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The Role of Marula Oil in Alleviating Photoaging: Insights into its Bioactive Components

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HIGHLIGHTS

- Fatty acids and antioxidants, mainly vitamin C and E, are major bioactives present in marula oil to alleviate photoaging
- Marula oil combats photoaging by mitigating oxidative stress, reducing collagen degradation, and improving skin hydration and elasticity
- Marula oil's moisturizing, anti-inflammatory, and non-irritating properties makes it a promising ingredient for sensitive and aging skin

ABSTRACT

Photoaging, caused by prolonged UV exposure, accelerates skin aging through oxidative stress, collagen degradation, and inflammation. With growing consumer demand for natural and sustainable anti-aging solutions, marula oil has gained attention for its potential in mitigating photoaging. Derived from *Sclerocarya birrea*, marula oil is rich in fatty acids (oleic and palmitic acids) and antioxidants such as vitamin C and E. This review aims to provide an overview of the bioactive constituents of marula oil and their roles in mitigating photoaging; primarily focusing on moisturizing, antioxidant, and photoprotective properties. In addition, it highlights clinical evidence on marula oil's capacity to improve skin hydration, enhance barrier function, and inhibit enzymes associated with collagen degradation. Despite its promise as a cosmeceutical, long-term studies are necessary to explore its sustained efficacy, molecular pathways, and potential synergy with other natural ingredients.

INTRODUCTION

Skin aging is a natural biological process characterized by the continuous loss of cutaneous function and structure, influenced by both genetic and environmental factors. It manifests through physiological changes over time, such as vascular prominence, fine wrinkles, loss of elasticity, and atrophy, which collectively diminish the skin's youthful appearance and resilience. These changes are linked to a decline in cellular repair mechanisms and an accumulation of oxidative damage, highlighting the interplay between intrinsic aging processes and external environmental exposures (Naidoo et al., 2017).

Skin aging can be attributed to intrinsic and extrinsic factors, each contributing uniquely to the process (Naidoo et al., 2017). The amount of skin lipid, blood flow, collagen formation, and rete ridge loss are all decreased by intrinsic alterations. Sagging skin and some signs of excessive wrinkles are signs of intrinsic aging, which cannot be reversed (Karim et al., 2021). Programmed aging and cellular senescence, which are brought on by endogenous oxidative stress and cellular damage, are linked to intrinsic aging and often influenced by hormones and genetics (Shin et al., 2023; Tobin, 2017). On the other hand, extrinsic factors are related to the cumulative effects of environmental conditions, such as solar radiation (Huang & Chien, 2020).

The skin aging condition, caused by solar radiation, is also known as photoaging. Photoaging hallmarks include wrinkles, laxity, roughness, telangiectasia pigmentary conditions, yellowing, and uneven skin tone observed on the face, neck, chest, and dorsal hands. Due to the visible and distressing nature of these symptoms, many individuals seek treatments intended to prevent or delay signs of photoaging. A significant portion of people's daily expenses, specifically women, is spent on medications and cosmetics that claim to halt or reverse skin aging (Zhang & Duan, 2018).

In recent years, natural ingredients in skin care products have gained popularity due to consumer demand for safe, sustainable, and effective cosmetic components. Their numerous alleged benefits to improve skin health, including their ability to moisturize, prevent aging, reduce inflammation, and soothe, offer a strong argument for their use in cosmetic goods today (Gonçalves & Gaivão, 2023). According to ethnomedicinal reports, *Sclerocarya birrea* (A.Rich.) Hochst. (Marula) is one of the several plants that have recently been well-liked as a natural component in cosmetic formulations (Shoko et al., 2018). Many parts of the marula plant have been linked to a wide range of biological activities, such as anti-diarrheal, anti-diabetic, anti-inflammatory, antimicrobial, antiplasmodial, antihypertensive, anticonvulsant, antinociceptive, and antioxidant qualities.

These biological activities provide pharmacological support for some of the plant's traditional medicinal uses (Komane et al., 2015). However, the traditional application of marula oil and its reputed anti-aging properties in reducing extrinsic skin aging have not yet been adequately supported by published clinical research. Exploring marula oil's anti-aging potential is essential, given the growing consumer demand for natural, sustainable, and effective cosmetic ingredients. Thus, this review aims to address the existing research gap by evaluating the bioactive components of marula oil and their possible mechanisms in alleviating photoaging. This will provide a scientific foundation for its inclusion in anti-aging formulations and contribute to the development of evidence-based cosmeceuticals.

PHOTOAGING AND ITS MOLECULAR MECHANISMS

Until recently, photoaging was thought to be primarily caused by exposure to ultraviolet (UV) radiation from the sun **(Figure 1)** (Krutmann et al., 2021). When UV photons react with the chromophore in the skin (trans-urocanic acid), a singlet oxygen will be formed. This triggers a series of processes that eventually produce reactive oxygen species (ROS). ROS are extremely hazardous, unstable substances that can harm proteins, cell membranes, and nucleic acids. UV-induced ROS triggers the signal transduction cascade, which results in the downregulation of transforming growth factor-ß and the overexpression of molecules, including nuclear factor-B and activation protein-1 (AP-1) (Al-Niaimi & Chiang, 2017). These transcription factors stimulate matrix metalloproteinases (MMPs), promoting elastin accumulation, breaking down collagen, and limiting collagen formation (Lee et al., 2020). Given collagen's central role in maintaining the strength, stability, and structural integrity of the dermal layers, its breakdown disrupts the extracellular matrix, weakens connective tissue support, and contributes to skin thinning or wrinkle formation (Al-Atif, 2022; Wu et al., 2023; Reilly & Lozano, 2021).

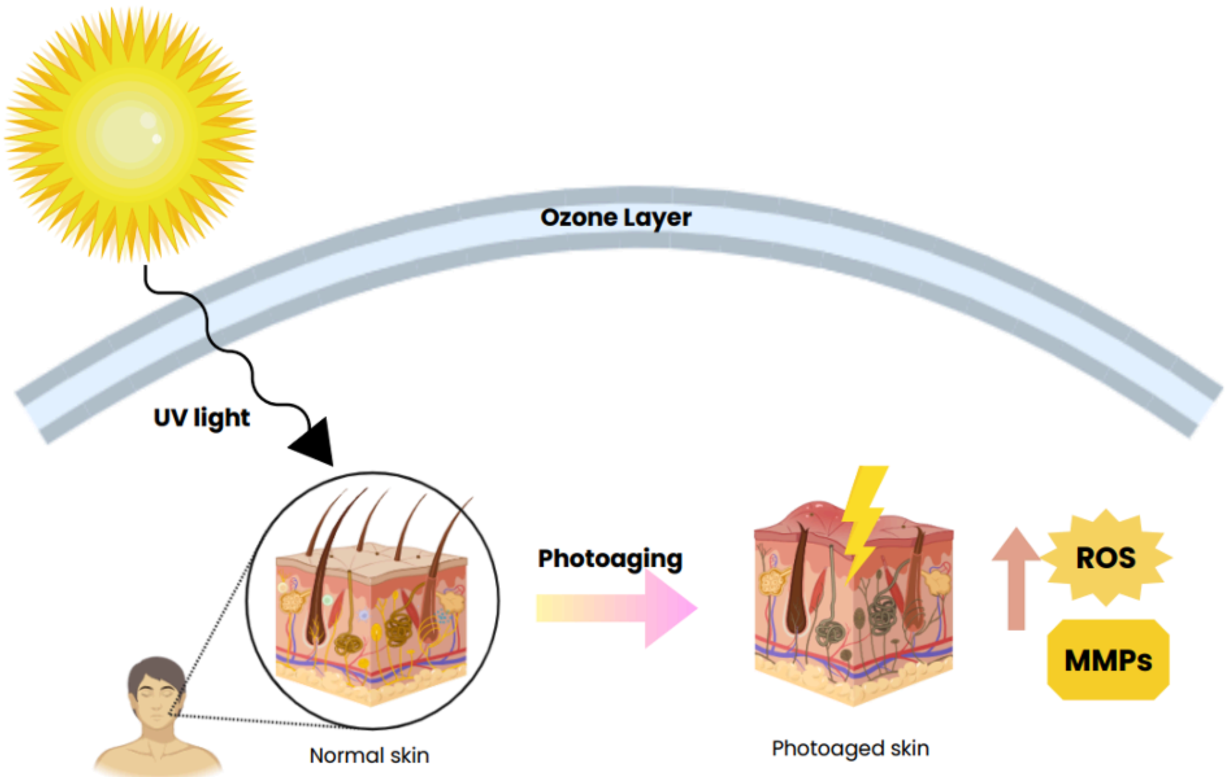

Figure 1. Mechanism of UV-induced photoaging on skin

Furthermore, ROS removes a hydrogen atom from the lipid, resulting in a lipid radical (L•), illustrated in **Figure 2**. When lipid radicals (L•) and oxygen react quickly during the propagation phase, a lipid peroxy radical (LOO•) is formed (Li et al., 2022). The lipid peroxy radical then extracts a hydrogen atom from another lipid molecule, producing an additional L• and lipid hydroperoxide (LOOH) (Ayala et al., 2014). These lipid hydroperoxides cause the membrane to become stiffer, allowing ions such as calcium to pass through, which significantly impairs membrane function. This results in the clinical appearance of deep wrinkles, coarse texture, telangiectasias, photoaging pigmentation, and solar elastosis (Cho et al., 2020).

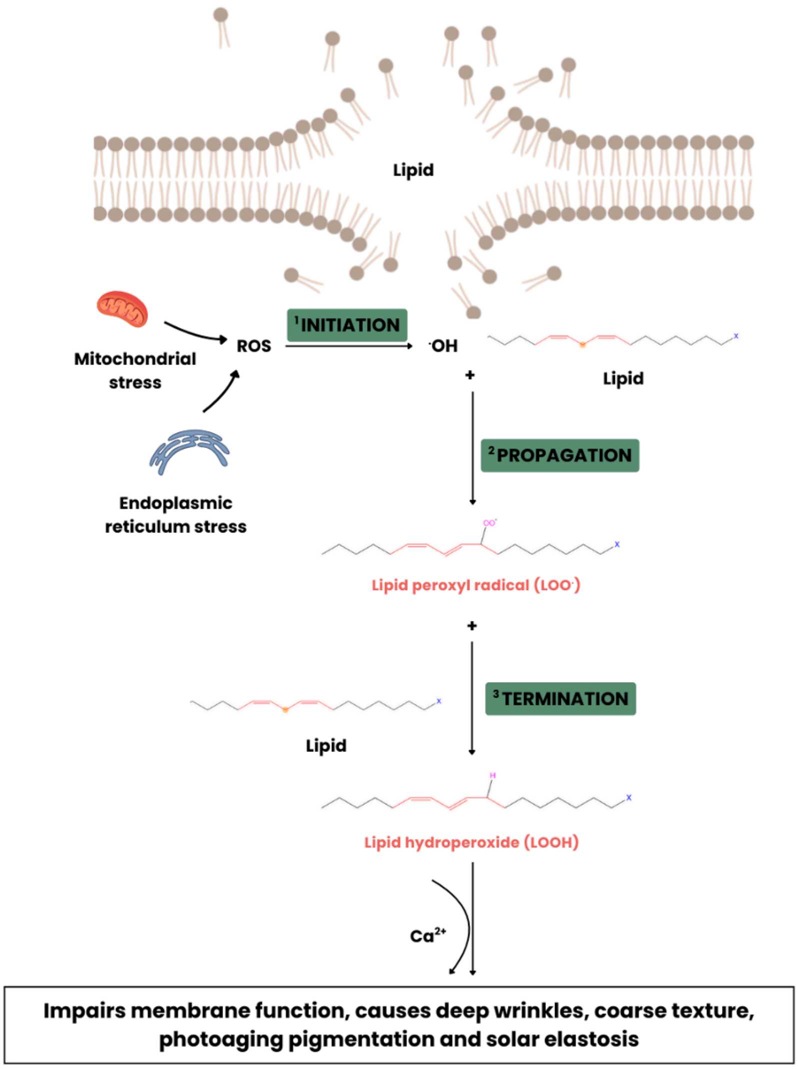

Figure 2. Mechanism of photoaging induced by ROS on the skin lipid bilayer

MARULA OIL

The marula tree, *Sclerocarya birrea*, from the family Anacardiaceae, is an integral part of African traditional medicine and a popular food source. The tree is found throughout Southern African countries, where the fruit is widely consumed by indigenous communities and many animal species. A wide range of biological activities, including antidiarrhoeal, antidiabetic, anti-inflammatory, antimicrobial, and antioxidant activities, are attributed to various plant parts of the tree (Jiménez-Sánchez et al., 2015). It has been stated that marula leaves have been traditionally used to treat skin disorders, including acne. In the majority of southern African nations, the oil extracted from marula kernels is used for a variety of cosmetic applications, such as moisturizing the skin, maintaining healthy skin, manufacturing soap, and producing shampoo for dry, damaged, and fragile hair. Marula oil is rich in different fatty acids, with oleic acid (70–78%) being the primary component, followed by palmitic (9%–12%), stearic (5%–8%), and linoleic fatty acids (4%–10%) (Schripsema et al., 2023). Owing to this composition, marula oil has been used for anti-aging, skincare, and moisturizing purposes, as well as in traditional medicine, cooking, and cosmetic formulations. Its high levels of natural antioxidants and monounsaturated fatty acids contribute to both its stability and strong antioxidant activity. Notably, while its fatty acid profile resembles that of olive oil, marula oil is up to ten times more resistant to oxidation (Alshaman et al., 2023).

Chemical composition

Oleic acid

Oleic acid ($C_{18}H_{34}O_2$) or octadecanoic acid, with a molecular weight of 282.46 g/mol, is a monounsaturated fatty acid. In **Figure 3**, the unbranched 18-carbon chain is kinked by the cis-double bond that oleic acid has at the 9th carbon. This structural bend results in a liquid state at room temperature because it prevents tight packing. Oleic acid's ability to balance stability and flexibility in formulations makes it useful as an emulsifier and in food and cosmetics (PubChem, 2019b).

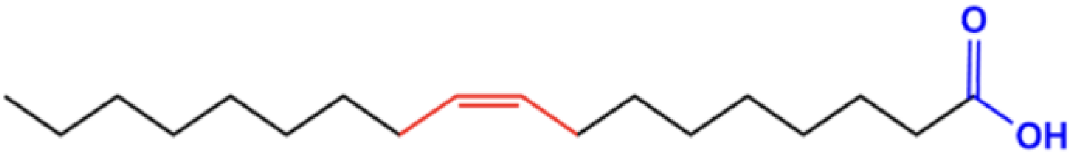

Figure 3. Oleic acid chemical structure

Palmitic acid

Palmitic acid ($C_{16}H_{32}O_2$), with a molecular weight of 256.42 g/mol, is a saturated fatty acid. It is made up of a 16-carbon straight chain that ends in a carboxylic group **(Figure 4)**. Palmitic acid slightly dissolves in water and is solid at room temperature. Often found in soaps, cosmetics, and processed meals, palmitic acid is one of the most prevalent saturated fatty acids in both plants and animals (PubChem, 2019c).

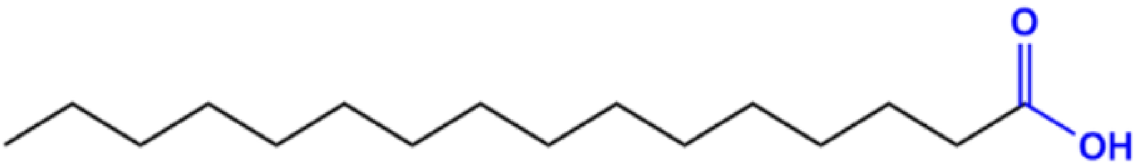

Figure 4. Palmitic acid chemical structure

Stearic acid

Stearic acid ($C_{18}H_{36}O_2$), with a molecular weight of 284.48 g/mol, is a long-chain saturated fatty acid. Stearic acid is an 18-carbon saturated hydrocarbon chain with a linear, unbranched structure, as depicted in **Figure 5**. Its solid state at normal temperature is a result of the linear chain. It dissolves in organic solvents like ethanol but is insoluble in water. Owing to its stability and hydrophobic properties, stearic acid is used in numerous applications, from soaps and lubricants to candles and cosmetics (PubChem, 2019d).

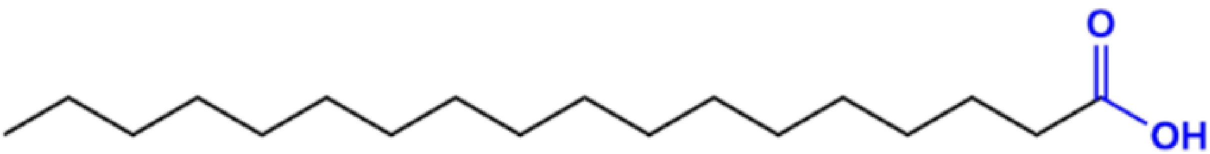

Figure 5. Stearic acid chemical structure

Linoleic acid

Linoleic acid ($C_{18}H_{32}O_2$), *cis*, *cis*-9,12-Octadecadienoic acid, with a molecular weight of 280.45 g/mol, is a polyunsaturated fatty acid. It has two cis double bonds at the 9th and 12th carbons, which contribute to the chain's 18 carbons to kink several times **(Figure 6)**. These kinks prevent straight alignment and promote fluidity, resulting in the fatty acid remaining in a liquid state at room temperature. Linoleic acid is a common ingredient in industrial, cosmetic, and nutritional products. Furthermore, it is essential for maintaining the integrity of the skin barrier (PubChem, 2019a).

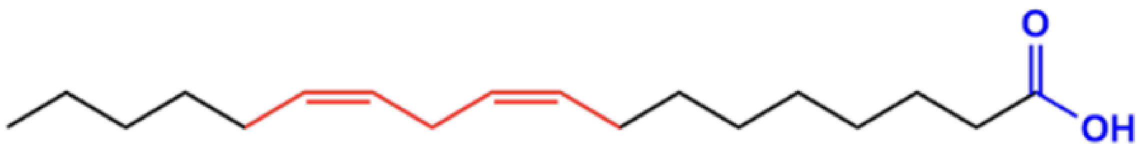

Figure 6. Linoleic acid chemical structure

Vitamin E (tocopherols)

The most common form of vitamin E is alpha-tocopherol, which is well-known for having powerful antioxidant activities based on its capacity to stabilize reactive species **(Figure 7)**. Tocopherol used topically has demonstrated several positive and protective benefits on the skin in the past. It is regarded as a photoprotector given that it may reduce oxidative damage caused by ultraviolet (UV) light (Caddeo et al., 2018). *Sclerocarya birrea* oil has a tocopherol concentration of 13.7 mg/100 g, with γ-tocopherol making up the majority at 13.0 mg/100 g, followed by α-tocopherol at 0.4 mg/100 g and δ-tocopherol at 0.3 mg/100 g (Mariod & Abdelwahab, 2012).

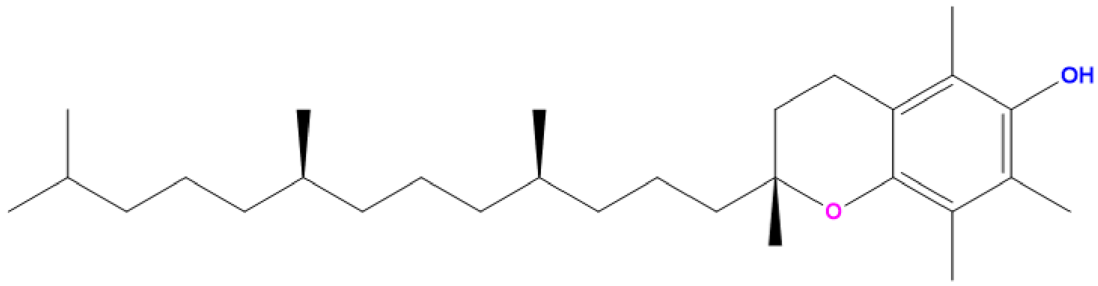

Figure 7. Vitamin E chemical structure

Vitamin C

Vitamin C, often known as ascorbic acid **(Figure 8)**, is a water-soluble vitamin and a well-known antioxidant medication that is applied topically in dermatology to treat and prevent photoaging-related changes and hyperpigmentation (Telang, 2013). Ascorbic acid can neutralize free radicals by interacting with superoxide, hydroxyl, and free oxygen ions, thereby preventing the development of cancer, inflammation, and other conditions that accelerate skin photoaging. Vitamin C further assists in forming the skin barrier and collagen in the dermis (Ravetti et al., 2019). Due to its dual function of pro-oxidation and antioxidation, vitamin C helps to keep the two physiological reactions in balance (Kim et al., 2015).

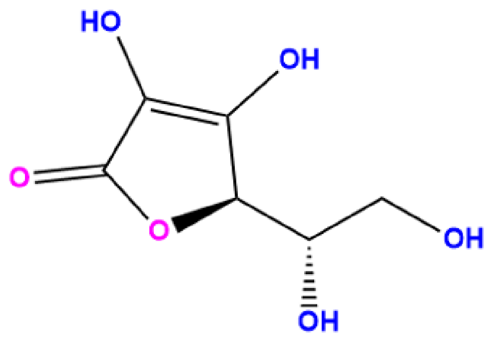

Figure 8. Vitamin C chemical structure

CURRENT MECHANISMS OF MARULA OIL

Oleic acid and palmitic acid are two of the most prevalent fatty acids found in marula oil and are also key constituents of the human epidermis. It has been established that exposure to UV light, the primary cause of photoaging, lowers oleic acid levels. According to a study by Wang & Wu (2019), supplementing with exogenous oleic acid may help prevent extrinsic skin aging, although its exact mechanism is still not well understood. Furthermore, both linoleic and oleic acids have been shown to lighten skin (Cristiano et al., 2021), indicating their significance in mitigating the negative effects of photoaging on the skin.

Other than fatty acids, marula oil also possesses antioxidant properties, including phenolic compounds and vitamins E and C. These components naturally quench free radicals that initiate the oxidation and ionization processes (Samikannu et al., 2022). Vitamin C is a highly effective antioxidant in the skin. It has been demonstrated that vitamin C performs its photoaging activity by inhibiting AP-1 activation, which lowers the production of MMPs and damages collagen (Al-Niaimi & Chiang, 2017). However, another study by Mumtaz et al. (2021) claims otherwise. In normal circumstances, the absence of ligand binding causes the receptor tyrosine kinases (RTKs) to be inactivated or in a dormant state by receptor tyrosine phosphatases (RPTPs), which continuously maintains them in a dephosphorylated state. Though, in the occurrence of UV radiations, ROS and other oxidative byproducts are liberated as a result of energy uptake by cellular chromophores. The ROS then binds and attaches itself by targeting cysteine residues within the active sites of RPTPs, inactivating and impairing their phosphatase activity in the process. This is then followed by initiating a signalling cascade of downstream pathways that activate AP-1, mitogen-activated protein kinases (MAPKs) and nuclear factor-κB (NF-κB). Once activated, AP-1 and NF-κB enhance transcription of MMP genes while suppressing collagen production, which underlie structural degradation in photoaged skin. Vitamin C counteracts this mechanism by inhibiting ROS-mediated binding of RPTPs, as observed in **Figure 9**, thereby promoting collagen formation and helps in preserving normal signalling balance.

Additionally, vitamin C is also referred to as a depigmenting agent since it reduces the production of melanin by blocking the tyrosinase enzyme and lowering dihydroxyphenylalanine (DOPA)-quinone (Pratiwi et al., 2021). In hyperpigmented skin, the pigment melanin, which helps with photoprotection and skin, hair, and eye pigmentation, is overproduced. By inhibiting melanin synthesis, vitamin C may help reduce the excess pigmentation that develops with photoaging (Mota et al., 2024).

Furthermore, vitamin C stimulates keratinocyte development, which is essential for protecting the integrity of the skin barrier and limiting transepidermal water loss, thereby maintaining skin moisture (Khalid et al., 2024). According to He et al. (2023), skin elasticity and strength are enhanced by moisture content, which also affects the depth of wrinkles. Besides maintaining barrier function, long-term moisturizer administration before UV exposure may postpone photoaging (Hong et al., 2017).

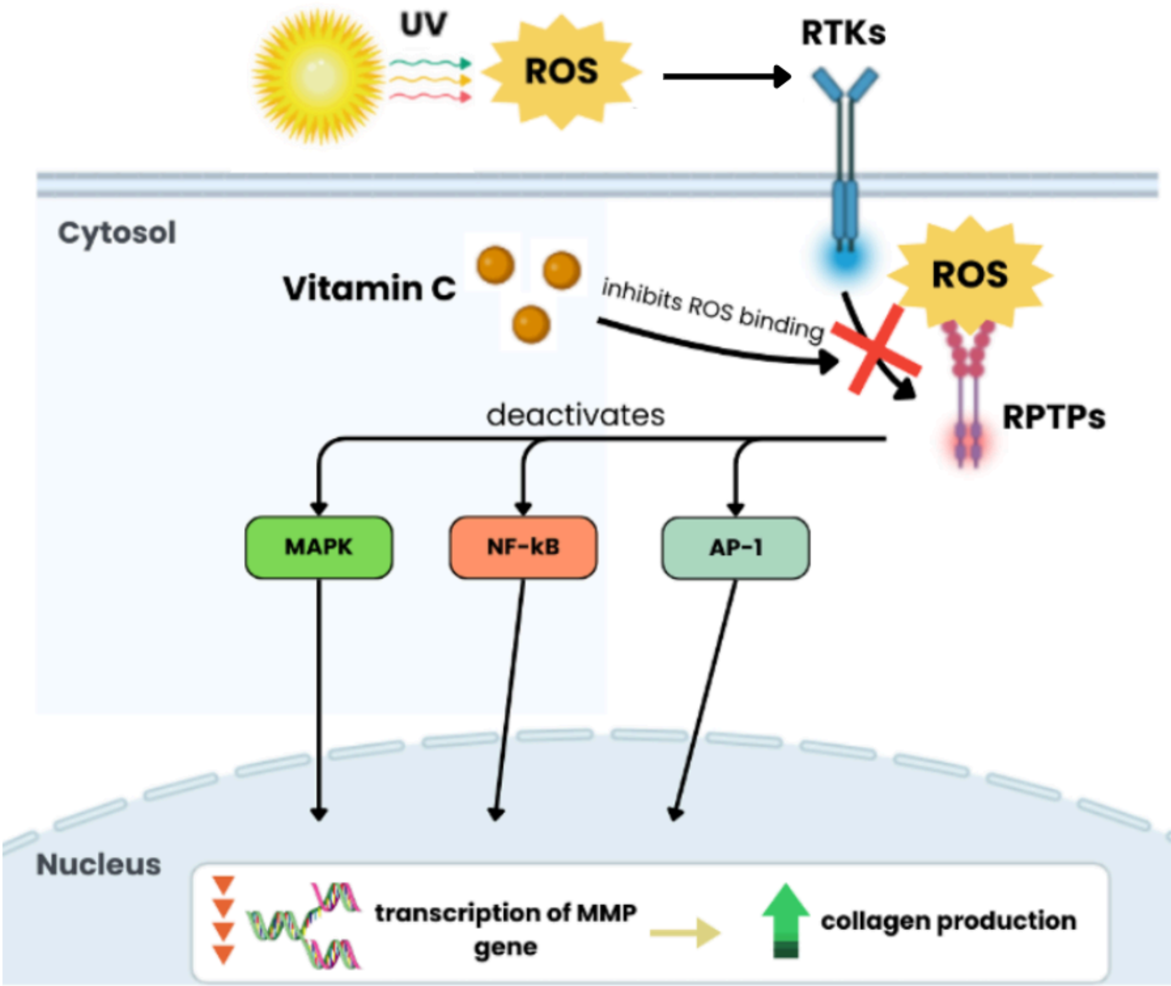

Figure 9. Mechanism of vitamin C in alleviating skin photoaging

Vitamin E is another vitamin that provides antioxidant activity to marula oil. Vitamin E is a fat-soluble and non-enzymatic antioxidant, owing to its capacity to block the activity of prooxidant agents produced by ROS (Niki & Noguchi, 2021). This vitamin can decrease UV radiation-induced immunosuppression, scavenge UVA-induced free radicals, protect endogenous epidermal antioxidant degradation, and stop lipid peroxidation (Delinasios et al., 2018). Its antioxidant activity is attributed from the phenolic hydroxyl (OH) group of vitamin E's structure, which donates a hydrogen atom to neutralize lipid peroxyl radical (LOO•) and produce a stable lipid species (LOOH), as illustrated in **Figure 2**. Without this protection, an uncontrolled lipid peroxidation obstructs the hydrophobic environment of the cell membrane, producing hydrophilic pore-like defects that enhance permeability and compromise the membrane's structural integrity.

The injured cell membrane or mitochondrial membrane becomes more permeable, and oxidative stress causes more harm to the cells or nearby cells. Accordingly, disorders linked to photodamage, including sunburn, photoaging, and polymorphic light eruption, will decline as a result of stable lipid species synthesis aided by vitamin E (Chen et al., 2021). Moreover, a low-energy tocopheroxyl stable radical (VE-O•) will be formed, which cannot function as a free radical generating agent (Aparecida Sales de Oliveira Pinto et al., 2021).

Additionally, several studies have demonstrated that a combination of vitamin C and vitamin E can lower the synthesis of melanin by blocking the tyrosinase enzyme, which catalyzes the conversion of tyrosine to melanin. Due to this property, the combination of the vitamins is useful as alternatives designed to lessen hyperpigmentation and preserve skin tone (Khalid et al., 2024).

SCIENTIFIC AND CLINICAL EVIDENCE

Laboratory studies examining the effects of marula oil on photoaging have yielded several promising findings regarding its potential as a cosmetic ingredient. Marula oil is rich in fatty acids, particularly oleic and palmitic acids, which contribute to its moisturizing and hydrating properties (Alshaman et al., 2023). The high oleic acid content (approximately 69%) in marula oil contributes to these properties, as it mimics the natural lipids found in the skin, facilitating absorption and improving skin barrier function. Moreover, oleic acid has been shown to have no negative impact on inflammatory markers when tested in vitro. Other studies on omega-3 fatty acid—particularly alpha-linoleic acid, also found in marula oil—have demonstrated that they can reduce UV-induced keratinocyte damage by modulating inflammatory pathways such as COX-2 and NF-κB. These findings suggest that the fatty acids in marula oil may similarly contribute to reducing inflammation and oxidative stress associated with photoaging (Huang et al., 2018).

One of the significant aspects of marula oil is its ability to inhibit enzymes associated with skin aging. In vitro studies on marula oil have focused on inhibiting enzymes that contribute to skin aging, such as elastase and collagenase. This antioxidant action helps prevent cellular damage associated with photoaging, including the degradation of structural proteins like collagen and elastin, with 25.89% collagenase inhibition activities. Consequently, marula oil stands out as a powerful agent for enhancing skin health and resilience against photoaging (Shoko et al., 2018).

As mentioned before, marula oil is also known for its antioxidant properties, particularly vitamins E and C. Other in vitro studies from Alshaman et al. (2023) have demonstrated that antioxidants like vitamin E can significantly reduce markers of oxidative damage. For instance, studies indicate that the topical application of antioxidants can lower lipid peroxidation levels in skin cells exposed to UV radiation. Marula oil's vitamin E content has been shown to effectively reduce these lipid peroxidation markers, particularly malondialdehyde (MDA) and 4-hydroxyalkenal (4-HNE), thereby protecting cellular structures from damage. Research stated that antioxidants can also reduce protein carbonylation by modifying the DNPH (2,4-dinitrophenylhydrazine), another indicator of oxidative stress in skin cells subjected to UV exposure. This reduction is crucial for maintaining the functionality of proteins involved in skin structure and repair (Samikannu et al., 2022).

Although no direct in vivo studies have been conducted on photoaging, some available animal studies highlight its systemic antioxidant and other protective properties. A study that supplemented marula juice at a dose of 100 to 200 mL/kg body weight per day for 3 weeks enhanced lipid profiles and elevated high-density lipoprotein (HDL) levels by reducing low-density lipoprotein (LDL), triglycerides, and total cholesterol levels, likely due to the high vitamin C and phenolic content. Similarly, in diabetic rat models, oral delivery of marula bark extract (120 to 300 mg/kg) elicited a hypoglycemic effect akin to metformin, while improving hepatic glycogen storage, plasma insulin level, and overall lipid metabolism. Beyond its metabolic activity, marula bark extract has proven to exert anti-inflammatory activity by reducing paw oedema in rats in a time- and dose-dependent fashion, whereas marula oil-loaded nanoemulsion conferred neuroprotection in rotenone-induced Parkinson's subjects by attenuating oxidative stress and downregulating pro-inflammatory markers, such as TNF-α and IL-1β (Olas, 2025).

In addition to in vitro and in vivo studies, clinical trials have also been conducted to assess the safety and efficacy of marula oil. A clinical study by Komane et al. (2015) found that marula oil is non-irritating and effectively improves skin hydration and occlusivity in healthy volunteers, aiding in the prevention of transepidermal water loss. Another such trial involved a group of 20 healthy Caucasian female volunteers, evaluating its effects on skin health. The study assessed various parameters, including irritancy levels, skin barrier function, transepidermal water loss (TEWL), and the hydrating and occlusive effects of marula oil on lipid-dry skin. The findings revealed that marula oil is non-irritant ($p<0.001$) and exhibits significant moisturizing ($p<0.001$) and hydrating properties when applied to abnormal dry skin. Additionally, the oil demonstrated occlusive effects ($p<0.001$) on normal skin, which can be attributed to its high oleic acid content. This biomimetic property allows marula oil to effectively mimic the skin's natural lipids, promoting hydration and protection against external aggressors (Komane et al., 2015). The clinical trials highlight that marula oil has significant potential as an ingredient in anti-aging skincare products, largely due to its excellent moisturizing properties **(Table 1)**.

Table 1. Summary of findings from studies investigating the anti-aging properties of marula oil

Author (year)	Title	Highlighted anti-aging agent	Findings
Komane et al. (2015)	Safety and efficacy of *Sclerocarya birrea* (A.Rich.) Hochst (marula) oil: A clinical perspective.	Oleic acid	Marula oil exhibits excellent moisturizing and hydrating properties, which protect the skin from external aggressors, including UVB.
Shoko et al. (2018)	Anti-aging potential of extracts from *Sclerocarya birrea* (A. Rich.) Hochst and its chemical profiling by UPLC-Q-TOF-MS	Anti-collagenase	Marula oil inhibits 25.89% collagenase activities, as effective as EDTA.
Samikannu et al. (2022)	Assessing the dielectric performance of *Sclerocarya birrea* (marula oil) and mineral oil for eco-friendly power transformer applications.	Vitamin C and E	Marula oil reduced protein carbonylation in UV-exposed skin cells.
Alshaman et al. (2023)	Marula oil nanoemulsion improves motor function in experimental parkinsonism via mitigation of inflammation and oxidative stress.	Vitamin E	Marula oil effectively reduces the lipid peroxidation markers (MDA, 4-HNE), protecting the skin barrier from damage.

COMPARATIVE EFFICACY OF MARULA OIL AND ESTABLISHED ACTIVES

Photoaging focuses on preventing skin aging from leading causes of UV or free radicals; however, there is no solid evidence proven to alleviate symptoms of photoaging. Indeed, many cosmetic products claim to eliminate the clinical signs of photoaging skin, but this does not necessarily correspond to the safety profile of these ingredients. Several product testing warranted by cosmetic industry claims and extensively regard the use of retinoids, hyaluronic acid and niacinamide for mitigating photoaged skins (Mohiuddin, 2019). Thus, to contextualize the role of marula oil, a comparative analysis against these well-established agents is necessary. **Table 2** below highlights the relative mechanism, efficacy, limitations, and advantages of marula oil with other leading anti-aging agents.

Table 2. Comparative overview of anti-aging agents based on mechanistic and clinical evidence

Agent	Mechanism of Action	Clinical Evidence	Advantages	Limitations	References
Marula Oil	Antioxidant and anti-inflammatory, rich in oleic acid, tocopherols, vitamin C → ↑ collagen production and ↓ MMP activity	Lack of *in vivo* and clinical trials for skin aging	Well-tolerated and natural, it increases barrier and hydration functionality	Limited evidence on wrinkle or pigmentation data	(Alshaman et al., 2023), (Mumtaz et al., 2021)
Retinoids	Binds and attaches to nuclear receptors → ↑ collagen production and ↓ MMP activity	Contains strong and concrete evidence for wrinkle reduction	Considered as gold standard for anti-aging, improves skin texture and wrinkles	High chances of irritation, photosensitivity, and erythema	(Zasada & Budzisz, 2019), (Fu et al., 2010)
Peptides	Signals fibroblasts → ↑ elastin, collagen, and glycosaminoglycans production	Highly effective in tandem with other agents and supported by *in vitro* and clinical trials	Causes minimal irritation and supports targeted extracellular matrix stimulation	Often unstable and contains variable penetration, with lower potency than retinoids	(Fu et al., 2010), (Skibska & Perlikowska, 2021), (Dierckx et al., 2024)
Niacinamide	↑ synthesis of barrier lipid, ↑ elasticity and antioxidant protection, ↓ transepidermal water loss (TEWL)	Multiple randomized controlled trials (RCTs) show significant improvement in hydration, wrinkles, pigmentation and barrier integrity	Generally well tolerated, multifunctional and suitable for long-term safety	Induce transient skin flushing at elevated concentrations	(Boo, 2021), (Fu et al., 2010), (Ong & Goh, 2024)

Agent	Mechanism of Action	Clinical Evidence	Advantages	Limitations	References
Hyaluronic Acid (HA)	↑ water retention in epidermal and dermal layer → enhance hydration, elasticity, and plumping	Multiple RCTs reveal significant improvement in hydration, smoothness, fine wrinkles or lines and plumping	Provides immediate hydration, compatible across all skin types, and is well-tolerated	Temporary effect; while requiring sustained usage for lasting months, and high-molecular-weight HA restricts deep penetration	(Bravo et al., 2022), (Bukhari et al., 2018), (Draelos et al., 2021)

POTENTIAL APPLICATIONS

Due to growing customer desire for more environmentally friendly products, the market for natural anti-aging cosmetics is expanding significantly (Gama et al., 2025). The global beauty market has been using marula oil in cosmetic compositions for a long time. The emollient qualities, UV protection, anti-aging, and wound-healing effects have made marula oil popular in the cosmeceutical sector (Gebashe et al., 2022). Marula oil is described as non-irritating, which means it does not cause redness, sensitivity, or inflammation when applied to the skin. This characteristic makes it particularly beneficial for those with sensitive skin, which can be more prone to irritation from many anti-aging products. Many common anti-aging ingredients (like retinoids or acids) can cause irritation or peeling, but marula oil, due to its gentle nature, can be used without these side effects. This makes it versatile and suitable for a wider range of consumers, including those with sensitive skin (Ojha et al., 2024). Therefore, it is worthwhile to investigate its potential synergy with other natural compounds.

Based on the previous study, marula oil proved to be easily absorbed by the skin and is resistant to oxidation, making the utilization of the oil gain a lot of attention (Kamanula et al., 2022). Marula oil has been reported to exhibit oxidative stability up to ten times greater than that of olive oil, making it one of the most stable natural oils available (Arora, 2020). Its exceptional oxidation resistance, combined with rapid skin absorption, a high concentration of oleic acid, the presence of linoleic acid, and an array of vitamins, underpins its well-documented anti-aging and moisturizing effects (Mahomoodally & Ramjuttun, 2017). These characteristics highlight its potential to serve as a superior alternative to other natural oils commonly used in the cosmetic industry. Therefore, incorporating well-established anti-aging actives together with marula oil can enhance the overall efficacy of skincare formulations by strengthening their anti-aging effects while simultaneously providing deep moisturization.

LIMITATIONS AND FUTURE DIRECTIONS

While many studies have demonstrated the effectiveness of marula oil and its vitamins for skin hydration, its role in anti-aging remains less conclusive due to the limited duration of existing trials. The vitamins in marula oil, notably vitamins C and E, offer additional promise in anti-photoaging therapies. However, their combined and individual contributions to skin health under chronic conditions require further examination. Moreover, most clinical and in vivo studies, such as those involving short-term applications, fail to provide long-term data on their sustained efficacy in preventing photoaging or reversing age-related skin changes. Long-term studies are crucial to understanding the cumulative benefits and potential side effects of prolonged use, especially when considering that photoaging is a gradual process. Moreover, clinical trials assessing prolonged use can provide valuable insights into its sustained ability to improve skin elasticity, reduce wrinkles, and maintain hydration. Such investigations should also evaluate cumulative safety, efficacy, and any adaptive effects over time.

Another notable research gap is the lack of detailed molecular pathway analyses. While marula oil is known for its antioxidant properties, which help reduce oxidative stress caused by UV radiation, the specific molecular mechanisms through which it alleviates photoaging are not well understood. Studies that explore how marula oil influences collagen synthesis, elastin preservation, and other key proteins related to skin aging are needed. Thus, understanding these molecular pathways would provide deeper insights into its anti-aging potential and help optimize its use in skincare formulations (Shoko et al., 2018).

Lastly, the potential for personalized skincare formulations incorporating marula oil and its vitamins represents an exciting frontier. Advances in genomics and skin microbiome profiling could enable tailored products designed to address individual skin concerns, such as sensitivity, pigmentation, or hydration levels. Innovative delivery systems like nanoemulsions or encapsulation could further improve penetration and efficacy, positioning marula oil as a cornerstone in precision skincare. These efforts will not only bridge existing knowledge gaps but also elevate marula oil's status in the cosmeceutical industry (Alshaman et al., 2023; Komane et al., 2015; Shoko et al., 2018).

This study is primarily focused on specific parts of the marula plant. Previous findings reported that stem extracts exhibited the most promising activity, with anti-elastase activity above 88% and anti-collagenase activity reaching 99%, which was more potent than EDTA. In contrast, the leaf extract showed only moderate anti-elastase activity (54%) and was inactive against collagenase, while the fruit and oil demonstrated limited activity in both assays (Shoko et al., 2018). Given that the ethanolic stem extract was identified as the most suitable for cosmetic applications due to its strong bioactivity and industry acceptability, future investigations should broaden the scope to other plant parts, such as the bark, roots, or seeds, to fully characterize the bioactive potential of marula.

CONCLUSION

Marula oil, derived from *Sclerocarya birrea*, has emerged as a promising natural ingredient in addressing photoaging, offering benefits through its rich composition of fatty acids and vitamins C and E. Its moisturizing, antioxidant, and photoprotective properties contribute to improved skin hydration, elasticity, and a reduction in oxidative stress and UV-induced damage. Current evidence supports its potential as a safe and effective ingredient in anti-aging formulations, with studies demonstrating its ability to enhance skin barrier function and inhibit enzymes associated with collagen and elastin degradation. Despite these promising findings, further research is needed to explore the long-term effects of marula oil on photoaging and to elucidate the molecular pathways through which its bioactive compounds act. Additionally, leveraging its properties in personalized skincare formulations, tailored to individual needs using advanced delivery systems, represents an exciting opportunity for innovation. By addressing these gaps, marula oil can solidify its role as a versatile and sustainable solution in the cosmeceutical industry, offering a natural approach to skincare that meets the growing demand for safe and effective anti-aging products.

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