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Centella Asiatica, Collagen Density, and MMP-1: A Review of Photoaging and Skin Repair Evidence

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Abstract

Centella asiatica is a medicinal plant widely investigated for dermatological and cosmeceutical applications, particularly in wound healing, anti-aging, collagen remodeling, and protection against ultraviolet-induced skin damage. This review analyzes recent studies published between 2021 and 2025, focusing on the relationship between Centella asiatica, collagen density, collagen synthesis, and matrix metalloproteinase-1 (MMP-1), a major collagen-degrading enzyme involved in skin photoaging. The reviewed evidence shows that C. asiatica and its major triterpenoid compounds—including asiaticoside, madecassoside, asiatic acid, and madecassic acid—support dermal matrix preservation through antioxidant activity, fibroblast stimulation, increased collagen production, and downregulation of matrix-degrading enzymes. Direct in vivo evidence indicates that topical C. asiatica cream may improve collagen density and influence MMP-1 expression in UVB-exposed skin. Additional studies using fibroblast models, nanoformulations, wound healing systems, and clinical skin-aging preparations support its role in improving collagen biosynthesis and skin structural recovery. However, the evidence remains heterogeneous, as many studies evaluate collagen markers or general MMP activity rather than MMP-1 specifically. Future research should prioritize standardized extracts, direct measurement of MMP-1, collagen type I/III expression, collagen density, and well-controlled human trials.

INTRODUCTION

Skin aging is a biological process influenced by intrinsic factors, such as chronological aging, and extrinsic factors, especially ultraviolet (UV) radiation. UVB exposure increases oxidative stress in the skin and activates signaling pathways that stimulate matrix metalloproteinases, particularly MMP-1, which degrades type I and type III collagen in the dermal extracellular matrix. As collagen fibers are degraded, the skin gradually loses elasticity, firmness, and structural density, leading to wrinkles, thinning, and visible photoaging (Chavoshnejad et al., 2021; Jiang et al., 2025). Therefore, substances capable of reducing MMP-1 activity and increasing collagen density are highly relevant for anti-aging and dermatological therapy.

Centella asiatica has become one of the most widely studied botanical ingredients in skin repair and anti-aging research. The plant contains bioactive triterpenoids, mainly asiaticoside, madecassoside, asiatic acid, and madecassic acid, which are associated with antioxidant, anti-inflammatory, fibroblast-stimulating, and collagen-promoting effects (Bandopadhyay et al., 2023; Lim et al., 2024). Recent experimental studies suggest that these compounds may protect dermal fibroblasts from oxidative stress, reduce collagen degradation, and support extracellular matrix remodeling (Buranasudja et al., 2021; Lim et al., 2024). In UVB-induced models, C. asiatica formulations have also been associated with increased collagen density and modulation of MMP-related pathways (Purmawanti et al., 2025; Retnaningtyas et al., 2024).

The urgency of this review is driven by several converging factors. First, the increasing prevalence of skin aging and photoaging-related concerns has created a large market for effective anti-aging ingredients. Second, synthetic anti-aging agents often have side effects or limited efficacy, driving demand for natural alternatives with better safety profiles. Third, C. asiatica has been used traditionally for centuries in Asian medicine, but its molecular mechanisms in photoaging and collagen preservation have only recently been elucidated. Fourth, the heterogeneity of existing evidence requires systematic synthesis to guide future research and clinical applications. Fifth, the growing interest in evidence-based cosmeceuticals demands a clearer understanding of which C. asiatica compounds, formulations, and delivery systems are most effective for specific skin-aging outcomes. Therefore, this review is timely and necessary to consolidate current knowledge and identify priority areas for future investigation.

The novelty of this review lies in three interconnected contributions. First, it focuses specifically on the relationship between C. asiatica, MMP-1, and collagen density, rather than general wound healing or antioxidant activity. Second, it synthesizes evidence from studies published between 2021 and 2025, providing an up-to-date perspective that includes recent advances in nanoformulations and delivery systems. Third, it identifies specific research gaps related to MMP-1 measurement, extract standardization, and human clinical evidence, offering clear recommendations for future research. Unlike previous reviews that broadly cover wound healing or general skin benefits, this review provides a targeted analysis of the molecular pathway linking C. asiatica to collagen preservation through MMP-1 regulation. This specificity is important because MMP-1 is the rate-limiting enzyme in collagen degradation, and understanding how C. asiatica modulates this enzyme is critical for developing effective anti-photoaging interventions.

The biological importance of MMP-1 makes it a central marker in skin-aging research. MMP-1, also known as collagenase-1, initiates the breakdown of fibrillar collagen, especially collagen type I, which is the dominant collagen type in the dermis. When MMP-1 expression is elevated, collagen density decreases, and the dermal matrix becomes weaker. Because of this, reducing MMP-1 while increasing collagen synthesis is considered an important therapeutic strategy for preventing photoaging and improving skin repair.

This review aims to synthesize recent evidence on Centella asiatica in relation to collagen density, collagen biosynthesis, and MMP-1 regulation. The review focuses on accessible journal articles published from 2021 to 2025 and discusses the findings based on phytochemical profile, anti-photoaging mechanisms, collagen-related outcomes, topical delivery systems, wound healing activity, methodological limitations, and future research needs.

RESEARCH METHOD

This article review used a structured literature search approach to identify relevant studies on Centella asiatica, collagen density, collagen synthesis, MMP-1, MMPs, photoaging, wound healing, and skin repair. Literature was searched using databases and platforms such as PubMed, ScienceDirect, MDPI, Springer, Frontiers, Taylor & Francis, Google Scholar, and other open-access journal platforms. Keywords included “Centella asiatica,” “asiaticoside,” “madecassoside,” “asiatic acid,” “collagen density,” “collagen synthesis,” “MMP-1,” “matrix metalloproteinase,” “photoaging,” “UVB,” “skin aging,” “fibroblast,” “wound healing,” and “topical formulation.”

The inclusion criteria were: articles published between 2021 and 2025; studies written in English or published in accessible international/open-access journals; and studies discussing at least one of the following outcomes: MMP-1 or MMP-related expression, collagen density, collagen biosynthesis, collagen type I/III, fibroblast proliferation, wound closure, photoaging, or topical delivery of C. asiatica bioactive compounds. Articles were prioritized when full-text, DOI, or downloadable PDF access was available.

The final review included 15 journal sources consisting of experimental studies, in vitro studies, in vivo animal studies, clinical/cosmeceutical studies, and recent review articles. The evidence was grouped into direct evidence related to MMP-1 and collagen density, mechanistic evidence related to collagen biosynthesis and MMP suppression, and supportive evidence from wound healing and formulation studies.

Phytochemical Profile and Skin-Relevant Compounds

The dermatological activity of *Centella asiatica* is mainly attributed to pentacyclic triterpenoids, particularly asiaticoside, madecassoside, asiatic acid, and madecassic acid. These compounds are repeatedly discussed in recent studies because they influence fibroblast behavior, oxidative stress response, collagen formation, and extracellular matrix remodeling. Asiaticoside and madecassoside are glycosidic triterpenes, while asiatic acid and madecassic acid are aglycone forms that may show stronger cellular activity in some experimental systems.

Asiaticoside

Asiaticoside is one of the most important active compounds in *C. asiatica* for wound healing and collagen biosynthesis. It has been associated with increased fibroblast proliferation, improved collagen deposition, and faster wound closure. In nanoparticle-based wound healing research, asiaticoside-loaded polymeric nanoparticles embedded in hydrogel systems improved fibroblast migration and increased collagen biosynthesis in diabetic wound models (Narisepalli et al., 2023). This supports the idea that asiaticoside contributes not only to wound closure but also to dermal matrix reconstruction.

Madecassoside

Madecassoside is another major triterpenoid that has been widely linked to anti-inflammatory and skin-repair activity. It may protect skin tissue by reducing oxidative stress and inflammatory signaling, both of which are important because inflammation and reactive oxygen species can increase MMP expression. In the context of photoaging, madecassoside-containing extracts are relevant because they may indirectly reduce collagen degradation by controlling oxidative and inflammatory pathways.

Asiatic Acid

Asiatic acid has shown strong anti-photoaging potential in fibroblast-based studies. Lim et al. (2024) compared four major triterpenes of *C. asiatica* and found that asiatic acid showed strong protective effects against UVB-induced oxidative stress in human dermal fibroblasts. The study reported that asiatic acid reduced MMP-1 and MMP-3 generation while increasing intracellular collagen content, making it highly relevant to the relationship between *C. asiatica*, MMP-1, and collagen preservation (Lim et al., 2024).

Madecassic Acid and Other Phenolic Compounds

Madecassic acid, together with other phenolic and antioxidant compounds, contributes to the overall skin-protective activity of *C. asiatica*. The antioxidant capacity of *C. asiatica* is important because oxidative stress is one of the main triggers of MMP activation. Buranasudja et al. (2021) reported that *C. asiatica* callus extract showed antioxidant and anti-skin-aging potential in human dermal fibroblast models by improving antioxidant defense and inhibiting MMP-related activity. These findings suggest that *C. asiatica* may protect collagen through antioxidant regulation and suppression of matrix-degrading enzymes (Buranasudja et al., 2021).

MMP-1 and Collagen Density as Main Pathways

The relationship between MMP-1 and collagen density is central to skin aging and photoaging. MMP-1 breaks down collagen fibers in the dermis, while collagen density reflects the structural strength and integrity of skin tissue. In UVB-exposed skin, MMP-1 expression tends to increase, while collagen density decreases. Therefore, an ideal anti-photoaging compound should reduce MMP-1 activity and increase or preserve collagen density.

Direct evidence from Purmawanti et al. (2025) specifically examined the effect of *C. asiatica* extract cream on MMP-1 expression and collagen density in UVB-induced BALB/c mice. The study used 10% and 20% *C. asiatica* extract cream and evaluated MMP-1 using immunohistochemistry and collagen density using Sirius Red staining. The results showed that the 10% cream group produced the lowest MMP-1 expression, although the MMP-1 result was not statistically significant, while collagen density showed a significant difference among groups. This finding is important because it directly links *C. asiatica* topical treatment with the two requested outcomes: MMP-1 and collagen density (Purmawanti et al., 2025).

Although not all studies measure MMP-1 specifically, several recent studies provide supportive evidence through related markers. Retnaningtyas et al. (2024) developed a topical gel combining *C. asiatica* transfersomes and bergamot essential oil nanoemulsion for UVB-radiated BALB/c mice. The study reported anti-photoaging effects and evaluated collagen-related outcomes, including type I collagen expression and dermal histological improvement. This suggests that advanced delivery systems may improve the ability of *C. asiatica* bioactive compounds to reach relevant skin layers and support dermal matrix preservation (Retnaningtyas et al., 2024).

At the cellular level, Lim et al. (2024) demonstrated that *C. asiatica* triterpenes, especially asiatic acid, inhibited UVB-induced MMP-1 and MMP-3 production in human dermal fibroblasts and helped preserve collagen content. This mechanistic evidence strengthens the biological plausibility that *C. asiatica* may protect collagen density by reducing collagenase activity and oxidative stress (Lim et al., 2024).

Table 1. Summary of 15 Journal Sources on *Centella asiatica*, Collagen, and MMP-Related Skin Effects

No.	Study	Type / Model	Main Focus	Key Result Related to Collagen / MMP	Relevance
1	Purmawanti et al. (2025)	UVB-induced BALB/c mice	*C. asiatica* cream, MMP-1, collagen density	10% cream showed lowest MMP-1 expression; collagen density differed significantly	Most direct source for MMP-1 and collagen density
2	Lim et al. (2024)	UVB-induced human dermal fibroblasts	Four *C. asiatica* triterpenes	Asiatic acid reduced MMP-1/MMP-3 and increased collagen content	Strong mechanistic evidence
3	Retnaningtyas et al. (2024)	UVB-radiated BALB/c mice	Transfersome + nanoemulsion gel	Improved anti-photoaging markers and type I collagen-related outcomes	Supports topical delivery and collagen preservation
4	Buranasudja et al. (2021)	Human dermal fibroblast oxidative stress model	Callus extract anti-aging activity	Improved antioxidant defense and inhibited MMP-related activity	Supports antioxidant–MMP pathway
5	Thong-on et al. (2024)	In vitro wound healing and anti-aging model	Glycoside-rich green extract	Promoted fibroblast/keratinocyte activity and collagen production	Supports collagen synthesis potential
6	Narisepalli et al. (2023)	In vitro and diabetic rat wound model	Asiaticoside nanoparticles in hydrogel	Increased collagen biosynthesis and improved diabetic wound healing	Supports collagen regeneration
7	Wang et al. (2024)	Diabetic wound model	*C. asiatica* extract-loaded poloxamer/ZnO nanocomposite	Enhanced wound healing and tissue repair	Supports advanced wound delivery
8	Kumar et al. (2024)	Review	Asiaticoside nanotechnology	Discussed collagen biosynthesis and improved dermal delivery	Supports formulation rationale
9	Arribas-López et al. (2022)	Systematic review	*C. asiatica* and wound healing	Reported enhanced angiogenesis, collagen I, FGF, and VEGF	Broad wound healing evidence
10	Witkowska et al. (2024)	Review	Topical *C. asiatica* in wound healing	Discussed migration, collagen, inflammation, and clinical efficacy	Supports topical mechanism

11	Poomanee et al. (2023)	Randomized double-blind placebo-controlled study	Multiherbal anti-aging formula containing *C. asiatica*	Improved skin hydration, elasticity, and wrinkles	Human anti-aging support
12	Xiao et al. (2025)	Diabetic mouse wound model	*C. asiatica* and macrophage inflammation	Enhanced wound healing and promoted collagen synthesis	Supports inflammation–collagen pathway
13	Lapmanee et al. (2025)	Rat excision wound model	Transfersomal delivery of *C. asiatica*	Promoted fibroblast proliferation and collagen production	Supports delivery-enhanced collagen repair
14	Dang et al. (2024)	Phytochemical / anti-photoaging study	Triterpenoids isolated from *C. asiatica*	Identified anti-photoaging activity of triterpenoids	Supports active compound basis
15	Handayani et al. (2025)	Review	Skin health and cosmeceuticals	Discussed mechanisms, clinical evidence, and delivery systems	Supports cosmeceutical relevance

Topical Formulation and Delivery Systems

Topical delivery is highly important in *C. asiatica* research because the active compounds must reach viable epidermal or dermal layers to influence fibroblast function, MMP expression, and collagen remodeling. Conventional creams and gels are commonly used, but recent studies increasingly use nanoformulations such as transfersomes, nanoparticles, nanoemulsions, and nanocomposite hydrogels to improve skin penetration and bioavailability.

Cream Formulations

Cream formulations are relevant for anti-aging applications because they combine skin hydration, occlusivity, and active compound delivery. Purmawanti et al. (2025) used *C. asiatica* extract cream in UVB-induced mice and found that collagen density was significantly affected by treatment. Although the effect on MMP-1 expression was not statistically significant, the lower MMP-1 expression in the 10% cream group suggests potential biological activity. This indicates that *C. asiatica* cream may be useful as a topical anti-photoaging preparation, but further studies with larger sample sizes and standardized extracts are needed.

Transfersomes and Nanoemulsions

Transfersomes are deformable lipid vesicles designed to improve skin penetration of active compounds. Retnaningtyas et al. (2024) combined *C. asiatica* transfersomes with bergamot essential oil nanoemulsion in a gel and reported anti-photoaging effects in UVB-radiated mice. This formulation approach is important because *C. asiatica* triterpenes may have limited penetration in conventional dosage forms, and nanocarriers may improve delivery to the dermis where collagen remodeling occurs (Retnaningtyas et al., 2024).

Lapmanee et al. (2025) also supported the use of transfersomal delivery by showing that *C. asiatica* transfersomes promoted excision wound healing in rats, including fibroblast proliferation and collagen production. This suggests that advanced delivery systems may increase the biological effectiveness of *C. asiatica* in tissue repair and collagen deposition.

Nanoparticles and Hydrogels

Asiaticoside nanoparticles embedded in hydrogels have shown strong wound-healing potential. Narisepalli et al. (2023) reported that asiaticoside polymeric nanoparticles improved fibroblast migration and increased collagen biosynthesis in diabetic wound healing. This is relevant because diabetic wounds often show impaired collagen deposition, chronic inflammation, and delayed tissue remodeling. By improving collagen biosynthesis, asiaticoside nanoparticles may help restore dermal matrix structure.

Wang et al. (2024) developed a *C. asiatica* extract-loaded poloxamer/ZnO nanocomposite wound material for diabetic foot ulcer treatment. The study focused on antibacterial action and wound healing efficacy, showing that *C. asiatica* can be combined with advanced biomaterials to improve tissue repair. Although this study did not focus specifically on MMP-1, it supports the role of *C. asiatica* in wound closure and dermal regeneration.

Recent reviews also emphasize that nanotechnology may improve the dermal delivery of asiaticoside and other *C. asiatica* compounds because these bioactives can have formulation limitations such as poor solubility, limited permeability, or instability (Kumar et al., 2024; Witkowska et al., 2024).

Biological Efficacy and Dermatologic Benefits

Anti-photoaging Activity

Anti-photoaging activity is one of the most relevant areas for connecting *C. asiatica* with MMP-1 and collagen density. UVB exposure increases oxidative stress and MMP expression, especially MMP-1, which degrades dermal collagen. In this context, *C. asiatica* may act through multiple pathways: antioxidant defense, reduction of MMP expression, fibroblast stimulation, and enhancement of collagen synthesis.

Purmawanti et al. (2025) provided direct evidence that *C. asiatica* cream influences collagen density in UVB-exposed skin. Lim et al. (2024) further showed that asiatic acid can reduce MMP-1 and MMP-3 production in UVB-stimulated fibroblasts. Together, these findings suggest that *C. asiatica* may reduce collagen breakdown while supporting collagen preservation.

Dang et al. (2024) also identified anti-photoaging activity of triterpenoids isolated from *C. asiatica*, supporting the relevance of triterpenoid compounds as active anti-aging agents. Since triterpenoids are the main bioactive markers of *C. asiatica*, this strengthens the pharmacological basis for using *C. asiatica* in collagen-related skin aging research.

Collagen Synthesis and Fibroblast Activity

Collagen synthesis depends heavily on fibroblast activity. In wound healing and skin repair, fibroblasts migrate into damaged tissue, proliferate, and produce extracellular matrix components, especially collagen. Several studies indicate that *C. asiatica* supports fibroblast function and collagen formation.

Thong-on et al. (2024) reported that glycoside-rich green extract from *C. asiatica* supported wound healing and anti-aging activity by promoting skin cell activity and collagen production. Similarly, Narisepalli et al. (2023) showed that asiaticoside nanoparticles increased collagen biosynthesis in diabetic wound healing models. Xiao et al. (2025) found that *C. asiatica* enhanced diabetic wound healing and promoted collagen synthesis through modulation of inflammatory pathways involving AKT, MAPK, and NF-κB signaling.

These findings indicate that *C. asiatica* may improve collagen density not only by preventing degradation through MMP suppression, but also by increasing collagen production through fibroblast activation. This dual mechanism is important because skin repair requires both reduced collagen breakdown and increased collagen formation.

Inflammation Control and Matrix Preservation

Inflammation is closely related to collagen degradation because inflammatory cytokines can stimulate MMP production. Chronic inflammation may increase MMP-1 expression, degrade extracellular matrix, and delay wound healing. *C. asiatica* has anti-inflammatory activity, which may indirectly protect collagen by reducing inflammatory stimulation of MMPs.

Xiao et al. (2025) showed that *C. asiatica* improved diabetic wound healing by reducing macrophage-driven inflammation through the AKT/MAPK/NF-κB pathway. This is relevant because NF-κB activation is associated with inflammatory mediator production and matrix degradation. By reducing inflammation, *C. asiatica* may create a more favorable environment for collagen deposition and tissue remodeling.

Human Skin Aging Evidence

Human clinical evidence remains more limited than animal and in vitro evidence, but recent studies provide supportive findings. Poomanee et al. (2023) evaluated a multiherbal anti-aging formulation containing *C. asiatica* in a randomized double-blind placebo-controlled study involving women and reported improvements in skin hydration, elasticity, and wrinkles. Although this study did not isolate the effect of *C. asiatica* alone, it supports the cosmeceutical relevance of *C. asiatica*-containing preparations for visible skin aging outcomes.

Handayani et al. (2025) also reviewed *C. asiatica* in skin health and cosmeceuticals, emphasizing its mechanisms, clinical evidence, and advanced delivery systems. This supports the broader application of *C. asiatica* in skin products designed for repair, hydration, anti-aging, and dermal matrix protection.

Table 2. Mechanistic Relationship Between *Centella asiatica*, MMP-1, and Collagen ensity

Mechanism	Explanation	Supporting Evidence
MMP-1 suppression	*C. asiatica* triterpenes may reduce collagenase activity induced by UVB and oxidative stress	Lim et al. (2024); Purmawanti et al. (2025)
Collagen density improvement	Topical *C. asiatica* may preserve or increase dermal collagen density in UVB-exposed skin	Purmawanti et al. (2025); Retnaningtyas et al. (2024)
Collagen biosynthesis	Asiaticoside and related compounds stimulate fibroblast activity and collagen production	Narisepalli et al. (2023); Thong-on et al. (2024); Xiao et al. (2025)

Antioxidant protection	Antioxidant activity reduces ROS-induced activation of MMP pathways	Buranasudja et al. (2021); Lim et al. (2024)
Anti-inflammatory activity	Reduced inflammation may decrease MMP stimulation and improve tissue remodeling	Xiao et al. (2025); Witkowska et al. (2024)
Enhanced topical delivery	Nanoformulations improve bioavailability and local effect of active compounds	Retnaningtyas et al. (2024); Kumar et al. (2024); Lapmanee et al. (2025)
Wound healing acceleration	Improved fibroblast migration, angiogenesis, and collagen deposition support skin repair	Arribas-López et al. (2022); Wang et al. (2024); Witkowska et al. (2024)

RESULTS AND DISCUSSION

Integrated Interpretation of Centella asiatica, MMP-1, and Collagen Density

The reviewed evidence suggests that Centella asiatica has meaningful potential in preventing collagen degradation and supporting collagen restoration. The most direct evidence comes from studies that examine UVB-induced photoaging models. Purmawanti et al. (2025) specifically measured MMP-1 expression and collagen density after topical application of C. asiatica cream. Although the MMP-1 result did not reach statistical significance, the lower expression in the 10% cream group and the significant difference in collagen density indicate that C. asiatica may influence dermal matrix preservation.

The mechanistic study by Lim et al. (2024) provides stronger cellular evidence that C. asiatica triterpenes can suppress MMP-1 and MMP-3 production while increasing collagen content in UVB-stimulated fibroblasts. This supports a plausible pathway in which C. asiatica reduces collagen degradation and improves collagen maintenance. Meanwhile, studies on wound healing and diabetic wounds consistently show improved collagen biosynthesis, fibroblast activity, and tissue repair, suggesting that C. asiatica has a broader regenerative effect beyond photoaging alone.

The biological activity of C. asiatica appears to be driven by multiple compounds rather than a single active ingredient. Asiaticoside may be more strongly related to fibroblast activation and collagen biosynthesis, while asiatic acid may show stronger anti-photoaging and MMP-suppressive effects. Madecassoside and madecassic acid may contribute through antioxidant and anti-inflammatory effects. Therefore, the total effect of C. asiatica on collagen density and MMP-1 likely results from synergistic activity among several triterpenoids.

Strength of Evidence

The strongest evidence for the topic comes from studies that directly evaluate MMP-1, collagen density, UVB exposure, or fibroblast collagen content. Purmawanti et al. (2025) is highly relevant because it directly measures MMP-1 and collagen density. Lim et al. (2024) is also highly relevant because it directly measures MMP-1 in fibroblasts. Retnaningtyas et al. (2024) supports the photoaging context through topical nanoformulation and collagen-related markers. Narisepalli et al. (2023), Thong-on et al. (2024), Xiao et al. (2025), and Lapmanee et al. (2025) support the collagen synthesis and wound healing mechanism.

Review articles by Arribas-López et al. (2022), Witkowska et al. (2024), Kumar et al. (2024), and Handayani et al. (2025) strengthen the interpretation by summarizing broader evidence on wound healing, topical application, nanotechnology, and cosmeceutical mechanisms. These reviews consistently suggest that C. asiatica supports collagen formation, inflammation control, and skin repair.

Methodological Limitations

Despite promising results, several limitations remain. First, only a limited number of studies directly measure MMP-1. Many studies measure general MMP activity, MMP-3, MMP-9, collagen type I, hydroxyproline, fibroblast proliferation, or collagen density, but not MMP-1 specifically. Therefore, the conclusion that C. asiatica reduces MMP-1 should be considered promising but not yet definitive.

Second, extract standardization varies across studies. Some studies use whole extract, some use triterpenoid-rich extract, while others use isolated compounds such as asiaticoside or asiatic acid. Without standardized marker levels, it is difficult to compare dose-response effects across studies. Third, formulation types differ widely, including creams, gels, transfersomes, nanoparticles, hydrogels, and nanocomposites. These differences can influence skin penetration, local concentration, and biological outcomes.

Fourth, most evidence is based on animal or in vitro models. Human clinical studies remain limited, especially those directly measuring MMP-1 or collagen density. Clinical skin-aging outcomes such as hydration, elasticity, and wrinkles are useful, but they do not fully explain molecular changes in collagen degradation. Future trials should combine clinical outcomes with molecular biomarkers such as MMP-1, procollagen type I, collagen type I/III ratio, and histological collagen density.

Future Research Directions

Future research should focus on experimental designs that directly connect C. asiatica treatment with MMP-1 suppression and collagen density improvement. Studies should use standardized extracts with quantified asiaticoside, madecassoside, asiatic acid, and madecassic acid content. UVB-induced photoaging models should measure MMP-1, collagen type I, collagen type III, procollagen, hydroxyproline, and histological collagen density in the same study.

In addition, advanced topical formulations should be tested using skin penetration methods such as Franz diffusion cells, tape stripping, or confocal microscopy. This is important because the anti-aging effect depends on whether active compounds can reach the dermis. Finally, human studies should be expanded to evaluate whether C. asiatica can clinically reduce wrinkles, improve elasticity, increase collagen density, and reduce MMP-1 expression in real skin aging conditions.

CONCLUSION

Centella asiatica shows strong potential as a dermatological and cosmeceutical ingredient for improving collagen density and protecting the skin from MMP-mediated collagen degradation. The most relevant evidence indicates that topical C. asiatica cream may improve collagen density and influence MMP-1 expression in UVB-induced skin damage. Mechanistic studies further show that C. asiatica triterpenes, especially asiatic acid and asiaticoside, can reduce MMP-related activity, increase collagen content, stimulate fibroblast activity, and support wound healing. Advanced delivery systems such as transfersomes, nanoparticles, hydrogels, and nanoemulsions may improve the effectiveness of C. asiatica by enhancing skin penetration and local bioavailability.

Overall, the evidence supports the use of C. asiatica as a promising natural active ingredient for anti-photoaging, collagen preservation, and skin repair. However, more direct studies on MMP-1, standardized extract composition, collagen density measurement, and human clinical outcomes are still needed before definitive claims can be made.

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