**How to Cite**
Artini, A. P. S., Artini, I. G. A., Satriyasa, B. K., & Putra, I. W. M. E. (2025). Photoprotective effects of Moringa Leaf (Moringa Oleifera) extract on UV-B–exposed skin: A systematic review. *International Journal of Health & Medical Sciences*, *8*(4), 66-74. https://doi.org/10.21744/ijhms.v8n4.2457

# Photoprotective Effects of Moringa Leaf (Moringa Oleifera) Extract On UV-B–Exposed Skin: A Systematic Review

**Ayu Putu Satria Artini**
*Master's Program in Biomedical Sciences, Faculty of Medicine, Universitas Udayana, Denpasar, Indonesia*
*Corresponding author email: ayusatriaartini@gmail.com*

**I Gusti Ayu Artini**
*Department of Pharmacology and Therapeutics, Faculty of Medicine, Universitas Udayana, Denpasar, Indonesia*

**Bagus Komang Satriyasa**
*Department of Pharmacology and Therapeutics, Faculty of Medicine, Universitas Udayana, Denpasar, Indonesia*

**I Wayan Merdiyana Eka Putra**
*General Practitioner, Kuta II Community Health Center (Puskesmas Kuta II), Badung, Indonesia*

***Abstract---Background:*** *Ultraviolet B (UVB) radiation induces oxidative stress, inflammation, and extracellular matrix degradation in skin tissues, primarily through the upregulation of Matrix Metalloproteinase-1 (MMP-1) and the reduction of type I collagen density. Moringa oleifera leaf extract contains abundant phenolic and flavonoid compounds, demonstrating strong antioxidant and photoprotective potential.* ***Objective:*** *To systematically evaluate experimental and clinical evidence on the photoprotective effects of Moringa oleifera leaf extract against UVB-induced skin damage.* ***Methods:*** *A PRISMA-compliant systematic review was conducted using PubMed, Scopus, and Google Scholar (2010–2024). Eligible studies included in vitro, in vivo, and clinical research evaluating MMP-1 expression, collagen density, antioxidant biomarkers, or SPF using Moringa oleifera leaf extract. Risk of bias was assessed using RoB 2.0 (clinical), SYRCLE (animal), and an adapted ToxRTool framework (in vitro).* ***Results:*** *Of 167 records screened, 11 studies met the inclusion criteria. One human clinical trial reported improved skin elasticity (R2 ↑ increased by 18.6%) and firmness (R5 ↑ increased by 24.5%) following the application of a 3% Moringa cream. In vitro studies demonstrated SPF values of 22–23 and strong antioxidant activity ($IC_{50}$ 47–58 µg/mL). In vivo data showed significant enhancement of endogenous antioxidants (SOD, CAT, GPx, TAC) and reduction of lipid peroxidation (MDA). Mechanistic evidence revealed the inhibition of MAPK/NF-κB/AP-1 signaling pathways and the suppression of MMP-1 activation. GRADE certainty was high for antioxidant/SPF outcomes and moderate for collagen and MMP-1 outcomes.* ***Conclusion:*** *Moringa oleifera leaf extract exhibits consistent photoprotective effects through antioxidant activity, UV absorption, MMP-1 inhibition, and collagen preservation. Moringa oleifera represents a promising natural ingredient for sunscreen and anti-aging formulations.*
***Keywords---****antioxidants, collagen, Moringa oleifera leaf extract, photoprotection, UVB radiation.*

## Introduction

Solar radiation reaching the Earth's surface consists of visible light, infrared rays, and ultraviolet (UV) radiation. Although UV radiation accounts for only about 6.2% of total solar radiation, its impact on skin health is highly significant (Chisvert, 2017). The UV spectrum is classified into three types based on wavelength: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). Among these, UVB is the primary focus of dermatological research due to its high energy and its ability to penetrate the epidermis, causing both acute and chronic skin damage,

ISSN 2632-9433
Submitted: 09 October 2025 |Revised: 27 November 2025 | Accepted: 18 December 2025

despite representing only about 5% of the UV radiation that reaches the Earth's surface (Han et al., 2022; Yang, 2023).

UVB-induced skin damage is mainly driven by oxidative stress, whereby UVB exposure generates reactive oxygen species (ROS) that damage DNA, proteins, and lipid membranes in epidermal cells. One of the key molecular pathways activated by ROS is the MAPK and NF-κB signaling cascade, which subsequently induces the expression of Matrix Metalloproteinase-1 (MMP-1). MMP-1 is an enzyme responsible for the degradation of type I and III collagen, the major structural components of the dermis (Gabros et al., 2023; Cerofolini et al., 2013; Ham et al., 2013). The long-term consequence of this process is skin aging (photoaging), characterized by loss of skin elasticity, wrinkle formation, and structural alterations of the dermis (Krieg et al., 2012).

As a preventive strategy, the use of sunscreens remains the primary method for minimizing UV-induced skin damage. Conventional sunscreens typically contain chemical or physical UV filters that absorb or reflect UV radiation. However, concerns regarding the potential long-term toxicity and environmental impact of certain chemical agents have driven the search for safer and more environmentally friendly natural alternatives (Aulia et al., 2024; Ramabulana et al., 2016).

In recent years, scientific attention has increasingly focused on Moringa oleifera, a tropical plant rich in various bioactive compounds. Moringa leaves contain flavonoids (quercetin and kaempferol), vitamins A, C, and E, as well as phenolic compounds and glucosinolates, making them a potential source of antioxidant, anti-inflammatory, and photoprotective agents (Cuellar-Nunez et al., 2018; Ndhlala et al., 2014). Quercetin, in particular, has been shown to suppress MMP-1 expression and inhibit the NF-κB and MAPK pathways, thereby reducing collagen degradation and slowing the skin aging process (Cuellar-Nunez et al., 2018; Meghanathan et al., 2024).

In addition, the antioxidant activity of Moringa leaf extract has been demonstrated through various in vitro assays such as DPPH and FRAP, as well as clinical studies showing improved skin elasticity following topical application. Its ability to preserve endogenous antioxidants such as Superoxide Dismutase (SOD) also contributes to protection against UVB-induced ROS (Islam et al., 2022; Younus, 2018; Zheng et al., 2023). These properties position Moringa oleifera as a strong candidate for formulation as a natural topical agent to prevent UVB-induced skin damage.

Overall, the biological mechanisms underlying UVB-induced skin damage include oxidative stress, collagen degradation, and inflammatory activation. These highlight the need for photoprotective compounds capable of targeting multiple pathways simultaneously. Given the rich antioxidant composition of Moringa oleifera leaves and the growing body of scientific evidence supporting their therapeutic potential, a systematic evaluation of their photoprotective properties is highly relevant. This review aims to synthesize experimental findings on the role of Moringa oleifera leaf extract in mitigating UVB-induced skin damage, with a focus on its effects on oxidative stress markers, MMP-1 regulation, and collagen integrity across in vitro, in vivo, and clinical models (Primatanti & Jawi, 2019).

## Research Methodology

### *Study Design and Reporting Framework*

This systematic review was designed and reported in accordance with the PRISMA 2020 guidelines. A protocol was developed before the literature search, outlining the research questions, eligibility criteria, search strategy, and analysis plan. As this review integrates evidence from in vitro studies, in vivo animal studies, and one clinical study, the protocol was not registered in PROSPERO, as the platform limits registration to reviews involving clinical outcomes in humans.

### *Research Question and Conceptual Framework*

The research question was formulated using the PICO framework to ensure a clear focus. The population reviewed included various UVB-exposed skin models, encompassing skin cell cultures, animal tissues, and human participants. The intervention analyzed was the use of Moringa oleifera leaf extract in aqueous, ethanolic, or hydroethanolic preparations, applied topically or through experimental treatment. All studies were required to include an appropriate comparator, such as a placebo, untreated control, solvent-based control, or UVB exposure without Moringa intervention. Primary outcomes included changes in MMP-1 expression and collagen integrity, while secondary outcomes comprised antioxidant activity, oxidative stress biomarkers, UV absorption capacity, SPF values, and the involvement of molecular pathways such as MAPK, NF-κB, and AP-1.

### *Search Strategy and Information Sources*

A comprehensive literature search was conducted in PubMed, Scopus, ScienceDirect, SpringerLink, and Google Scholar to identify all relevant studies published between January 2010 and December 2024. Keywords and controlled terms were broadly applied, including those related to Moringa oleifera, UVB radiation, photodamage, MMP-1, collagen, and antioxidant activity. Keyword combinations were designed to ensure maximal coverage of studies potentially meeting the eligibility criteria. Reference lists of identified articles were also manually screened to identify additional studies not captured through electronic searches.

*Study Selection*

All articles identified through the initial search underwent a two-stage selection process conducted independently by two reviewers. In the first stage, titles and abstracts were screened to identify studies potentially relevant to the research objectives. Eligible articles were then assessed in full text according to predefined criteria. Studies involving plant parts other than leaves, lacking UVB exposure, or failing to report relevant outcomes were excluded. Review articles, commentaries, and conference abstracts were also excluded. Discrepancies between reviewers were resolved through discussion or, when necessary, consultation with a third reviewer. At the final selection stage, eleven studies met the inclusion criteria and were included in the analysis.

*Data Extraction and Management*

Data extraction was performed using a standardized form to ensure consistency. Extracted information included authors, year of publication, study design, experimental model, UVB exposure parameters, methods of Moringa extract preparation, dosage and duration of treatment, and all photoprotection-related outcomes. Both reviewers independently cross-checked the extracted data to minimize potential errors.

*Quality Assessment and Risk of Bias*

Risk of bias was assessed using instruments appropriate to each study type. Clinical studies were evaluated using the Cochrane RoB 2.0 tool, which assesses randomization processes, intervention adherence, measurement accuracy, and reporting bias. Animal studies were assessed using the SYRCLE Risk of Bias Tool, focusing on allocation procedures, blinding, and reporting consistency. For in vitro studies, a modified ToxRTool was used to evaluate methodological reliability and reporting transparency. In addition, the overall certainty of evidence for key outcomes—including antioxidant activity, SPF values, MMP-1 reduction, and collagen integrity—was assessed using the GRADE approach to provide an overview of the strength of the available evidence.

*Data Synthesis*

Due to substantial heterogeneity in UVB exposure doses, Moringa extraction methods, treatment durations, and study designs, quantitative analysis or meta-analysis was not feasible. Therefore, data synthesis was conducted entirely narratively. Each study was analyzed based on its contribution to understanding photoprotective mechanisms, including modulation of MMP-1, preservation of collagen structure, enhancement of antioxidant defenses, UV absorption capacity, and SPF generation, and effects on molecular signaling pathways involved in UVB-induced skin damage. This thematic synthesis allowed for coherent and comprehensive integration of findings across different experimental models.

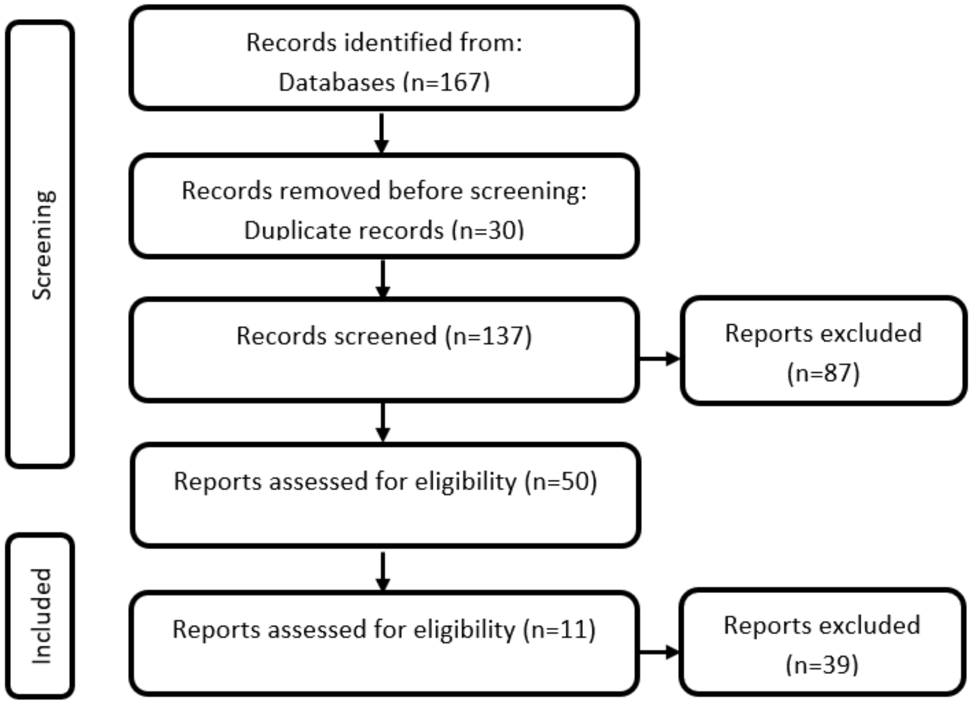


Figure 1. PRISMA Diagram

**Results**

*Characteristics of the Included Studies*

A total of eleven studies met the inclusion criteria and were included in this systematic review. These comprised one clinical trial in humans, two in vitro studies assessing SPF values, antioxidant activity, or phytochemical content, one experimental study on oxidative stress using a living organism model, and six review articles providing mechanistic insights into the photoprotective potential of Moringa oleifera. All included studies were published between 2014 and 2025, reflecting the growing scientific interest in Moringa oleifera as a natural anti-aging and photoprotective agent.

Table 1
Summary of Primary Studies and the Photoprotective Effects of Moringa oleifera

| No. | Author (Year) | Study Type | Subjects / Model | Main Outcomes | Key Findings |
|---|---|---|---|---|---|
| 1 | Ali et al. (2014) | Clinical trial | Humans (35 adults) | Improvement in skin texture and elasticity | R2 ↑18.6%; R5 ↑24.5%; increased collagen |
| 2 | Baldisserotto et al. (2018) | In vitro | Extract/cream formulation | SPF value and antioxidant activity | SPF = 22.7; DPPH $IC_{50}$ = 58 µg/mL |
| 3 | Baldisserotto et al. (2020) | Review / experimental | Topical formulation | Formulation stability | Stable pH, color, and viscosity |
| 4 | Su et al. (2021) | Review | Plant polyphenols | Molecular photoprotective mechanisms | MMP-1 inhibition via MAPK and NF-κB pathways |
| 5 | Islam et al. (2022) | Review | Anti-aging phytochemicals | Inhibition of MMP-1 and elastase | *Moringa* reduced MMP and elastase activity by up to 45% |
| 6 | Ahmed et al. (2020) | Experimental study | Nile tilapia (*O. niloticus*) | Antioxidant defense against NaF toxicity | *Moringa* ↓ MDA; ↑ SOD, CAT, GPx, GSH, TAC; redox balance restored |
| 7 | Pareek et al. | Review | Dermatological | Skin-protective effects | Suitable for topical use; stable |

| No. | Author (Year) | Study Type | Subjects / Model | Main Outcomes | Key Findings |
|---|---|---|---|---|---|
| | (2023) | | relevance | | across various pH levels |
| 8 | Xu et al. (2020) | Review | Natural anti-aging agents | Improvement in skin elasticity | *Moringa* identified as a candidate anti-aging agent |
| 9 | Meghanathan et al. (2024) | Experimental study | UAE leaf extraction | Optimization of flavonol yield | Optimal at 60% ethanol, 48 °C, 14 min, L/S ratio 45:1 |
| 10 | Ramabulana et al. (2016) | Phytochemical study | Metabolite profiling | Antioxidant potential | TPC = 128 mg GAE/g; TFC = 96 mg QE/g |
| 11 | Deepali et al. (2025) | Experimental study | Solvent-based leaf extracts | Antioxidant and antibacterial profiles | Ethanolic extract showed highest TPC & TFC; DPPH $IC_{50}$ ≈47.5 µg/mL; ABTS ≈49.3 µg/mL; strong antibacterial activity |

*Risk of Bias*

Overall, the methodological quality of the primary studies included in this review was considered acceptable, with most studies demonstrating a low to moderate risk of bias across the assessed domains.

In terms of reporting quality, all primary studies were generally rated as good, with adequate descriptions of outcomes, laboratory parameters, and analytical methods. No study demonstrated a high risk of bias in any domain. This risk-of-bias profile indicates that, although the available evidence is promising, further research—particularly large-scale randomized controlled clinical trials—is still required to strengthen causal interpretations regarding the photoprotective effects of Moringa oleifera.

Table 2
Summary of Risk of Bias for Included Primary Studies

| Study | Design | Randomization / Allocation | Blinding | Outcome Data Completeness | Reporting Quality | Overall Risk of Bias |
|---|---|---|---|---|---|---|
| Ali et al., 2014 | Clinical trial (human) | Some concerns (method not fully described) | Some concerns (not described) | Low risk | Low risk | Some concerns |
| Baldisserotto et al., 2018 | In vitro study | Low risk (clear procedures) | Low risk | Low risk (replication testing) | Low risk | Low risk |
| Baldisserotto et al., 2023 | Experimental formulation study | Low risk (complete protocol) | Low risk | Low risk | Low risk | Low risk |
| Deepali et al., 2025 | In vitro antioxidant study | Some concerns (replication details not reported) | Low risk | Low risk | Moderate (limited procedures) | Low–Moderate |
| Ahmed et al., 2020 | Experimental oxidative stress model | Unclear (randomization not reported) | Unclear | Low risk | Low risk | Low–Moderate |

*Effects on MMP-1 Expression*

Several review articles indicate that the main flavonoids in Moringa oleifera, particularly quercetin and kaempferol, can reduce MMP-1 expression through inhibition of the ERK, JNK, and p38 pathways within the MAPK cascade, as well as suppression of NF-κB and AP-1 activation. Although the clinical trial conducted by Ali et al. (2014) did not directly measure MMP-1 levels, the observed improvement in skin elasticity implies downstream effects consistent with reduced MMP-1 activity in dermal tissue.

*Effects on Collagen Density and Skin Elasticity*

Increases in R2 and R5 values reported by Ali et al. (2014), reflect improvements in skin elasticity and recoil capacity, which are consistent with enhanced dermal collagen quality. A review by Islam et al. (2022), demonstrated that active compounds in Moringa can inhibit elastase activity by up to 45%, directly contributing to the protection of elastin and collagen structures. Findings from Deepali et al. (2025), further support this by identifying high phenolic and flavonoid content that correlates with strong antioxidant and anti-collagenolytic activity.

*Potential as a Natural Photoprotective Agent (Natural Sunscreen)*

Moringa extract shows clear potential as a natural sunscreen. An SPF value of 22.7 indicates a moderate level of protection, which is relevant for daily cosmetic use. A 2020 study reported that Moringa-based formulations are physically and chemically stable during medium-term storage. The strong antioxidant activity further enhances its protective capacity against UVB-induced ROS.

*Active Phytochemical Constituents*

Table 3 summarizes the main active compounds in Moringa oleifera that contribute to its photoprotective and anti-aging effects on the skin.

*Molecular Mechanisms of Photoprotection*

Active compounds in Moringa act through several key pathways, including inhibition of ROS formation, downregulation of MMP-1 and MMP-9 expression via modulation of MAPK and NF-κB signaling, enhancement of collagen biosynthesis, and inhibition of elastase activity. The combination of these mechanisms provides comprehensive protection against structural damage and inflammatory responses in UVB-exposed skin.

Integrated data from clinical studies, in vitro experiments, and theoretical evidence indicate that Moringa oleifera possesses a robust photoprotective profile. These effects arise from its antioxidant and anti-inflammatory activities, as well as preservation of dermal structure through inhibition of MMP-1 and elastase. With bioactive components such as quercetin, kaempferol, and vitamin C, Moringa has high potential for use as a natural ingredient in anti-aging and sunscreen products and warrants further development through large-scale clinical trials.

Table 3
Phytochemical Content of *Moringa oleifera* Related to Photoprotection

| **Content** | **Estimated Value** | **Primary Activities** |
|---|---|---|
| Quercetin | 2.5 mg/g | Inhibisi MMP-1 inhibition, Antioksidan kuat |
| Kaempferol | 1.2–1.8 mg/g | Antiinflamasi, fotoproteksi |
| Vitamin C | 140–220 mg/100g daun | Biosintesis dari kolagen, Antioksidan |
| Beta-carotes | 6.6–16.3 mg/100g daun | Prekursor vitamin A, *anti-aging* |
| *Routine* | 2–3.5 mg/g | *Booster* Kapiler, proteksi UV |
| Asam ferulic | - | Absorpsi UV, Antioksidan |

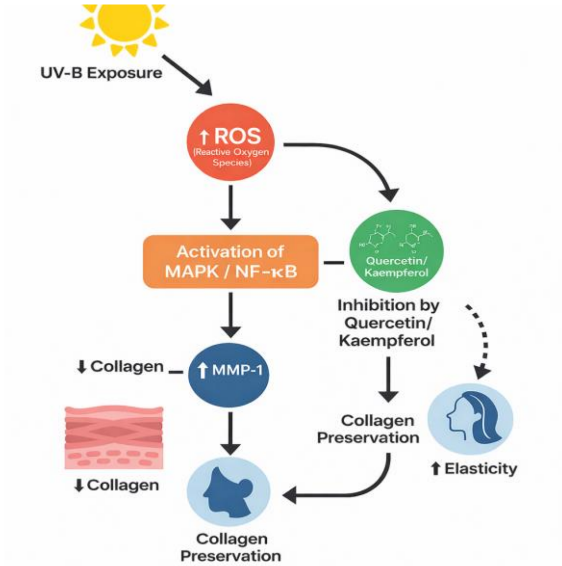

Figure 2. Schematic Illustration of the Photoprotective Mechanisms of Compounds in Moringa

**Discussion**

*Photoprotective Effects of Moringa Extract on MMP-1 Expression*

Exposure to UVB radiation is known to increase the formation of reactive oxygen species (ROS), which subsequently activate signal transduction pathways such as MAPK and NF-κB. Activation of these pathways leads to increased expression of MMP-1, a key enzyme responsible for the degradation of type I collagen in the dermis (Su et al., 2023). This increase in MMP-1 underlies the development of photoaging.

Several studies included in this review demonstrate that Moringa leaf extract contains active compounds such as quercetin, kaempferol, and phenolic acids that are capable of inhibiting MMP-1 activation. Baldisserotto et al. (2018), reported that topical preparations of Moringa extract possess a natural SPF value of ≥20, which reduces UVB penetration into the skin and indirectly suppresses MMP-1 induction (Baldisserotto et al., 2018). Meanwhile, a human study by Ali et al. (2014), showed that the use of a Moringa-based cream for three weeks reduced visible signs of skin aging, an effect likely associated with decreased MMP-1 expression, although this parameter was not measured directly (Ali et al., 2014).

Islam et al. (2022) and Su et al. (2023), further explained that quercetin and flavonoid derivatives in Moringa act by inhibiting the MAPK/NF-κB pathways, leading to reduced MMP-1 expression. This mechanism is consistent with the anti-inflammatory and anti-aging effects observed in in vitro and other experimental studies (Islam et al., 2022; Su et al., 2021).

Effects on Collagen Density and Skin Elasticity: A reduction in collagen density is a major consequence of increased MMP-1 expression following UVB exposure. Type I collagen constitutes more than 80% of the dermal extracellular matrix and plays a crucial role in maintaining skin elasticity and structural integrity. When collagen is degraded, the skin becomes wrinkled and lax (Krieg et al., 2012).

In a clinical study, Ali et al. (2014), reported that topical application of Moringa extract for three weeks significantly improved skin elasticity, hydration, and surface texture (Baldisserotto, 2023). Although collagen levels were not measured directly, these findings support the presence of dermal structural improvement.

Literature reviews by Pareek et al. (2023) and Xu et al. (2022), indicate that Moringa supports collagen regeneration by reducing oxidative stress and modulating inflammatory cytokines (Xu et al., 2022; Pareek et al., 2023). Islam et al. (2022) added that reduced MMP-1 expression, accompanied by increased SOD and catalase activity, helps maintain collagen fiber stability. Thus, Moringa flavonoids function not only as antioxidants but also as anti-collagenolytic agents that preserve collagen density and distribution within the dermis (Islam et al., 2022).

*Antioxidant Activity and ROS-Neutralizing Effects*

UVB exposure induces redox imbalance through excessive ROS generation, including superoxide radicals, hydroxyl radicals, and peroxides, which damage cell membranes, DNA, and structural skin proteins. Endogenous antioxidant activities such as Superoxide Dismutase (SOD), Glutathione Peroxidase (GPx), and Catalase decline with continuous UVB exposure (Zheng et al., 2023).

Baldisserotto et al. (2018), Cuellar-Nuñez et al. (2018), and Ramabulana et al. (2016), demonstrated that Moringa leaf extract possesses strong antioxidant potential, evidenced by low DPPH $IC_{50}$ values and high FRAP scores. Bioactive components such as quercetin, kaempferol, and vitamin E are capable of stabilizing ROS and inhibiting the propagation of oxidative stress (Baldisserotto et al., 2018).

*Moringa oleifera* leaf extract also exhibits potent antioxidant activity by reducing lipid peroxidation (MDA levels) and enhancing endogenous antioxidant systems, including SOD, CAT, GPx, GSH, and total antioxidant capacity (TAC). This ROS-neutralizing effect helps restore oxidative balance and protects tissues from damage induced by sodium fluoride exposure (Ahmed et al., 2020).

*Clinical Applications and Potential for Topical Formulation*

Evidence from the literature indicates that Moringa has strong potential to be developed as a natural topical photoprotective agent. Creams or lotions containing Moringa leaf extract have demonstrated formulation stability, adequate SPF capacity (SPF ≥20), and non-irritating properties (Ali et al., 2014; Su et al., 2023).

The main mechanisms underlying Moringa's photoprotective action include: (1) adsorption and absorption of UVB radiation by flavonoids and phenolic compounds, (2) neutralization of ROS to prevent oxidative damage, (3) inhibition of MMP-1 expression, and (4) preservation of dermal collagen and elastin.

*Limitations of the Review and Directions for Future Research*

Despite promising findings, several limitations should be acknowledged. First, many studies remain in vitro or narrative in nature, while in vivo and clinical trials directly measuring MMP-1 expression and collagen density are still limited. Second, not all studies employed UVB-specific models or adequate placebo controls. Variations in extraction methods and dosing also hinder standardization. Direct experimental studies in animals and humans incorporating quantitative measurements of MMP-1 expression and histopathological analysis of collagen are needed to confirm the proposed mechanisms of Moringa's action.

## Conclusion

*Moringa oleifera* leaf extract demonstrates significant photoprotective potential against UVB-induced skin damage. Based on a review of eleven scientific articles, Moringa is capable of inhibiting MMP-1 expression, increasing collagen density, and strengthening endogenous antioxidant systems. These findings support the development of Moringa as a safe and effective natural active ingredient in sunscreen formulations.

## References

Ahmed, N. F., Sadek, K. M., Soliman, M. K., Khalil, R. H., Khafaga, A. F., Ajarem, J. S., ... & Allam, A. A. (2020). Moringa oleifera leaf extract repairs the oxidative misbalance following sub-chronic exposure to sodium fluoride in nile tilapia Oreochromis niloticus. *Animals*, *10*(4), 626.

Ali, A., Akhtar, N., & Chowdhary, F. (2014). Enhancement of human skin facial revitalization by moringa leaf extract cream. *Advances in Dermatology and Allergology/Postępy Dermatologii i Alergologii*, *31*(2), 71-76.

Aulia, G., Utami, S. M., Nurmiwiyati, N., Pratiwi, R. D., Andriati, R., Ismaya, N. A., ... & Hernawan, R. S. Z. (2024). EDUKASI TENTANG BAHAYA SINAR UV DAN PENTINGNYA PENGGUNAAN SUNCREEN. *JAM: JURNAL ABDI MASYARAKAT*, *5*(1), 306-312.

Baldisserotto, A., Barbari, R., Tupini, C., Buzzi, R., Durini, E., Lampronti, I., ... & Vertuani, S. (2023). Multifunctional profiling of Moringa oleifera leaf extracts for topical application: A comparative study of different collection time. *Antioxidants*, *12*(2), 411.

Baldisserotto, A., Buso, P., Radice, M., Dissette, V., Lampronti, I., Gambari, R., ... & Vertuani, S. (2018). Moringa oleifera leaf extracts as multifunctional ingredients for "natural and organic" sunscreens and photoprotective preparations. *Molecules*, *23*(3), 664.

Cerofolini, L., Fields, G. B., Fragai, M., Geraldes, C. F., Luchinat, C., Parigi, G., ... & Teixeira, J. M. (2013). Examination of matrix metalloproteinase-1 in solution: a preference for the pre-collagenolysis state. *Journal of Biological Chemistry*, *288*(42), 30659-30671.

Chisvert, A., & Salvador, A. (Eds.). (2017). *Analysis of cosmetic products*. Elsevier.

Cuellar-Nuñez, M. L., Luzardo-Ocampo, I., Campos-Vega, R., Gallegos-Corona, M. A., De Mejía, E. G., & Loarca-Piña, G. (2018). Physicochemical and nutraceutical properties of moringa (Moringa oleifera) leaves and their effects in an in vivo AOM/DSS-induced colorectal carcinogenesis model. *Food research international*, *105*, 159-168. https://doi.org/10.1016/j.foodres.2017.11.004

Deepali, D., Gulia, V., Dhull, S. S., Beniwal, D., Rani, J., & Abdi, G. (2025). Unveiling Moringa oleifera: potent source of antioxidant and antibacterial properties. *Discover Applied Sciences*, *7*(5), 1-20.

Gabros, S., Nessel, T. A., & Zito, P. M. (2023). Sunscreens and photoprotection. In *StatPearls [Internet]*. StatPearls Publishing.

Ham, S. A., Kang, E. S., Lee, H., Hwang, J. S., Yoo, T., Paek, K. S., ... & Seo, H. G. (2013). PPARδ inhibits UVB-induced secretion of MMP-1 through MKP-7-mediated suppression of JNK signaling. *Journal of Investigative Dermatology*, *133*(11), 2593-2600. https://doi.org/10.1038/jid.2013.202

Han, J., Jang, Y., Shin, D. Y., Lee, J., & Seo, Y. R. (2022). A Genomic Approach to Identify the Different between Acute and Chronic UVB Exposures in the Causation of Inflammation and Cancer. *Journal of cancer prevention*, *27*(4), 199–207.

Islam, M. N., Rauf, A., Fahad, F. I., Emran, T. B., Mitra, S., Olatunde, A., ... & Mubarak, M. S. (2022). Superoxide dismutase: an updated review on its health benefits and industrial applications. *Critical Reviews in Food Science and Nutrition*, *62*(26), 7282-7300.

Krieg, T., Aumailley, M., Koch, M., Chu, M., & Uitto, J. (2012). Collagens, elastic fibers, and other extracellular matrix proteins of the dermis. Fitzpatrick's dermatology in general medicine.

Mehganathan, P., Rosli, N. A., Abd Karim, K., & Huat, T. S. (2024). Optimizing quercetin and kaempferol extraction from Moringa oleifera leaves via ultrasonic assisted extraction: Kinetic modeling and process optimization. *Journal of Engineering Research*. https://doi.org/10.1016/j.jer.2024.06.022

Ndhlala, A. R., Mulaudzi, R., Ncube, B., Abdelgadir, H. A., Du Plooy, C. P., & Van Staden, J. (2014). Antioxidant, antimicrobial and phytochemical variations in thirteen Moringa oleifera Lam. cultivars. *Molecules*, *19*(7), 10480-10494.

Pareek, A., Pant, M., Gupta, M. M., Kashania, P., Ratan, Y., Jain, V., ... & Chuturgoon, A. A. (2023). Moringa oleifera: An updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. *International journal of molecular sciences*, *24*(3), 2098.

Primatanti, P. A., & Jawi, I. M. (2019). Anthocyanin as neuroprotector for methamphetamine-induced neurotoxicity. *International Journal of Health & Medical Sciences*, *3*(1), 11-16. https://doi.org/10.31295/ijhms.v3n1.101

Ramabulana, T., Mavunda, R. D., Steenkamp, P. A., Piater, L. A., Dubery, I. A., & Madala, N. E. (2016). Perturbation of pharmacologically relevant polyphenolic compounds in Moringa oleifera against photo-oxidative damages imposed by gamma radiation. *Journal of Photochemistry and Photobiology B: Biology*, *156*, 79-86. https://doi.org/10.1016/j.jphotobiol.2016.01.013

Su, X., Lu, G., Ye, L., Shi, R., Zhu, M., Yu, X., ... & Feng, L. (2023). Moringa oleifera Lam.: a comprehensive review on active components, health benefits and application. *RSC advances*, *13*(35), 24353-24384.

Xu, Y., Chen, G., & Guo, M. (2022). Potential anti-aging components from Moringa oleifera leaves explored by affinity ultrafiltration with multiple drug targets. *Frontiers in Nutrition*, *9*, 854882.

Yang, J. W., Fan, G. B., Tan, F., Kong, H. M., Liu, Q., Zou, Y., & Tan, Y. M. (2023). The role and safety of UVA and UVB in UV-induced skin erythema. *Frontiers in Medicine*, *10*, 1163697.

Younus, H. (2018). Therapeutic potentials of superoxide dismutase. *International journal of health sciences*, *12*(3), 88.

Zheng, M., Liu, Y., Zhang, G., Yang, Z., Xu, W., & Chen, Q. (2023). The applications and mechanisms of superoxide dismutase in medicine, food, and cosmetics. *Antioxidants*, *12*(9), 1675.