

**CAPERS (CAPPARIS SPINOSA): RECENT APPROACHES IN NOVEL  
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Article Received on 29 April 2026,  
Article Revised on 19 May 2026,  
Article Published on 01 June 2026,

<https://doi.org/10.5281/zenodo.20438187>

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**How to cite this Article:** Sanika Yadav\*<sup>1</sup>, Mukta Shingade<sup>2</sup>, Pallavi Hake<sup>3</sup>, Dr. Shashikant Dhole<sup>4</sup>. (2026). Capers (Capparis Spinosa): Recent Approaches In Novel Drug-Delivery System. World Journal of Pharmaceutical Research, 15(11), 01–18.

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**ABSTRACT**

Capparis spinosa L., commonly known as the caper plant, is a perennial shrub that grows widely in Asia and the Mediterranean. It belongs to the family Capparidaceae, also known as Capparaceae. It has long been used to treat rheumatism, diabetes, and liver disease due to its therapeutic, nutritional, and aromatic properties. The plant has a wide range of pharmacological activities due to its abundance of bioactive substances, including phenolic acids, alkaloids, glucosinolates, flavonoids (kaempferol, quercetin, and rutin), and essential oils. These compounds possess antioxidant, hepatoprotective, antimicrobial, anticancer, anti-inflammatory, and antidiabetic qualities. However, the clinical use of *C. spinosa* is limited due to the phytoconstituents' instability, low bioavailability, and poor solubility. To overcome these challenges, recent research has focused on incorporating isolated compounds or caper

extracts into novel drug delivery systems (NDDS) such as hydrogels, liposomes, nanoemulsions, and nanoparticles. These systems improve pharmacokinetic and pharmacodynamic profiles by enhancing the stability, solubility, and controlled release of bioactive components. This review of Capparis spinosa's phytochemical composition, pharmacological characteristics, and novel formulation methods highlights how nanotechnology can improve the plant's stability and therapeutic effectiveness. It ends by highlighting areas that need further investigation and providing perspectives for the development of standardized, safe, and effective formulations based on capers for use in

clinical and nutraceutical settings.

## 1. INTRODUCTION

Native to arid and semi-arid areas of the Mediterranean basin, the Middle East, and portions of Asia, *Capparis spinosa* L. is a perennial shrub belonging to the Capparaceae family.<sup>[1]</sup> It has long been grown for its edible flower buds (called "capers") and fruits (called "caper berries"), and it grows naturally in rocky, dry soils with exceptional drought resistance.<sup>[1,2]</sup> Beyond its culinary value, *C. spinosa*'s rich phytochemical profile and variety of therapeutic properties have drawn growing pharmacological and nutraceutical interest.<sup>[3,4]</sup> In traditional medicine, rheumatism, hepatic disorders, diabetes, toothaches, and inflammatory conditions have all been treated with the roots, bark, leaves, and buds of the caper plant.<sup>[2,5]</sup> Decoctions of *C. spinosa* were used as digestive, diuretic, and antirheumatic treatments in ancient Greek, Persian, and Ayurvedic systems.<sup>[2,5]</sup>

These applications align with current research on its anti-inflammatory and antioxidant properties.<sup>[4,6]</sup> Flavonoids (rutin, quercetin, kaempferol), alkaloids, glucosinolates, phenolic acids, terpenoids, essential oils, and fatty acids have all been found in *C. spinosa*, according to phytochemical analyses.<sup>[3,4,7]</sup> Among these, rutin and quercetin are thought to be important bioactive markers that support vascular-protective and antioxidant properties.<sup>[4,7]</sup> The plant part, place of origin, and extraction technique all affect the phytochemical content.<sup>[7,8]</sup>

### 1.1 Classification

Kingdom: Plantae

Subkingdom: Tracheobionta (Vascular plant)

Superdivision: Spermatophyta (seed plants)

Class: Magnoliopsida (Dicotyledon)

Subclass: Dilleniidae

Family: Capparaceae (Caper family)

Genus: *Capparis* L.

Species: *Capparis spinosa* L.

Common Name: Caper Plant

### 1.2 Vernacular Name

English -Caper plant

Hindi -Kabra

Sanskrit -Himsra

Marathi -Kabra

Tamil -Kabarai

Telugu –Kaburi

### 1.3 Cultivation

The xerophytic perennial shrub *Capparis spinosa* grows well in arid and semi-arid regions. Although it originated in the Mediterranean Basin, it is currently grown in parts of India (Rajasthan, Gujarat, and Maharashtra), North Africa, the Middle East, Southern Europe, and Central Asia. It has a high tolerance to drought and salinity and grows well on walls, rocky slopes, and poor sandy soils.<sup>[9,10]</sup>

The ideal temperature range is between 20 and 30°C. Warm to hot climates are preferred. Rainfall of 200–400 mm per year is sufficient. For best growth and flowering, it needs full sunlight. Although it can withstand high summer temperatures, it is sensitive to severe frost.<sup>[11]</sup>

*Capparis spinosa* commonly known as the cappers plant, contain various compounds in its different parts:

**Flowers:** Stachydrine, Spermidine, Capparisine A–C, Capparispine, Capparispine 26-O-β-D-glucoside, Rutin, Quercetin, Kaempferol

**Steam Bark:** β-Sitosterol, Campesterol, Cappariloside A, Rutin, Quercetin, Kaempferol, Glucocapparin

**Leaves:** Rutin, Quercetin, Kaempferol, Syringic acid, Vanillic acid, Caffeic acid, Ferulic acid, p-Coumaric acid.

**Buds:** Rutin (major), Quercetin, Kaempferol, Isorhamnetin, Capparoside A, Stachydrine, Tocopherols, Volatile oils (methyl isothiocyanate, benzyl isothiocyanate)

**Caper berries:** Glucocapparin, Glucobrassicin, Rutin, Quercetin, Kaempferol, Ascorbic acid, Tocopherols, Fatty acids (linoleic, palmitic, oleic acids)

Quercetin is major flavonoid in *Capparis spinosa*.and shows anti irritation activity by reducing inflammation, oxidative stress, and histamine release. Its protective action against skin irritation.<sup>[12]</sup>

## 2. Pharmacological activities

### 1. Antioxidant Activity

Capparis spinosa has been widely studied for its strong antioxidant potential, with extracts from its buds, leaves, roots, and fruits showing high free-radical-scavenging activity.<sup>[13]</sup> This antioxidant effect is mainly due to phenolic and flavonoid compounds such as quercetin, rutin, and kaempferol, which are abundant in different plant parts.<sup>[13,14]</sup> By neutralizing reactive oxygen species (ROS) and shielding cellular components from oxidative damage, these phytochemicals function as natural antioxidants.<sup>[15]</sup> Caper extracts have been shown to effectively reduce oxidative stress and inhibit lipid peroxidation in experimental assays such as DPPH, ABTS, and FRAP.<sup>[14]</sup> Further in vivo research demonstrates that *C. spinosa* boosts endogenous antioxidant enzymes like glutathione peroxidase (GPx), catalase, and superoxide dismutase (SOD), thereby offering biological defence against oxidative damage.<sup>[15,16]</sup> Additionally, studies on humans show that topical formulations containing caper extract can lessen oxidative irritation and UV-induced skin erythema, which supports its use in dermatological and cosmetic applications.<sup>[17]</sup>

### 2. Anti-inflammatory and Anti-irritation Activity

The anti-inflammatory and anti-irritant properties of *Capparis spinosa* are among its most important pharmacological actions.<sup>[18]</sup> In animal models, such as carrageenan-induced paw swelling, the hydromethanolic extracts of caper buds and leaves have shown a significant inhibition of inflammation-induced oedema.<sup>[19]</sup> Tumour necrosis factor-alpha (TNF- $\alpha$ ), interleukins (IL-1 $\beta$ , IL-6), prostaglandins, and leukotrienes are among the inflammatory mediators that the extract suppresses.<sup>[20,21]</sup> Additionally, it modifies the production of cytokines, increasing anti-inflammatory markers and suppressing pro-inflammatory cytokines like IL-17 and IFN $\gamma$ .<sup>[22]</sup> Its antioxidant capacity and the presence of flavonoids like quercetin, which block COX and LOX enzymes, are closely linked to this mechanism.<sup>[23]</sup> Consequently, *C. spinosa* may be used to treat dermatitis, skin irritation, and other inflammatory conditions.<sup>[24]</sup>

### 3. Antidiabetic and Metabolic Modulation Effects

Strong antihyperglycemic and hypolipidemic properties have been discovered in the caper plant.<sup>[25]</sup> Fruit extracts from *Capparis spinosa* have been shown to dramatically lower serum cholesterol, triglycerides, and fasting blood glucose levels in diabetic rats.<sup>[26]</sup> By encouraging glucose uptake in peripheral tissues, the plant extract also increases insulin sensitivity and

glucose tolerance.<sup>[27]</sup> Additionally, it decreases liver gluconeogenesis and shields pancreatic  $\beta$ -cells from oxidative stress-induced damage.<sup>[28]</sup> It is thought that quercetin and other polyphenolic components contribute to this activity by modifying enzymes that metabolize carbohydrates, such as glucokinase and glucose-6-phosphatase.<sup>[29]</sup> According to these results, *C. spinosa* may be used as a natural supplement to treat metabolic disorders and diabetes.<sup>[30]</sup>

#### 4. Hepatoprotective and Organ-Protective Effects

The hepatoprotective potential of *Capparis spinosa* against chemical-induced liver damage caused by toxins such as carbon tetrachloride ( $\text{CCl}_4$ ), paracetamol, and thioacetamide has been shown in a number of experimental studies.<sup>[31]</sup> By lowering lipid peroxidation markers (MDA) and increasing antioxidant enzyme levels (GSH, SOD, and CAT), the extracts preserve hepatocellular integrity.<sup>[32]</sup> Its phenolic and flavonoid components, which lower oxidative stress and stabilize liver membranes, are primarily responsible for the protective effect.<sup>[33]</sup> The decrease in necrosis and inflammation in hepatic tissues treated with caper extract is further confirmed by histopathological analysis.<sup>[34]</sup> It is also a potential organ-protective phytomedicine because it has been shown to protect the kidneys and heart in models of oxidative injury and ischemia.<sup>[35]</sup>

#### 5. Antimicrobial, Antifungal, and Antibiofilm Activity

Broad-spectrum antimicrobial properties have been demonstrated by extracts from different parts of *Capparis spinosa*.<sup>[36]</sup> Gram-positive bacteria like *Staphylococcus aureus* and Gram-negative bacteria like *Escherichia coli* and *Pseudomonas aeruginosa* have both been shown to be inhibited by methanolic and ethanolic extracts.<sup>[37]</sup> Furthermore, there have been reports of antifungal activity against *Candida albicans* and other pathogenic fungi.<sup>[38]</sup> According to recent research, caper extracts can prevent the formation of biofilms, which is essential for managing persistent bacterial infections.<sup>[39]</sup> Additionally, the antibacterial and antifungal potency of green-synthesised silver nanoparticles made with caper extract is further enhanced, suggesting that *C. spinosa* has potential in the field of nanophytomedicine.<sup>[40]</sup>

#### 6. Potential for Cytotoxicity and Anticancer

Because *Capparis spinosa* contains bioactive components that have cytotoxic effects on tumor cells, its anticancer activity has drawn more attention.<sup>[41,42]</sup> Significant antiproliferative effects against a number of cancer cell lines, including MCF-7 (breast cancer), HepG2 (liver cancer), and MB231 (triple-negative breast cancer), have been demonstrated by extracts from the roots, fruits, and leaves.<sup>[43,44]</sup> Apoptosis induction, cell proliferation inhibition, and

disruption of cancer cell signaling pathways are all part of the mechanism.<sup>[45]</sup> Tumor growth and metasis are also inhibited by its anti-inflammatory and antioxidant qualities.<sup>[46,47]</sup> These results imply that *C. spinosa* might be a useful natural source for the creation of anti cancer drugs.<sup>[48]</sup>

### 3. Recent approaches in novel drug delivery systems

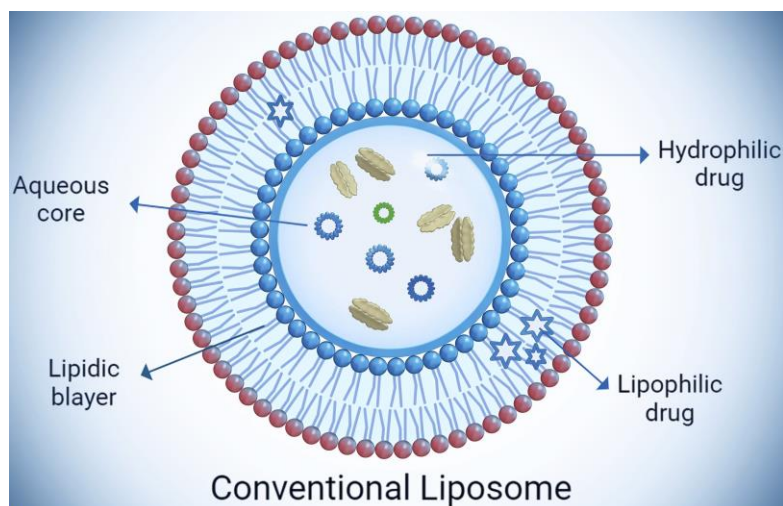
#### 1. Capparis oil nanoemulgel

The medicinal plant *Capparis spinosa*, also known as the caper plant, has antibacterial, antioxidant, and anti-inflammatory properties.<sup>[49]</sup> Although this plant's oil can help with skin issues, it is difficult to absorb through the skin and does not mix well with water. Scientists created a novel formulation known as nanoemulgel to address these issues. A nanoemulsion and a gel are combined to create a nanoemulgel.<sup>[49]</sup> Very tiny oil droplets (less than 200 nanometers) make up a nanoemulsion. A gel provides a stable, smooth foundation for effortless skin application. When combined, they improve caper oil's penetration and effectiveness.<sup>[49,50]</sup> Researchers created a *Capparis* nanoemulsion using Tween 80 and Span 80 as emulsifiers.<sup>[49]</sup> Very tiny oil droplets (less than 200 nanometers) make up a nanoemulsion. A gel provides a stable, smooth foundation for effortless skin application. When combined, they improve caper oil's penetration and effectiveness.<sup>[49,50]</sup> Researchers created a nanoemulsion of *Capparis spinosa* oil using Tween 80 and Span 80 as emulsifiers.<sup>[49]</sup> To create a nanoemulgel, they subsequently incorporated this nanoemulsion into a Carbopol 940 gel base.<sup>[49]</sup> This nanoemulgel's droplets were between 100 and 200 nanometers in size, which is extremely tiny and ideal for effective skin absorption. The benefits of employing MONPs based on *Capparis spinosa* include increased skin penetration, which increases the bioavailability of herbal compounds.<sup>[57]</sup> The formulation's increased stability and extended shelf life.<sup>[60]</sup> The effect lasts longer because it provides controlled release. It is more comfortable for patients, non-greasy, and simple to apply.<sup>[49,50]</sup> It is a promising system for anti-irritation gels and creams because of these advantages.<sup>[51]</sup> demonstrates the significance of anti-irritation therapy as well. Quercetin and rutin, two substances found in *Capparis spinosa* oil, help lessen skin irritation, burning, and redness.<sup>[51]</sup> Because it can penetrate deeper skin layers, using this oil in a nanoemulgel increases its efficacy for anti-irritation and skin repair.<sup>[51]</sup>



## 2. Capers fruit extract-loaded nanoliposomes

Rich in flavonoids, alkaloids, and phenolic compounds like ferulic acid, rutin, kaempferol, and quercetin, the caper plant (*Capparis spinosa* L.) is a traditional medicinal plant with anti-inflammatory, antioxidant, and skin-protective qualities.<sup>[52]</sup> Although these active molecules are highly effective in treating oxidative stress, inflammation, and skin irritation, they are poorly soluble and readily broken down by oxygen and light.<sup>[52]</sup> In order to improve the stability and activity of such extracts, researchers created nanoliposomes, a novel drug delivery system.<sup>[53]</sup> Phospholipids form a lipid bilayer around an aqueous core to form nanoliposomes, which are nanoscale vesicles (50–200 nm).<sup>[53]</sup> They are capable of encasing both lipophilic (soluble in oil) and hydrophilic (soluble in water) substances.<sup>[53]</sup> The bioavailability of natural compounds, such as those found in *Capparis spinosa*, is increased by their lipid nature and small size, which allow them to easily pass through skin or cell membranes.<sup>[53,54]</sup> Zahedi *et al.* (2024) used the thin-film hydration method to create nanoliposomes containing fruit extract from *Capparis spinosa*.<sup>[54]</sup> They hydrated the thin lipid film with an aqueous extract of caper fruit and employed soy lecithin and cholesterol as lipid materials.<sup>[54]</sup> Following sonication, the nanoliposomes exhibited good stability for more than three months and had an average size of 100–120 nm.<sup>[54]</sup> The effectiveness of encapsulating total phenolic compounds, primarily quercetin and rutin) was discovered to be greater than 80%, indicating that the system is capable of efficiently retaining the active components.<sup>[54]</sup> Due to improved penetration and prolonged release of active molecules, it also demonstrated anti-inflammatory and anti-irritation effects in *in vitro* skin models.<sup>[54,55]</sup> It also enhanced skin hydration and barrier repair, assisting in the restoration of the skin's natural protective layer.<sup>[55]</sup> Because of this, it is perfect for use in dermatological products, anti-irritation gels, and cosmetic creams. The bioactive substances stay stable, reach deeper skin layers, and have a longer half-life thanks to the use of nanoliposomes.<sup>[53]</sup> This contemporary nanotechnology-based system contributes to the increased efficacy, safety, and patient-friendliness of herbal remedies such as *Capparis spinosa*.<sup>[52,54,55]</sup>

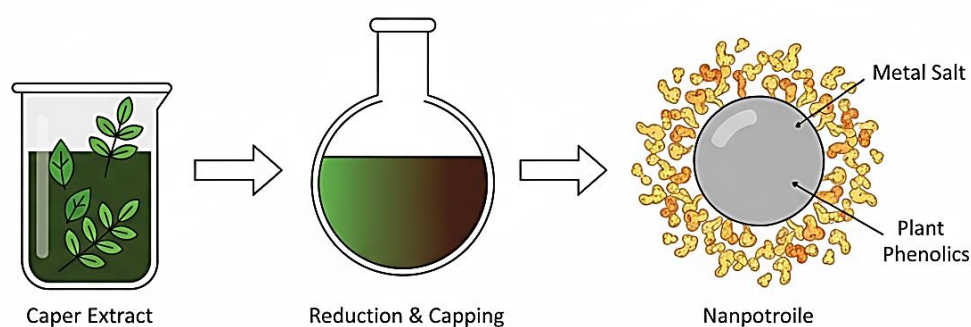


**Figure 1: Capers Fruit extract Loaded Nano emulsion Molecule.**

### 3. CaperExtract-Based Metal-Oxide Nanoparticles

Metal oxide nanoparticles (MONPs) are incredibly tiny particles created by mixing oxygen with metals like potassium, copper, or zinc. These nanoparticles, which typically range in size from 1 to 100 nanometers, have special physical, chemical, and biological characteristics that make them valuable in formulations for skin care, wound healing, and medication delivery.<sup>[56]</sup> Researchers have recently concentrated on preparing these nanoparticles using plant-based "green synthesis" techniques rather than chemical ones, which are frequently costly and hazardous.<sup>[57]</sup> Alkaloids, phenolic acids, and flavonoids (quercetin, kaempferol, and rutin) are among the naturally occurring bioactive substances found in the extract of *Capparis spinosa*, also referred to as the caper plant. These substances function as stabilizing agents to keep metal ions from clumping together and as reducing agents to turn them into nanoparticles.<sup>[57,58]</sup> This environmentally friendly approach adds therapeutic benefits from the plant's natural constituents while also reducing pollution.<sup>[58]</sup> Neamah *et al.* (2023) used fruit extract from *Capparis spinosa* to create zinc oxide nanoparticles (ZnO-NPs). The nanoparticles' strong antioxidant activity and biocompatibility, along with their average size of roughly 37 nm, made them appropriate for use in cosmetic and medical applications.<sup>[58]</sup> *Capparis spinosa* flower extract was used in another study by Khan *et al.* (2024) to create potassium oxide nanoparticles (K<sub>2</sub>O-NPs), which demonstrated superior antibacterial and anti-biofilm qualities. These nanoparticles demonstrated potential for use in topical medication formulations for the treatment of infections and skin irritation, and they were effective against a number of skin pathogens.<sup>[59]</sup> Because the metal oxide and caper plant phytochemicals work together, these green-synthesised nanoparticles can help improve skin

barrier repair, reduce inflammation, and enhance hydration when used in topical creams or gels (60). Additionally, the extract's antioxidant components lessen oxidative skin damage by scavenging free radicals.<sup>[60,61]</sup> Therefore, metal oxide nanoparticles derived from *Capparis spinosa* offer a viable and sustainable strategy in the field of innovative drug delivery systems, particularly in wound-healing, dermatological, and cosmetic applications.<sup>[61]</sup> The bioactive compounds from the plant extract that coat the surface of *Capparis spinosa*-based metal oxide nanoparticles (MONPs) and their large surface area are the primary factors influencing their mechanism of action.<sup>[56]</sup>



**Figure 2: Caper Extract Metal oxide Nanoparticle.**

These qualities increase their biological activity and facilitate their interaction with bacteria or skin cells. When applied topically, these nanoparticles deliver the plant's natural compounds directly to deeper layers by penetrating the stratum corneum, the outermost layer of skin, improving absorption and acting more quickly than traditional creams.<sup>[61]</sup> *Capparis spinosa* extract contains flavonoids and phenolic compounds that function as antioxidants to counteract dangerous free radicals that can harm skin cells. This lessens redness, irritation, and inflammation.<sup>[57]</sup> The antibacterial, UV-protective, and wound-healing properties of the metal oxide core, such as zinc oxide (ZnO) or potassium oxide (K<sub>2</sub>O), also contribute to the overall effect.<sup>[58]</sup> Together, the metal core and plant extract create a synergistic system in which the metal oxide improves skin protection and antimicrobial activity and the plant extract increases healing and calming effects.<sup>[59]</sup> The gradual and regulated release of active compounds from the nanoparticles is another crucial mechanism. These nanoparticles gradually release the plant's bioactive compounds over time due to their small size and stable

structure, preserving the therapeutic, sustaining the therapeutic effect for extended periods of time.<sup>[60]</sup> Because it guarantees continuous action on the skin and minimizes the need for frequent application, this feature is especially helpful in topical drug delivery systems.<sup>[60,62]</sup>

The benefits of employing MONPs based on *Capparis spinosa* include increased skin penetration, which increases the bioavailability of herbal compounds.<sup>[57]</sup> The formulation's increased stability and extended shelf life.<sup>[60]</sup> synthesis that is both non-toxic and environmentally friendly because no dangerous chemicals are used.<sup>[61]</sup> One formulation has several functions, including antioxidant, anti-inflammatory, antibacterial, and skin barrier repair.<sup>[59,62]</sup> All things considered, metal oxide nanoparticles derived from *Capparis spinosa* offer a cutting-edge, efficient, and environmentally friendly method of topical and transdermal medication delivery. They are useful for treating skin irritation, infections, and disorders linked to oxidative stress because of their multi-targeted mechanism. They are useful for treating oxidative stress-related disorders, infections, and skin irritation due to their multi-targeted mechanism, which also helps to maintain healthy, hydrated skin.<sup>[62]</sup>

#### **4. Topical application of *Capparis spinosa* leaf essential oil emulsion**

The essential oil found in *Capparis spinosa* leaves is rich in oxygenated terpenes and volatile sulfur compounds, both of which have potent antibacterial and antioxidant qualities.<sup>[57]</sup> In a recent study, caper leaves growing in Sicily were hydrodistilled to extract the essential oil, which was then combined into an oil-in-water (O/W) emulsion to improve stability, decrease volatility, and increase dispersion of the oil components.<sup>[63]</sup> The study examined over 100 volatile compounds in the emulsion, and the main components were terpinen-4-ol, dimethyl tetrasulfide, dimethyl trisulfide, and methyl isothiocyanate.<sup>[63]</sup> Despite the formulation strategy used in the study, bioactivities (antibacterial/antioxidant) indicate strong potential for topical skin use, particularly in formulations for sensitive or irritated skin.<sup>[63]</sup> When applied topically, the emulsion format enhances the penetration of active compounds by improving contact with the stratum corneum and facilitating the uniform dispersion of essential oil droplets across the skin's surface.<sup>[64]</sup> The volatiles based on sulfur and terpenes work by rupturing microbial membranes (antibacterial action) and scavenging free radicals (antioxidant action), which cause oxidative stress and skin irritation.<sup>[63]</sup> The emulsion helps lessen inflammation, redness, and barrier disruption related to irritated skin by lowering microbial colonization and neutralizing free radicals.<sup>[60]</sup> Additionally, the gel/cream matrix of an emulsion reduces burst evaporation and improves sustained effect by controlling the

release of the oil components and extending the residence time on the skin.<sup>[64]</sup> Travel and tourism: Such a caper leaf essential oil emulsion can be applied topically, such as in hand creams for sensitive or damaged skin, anti-redness serums, post-sun exposure gels, and calming lotions. It may be especially helpful for skin conditions like mild dermatitis and post-shaving irritation where microbial overgrowth exacerbates irritation due to its antibacterial and antioxidant properties.<sup>[63]</sup> A formulation using this emulsion can also function as a natural "barrier-repair" product because the antioxidant components shield the skin from oxidative stress and the oil droplets aid in replenishing the skin's lipid layer.<sup>[60]</sup> Instead of using artificial actives, it makes use of the bioactive oil found in caper leaves. It improves skin delivery and increases the stability of volatile oil components. It displays The emulsion's controlled release prolongs its effects and slows the evaporation of volatile oil. It displays The emulsion's controlled release prolongs its effects and slows the evaporation of volatile oil.<sup>[64]</sup> Depending on the needs of the skin, it can be added to a variety of topical vehicles (creams, gels, serums). The risk of skin irritation from neat essential oils is decreased when they are used in appropriately formulated emulsions at safe concentrations.<sup>[64,60]</sup> Droplet size and emulsifier selection are crucial in formulation design. For topical application, droplet sizes between 50 and 200 nm are ideal for mild penetration and good skin spread without deep systemic absorption.<sup>[64]</sup> To promote barrier repair, the oil-in-water vehicle should have a skin-friendly pH (~5.5) and include lipids (like ceramides) and humectants (like glycerin). Because excessively concentrated essential oils can cause sensitization, safety testing (patch test, irritation study) is crucial.<sup>[60]</sup> The emulsion should prevent the active volatiles from evaporating or degrading, and stability testing (volatile loss, oxidation) should be carried out. Finally, the soothing/anti-irritant claim will be verified by clinical or semi-clinical testing on skin irritation models (e.g., SLS patch, UV-induced erythema).

## **5. Topical Moisturizing and Barrier-Repair Method Using Capparis Spinosa Fruit Extract**

Several bioactive substances with potent anti-inflammatory and antioxidant qualities, including quercetin, rutin, and kaempferol, are found in the fruit of the caper plant, *Capparis spinosa*.<sup>[57]</sup> A particular polysaccharide-free extract made from *C. spinosa* fruit has been shown in recent studies to have a significant moisturizing and barrier-repairing effect on human skin when applied topically.<sup>[60]</sup> The extract's moisturizing action is primarily due to its ability to stimulate the synthesis of filaggrin, an essential protein responsible for maintaining the structure and hydration of the stratum corneum. Filaggrin breakdown products, such as

pyrrolidone carboxylic acid (PCA), act as natural moisturizing factors (NMFs) that improve the skin's elasticity and softness. Additionally, the extract affects the activity of caspase-14, an enzyme that controls the appropriate breakdown of filaggrin into NMF components, improving the elasticity and softness of the skin.<sup>[65]</sup> Furthermore, the fruit extract contains antioxidant molecules like quercetin and rutin that neutralize free radicals and suppress inflammatory mediators like TNF- $\alpha$  and IL-6, which are known to cause skin redness and dryness.<sup>[57,66]</sup> By preventing trans-epidermal water loss and restoring the protective lipid barrier, the extract preserves the skin's natural moisture balance.<sup>[60,66]</sup> Many formulation techniques have been investigated to enhance its stability and delivery. It has been discovered that traditional oil-in-water creams with 2–5% *C. spinosa* extract greatly improve skin hydration and smoothness.<sup>[60]</sup> But more recent studies have concentrated on sophisticated systems like solid lipid nanoparticles (SLNs), nanoliposomes, nanoemulsions, and nanoemulgels. The extract is encapsulated in phospholipid vesicles by nanoliposomal formulations, which improve penetration into deeper skin layers and shield delicate substances from deterioration.<sup>[54]</sup> In a similar vein, stable, light formulations that spread readily on the skin and guarantee controlled release of active ingredients are offered by nanoemulgels and nanoemulsions.<sup>[67]</sup> Conversely, SLNs reduce water loss and improve the extract's sustained release for extended hydration by creating a thin occlusive film on the skin's surface.<sup>[68]</sup> Additionally, hydrogels with caper fruit extract have been created, providing a calming texture that enhances user comfort and preserves stability over time.<sup>[69]</sup> Applying *C. spinosa* fruit extract topically offers several. It is a safe, natural ingredient that provides both short-term and long-term moisturization through two different mechanisms: enhanced filaggrin synthesis for long-term barrier repair and rapid hydration by raising PCA content.<sup>[60]</sup> Its potent anti-inflammatory and antioxidant properties shield the skin from UV rays, pollution, and irritation.<sup>[57,66]</sup> Additionally, the active compounds' bioavailability, stability, and efficacy are enhanced by incorporation into nanocarriers, which makes these contemporary delivery systems appropriate for dermatological and cosmetic applications.<sup>[54,68]</sup> In summary, fruit extract from *Capparis spinosa* is a promising natural component for topical formulations that moisturize and repair barriers. Its therapeutic potential for dry and sensitive skin is highlighted by its capacity to promote the production of filaggrin, support the generation of NMF, and prevent oxidative and inflammatory damage. Its delivery and effectiveness are further improved by the creation of nano-based formulations like nanoliposomes, nanoemulgels, and SLNs, which makes it a prime candidate for upcoming advancements in skin care.<sup>[60,54,68]</sup>

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