancers (nPEs) such as N-acetyl-L-cysteine, thioglycolic acid, and thiourea were effectively loaded into solid lipid nanoparticles (SLNs) containing terbinafine HCl (TFH). When compared to the commercially available cream Lamifen, thiourea was revealed to be the most efficient nPE tested, leading to improved SLN formulations with good physicochemical features, high drug entrapment efficiency, and higher antifungal activity against Trichophyton rubrum [36]. The goal of another recent investigation is to create a cosmetic item that can transfer antibiotics between and within the nail plate to cure onychomycosis, a nail fungal infection. The goal of the research is to improve medication delivery following topical administration by using quality-targeted product profiles (QTPPs) and factorial design of experiments (DoEs). More research is required to evaluate the long-term effects on nail plate development of the hydrogel formulation of TBI nanospheres, which has shown promise in supplying effective antibiotics for the treatment of onychomycosis [37].

Nano Lip Care

Nanolip cosmetics represent a burgeoning niche within the cosmetics industry. At present, an array of synthetic and metallic particles is being employed at the nanoscale to provide efficient lip shielding and improved tint [6]. These lip treatments with nanoparticles feature prolonged longevity and consistent pigment dispersion over the lips, resulting in heightened protection. However, considering the delicate nature of lip skin, it is prudent to exercise caution when employing metallic and synthetic nanoparticles. Traditionally, lip care has involved the use of phytoconstituents at larger scales, including curcumin, coconut oil, and other biologically active compounds known for their defensive properties [38, 39]. Lip care products have recently integrated phyto betalains, innovative dietary pigments derived from indole. The process of extracting and encapsulating these compounds not only enhances their storage stability but also broadens their applications. For example, Bixa orellana, which has better organoleptic qualities for lipstick, has been used as a colorant for lip jelly. Similarly, Propolis has also found its way, in the creation of a brand-new lipstick. Still in its early phases, nevertheless, is the application of nanotechnology to the creation of phyto-based lipsticks [9].

Phytoconstituent-Based Nano Delivery Systems

Nano-delivery systems enhance the solubility and skin penetration of phyto-derived bioactive substances, boosting the efficacy of cosmeceuticals. These systems address various skin problems effectively, with nanotechnology amplifying their therapeutic benefits. Formulations with nanoparticles improve product retention on the skin's outer layer. **Figure 3** illustrates nano-delivery methods in cosmeceuticals, such as nanostructured lipid carriers, phytosomes, solid lipid nanoparticles, nano lipospheres, liposomes, nanocapsules, nano niosomes, and nanoemulsions. For instance, resveratrol in solid lipid nanoparticles enhances penetration into pig skin, while quercetin in colloidal silica emulsion improves human skin penetration due to nanostructuring. The choice of nanotechnology depends on factors like the active component's hydrophilic/hydrophobic nature, formulation type (emulsion or gel), and particle properties (degradability, size, toxicity). This section explores the several methods of delivering nanotechnology used in the creation of phytobioactive compound-based nanocosmeceuticals [9].

Solid Lipid Nanoparticles

Solid lipid nanoparticles (SLNs) are widely used in the pharmaceutical and cosmetic industries. They are very efficient nanocarriers with a solid lipid core stabilized by emulsifiers [40]. Solid lipids like cetyl, stearic acid, and palmitic acid are combined with plant-derived compounds like flavonoids and phenolic acids to create these nanoparticles, which are used in skin care products [6]. In addition to preventing skin irritation, SLNs provide several benefits, such as photostability, controlled release, improved penetration, and odor masking [41]. For skincare applications, they provide steady delivery methods that improve lipophilic medication stabilization and encapsulation, increase oral bioavailability, and prolong drug release [42, 43]. Microemulsion, solvent emulsification/evaporation procedures, hot or cold high-pressure homogenization, and the lipid matrix, emulsifier, and encapsulated medication all affect the characteristics of solid-liquid nanoparticles (SLNs). Furthermore, SLNs enhance skin penetration by evaporating and then producing an occlusion layer that enhances skin hydration and decreases transepidermal water loss [44]. Kojic acid solid lipid nanoparticles (KA-SLNs) were improved using tween 20, span 60, cholesterol, and glyceryl monostearate, resulting in particles with good entrapment efficiency and durability. The characterization revealed that KA was contained in an amorphous form and that there were no intermolecular chemical interactions. The KA-SLNs formulation showed signs of better percutaneous absorption, regulated release, and greater tyrosinase inhibition, indicating that it may be a useful topical therapy for hyperpigmentation [45]. Similarly, recent research involving SLNs loaded with curcumin and turmerone demonstrated biocompatibility and safety, along with benefits like improved stability and enhanced skin penetration. This novel delivery method is a promising strategy for topical skincare formulations because it may be able to address issues related to the low solubility and bioavailability of these chemicals [46].

Nanostructured Lipid Carriers

One more important delivery method used in cosmeceuticals to improve the effectiveness of delivering both natural and synthetic bioactive substances is nanostructured lipid carriers. Several benefits distinguish nanostructured lipid carriers from other nanotechnologies: they can produce lipids in larger quantities, they are more stable, and they differ from solid lipid nanocarriers by using lipids in liquid form such as oleic acid [9, 47]. The potential of nanostructured lipid carriers (NLCs) to improve the bioavailability and effectiveness of active substances in natural cosmetics has drawn a lot of interest in their application to skin delivery [48]. NLCs are second-generation lipid nanoparticles that have better drug loading and stability because of their less structured lipid core, which contains up to 30% liquid lipids [49, 50]. In addition to providing efficient UV protection and skin regeneration by strengthening the compromised epidermal lipid matrix, they also generate an occlusive film that decreases water loss and increases hydration. They also offer superior lubrication due to their spherical form, which lessens friction between the skin and surrounding skin regions or clothing. High levels of biocompatibility may be maintained, and their emollient qualities can be further improved by carefully choosing lipids and surfactants [50-52]. To cure psoriasis, the researchers created a nanostructured lipid carrier (NLC)-gel system that contains luteolin (LUT). The LUT-NLC, which was made via solvent emulsification ultrasonication, has high drug loading, entrapment efficiency, and small particle sizes. After its structure was verified by characterization, the NLC was distributed in carbomer 940 to create a gel that exhibited exceptional shear-thinning properties. When compared to a LUT gel, the LUT-NLC-gel demonstrated better penetration and sustained release over 36 hours. The LUT-NLC-gel showed promise as a skin disease therapy by drastically reducing inflammatory cytokines and improving skin conditions in models of psoriasis in mice [53]. Using the High Shear Homogenization technique, a recent study sought to characterize and ascertain the penetration profile of resveratrol-loaded nanostructured lipid carriers (RSV-NLCs). Several plants, including red grapes, peanuts, berries, and the root of Japanese knotweed, contain the polyphenol chemical resveratrol, which has strong anti-aging and antioxidant properties. The study used two distinct surfactants (Span 20 and Tween 80) to create four distinct concentrations of RSV-NLCs. The combination that worked best for RSV-NLC characterization and penetration profile was Tween 80: Span 20 (5:5) [54].

Lipid-Based Nanocapsules

Lipid-based nanoparticles, or LBNs, are composed of a lipid matrix encased in surfactants and are used as targeted drug-delivery vehicles. These adaptable carriers are usually 1–100 nm in size, and if they are larger than 100 nm, they are categorized as lipid colloidal carriers [55-58]. For topical administration, nano-sized lipid formulations with polyoxazolines (POx) rather than poly(ethylene glycol) (PEG) offer improved antioxidant action, stability, and drug loading. This innovative technique offers a possible substitute for skin treatments by creating stable ~30 nm lipid nanocapsules [59]. The goal of a recent study was to create luteolin-loaded phospholipid-based lipid nanocapsules for topical administration. Along with chitosan coating, variations in the phospholipid/oil ratio and surfactant type were investigated. The medication encapsulation and particle sizes of Cremophor EL were ideal. Formulations coated with chitosan exhibited better skin penetration and retention. In animal models, a few chosen formulations showed sustained release, antioxidant activity, and effectiveness, indicating that lipid nanocapsules might be a viable method for delivering luteolin in medicinal and cosmetic applications [60].

Nanoliposomes

Liposomes are self-assembling structures made of phospholipid and cholesterol-based bilayers encircling aqueous compartments. They can encapsulate hydrophilic substances in their aqueous space and hydrophobic substances in their lipid bilayer. Liposomes can be modified to create ethosomes, niosomes, or transferosomes based on the ratio of phospholipids to surfactants. With a size range of 10–300 nm, they are widely used in agriculture, cosmetics, and nanotherapy. Liposomes enhance the solubility and penetration of medicinal molecules and inhibit unwanted interactions. They are used in pharmaceutical and cosmetic products for the targeted and regulated release of vitamins, antioxidants, and moisturizers, improving the stability and effectiveness of active components [61-65]. Nanoliposomes are found in sunscreens, skin and hair moisturizers, and anti-aging lotions with synthetic and phytoactive ingredients [9]. Recent studies on resveratrol nanoliposomes for transdermal delivery show promising anti-aging and skin-brightening results, indicating potential for advanced skincare formulations [66]. Additionally, research on coffee berry nanoliposomes has shown efficacy in reducing signs of aging and improving skin elasticity, hydration, and texture, suggesting they may be an effective new anti-aging skincare intervention. Further research could optimize formulations and explore additional mechanisms to fully harness their therapeutic potential [67].

Nanoniosomes

Niosomes are recently discovered, sac-like, self-assembling transporters made of non-ionic surfactants including Brij, Tween, and Span [68, 69]. They resemble liposomes physically but are less expensive to make and more stable at ambient temperature. By delivering medications to targeted areas, niosomes improve pharmaceutical availability and extend the healing benefits. Because of the surfactants that make the nanovesicles more flexible and deformable, they penetrate the skin more deeply than liposomes. For niosome production, the hydrophilic-lipophilic balance (HLB), which ranges from 4 to 8, is crucial [70-72]. Because of their stability, enhanced skin penetration, low toxicity, and efficient retention of active ingredients, niosomes are preferred in the cosmeceutical sector. Micrometers to nanometers are their sizes; lower sizes (10–100 nm) are very effective. They have been extensively employed in medicine for delivering antioxidants like ellagic acid, ascorbic acid, and resveratrol orally and via the skin [9]. The goal of a recent study was to decrease unpleasant effects and increase efficacy in the treatment of cutaneous leishmaniasis by developing niosomes loaded with artemether (ART). The thin-film hydration method was used to create the spherical, highly encapsulation-efficient ART-loaded niosomes, which ranged in size from 100 to 300 nm. When ART-loaded niosomes were compared to liposomal amphotericin B and ART alone, they demonstrated much greater antileishmanial action, reduced toxicity, and superior selectivity. These findings were observed both in vitro and in vivo. These results point to ART-loaded niosomes as a potentially effective topical treatment for cutaneous leishmaniasis [73]. According to another study, the prevalence of skin cancer is on the rise, with melanoma being the most common kind. This means that effective treatment options are needed to boost anticancer efficacy, lower costs, and adverse effects, and prevent drug resistance. Because of their high drug-loading capacity, scalability, biocompatibility, stability, and targeted delivery, niosomal delivery systems have great promise for the treatment of skin cancer. They also effectively destroy skin tumor cells. While lowering the required dosage and limiting adverse effects, the use of niosomal formulations of natural and synthetic medicines has greatly increased anticancer and antibacterial activities. Stable drug structures, less leakage, and more targeted tissue distribution are all features of these formulations. Future studies might combine hybrid niosomes with stabilizing agents like salts and organic molecules for better medication delivery, further advancing the creation of durable nanocarriers [74].

Fullerene

Fullerene, a cutting-edge carbon-based technology composed of 1 nm-sized carbon atoms, specifically in even-numbered clusters like C60, has found its niche in the cosmeceutical industry for its role in transporting phytocompounds. Acting as an antioxidant, fullerene effectively combats premature skin aging by delivering essential vitamins, thereby enhancing skin health. Recent advancements include the creation of fullerene nanocapsules incorporating ascorbic acid and vitamin E, which have demonstrated superior skin protective properties against premature aging through their antioxidant actions [9]. Apart from its demonstrated antioxidant and anti-inflammatory properties, fullerene C60 shows considerable promise as a wound-healing agent. The water-based dispersion of fullerene C60, which is manufactured by "green technology," has significant promise in wound healing. Through its utilization, significant advancements have been observed in wound management, indicating accelerated healing processes. This environmentally friendly approach offers a sustainable solution while harnessing the unique properties of fullerene C60 [75]. Additional investigation and clinical trials are needed to thoroughly understand its effectiveness and safety characteristics, leading to its incorporation into conventional wound care practices.

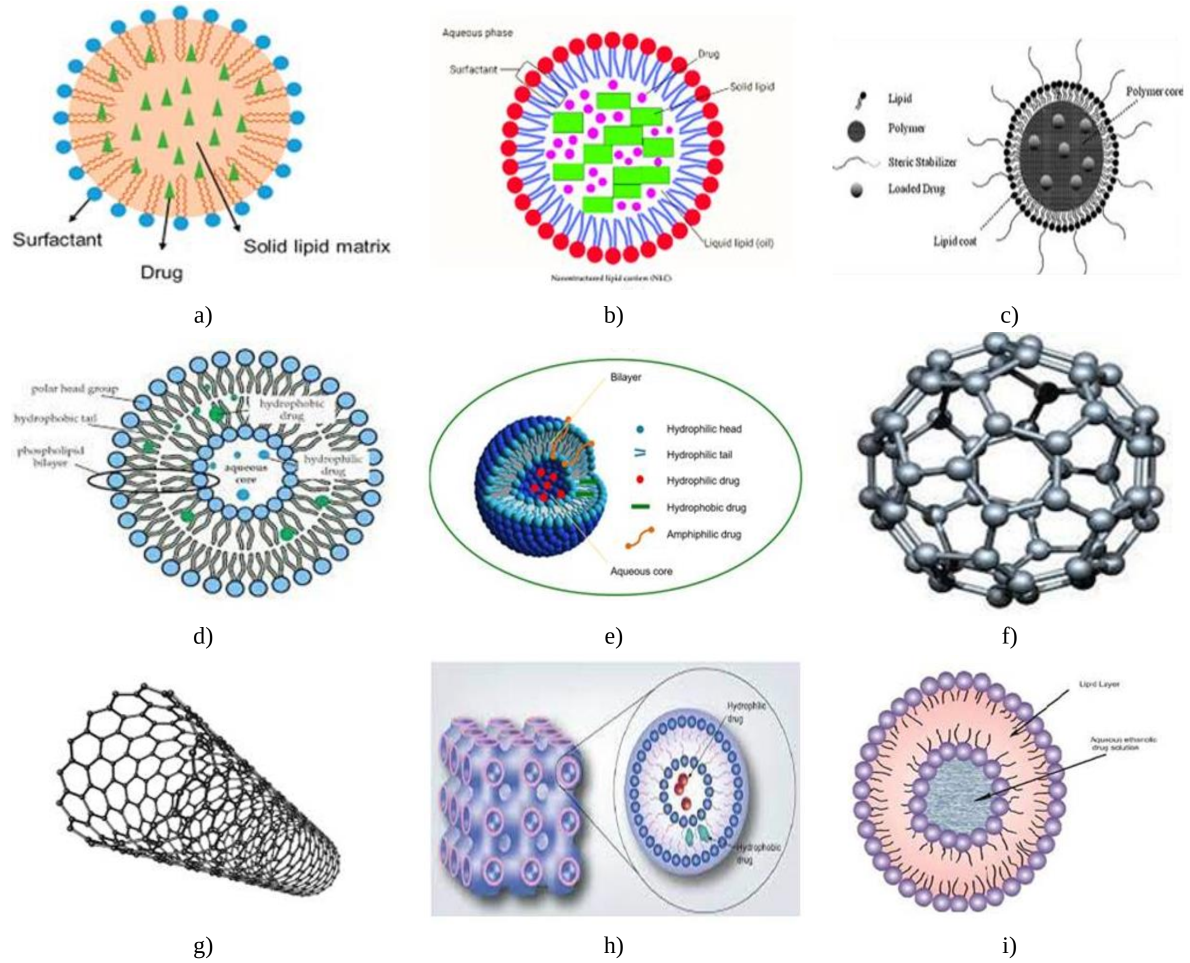

Figure 3. Different types of Nanocarrier systems: a) Solid lipid nanoparticles, b) Nanostructured lipid carriers, c) Lipid-based nanocapsules, d) Nanoliposomes, e) Nanoniosomes, f) Fullerene, g) Carbon tubes, h) Cubosomes, i) Ethosomes.

Carbon Tubes

Carbon nanotubes represent an innovative technology currently utilized in the cosmeceutical industry, particularly in skincare applications. Much like fullerene, carbon nanotubes possess antioxidant properties and are approximately 100 nm in size [9].

Beyond their role in cosmeceuticals, they serve as effective delivery systems for phytocompounds in biomedical contexts. Recent advancements include the conjugation of curcumin to single-wall carbon nanotubes for enhanced delivery [76]. Additionally, there has been exploration into the utilization of hyaluronic acids in drug delivery facilitated by carbon nanotubes, although further clinical trials are necessary to evaluate their safety [77]. Despite these advancements, there is still a dearth of research on the use of carbon nanotubes and phyto compounds in beauty and cosmeceuticals, which calls for further investigation

Cubosomes

Cubosomes are lipid-based, nanostructured particles that have drawn a lot of interest in the fields of nanomedicine and drug delivery. Bicontinuous cubic liquid crystals in the form of minuscule, nanoscale particles are known as cubosomes. The intriguing drug delivery mechanism known as the cubic crystalline phase is composed of two corresponding cross-sectional water channels and a densely coiled, unbroken layer of lipids. The capacity of cubosomes to encapsulate and transport both hydrophilic and hydrophobic medications is one of their main benefits. Lipophilic medications are best incorporated into the hydrophobic sections of lipid bilayers, whereas water-soluble pharmaceuticals can be encapsulated in the hydrophilic parts [78-80]. Lipid vesicles called cubosomes are similar to other vesicular systems, such as liposomes [81]. In addition, cubosomes can be an effective vehicle for releasing a variety of pharmacological compounds, including BCS class 2 medicines, antibiotics, and anticancer medications as well as local anesthetics [82]. A recent study on the utilization of dexamethasone-loaded cubosomes presents a promising therapeutic approach for the treatment of vitiligo. Dexamethasone, known for its potent anti-inflammatory and immunosuppressive properties, addresses the underlying inflammatory processes and autoimmune responses associated with vitiligo, thereby halting further depigmentation and potentially promoting repigmentation of affected skin areas. By encapsulating dexamethasone in cubosomes, this study capitalizes on the unique advantages of cubosomal drug delivery, including sustained release and prolonged residence on the skin surface. This targeted and controlled release mechanism enhances the efficacy of dexamethasone while minimizing the frequency of application, thus improving patient compliance and reducing the risk of adverse effects associated with long-term corticosteroid use [83]. Further research and clinical trials are warranted to validate the efficacy, safety, and long-term outcomes of dexamethasone-loaded cubosomes as a promising treatment modality for vitiligo.

Ethosomes

Ethosomes are innovative vesicular nanocarriers highly effective at delivering active substances via the skin. Comprising phospholipids and high ethanol concentrations (20–45%), ethosomes are flexible, deformable, and stable, facilitating deep skin penetration and medication deposition. The high ethanol content disrupts the skin's lipid bilayer, increasing permeability and bioavailability, allowing ethosomes to non-invasively deliver both hydrophilic and hydrophobic drugs into deeper skin layers. Their malleable, nanoscale nature enables them to overcome the stratum corneum barrier, which typically blocks large molecular weight drugs. Ethosomes' unique properties result in increased drug loading capacity, reduced irritability, and effective administration in both occlusive and non-occlusive conditions, making them advantageous for transdermal treatment. They are frequently combined with a gel matrix for increased skin retention [84-87]. Recently, an in vitro evaluation of a topical ethosomal gel formulation containing herbs for treating acne vulgaris was investigated. The study utilized the anti-acne properties of herbal methanolic extract from *Glycyrrhiza glabra*, integrating it into an ethosomal gel to enhance skin penetration and efficacy. The ethosomal gel demonstrated favorable physicochemical characteristics, ensuring stability and efficient delivery of active components. Compared to traditional gels, it exhibited enhanced skin permeation due to the ethosomal vesicles' capability to penetrate the skin barrier. The formulation also showed significant antimicrobial activity against acne-associated bacteria, suggesting its potential as an effective treatment for acne vulgaris [88]. However, further *in vivo* studies are needed to validate its clinical efficacy and safety.

Phytoconstituents in Beauty and Skin Therapy

Nano-sized phytoconstituents are gaining popularity as key ingredients in cosmeceuticals because of their potential to boost beauty and offer remedial advantages in areas like UV shielding, preventing aging, and the avoidance of skin-related ailments. Resveratrol has recently shown greater skin absorption when encased into solid lipid nanoparticles, resulting in increased protection and antioxidant benefits. In contrast, the efficiencies of skin retention for nanostructured lipid carrier systems and solid lipid nanoparticles were similar. Nanodelivery technologies have the potential not only to enhance bioavailability on the skin but also to facilitate delivery to the brain for conditions like Parkinson's disease. Further advancements, in the modification of biologically active substances and nanodelivery techniques have the potential to enhance skin bioavailability and hence boost protection. Likewise, quercetin, when enclosed within solid lipid nanoparticles, demonstrated enhanced skin adhesion and antioxidant potency. Nanoemulsions loaded with genistein, incorporated into hydrogels, enabled improved transportation of the biologically active substances to the skin for beauty-related treatments. Additionally, co-encapsulation of curcumin and resveratrol within the lipid core of nanocapsules enhanced the transportation of resveratrol to the dermis. Several more, plant-derived biologically active substances have also been effectively enclosed into various nano-delivery techniques to strengthen both beauty and therapeutic functionalities [9].

Aloe vera

Aloe vera is named after the Arabic word "Alloeh," which means "shining bitter substance," and the Latin word "vera," which means "true." Two millennia ago, Aloe vera was considered the universal remedy by Greek scientists. Aloe was known to the Egyptians as "the factory of eternity." In Egyptian culture, aloe vera was known as the "plant of immortality" [89, 90]. From the inside of the leaf, aloe vera contains several active ingredients that are employed in skin care products and medications, including proteins, minerals, carbohydrates, and vitamins [9]. Aloe gel substantially enhances moisturizing effectiveness and anti-aging properties by stimulating the production of collagen and elastin fibers. Furthermore, it aids in the healing of wounds. Aloe gel's enhanced moisture, bioactive component, and mineral content improve its skin-protective and moisturizing properties. Aloe is so frequently used in cosmetic items including gels, creams, and lotions. However, nano-delivery methods have lately been employed in the cosmeceutical areas due to the aloe components' increased bioactivity. Moreover, the manufacture of cosmeceutical products using aloe vera at the nanoscale is still in its infancy. Recent research developed aloe vera and montmorillonite clay that incorporated polyvinyl alcohol (PVA) gel with excellent antimicrobial activity, making them suitable for face masks to adsorb dust. These gels have broad applications in cosmetics due to their anti-inflammatory properties, benefiting individuals with various skin conditions. Surface treatment response was used as a statistical tool to optimize concentrations for refined-particle-size green clay and Aloe vera peel-off facial masks. Clinical trials are needed to confirm the effectiveness of topical aloe vera in managing radiation-induced skin reactions. The demand for Aloe vera products in the food industry is expected to rise, creating opportunities for its use in sealed drinking water, low-calorie fruit juice, and peel-off formulations and expanding its scope in pharmaceutical ingredients [91].

Curcumin

One of the earliest known cosmetics was turmeric, discovered and used topically by women. It is believed to reduce facial hair, clear acne, and even out skin tone [92]. The active ingredient in turmeric is curcumin. Native to Asia, including India, turmeric is used in culinary, medicinal, cosmetic, and wellness products due to its numerous health benefits, such as antioxidant properties, moisture preservation, and anti-aging effects. South Indian women often incorporate turmeric into their skincare routines as a powdered plant or crude extract [9]. Hydrogel and nanoemulgel formulations have gained attention for developing curcumin-based systems to improve wound healing. However, issues remain regarding curcumin's mechanisms in wound healing, especially for conditions like keloids and hypertrophic scars, and a lack of comprehensive clinical trials. More research is needed to determine optimal dosing and delivery needed to determine optimal dosing and delivery methods for curcumin while addressing its low bioavailability and potential side effects. Despite curcumin's known benefits for wound healing, few curcumin-based formulations are available [93]. A recent study developed curcumin-loaded nanostructured lipid carriers (CURC-NLCs) to enhance curcumin's bioavailability and absorption for better wound healing. These carriers showed increased phenolic and flavonoid content, enhancing antioxidant activity and exhibiting potent antibacterial action against both Gram-positive and Gram-negative bacteria and fungi. In vivo, research demonstrated that CURC-NLCs significantly accelerated wound closure in rabbits and improved wound healing compared to curcumin alone and controls. This indicates that CURC-NLCs' enhanced antioxidant and antibacterial properties contribute to their effectiveness in promoting skin regeneration [94].

Vitamin E

Heat-resistant and soluble in fat, vitamin E is extensively employed in cosmeceutical products for its skin protection properties, including anti-aging effects, enhanced skin hydration, and prevention of skin ailments [9]. Eight different molecules make up vitamin E: α-, β-, γ-, and δ-tocopherols as well as tocotrienols. It is the first line of defense against damage induced by free radicals on cell membranes. Vitamin E levels in the skin can be reduced by exposure to UV radiation or ozone. This is especially true in the stratum corneum. Moreover; it has been shown that as people age, their skin's levels of vitamin E decrease [95]. A recent study developed a water-in-oil microemulsion comprising vitamin E (α tocopherol) and vitamin A (retinol). It functions as a multifunctional nanosystem that delivers antioxidants with an additive impact against acute inflammation of the skin. The microemulsion formulation exhibited minimal cytotoxicity and demonstrated physical stability. It was built by combining water, isopropyl myristate, and a combination of surfactants. Through the use of α-tocopherol and retinol, *in vivo* tests showed a decrease in dermal TNF-α expression. This suggests that both vitamins work synergistically to reduce inflammation. This study demonstrates how water-in-oil microemulsions may cure skin irritation and co-deliver antioxidants [96]. The researchers investigated a combined strategy that avoided the skin-thinning effects of steroids by administering α-tocopherol and γ-tocotrienol against dermatitis utilizing nanocarriers and microwave technology. Vitamin E nanoemulsions that were water-rich and water-poor were created and evaluated using a range of factors. Microwave pretreatment improved the skin's ability to absorb nanoemulsions, especially in the epidermis. Using this combined technique, dermatitis could be effectively treated without causing skin thinning, as nanoemulsions were distributed mostly in the epidermis. The study offers encouraging possibilities for more research into this method of managing dermatitis [97].

Vitamin C

These days, vitamin C is one of the cosmeceuticals that dermatologists prescribe the most worldwide. Its popularity has increased dramatically over the last five years, and in 2020, with over a million searches, it was the most sought-after cosmetic component online—a 204% annual rise. This confirms the well-established role that vitamin C plays in the typical person's skincare regimen [98]. Vitamin C, abundantly present in plants, serves various functions in both health and beauty, including collagen production. However, it readily deteriorates when exposed to harsh environments including UV radiation. Constant exposure to vitamin C molecules improves the appearance of the skin. Nanodelivery methods sustain the effectiveness of topically applied vitamin C without compromising its biological activity [9]. The potential of ascorbic acid (AA) as a cosmeceutical for skin health and attractiveness is highlighted in a recent review. To counteract the signs of aging on the skin, AA has been demonstrated to lower oxidative stress and increase collagen synthesis. Several approaches are presented to improve the effectiveness of amino acid analogs (AA) in skincare, such as mixing them with amino acid analogs like glycinamide, which has demonstrated potential in promoting the manufacture of collagen in human dermal fibroblasts. A viable strategy for successful skin anti-aging treatment is this combo therapy [99]. Another work addressed the limits of AA in cosmetic applications by investigating its administration using a nanoemulsion. With 80 mg/mL of AA, the nanoemulsion showed high stability and a tiny droplet size. This nanoemulsion combined plasticizers (Polyethylene glycol and isopropanol), sodium carboxymethyl cellulose (NaCMC), and hydroxypropyl methylcellulose (HPMC) to create patches. *Ex vivo* permeation research revealed that AA was successfully delivered across the stratum corneum in these patches, which also demonstrated stability and regulated release of AA. This nanoemulsion-based patch system presents a promising approach for dermal delivery of unstable hydrophilic compounds [100].

Conclusion

The rising demand for nanoscale phyto-derived biologically active compounds in the creation of nanocosmeceuticals for the treatment of skin issues, including hydrating, protection from the sun, anti-aging, and brightening effects, has spurred researchers to explore novel nanocosmeceutical-based therapies. The skin retains phyto-derived biologically active substances for a longer time, more steadily and more appealingly when applied as nano-sized cosmeceuticals. It's important to remember, though, that reducing the nanoparticle size can reduce the capacity of biologically active substances to penetrate the skin, which limits their ability to provide therapeutic and cosmetic benefits. The choice of delivery technology for the development of nano-cosmeceuticals is influenced by factors such as the types of solubility and the applications of phyto-derived Herbabiologically active substances in cosmeceuticals. This necessitates further investigation into the mechanisms for targeted release from delivery agents. Consequently, research focusing on nanosized phyto-bioactive compound-based cosmeceuticals and their impact on skin health continues to gain momentum.

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