REVIEW PAPER

Beyond conventional comparisons: a critical and integrative review of lipid-based and vesicular nanocarriers in cosmetic applications

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ABSTRACT

Background: The stratum corneum represents a major barrier to dermal delivery, limiting the effectiveness of conventional cosmetic formulations. Nanotechnology-based systems have emerged as promising strategies to enhance skin penetration, stability, and bioavailability of active ingredients.

Objective(s): This review provides a critical and integrative evaluation of widely used lipid-based and vesicular nanocarriers in cosmetic applications, with emphasis on identifying research gaps and inconsistencies.

Materials and Methods: Relevant studies published from 2020 onwards were identified through Web of Science, PubMed, and Google Scholar. The selected literature was analyzed comparatively, focusing on formulation characteristics, performance outcomes, and reported limitations.

Results: Four major nanocarrier systems—solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), liposomes, and niosomes—were examined. These systems exhibit distinct physicochemical properties affecting encapsulation efficiency, stability, and dermal delivery. While several studies suggest improved performance of NLCs over SLNs and niosomes over liposomes, the evidence remains context-dependent and influenced by formulation variables and experimental conditions. Moreover, inconsistencies across studies and the lack of standardized comparative data limit definitive conclusions. Emerging and hybrid nanocarrier systems are also gaining increasing attention.

Conclusion: This review advances current knowledge by emphasizing critical comparison rather than descriptive reporting. It highlights the need for standardized methodologies, quantitative analyses, and consideration of safety, regulatory, and scalability aspects to support the rational development of cosmetic nanocarriers.

Keywords: *Nanotechnology; Cosmetics; Drug delivery systems; Liposomes; Nanostructures*

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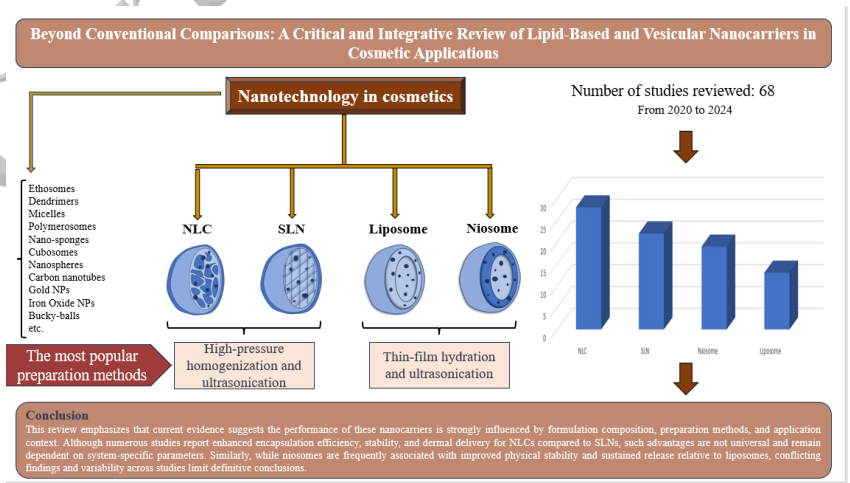
GRAPHICAL ABSTRACT



Schematic representation of lipid-based and vesicular nanocarriers in cosmetic applications.

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INTRODUCTION

The use of cosmetics can be traced back to prehistoric times, with significant advancements observed in ancient Egyptian civilization. Personal hygiene practices, including bathing in domestic environments or natural water sources, represented an essential component of daily life. In addition, perfumed unguent oils derived from aromatic plant materials were widely applied for both aesthetic and protective purposes. Early cosmetic formulations, typically composed of animal fats or vegetable oils combined with natural fragrances, served not only beautification purposes but also protection against environmental stressors such as sunlight, wind, and dry climatic conditions. In the contemporary era, cosmetics continue to play a crucial role in protecting the body from external stressors, including ultraviolet (UV) radiation, environmental pollutants, and microbial exposure, while simultaneously contributing to personal hygiene and aesthetic enhancement. Cosmetic products are also widely used to improve skin and hair condition through specialized formulations designed for targeted care application [1, 2].

A cosmetic product is defined as any substance or mixture intended for application to external body surfaces, including the epidermis, lips, nails, hair, and external mucosal surfaces of the oral cavity and teeth. The primary functions of cosmetic products include cleansing, protecting, perfuming, modifying appearance, and maintaining these body regions in optimal physiological condition [3].

Cosmeceuticals are generally regarded as hybrid formulations that bridge cosmetics and pharmaceuticals by incorporating biologically active compounds with potential functional effects on skin physiology. These products aim to improve skin appearance while also supporting biological processes such as barrier function, hydration, and cellular activity. Depending on formulation design and physicochemical properties, cosmeceutical agents may interact with the stratum corneum and, in some cases, penetrate into deeper skin layers. However, their extent of activity is highly dependent on delivery systems and formulation strategies. Unlike conventional cosmetics, which primarily exert effects on superficial skin layers, cosmeceuticals are proposed to provide additional bifunctional benefits; nevertheless, their classification remains subject to scientific and regulatory interpretation.

Cosmetic raw materials are generally categorized into natural, organic, naturally derived, nature-identical, and synthetic compounds [4, 5]. In formulation design, ingredients are further classified into functional and performance (active) ingredients. Functional ingredients ensure product stability, usability, and structural integrity and include thickeners, surfactants, emulsifiers, solvents, preservatives, colorants, and fragrances. In contrast, performance ingredients are responsible for specific biological effects and include moisturizers (emollients and humectants), antioxidants, chelating agents, exfoliants, anti-aging compounds, and UV filters. The overall efficacy of a cosmetic formulation depends on the balanced integration of these components to achieve optimal physicochemical stability and biological performance [3].

Several mechanisms have been proposed for cosmeceutical active ingredients, including enhancement of skin barrier function, activation of cellular receptors, modulation of growth factors, induction of controlled exfoliation, regulation of the skin microbiome, antioxidant protection against oxidative stress, stimulation of DNA repair mechanisms, inhibition of melanogenesis, and protection against environmental damage [6].

Despite the growing body of literature on cosmetic nanocarriers and cosmeceutical agents, existing reviews remain largely descriptive and often focus on isolated aspects of skin biology or specific delivery systems. Therefore, this review provides a structured and integrative synthesis of cosmetic and cosmeceutical science**,** with particular emphasis on skin structure, permeation mechanisms, and advanced delivery systems. In addition, it critically evaluates recent literature to identify inconsistencies, research gaps, and limitations in current formulation strategies. By doing so, this work aims to provide a more comprehensive framework for understanding the role of nanotechnology and modern formulation approaches in cosmetic science.

MATERIALS AND METHODS

A comprehensive and structured literature search was conducted using three major scientific databases, including Web of Science, PubMed, and Google Scholar. The search strategy was designed to identify relevant studies related to cosmetic and cosmeceutical formulations, dermal drug delivery systems, skin permeation mechanisms, and nanotechnology-based cosmetic applications. The following keywords and combinations were used: cosmetics, cosmeceuticals, dermal drug delivery, topical formulations, skin structure, skin permeation, stratum corneum, permeation enhancers, nanoparticles, nanocarriers, lipid nanoparticles, liposomes, niosomes, antioxidant activity, anti-aging, wound healing,

photoprotection, antimicrobial activity, and skin regeneration. Original research articles, review papers, in vitro studies, in vivo experiments, and clinical investigations were included without restrictions regarding study type, cell line, animal model, or population characteristics. Studies published up to 2025 were considered to ensure inclusion of the most recent developments in the field. Retrieved studies were screened based on relevance to dermal and cosmetic applications. Data extraction focused on formulation characteristics, mechanisms of action, delivery efficiency, biological effects, and reported limitations. The collected information was then organized into thematic categories corresponding to skin biology, permeation pathways, enhancement strategies, and nanoparticle-based delivery systems. This structured approach enabled a comparative and integrative evaluation of current knowledge while highlighting inconsistencies, limitations, and emerging trends in cosmetic and cosmeceutical research.

Skin structure and dermal permeation pathways

The skin is composed of three primary layers: the epidermis, dermis, and hypodermis. The epidermis represents the outermost layer, with a thickness ranging approximately from 50 to 1500 µm depending on anatomical location. It plays a critical protective role against environmental stressors and is organized into five distinct sublayers, arranged from superficial to deep: the stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum, and stratum basale. The dermis constitutes the middle layer of the skin and is primarily responsible for providing structural integrity and elasticity. It is mainly composed of collagen and elastin fibers, with a thickness typically ranging from 0.5 to 3 mm. This layer also contains essential skin appendages and structures, including sebaceous glands, sweat glands, blood vessels, nerve endings, and hair follicles. Beneath the dermis lies the hypodermis, the deepest layer of the skin, which is predominantly composed of adipose tissue and connective tissue. The hypodermis functions as a protective and insulating layer, contributing to thermoregulation, mechanical cushioning, and energy storage, while also supporting underlying structures and facilitating metabolic exchange [7-10].

Three primary pathways have been identified for the penetration of drugs across the stratum corneum (SC): the intercellular, transcellular, and appendageal routes. The intercellular (paracellular) route is considered the most common pathway, in which molecules diffuse through the lipid-rich intercellular spaces between corneocytes within the SC. This route can accommodate a range of compounds, including relatively larger or hydrophilic molecules, depending on their physicochemical properties and formulation characteristics. In contrast, the transcellular route involves direct permeation through corneocytes and their lipid bilayers. Although this pathway is often described as more direct, it requires repeated partitioning between hydrophilic and lipophilic domains, making it generally more restrictive. Consequently, efficient transport via this route is typically limited to small, lipophilic molecules. The appendageal route involves penetration through skin appendages such as hair follicles and sweat glands and may provide an alternative pathway, particularly for particulate or nanocarrier-based systems [11]. The appendageal pathway, also referred to as the shunt route, enables the transport of molecules through skin appendages, including hair follicles, sebaceous glands, and sweat glands. Although this route accounts for a relatively small fraction of the total skin surface area, it can play a significant role in the penetration of certain molecules, particularly particulate and nanocarrier-based systems. The extent of permeation via this pathway is influenced by several factors, including the density and distribution of hair follicles, the physicochemical properties and volume of the applied formulation, and the size and morphology of the carrier system. In addition, the diameter of follicular openings and the presence of sebum and sweat can further modulate the extent of drug penetration through this route [7, 8, 12].

Strategies for enhancing skin permeation

Permeation enhancers (chemical and physical approaches)

The SC represents the primary barrier to dermal drug delivery; therefore, various strategies have been developed to enhance skin permeability and facilitate drug transport into deeper layers. These approaches are generally classified into physically enhanced, chemically enhanced, and stimuli-responsive methods. Physically enhanced techniques involve transient disruption or bypass of the SC to improve drug permeation. These include ablation-based methods such as microdermabrasion and tape stripping, which remove superficial skin layers but may cause irritation and suffer from limited reproducibility. Microneedles create microchannels across the SC, enabling minimally invasive and patient-friendly drug delivery; however, challenges remain regarding sterility, formulation stability, and drug

integrity. Emerging stretch-triggered systems offer controlled release by mechanically induced structural changes in response to external forces. Chemically enhanced methods rely on penetration enhancers that temporarily alter the lipid and protein structure of the SC to increase drug diffusion. Common enhancers include ethanol, propylene glycol, urea, and salicylic acid derivatives, which improve hydration, reduce barrier resistance, and facilitate drug permeation. These agents are commonly incorporated into semisolid formulations such as creams and ointments, although systemic delivery remains limited due to the skin barrier [13, 14].

Nanoparticle-based delivery systems in cosmetics

In addition, nanotechnology-based approaches have gained significant attention in cosmetic and dermal delivery systems. Nanoparticles (1–1000 nm), composed of lipids, polymers, or metals, are engineered to enhance drug stability, penetration, and controlled release, making them important components of modern nanocosmetic formulations [15]. Nanocosmetics are designed for application on the human body, aiming to cleanse, enhance appearance, and improve skin condition**,** improving attractiveness, or changing appearance, all while ensuring that no physiological harm is inflicted upon the body [13, 14]. Utilizing nanostructured particles that produce a thin moisture-retention layer to prevent water from evaporating fast so the most widely recognized cosmetic creations that have nanostructured particles are moisturizers. The nanostructured particles that are frequently employed in humidifying formulations include liposomes, nano-emulsions, and solid lipid nanostructured particles [14].

Overall, Nanocarriers represent highly operative drug delivery systems in the field of cosmetics, as their diminutive particle size enables them to traverse biological barriers, reduce degradation, and ensure the optimal quantity of the drug is delivered to the targeted tissue place [13, 16].

These are some advantages of nanocarriers in cosmetics:

- Durability, strength and improved conductivity thus effective penetration [14]
- Increased surface area, specific targeting, controlled drug release, high entrapment, high stability, increased efficacy and free radical scavenging [14]
- Capability to absorb UV light [14, 17, 18]
- High loading capacity (LC%) and encapsulation efficiency (EE%) [19, 20]
- Improve the bioavailability of hydrophobic medicines [16]
- Care for enzymatic degradation by functioning as a protective transporter system [16]
- Improves their appearance and adherence without changing the cosmetic products' fundamental potentials [13]
- The majority of these NPs possess the capability to transport drugs in both hydrophilic and lipophilic formulas [13]
- Better patient compliance [21]
- No valley or peak plasma level [21]
- Avoidance of first-pass effect [21]

Disadvantages of nanocarriers in cosmetics:

- Concerns persist regarding the health, protection, and toxicity hazards related to the utilization of these nanoparticles in cosmetic products [16]
- Hazardous to environment [14]
- Unknown effects [14]
- Expensive [14]
- Lack of characterization [14]
- Chance of local irritation at application site [21]

Nanostructured materials utilized within the cosmetics industry are classified into two distinct categories: organic and inorganic.

Organic nanostructured materials are mutable in size, nontoxic, biodegradable and sensitive to thermal and electrical radiation. These are used in numerous pharmaceutical applications, including transdermal drug delivery and skincare. Solid lipid nanostructured particles (SLNs), nanostructured lipid carriers (NLCs), ethosomes, liposomes, niosomes, dendrimers, polymersomes, cubosomes, micelles, nanocapsules and nanoemulsions are some models of organic NPs (Figure 1).

Inorganic nanostructured materials are composed of metal/metal oxides for example bucky-ball, silver, gold, carbon nanotubes (CNTs), titanium and zinc oxide, silica and nano-spheres (Figure 2)[14, 16, 22].

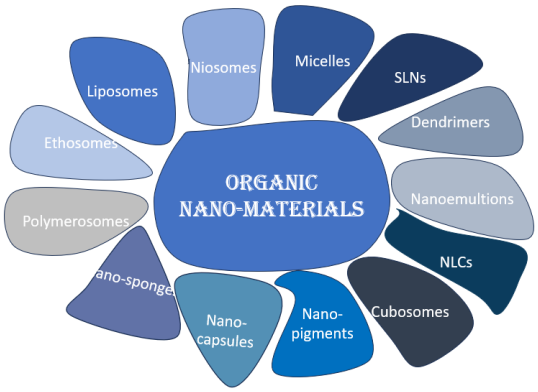

Fig. 1. Organic Nanostructured Materials

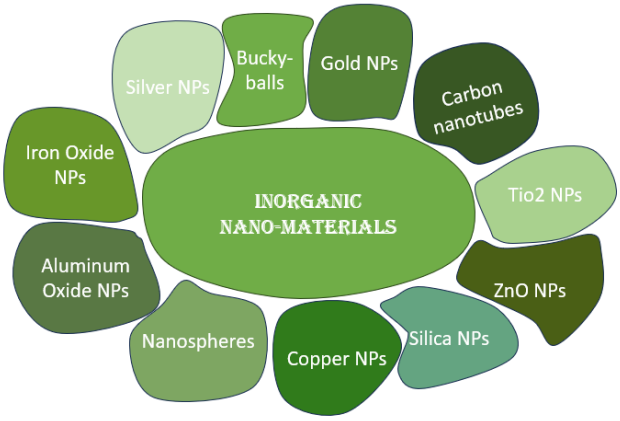

Fig. 2. Inorganic Nanostructured Materials

There are a number of key factors for choosing a nano-based delivery system [9, 10, 23]:

- Particle size, size distribution and zeta potential: compared to all features, the intrinsic nanometer influences represent the most significant factor. Overall, nano-systems with a diameter of 600 nm or larger cannot deliver encapsulated drugs to lower skin layers. Nanovesicles with a diameter of 300 nm or fewer could penetrate into deeper layers of the skin but nanoparticles with a diameter of 100 nm or less can properly deliver and permit the initiation of action.
- Electrostatic charges: The surface charge of the particles facilitates their bonding to the tissue and their adherence to cell membranes. Alterations in the direction of the charge influence cellular compartments in both in vitro and in vivo locations. The charge of surface effect on permeation and penetration of nano-systems on skin. Actually, the surface of cells exhibits a negative charge, primarily attributable to the presence of sulfated proteoglycan molecules. Consequently, when nano-systems possess a positive charge, electrostatic connections between the cell membrane and the nano-systems can be established, thereby facilitating transdermal permeation. Meanwhile, the negatively charged nano-systems exhibit a significant cellular absorption due to a non-specific mechanism of nano-system adsorption onto the cell membrane.
- Ideal drugs for dermal delivery: Because of the selective nature of skin, only some medications can be practical for dermal delivery systems. Disc-shaped, cylindrical and hemispherical molecules with a low melting point and a molecular weight of under 1000 Daltons, good similarity for both hydrophilic and lipophilic phases, high potency, brief half-life and low irritation are desirable for dermal delivery.
- Hydrating effects: Skin hydration can enhance the dermal uptake of both hydrophobic and hydrophilic pharmaceuticals; however, it is noteworthy that hydrophobic compounds may exhibit limited penetration and, in certain circumstances, can lead to skin irritation.
- pH-Responsiveness: Owing to variations in pH across distinct layers of the skin and varying environmental conditions, pH, alongside temperature, constitutes a significant stimulus-

response mechanism that has been extensively utilized to initiate drug release.

Cosmetic nanocarrier systems: classification and comparative analysis

Accordingly, a series of nanoparticles showed better and more desirable stability, which we mentioned in this study:

SLNs are characterized as solid components at ambient room temperature that contain stabilizers and lipid droplets which help the active constituents to enter into the lower layers of the skin more simply. These particles improve stability, bioavailability, hydration, skin coverage and can also be used in perfume and fragrance structures because of perfume's long-lasting aroma [24, 25].

NLCs were initially utilized in the late 1990s to address the limitations associated with SLNs, specifically their inadequate drug loading capacity and reduced stability. The second generation of lipid nanoparticle, NLCs, are composed of a blend of functional and biocompatible solid and liquid lipids (oils) in a percentage of 70:30, supplemented with surfactants and co-surfactants [24, 26, 27].

Liposome is derived from the words 'lipo' and 'soma'. The formation of liposomes is characterized by hydrophobic phospholipid bilayers that contain an aqueous medium in sphere-shaped vesicles. They are constituted from cholesterol and standard phospholipids within a fluidic site, maintained at an appropriate lipid-to-water ratio and subjected to significant power input. Minimizing acne rashes, reducing wrinkles and improving skin smoothness are some effects of these particles. Owing to their recyclable, safe, and biocompatible characteristics, liposomes are employed in a variety of cosmeceuticals, as they effectively encapsulate active ingredients [13, 25].

Niosomes are similar to liposomes, except for their superior adaptability and dependability. These are lipid-based nano-vesicles and non-ionic surfactants synthesized in an aqueous medium consisting of cholesterol. A bilayer composed of self-collecting surfactants encapsulates the fluid configuration. These nanoparticles are used in cosmetics largely by reducing the resistance of the horny layer and improving skin dispersion of ingredients [13, 16, 20, 25].

Lipid-based nanocarriers

SLNs and NLCs

SLNs (Figure 3) and NLCs (Figure 4) represent two distinct categories of nanoparticulate systems characterized by a lipid core composed of solid lipids, which remain solid at room and body temperature, or by combinations that include liquid lipids (which are liquid at room temperature). The variability in fatty acid structure afforded by the inclusion of liquid lipids permits for quite large distances within matrix. SLNs were developed in the early 1990s to avoid the disadvantages of the previous colloidal carriers such as emulsions , liposomes, and polymeric nanoparticles [28]. In SLNs which are solid components at room temperature, the drug particles are distributed in their molecular form. Nanoparticles, upon administration, maintain their solid state, thereby facilitating an organized release of the encapsulated drug.

The extended half-life of the drug, which enhances the bioavailability of active constituents with low water solubility, along with the improved stability of chemically labile drugs, the high entrapment efficiency of these active constituents, and the potential for lyophilization, represent several advantages of SLNs. However, despite these notable benefits, certain drugs exhibit superior solubility or compatibility with liquid lipids.

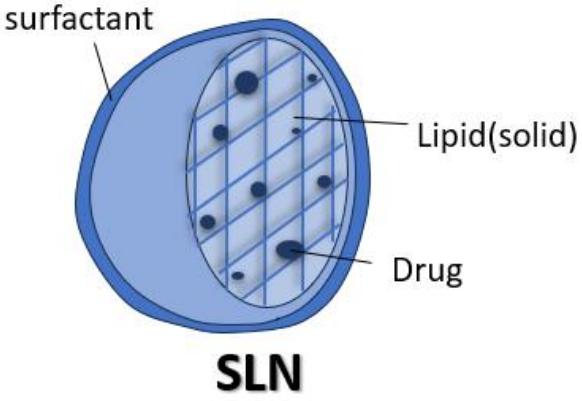

Fig. 3. SLN structure

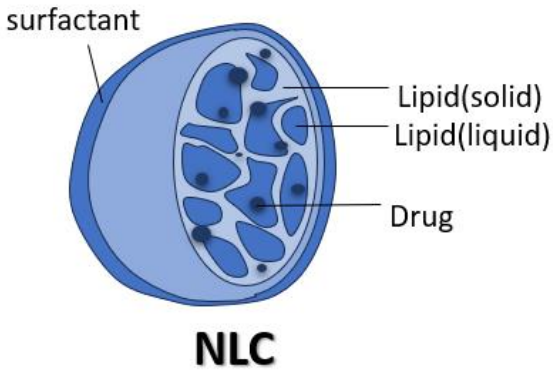

Fig. 4. NLC structure

Additionally, challenges such as inadequate drug loading capacity, elevated water content in the dispersions (ranging from 70% to 99.9%), an unpredictable propensity for gelation, erratic dynamics of polymer alterations, drug expulsion during storage following a polymeric transition, and the potential for particle growth have prompted researchers to pursue the growth of novel constructions of lipid nanocarriers capable of addressing these issues [26, 29].

NLCs are the second group of lipid nanoparticles [30]. NLCs can be synthesized by combining numerous proportions of solid and liquid lipids in a ratio ranging from 70:30 to 99:1, which maintain a solid state at both physiological and ambient temperatures. The structural imperfections within the matrix, arising from the disparities between solid and liquid lipids, create additional places that facilitate the accommodation of pharmaceutical compounds, thereby enhancing the combination of drug molecules in molecular and amorphous clusters form both. The average particle size of SLNs and NLCs typically falls within the submicron range, approximately between 40 and 1000 nanometers, contingent upon the composition of the lipid matrix and the method of production employed [30]. There are some differences between these two types of nanoparticles: NLCs have more water content and more drug loading capacity. Reports have established that with the same lipid content, SLNs have a larger occlusive effect than NLC matrices, however, the drug release profile in NLCs is better controlled [31]. Other advantages of NLCs are better biocompatibility, biodegradability, non-immunogenicity, physical stability and drug-retaining capacity during storage than SLNs [32]. Possible cytotoxicity and risks of skin inflammation because of surfactants are major disadvantages of these nanoparticles [28, 33, 34].

Lipids: The solid lipids utilized in the formulation of SLNs and NLCs are characterized via their biocompatibility and biodegradability. These lipids may be employed either independently, as in the case of SLNs, or in combination, comprising two or more lipids in a predetermined ratio, as observed in NLCs. Glyceryl behenate (Compritol®), glyceryl palmitostearate (Precirol®), cetyl palmitate, beeswax, carnuba wax and stearic acid as solid lipids and oleic acid, olive oil, castor oil, squalene, linoleic acid and α-tocopherol as liquid lipids are some common excipients in nanoparticle formulations. Medium- bind triglycerides, for example Miglyol® 812, in conjunction via oleic acid and linoleic acid, are frequently employed as penetration enhancers. The amount of solid-to-liquid lipids utilized in the formation of nanoparticles, as well as the specific type of lipid selected, significantly influences both the drug loading capacity and the structural characteristics of the particles.

Surfactants: Surfactants function by diminishing the interfacial tension between the lipid and aqueous phases, consequently improving the stability of the final formulation. Ionic surfactants (e.g., sodium cholate, sodium deoxycholate and sodiom oleat) increase the nanoparticle's surface charge due to electrostatic repulsion and improves their physical stability. Nonionic surfactants (like poloxamer 188, soybean lecithin, tyloxapol, phosphatidylcholine, sorbitan sters and polysorbates) keep nanoparticles from clumping together through the application of a steric stabilization effect. Co-emulsifying surfactants characterized by high movement facilitate the gelation of colloidal nanoparticle scatterings too.

Surface modifiers: Surface modifiers enhance not only the stability and dispersibility of SLNs and NLCs, but they facilitate their interaction with mucosal membranes too, thereby allowing for customized drug targeting. Furthermore, these components can diminish the thrombogenicity of nanoparticles and enable assessing the viability of a depot effect for the controlled release of hydrophobic pharmaceuticals from drug delivery systems. that are coated with a hydrophilic layer [26, 30]. Table 1 provides an overview of studies investigating cosmetic formulations based on SLNs and NLCs, highlighting their applications and outcomes in cosmetic delivery systems. (*Table 1 is after the references*).

Vesicular systems

Liposomes and niosomes

Liposomes (Figure 5) were first identified in the 1960s by Bengham and then turned into one of the most extensively studied drug delivery systems [75]. The inaugural liposomal product within the cosmetic industry was Capture TM, an anti-aging gel for the face developed by Christian Dior in 1987. Spherical liposomes, ranging in size from nano to micron, function as inert carriers, adept at encapsulating both hydrophobic and hydrophilic substances [76]. Liposomes are defined as spherical lipid vesicles, usually ranging in diameter from 50 to 500 nm. These structures are comprised of several lipid bilayers, designed through the emulsification of either natural or artificial lipids within an aqueous medium [75]. Liposomes are biocompatible, completely recyclable, non-toxic and non-immunogenic. Also well-suited for the

transfer of hydrophobic, hydrophilic and amphipathic drugs, and their synthesis is straightforward [77]. They increase the effectiveness, bioavailability and stability via encapsulation and provide sustained release. It increases the drug loading efficiency and protect it from toxic substances and the external environment. Owing to their dimensions, hydrophobic and hydrophilic properties, as well as their capacity to encapsulate drug molecules, either inside the aqueous vesicles or in the lipophilic membrane, they are widely used in nanoparticles today. However, high manufacturing price, leakage and integration of surrounding drugs/molecules, limited solubility and stability and brief half-life, the possibility of allergic reactions and the difficulty of targeting different tissues due to their large size are some of the disadvantages of these nanocarriers [75, 77].

Niosomes (Figure 6) are novel vesicular drug delivery systems that are physically like liposomes as they are made up of a bilayer too [78]. In the context of niosomes, the bilayer is composed of non-ionic surfactants rather than phospholipids. This structure is established solely when surfactants and cholesterol are blended in a precise ratio at temperatures that surpass the liquid transition point of the gel [78, 79]. It has an empty area in the center where hydrophilic and hydrophobic drugs are surrounded. Niosomes exhibit greater stability and are more cost-effective to produce and their size is between 100 and 200 nm. Materials that possess both biodegradable and biocompatible properties are employed in the fabrication of niosomes. Owing to their unique structure, niosomes serve as a quintessential example of an innovative drug delivery system capable of transporting amphiphilic, lipophilic, and hydrophilic molecules [80]. The organized and exact freedom of the drug, increasing the bioavailability, improving the skin penetration of the drug and the capability to protect the main part from the physiological movement are the advantages of these nanoparticles [78-80]. Physical instability, insufficient drug loading capacity, the need for specialized equipment and time-consuming operation, the possibility of impregnation of the surface of vesicles and the leakage of trapped drugs are among the disadvantages of these nanoparticles [78].

Characteristic components in the structure of liposomes and niosomes are explained below:

Lipids and phospholipids: Structurally, liposomes are defined as sphere-shaped or complicated spherical vesicles that are shaped through the self-aggregation of diacyl-chain phospholipids in an aqueous mixture. These liposomes can be synthesized from both phospholipid types (natural and synthetic). The lipids utilized in the formulation of liposomes are categorized as [75]:

Natural lipids: The membrane bilayer of regular cells is predominantly constituted of glycerophospholipids. Phospholipids are comprised of a glycerol part that is covalently attached to a phosphate unit and two fatty acid components. Additionally, the phosphate group may be associated with little, essential choline molecule. Owing to the unsaturated nature of the hydrocarbon chain, natural phospholipids exhibit a lower stability compared to their synthetic counterparts during the preparation of liposomes. Natural phospholipids are characterized by a diverse array of fatty acids, including a saturated fatty acid such as palmitic acid or margaric acid, alongside an unsaturated fatty acid. These phospholipids can be sourced from numerous origins, including soybean and egg yolk.

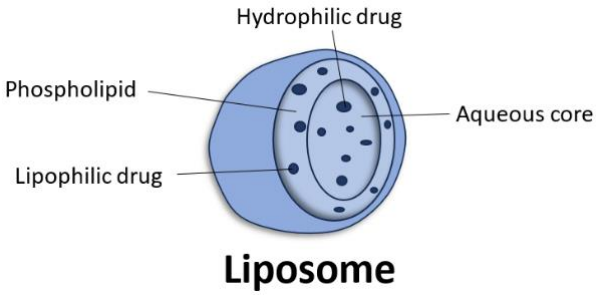

Fig. 5. Liposome structure

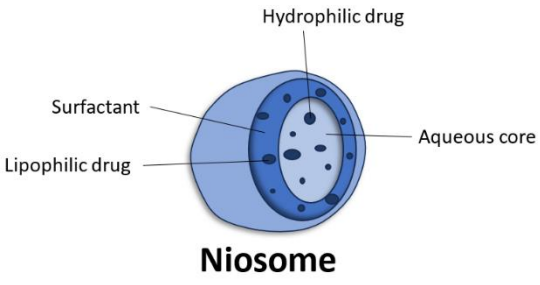

Fig. 6. Niosome structure

Synthetic lipids: Synthetic phospholipids are synthesized through precise chemical alteration of the non-polar and polar regions of natural phospholipids. These modifications facilitate the creation of an extensive array of clearly defined and sorted phospholipids. The predominant saturated synthetic phospholipids are derived from the utilization of stearic and/or palmitic fatty acids.

Steroids: Steroids are hydrophobic lipids characterized by a four-ring formation, with their diversity arising from the numerous main groups that are connected to these rings. Cholesterol is the predominant steroid employed in the arrangement of liposomes, typically utilized at a ratio of less than 30% of the whole lipid content, in order to improve the rigidity and constancy of the liposomes.

Surfactants: Surfactants are used in liposome formulations to adapt the encapsulation and discharge characteristics of liposomes by reducing surface energy between disparate non-miscible phases. A variety of surfactant-containing liposomes have been extensively utilized as carriers in drug delivery systems to improve the transdermal transformation of encapsulated therapeutic materials. Ultra-deformable liposomes, commonly referred to as transfersomes, are surfactant-based nanovesicles that have demonstrated favorable outcomes in transdermal drug delivery. The surfactants frequently utilized in liposome formulations include sodium cholate, Span® 80, Span® 60, Tween® 80 and Tween® 60 [75].

Cholesterol: Cholesterol is classified as an amphiphilic component, characterized by its hydroxyl (OH) group oriented towards the aqueous phase, while its aliphatic chain is directed towards the hydrocarbon chain of surfactants. As a precursor to steroids, cholesterol plays a crucial role in modulating the motion of hydrocarbon carbons by strategically positioning a rigid steroidal backbone adjacent to surfactant molecules within the bilayer. This arrangement contributes to the rigidity and optimal morphology of liposomes and niosomes. Furthermore, research has demonstrated that cholesterol effectively inhibits leakage by obstructing the conversion from the gel phase to the liquid phase [78].

Non-ionic Surfactants: Nonionic surfactants are characterized by their amphiphilic nature, possessing two different areas: one that is water-soluble (hydrophilic) and another that is organic-soluble (hydrophobic). These surfactants exhibit greater stability, biocompatibility, and reduced toxicity than anionic, cationic or amphoteric counterparts. Consequently, they are preferred for the formulation of enduring niosomes. Notable examples of primary classes of nonionic surfactants include alkyl amides, alkyl ethers, alkyl esters and fatty acids. The hydrophilic-lipophilic balance (HLB) and critical packing parameter (CPP) standards are crucial factors in defining the appropriate surfactants for niosome mixture [78].

Charged molecule: The vesicle fusion is inhibited by the repulsive forces arising from like charges, which results in an increase in zeta potential values. Consequently, this phenomenon contributes to the enhanced stability of the vehicle. Dicetyl phosphate and phosphatidic acid are among the greatest frequently utilized negatively charged compounds in the synthesis of niosomes, while stearylamine and stearyl pyridinium chloride are recognized as prominent positively charged molecules. Nevertheless, an increase in the amount of charged compounds may obstacle the production of niosomes [78]. Table 2 summarizes reported studies on cosmetic formulations utilizing liposomes and niosomes, with a focus on their roles in enhancing the performance and stability of cosmetic products. (*Table 2 is after the references*).

CONCLUSION

Nanotechnology has significantly advanced cosmetic science by enabling improved dermal delivery, enhanced stability, and controlled release of bioactive compounds. Lipid-based and vesicular nanocarriers, including SLNs, NLCs, liposomes, and niosomes, have been extensively explored as promising platforms for topical applications.

This review emphasizes that current evidence suggests the performance of these nanocarriers is strongly influenced by formulation composition, preparation methods, and application context. Although numerous studies report enhanced encapsulation efficiency, stability, and dermal delivery for NLCs compared to SLNs, such advantages are not universal and remain dependent on system-specific parameters. Similarly, while niosomes are frequently associated with improved physical stability and sustained release relative to liposomes, conflicting findings and variability across studies limit definitive conclusions (Figure 7).

A key limitation identified across the literature is the lack of standardized methodologies and quantitative comparative analyses, which hinders robust cross-study evaluation. Furthermore, critical aspects such as long-term safety, nanotoxicity, regulatory considerations, scalability, and sustainability remain insufficiently addressed.

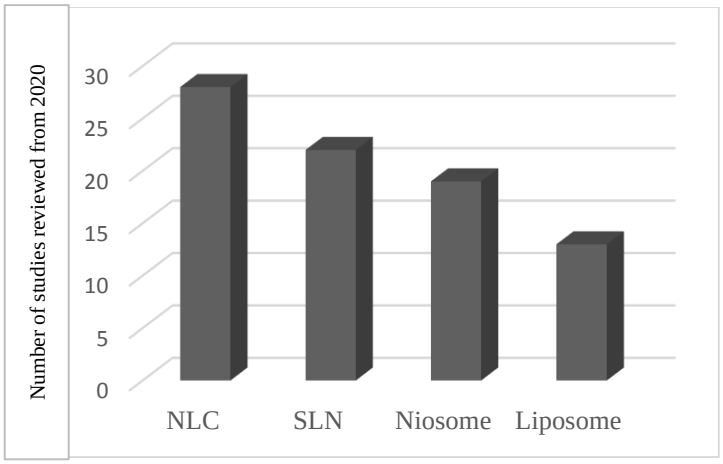

Fig. 7. Number of studies reviewed different nanoparticles in cosmetics

Overall, rather than establishing definitive superiority among nanocarriers, this review emphasizes the need for rational design based on application-specific requirements. Future research should focus on standardized evaluation frameworks, integration of safety and regulatory perspectives, and development of advanced and hybrid systems to support the translation of nanocarriers into clinically and commercially viable cosmetic products.

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AUTHOR'S CONTRIBUTIONS

SG and FR conceptualized the study. HAN drafted the manuscript with support from FR. SG critically revised the manuscript. All authors reviewed, discussed, and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no competing financial interests or personal relationships that could have influenced the work reported in this paper.

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ARTIFICIAL INTELLIGENCE STATEMENT

During the preparation of this manuscript, AI-assisted tools were used to support language editing and drafting. All generated content was critically reviewed and revised by the authors, who take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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TABLES

Table1. Studies of cosmetic products with SLN and NLC formulations in cosmetics

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
NLC	Pumpkin seed oil	Poloxamer 188 Tween 20 Soy lecithin Carnauba wax Beeswax	High shear homogenization and ultrasonication	Photo protective properties Antioxidant activities Increase in EE%	[35]
NLC SLN	Protocatechuic acid	*DMSO* Tween 80 Precirol Miglyol	Hot high pressure homogenization	Photo protective properties Increase in skin permeation Increase in safety	[36]
NLC	Folic acid	Apifil Plurol stearique Labrafil Capryol Tween 80 Soft paraffin Liquid paraffin	High shear homogenization and ultrasonication	Anti-photo aging activity Increase in skin permeation Increase in stability Increase in EE%	[37]
NLC	α-Tocopherol	Oleic acid Lauric acid Tween 80 Sodium acetate trihydrate Carbopol 940	Hot melt emulsification	Moisturize effects Antiaging activity Increase in stability Increase in safety	[38]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
NLC	Kojic acid	Palmitic acid Oleic acid Span 80 Span 60 Tween 20 Cholesterol Stearic acid Beeswax Glyceryl monostearate	High shear homogenization and ultrasonication	Anti-photo aging activity Antioxidant activities Anti-hyperpigmentation activity Increase in skin permeation Increase in stability	[39]
NLC	Caffeoylquinic acid	Precirol Compritol Poloxamer 188 Tween 80 Glyceryl monostearate	High shear homogenization and ultrasonication	Antiaging activity Increase in stability Increase in safety Increase in skin permeation	[40]
NLC SLN	Coenzyme Q10	Compritol Glyceryl tripalmitate Tween 80 MCT oil Span 80	High shear homogenization and ultrasonication	Anti-hyperpigmentation activity Antiaging activity Antioxidant activities Increase in stability Increase in EE%	[41]
NLC	Glycyrrhiza glabra extract	Precirol Tween 80 MCT oil Span 80	High shear homogenization and ultrasonication	Increase in stability Increase in EE% Anti-hyperpigmentation activity	[42]
NLC	Coenzyme Q10	MCT oil Tripalmitin Compritol Tween 80 Span 80	High shear homogenization and ultrasonication	Antiaging activity Increase in EE% Increase in stability	[43]
NLC	N-undecylenoyl-phenylalanine	Precirol Cetyl palmitate Glyceryl monostearate Tween 80 Poloxamer 188 Span 80 MCT oil	High shear homogenization and ultrasonication	Increase in stability Anti-hyperpigmentation activity Increase in safety Increase in skin permeation	[44]
NLC	Auraptene	Compritol Tween 80 Oleic acid	High shear homogenization and ultrasonication	Antioxidant activities Anti-hyperpigmentation activity	[45]
NLC	Elaeagnus rhamnoides extract	Glyceryl monostearate Poloxamer 407 PEG 400 Tween 80	Melt emulsification and high pressure homogenization	Hydration effect Increase in skin permeation	[46]
NLC	Azelaic acid Panthenol	Poloxamer 84 Phosphatidylcholine Tween 20 Cethyl palmitate Glycerol monostearate	High pressure homogenization and high shear homogenization	Hydration effect Antioxidant activity Moisturize effect Acne treatment Increase in stability Increase in EE%	[47]
NLC	Pomegranate seed oil Wheat germ oil Kenaf seed oil	Sodium cholate Polaxamer 68 Tween 20 Glycerol monostearate Emulgade Luminol	Modified high pressure homogenization	Photo protective properties Antioxidant activities Increase in stability Increase in safety	[48]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
NLC SLN	Stearic acid	Tween 80 Capryol Precirol	Ultrasonication	Hydration effect Moisturize effect Increase in skin compatibility Increase in stability	[49]
NLC	Curcuminoids	Compritol Precirol Labrafil Gelot Apifil Gelucire 44/14 Suppocire Soya lecithin Stearic acid Capryol Tween 80	High shear homogenization	Antioxidant activities Increase in skin permeation Increase in stability	[50]
NLC	Passiflora edulis seeds oil	Tween 80 Precirol Compritol Cetyl Palmitate Cetrimide	High shear homogenization and ultrasonication	Increase in skin compatibility Increase in stability Increase in safety	[51]
NLC	Coenzyme Q10	Quaternized chitosan Alkyl polyglucoside Hard Stearin Tween 80	High pressure homogenization	Increase in skin permeation Increase in stability	[52]
NLC	Resveratrol	Methylisothiazolinon Vitamin E Sodium hyaluronate Glycerol Shea butter Allantoin	Ultrasonic emulsification	Photo protective properties Antioxidant activities Antiaging activity Increase in stability Increase in safety	[53]
NLC	Ellagic acid	Tricaprylin Labrasol Miglyol Poloxamer 188	High shear homogenization and ultrasonication	Antioxidant activities Increase in solubility Increase in safety Increase in skin permeation	[54]
NLC	Rosmarinic acid (ocimum sanctum)	Tween 20 Tween 80 Cteareth 10 Decyl glucoside Polyethylene glycol 400 Propylene glycol Glycerin Cholesterol	High pressure homogenization	Antioxidant activities Increase in safety Increase in skin permeation	[55]
NLC SLN	Orobol	MCT oil Cocoa butter Shea butter Capmul Labrafac Labrasol Transcutol Miglyol Tween 20	High shear homogenization and ultrasonication	Antiaging activity Increase in skin permeation Increase in safety	[56]
NLC	Quercetin Omega 3	Dioctyl sodium sulfosuccinate Soy lecithin Tween 80 Triethanolamine Glycerin Precirol Gelucire Labrasol Poloxamer 407	Modified melt emulsification and ultrasonication	Antioxidant activities Antimicrobial properties Increase in skin permeation	[57]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
NLC	Curcumin extract Marigold extract Azelaic acid	Tween 20 Glycerol monostearate Poloxamer 188 Phosphatidylcholine Cetyl palmitate	High pressure homogenization and melt emulsification and	Antioxidant activities Antimicrobial properties Moisturize effects Antiaging activity Acne treatment Anti-inflammatory properties Increase in skin permeation	[58]
NLC	Passiflora edulis seeds oil	Precirol Tween 80 Cetrimide Carbopol 940	Ultrasonication	Anti-hyperpigmentation activity Increase in skin permeation Increase in stability Increase in safety	[59]
SLN	*Aloe vera*	Stearic acid Tween 80 Cetosteryl alcohol Liquid paraffin Glyceryl monostearate	Modified solvent emulsification	Photo protective properties Increase in safety	[60]
SLN	α-Tocopherol	Phosphatidylcholine Stearic acid Chitosan	Modified high shear homogenization and solvent diffusion	Increase in skin permeation Increase in EE%	[61]
SLN	Kojic acid	Tween 20 Span 80 Span 60 Stearic acid Ccholesterol Beeswax Glyceryl monostearate	Ultrasonication	Anti-hyperpigmentation activity Increase in skin permeation	[62]
SLN	Flavonol Glycoside of Prunus persica	Span 80 Cetearath 20 Liquid paraffin Propylene glycol Beeswax Cetostearyl alcohol	High shear homogenization	Anti-hyperpigmentation activity Antioxidant activities Antiaging activity Increase in stability Increase in safety	[63]
SLN	Vitamin A	Tween 80 Span 80 Triethanolamine Beeswax Carbopol 941	Ultrasonication	Increase in skin permeation Increase in stability Increase in safety	[64]
SLN	Fucoxanthin	Cetyl palmitate Triglyceride Caprylic Polyglyceryl Disterate Methylglucose Dimethicone	High shear homogenization	Photo protective properties Hydration effect Increase in safety	[65]
SLN	Palm fruit oil	Glyceryl monostearate Tween 80 Span 80 Liquid paraffin Propylene glycol Glycerin Titanium dioxide	Hot high pressure homogenization	Hydration effect Anti-hyperpigmentation activity Antiaging activity Increase in safety	[66]
SLN	Kojic acid	Stearic acid Mineral oil Arlacel 83	High shear homogenization	Anti-hyperpigmentation activity Increase in skin permeation	[67]
SLN	Caffeic Acid	Glyceryl tristearate Poloxamer Soybean lecithin	Hot melt emulsification, homogenization and ultrasonication	Antioxidant activity Increase in skin permeation	[68]
SLN	L-Arginine	Compritol Oleic acid Poloxamer 188	Ultrasonication	Increase in skin permeation	[69]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
SLN	Adenosine	Stearic acid Lauric acid Palmitic acid Myristic acid Glycerol monostearate Poloxamer 188 Poloxamer 407 Span 80 Span 40 Span 20 Tween 80	Modified emulsification and hot high pressure homogenization	Hydration effect Increase in safety Increase in skin permeation	[70]
SLN	Epigallocatechin gallate Resveratrol Myricetin	Precirol Gelucire 39/01 Gelucire® 50/13 Cetyl palmitate Compritol Apifil Dynasan 114 Softisan 100 Softisan 154	High shear homogenization and ultrasonication	Antioxidant activities Antiaging activity Increase in stability	[71]
SLN	β-carotene	Lecithin Citric acid Sodium azide Sodium dihydrogen phosphate Disodium hydrogen phosphate	Hot high pressure homogenization	Increase in stability	[72]
SLN	Octyl methoxycinnamate	Tetraethyl orthosilicate Cetyl palmitate Tegocare 450 Carbopol 971	High shear homogenization	Photo protective properties Increase in stability Increase in safety	[73]
SLN	Caffeic Acid	POP 67 PEO 98 PEO 98 Hyaluronic acid Poloxamer 188	High shear homogenization and ultrasonic homogenization	Antioxidant effects Increase in skin permeation	[74]

Table 2. Studies of cosmetic products with liposomes and niosomes formulations in cosmetics

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
Liposome	Vitamin D_3 Vitamin K_2 Vitamin E Curcumin	Phosphatidylcholine Cholesterol Ethanol	Microfluidization	Antioxidant activities Increase in skin permeation Increase in stability	[81]
Liposome	Resveratrol	Labrasol Transcutol Orthophosphoric acid Hematoxylin Eosin Ethanol	Ultrasonication	Increase in skin permeation Increase in stability Increase in solubility	[82]
Liposome	Aloe vera	Soybean lecithin Phosphatidylethanolamine Phosphatidylcholine Phosphatidic acid Phosphatidylinositol	Homogenization and microfluidization	Anti-hyperpigmentation activity Antiaging activity Increase in skin permeation	[83]
Liposome	Phenyl ethyl resorcinol	Phosphatidylcholine Tween 80 Propylene glycol Ethanol	Solvent evaporation	Increase in stability	[84]
Liposome	Phenyl ethyl resorcinol	Lecithin Cholesterol	Modified ethanol injection	Anti-hyperpigmentation activity Increase in stability Increase in safety Increase in skin permeation	[85]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
Niosome Liposome	Kenaf seed oil	-	Modified ethanol injection	Increase in skin permeation	[86]
Liposome	Coenzyme Q10	Imwitor 375 Diglycerol monooleate Soybean oil Ethanol Ethyl oleate	High pressure homogenization	Increase in skin permeation	[87]
Liposome	Coffee extracts	Lecithin Cholesterol	Ultrasonication and solvent evaporation	Photo protective properties Anti-inflammatory properties Increase in safety Increase in stability	[88]
Liposome	Asparagus racemosus	Chloroform Methanol Sulfuric acid Cholesterol	Chloroform film method Reverse phase evaporation Polyol dilution Freeze drying of monophase solution	Anti-hyperpigmentation activity	[89]
Niosome	*Kojic acid*	Span 60 Tween 80 Cholesterol Carbopol 940 Triethanolamine	Ultrasonication	Anti-hyperpigmentation activity Antioxidant activity Increase in skin permeation	[90]
Niosome	Glutathione tripeptide	Cholesterol Span 60 Carbopol 934 Cetearyl alcohol Cetyl alcohol	Thin film hydration	Antiaging activity Increase in skin permeation	[91]
Niosome	Ascorbic acid	Tween 80 Span 80 Cholesterol	Thin film hydration	Antioxidant activity Increase in skin permeation	[92]
Niosome	Soybean extract	Span 60 Cholesterol	Reverse phase evaporation	Hydration effect Antiaging activity Increase in safety	[93]
Niosome	Natural phenolic acids	Tween 80	Thin film hydration	Antioxidant activity	[94]
Niosome	Epigallocatechin gallate	Tween 40 Span 60	Thin film hydration	Antioxidant activity Increase in skin permeation	[95]
Niosome Ethosome	Magnesium ascorbyl phosphate	Phosphatidylcholine Carbopol 934 Span 60 Span 80 Cholesterol	Thin film hydration	Anti-hyperpigmentation activity Increase in skin permeation Increase in EE%	[96]
Niosome	Arbutin	Cholesterol Tween 20 Span 20	Ultrasonication	Increase in EE% Increase in safety Increase in stability	[97]
Liposome Niosome	Rosmarinic acid (ocimum sanctum)	Lecithin Cholesterol Span 20	Thin film hydration	Antioxidant activity Increase in safety Increase in skin permeation	[55]
Niosome	Purple glutinous rice extract	Tween 60 Cholesterol Carbopol Propylene glycol Glycerin Sorbitol	Thin film hydration and sonication	Hydration effect Anti-hyperpigmentation activity Antiaging activity Antioxidant activity Increase in safety Increase in stability Increase in solubility	[98]
Niosome	Resveratrol	Tween 80 Span 80	Thin film hydration	Antioxidant effects Increase in stability	[99]
Niosome	Porcine placenta extract	Span 20 Cholesterol Phosphatidylcholine PEG 2000	Thin film hydration and sonication	Increase in skin permeation Increase in EE%	[100]

Nanoparticles	Main substances	Excipients	Preparation method	Conclusion	
Niosome Transfersomes	Melatonin	Phosphatidylcholine Tween 80 PEG 400 Cholesterol Span 60	Ultrasonication	Anti-inflammatory properties Increase in skin permeation	[101]
Niosome Liposome	α-tocopherol	Sweet almond oil Soybean Phosphatidylcholine Cholesterol Tween 20 Tween 60	Thin film hydration	Antioxidant effects Increase in EE%	[102]
Niosome	*Jellyfish collagen*	Lecithin Cholesterol Span 60 Tween 60	Thin film hydration and sonication	Antioxidant effects Antimicrobial properties Increase in stability	[103]