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The Potential of Purple Eggplant Skin in Improving Skin Health in Postmenopausal Women

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A B S T R A C T

The skin of purple eggplant (Solanum melongena L.) is recognized as a rich source of diverse bioactive compounds, particularly anthocyanins such as nasunin, and other phenolic compounds including chlorogenic acid. These phytochemicals endow purple eggplant skin with potent antioxidant and anti-inflammatory properties, making it a promising natural resource for combating skin aging, especially in postmenopausal women. This review comprehensively examines the phytochemical profile of purple eggplant skin, elucidating the chemical structures and biological activities of its dominant compounds. It then delves into the specific mechanisms through which these compounds exert antioxidant effects by scavenging free radicals and anti-inflammatory actions by modulating signaling pathways relevant to aging skin. Furthermore, the review explores the potential of purple eggplant skin extracts to improve the extracellular matrix by stimulating collagen and elastin synthesis and inhibiting degradative enzymes, enhance skin hydration and barrier function, and offer photoprotection against UV-induced damage. Drawing upon in vitro, in vivo, and limited clinical studies, this work synthesizes current scientific evidence to highlight the therapeutic potential of purple eggplant skin extracts for mitigating the signs of skin aging in postmenopausal women, while also identifying critical gaps in research and outlining future directions for targeted clinical investigations

Keywords: Purple Eggplant Skin, Postmenopausal Women, Skin Aging, Anthocyanins, Antioxidants

Introduction

The Solanaceae family encompasses over 3,000 plant species, adapted to various geographical conditions across all continents except Antarctica, with economically significant representatives including eggplants (*Solanum melongena*), tomatoes (*S. lycopersicum*), and potatoes (*S. tuberosum*) (1). Among these, Asian eggplants (S. melongena L.) hold a prominent position globally, ranking as the sixth most cultivated crop, primarily in Southeast Asian, African, and Mediterranean regions, with China and India accounting for 90% of total production (1). Beyond its culinary importance, eggplant has been traditionally utilized for its therapeutic properties, recognized for its antioxidant capacity due to its high content of phenolics and flavonoids (1,2). The plant offers a wide array of therapeutic benefits, including analgesic, antipyretic, antioxidant, anti-inflammatory, anti-asthmatic, hypolipidemic, hypotensive, and antiplatelet activities, along with the ability to lower intraocular pressure and prevent anaphylaxis (3,4). Eggplant leaves, for example, have been traditionally used to treat inflammatory conditions, cardiac debility, neuralgia, nasal ulcers, and cholera (5).

The outer part of the eggplant fruit, particularly the skin, is a significant reservoir of these bioactive compounds (3,6). Studies have shown that eggplant fruit skins generally contain more phenolics than the pulp, and the epicarp (the outer rind) is a primary site for anthocyanic compounds (7). These natural products are secondary metabolites, not essential for basic plant processes, but form the basis of traditional and modern medicinal systems (7). The peel, often discarded as agricultural waste, represents an underutilized resource rich in potent phytochemicals, including phenolic acids, flavonoids, tannins, alkaloids, and glycoalkaloids, known for their antioxidative and cytotoxic properties (8,9).

Skin aging is a complex process influenced by both intrinsic and extrinsic factors, leading to visible changes such as wrinkles, loss of elasticity, and dryness (6,10). Postmenopausal women, in particular, experience accelerated skin aging due to declining estrogen levels, which impact collagen synthesis, skin hydration, and antioxidant defenses (10,11). A key contributor to skin aging is oxidative stress, an imbalance between the generation and neutralization of reactive oxygen species (ROS) and free radicals, which damages critical biomolecules like lipids, proteins, and DNA (3,6,12). This damage is associated with premature aging and other degenerative conditions (3). Consequently, there is a growing interest in identifying natural antioxidants and anti-inflammatory agents that can mitigate these detrimental effects and support skin health (3,6,12,13).

The objective of this literature review is to provide a comprehensive and detailed analysis of the potential of purple eggplant skin in improving skin health in postmenopausal women. By synthesizing the available evidence, this review seeks to highlight the therapeutic promise of purple eggplant skin extracts as a natural intervention for enhancing skin health in postmenopausal women and to guide future research in this vital area.

Phytochemical Profile in Purple Eggplant Skin

Purple eggplant skin is a remarkably rich source of diverse phytochemicals, playing a significant role in both the plant's defense mechanisms and its health-promoting properties (8,9). These compounds, largely secondary metabolites, contribute to the plant's color, taste, and therapeutic activities (7,14). The major groups of metabolites identified in eggplant residues include terpenes, flavonoids, and saponins/alkaloids (9).

The most predominant and characteristic phytochemical in purple eggplant skin is nasunin, an anthocyanin pigment responsible for its distinctive dark purple color (7,15,16). Nasunin is specifically identified as delphinidin-3-(p-coumaroylrutinoside)-5-glucoside. This complex glycosidic structure contributes significantly to the eggplant's antioxidant capacity (15). Anthocyanins, as a class, are water-soluble pigments conferring red-to-blue coloration to plant tissues (17,18). In purple eggplant, delphinidin and cyanidin derivatives are the major detected anthocyanins, with delphinidin being the most abundant (17). The presence of delphinidin-type anthocyanins is more responsible for the red to black-purple pigmentation (17). Other anthocyanin molecules identified in eggplant epicarp include delphinidin-3-O-rutinoside, delphinidin-3-O-rutinoside-5-O-glucoside, petunidine-3-O-rutinoside, malvidine-3-O-rutinoside-5-O-glucoside, and cyanidin-3-O-rutinoside (14).

Beyond anthocyanins, purple eggplant skin is abundant in other important phenolic compounds. Chlorogenic acid is one of the most significant phenolic acids found in eggplant, with concentrations varying depending on the plant part and growing conditions (2,7,9,19). Eggplant is considered one of the fruits rich in phenolic acids, mostly chlorogenic acid, and its content can be affected by the harvesting season (7,9). The amount of chlorogenic acid in eggplant extracts has been quantified by HPLC, confirming its presence as a major component (19). This compound is known for its various health benefits, including anticancer properties, antimicrobial effects, antiviral activity, and inhibition of LDL cholesterol (2). In fact, 5-O-caffeoylquinic acid, a form of chlorogenic acid, was identified as a major and ubiquitous phenolic compound in all studied eggplant samples (whole fruit, pulp, and epicarp), with the highest concentration found in the epicarp (14).

Other important phenolic compounds found in eggplant include various flavonoids and phenolic acids (7,9,20). Flavonoids, a group of polyphenolic compounds widely distributed throughout the plant kingdom, exhibit several biological effects such as anti-inflammatory, anti-hepatotoxic, and anti-ulcer actions, and are potent antioxidants with free radical scavenging abilities (12,13,20). In eggplant, flavonoid content is particularly high in the fruit peel and leaves (7,9). Glycoside flavonoids like quercetin 3-O-glucoside, quercetin 3-O-malonyl glucoside, cyanidin 3-O-rutinoside, rutin, luteolin 7-glucoside, delphinidin 3-rutinoside, and isorhamnetin 3-glucoside-4'-glucoside have been identified (9). The fruit showed the highest content of total flavonoids, followed by leaves (9). Other phenolic acids identified include caffeic acid hexoside and protocatechuic acid, which were found in the whole fruit, pulp, and epicarp, with protocatechuic acid being detected only in the epicarp (14).

In addition to these, eggplant agricultural residues contain other secondary metabolites. Various steroidal glycoalkaloids, such as khasianine, solamargine, solasonine, and solasodine, have been identified, particularly in the roots, but solamargine and solasonine have also been reported in the leaf, stem, and fruit (7,9). These glycoalkaloids have been associated with beneficial effects on human health (9,21,22). Terpenes, primarily monoterpenoids and sesquiterpenoids, are more abundant in the leaf and root (9). Saponins are also present, predominantly in the root and fruit, and to a lesser extent in the stem (9). Tannins, mostly hydrolyzed tannins, are also present, with the leaf and fruit residues being primary sources (9). The presence of these diverse phytochemicals in purple eggplant skin underscores its complex and potent biological activity profile.

Antioxidant and Anti-inflammatory Properties in Purple Eggplant Skin

Purple eggplant skin is well-regarded for its significant antioxidant and anti-inflammatory capabilities, primarily due to its rich phytochemical composition (3,6). These properties are crucial for mitigating oxidative stress and chronic inflammation, which are key contributors to skin aging, especially in postmenopausal women (3,6).

The antioxidant activity of purple eggplant skin extracts is largely attributed to its high content of phenolic compounds and flavonoids (6,8,9,13,15). These compounds act through various mechanisms to neutralize harmful free radicals and reactive oxygen species (ROS). One primary mechanism involves free radical scavenging, which can be measured using assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) (3,6,8,9,23,24). For instance, ethanol extracts of eggplant skin have demonstrated significant antioxidant properties, effectively neutralizing free radicals, with promising half-maximal inhibitory concentration (IC50) values in both ABTS and DPPH assays (3). A lower IC50 value indicates higher antioxidant activity, reflecting a greater radical scavenging ability (3,8). The ethyl acetate extract of eggplant peel, for example, showed a maximum of 8.95% inhibition in the DPPH assay at 50 µg/mL, outperforming gallic acid at higher concentrations (8).

Beyond DPPH and ABTS, eggplant extracts exhibit the ability to inhibit hydroxyl radicals and superoxide anions (15,23). Nasunin, the dominant anthocyanin in purple eggplant peel, is particularly implicated in both inhibiting hydroxyl radical generation and scavenging superoxide anions (7,15,16). The capacity of these compounds to donate electrons plays a crucial role in converting free radicals into more stable products, thereby terminating radical chain reactions (13). The presence of N-trans-coumaroyltyramine, N-trans-feruloyltyramine, and N-trans-feruloyloctopamine in *Solanum melongena* also contributes to radical scavenging activity (3). Overall, the antioxidant potential is dose-dependent, with effectiveness increasing with concentration (3). This is supported by studies showing that extracts from purple-colored small-sized eggplant fruits demonstrate better antioxidant activities due to higher phenolic and anthocyanin content (23).

In terms of anti-inflammatory properties, eggplant extracts have been recognized in traditional Chinese medicine for these effects (3). Inflammation is a key factor in the pathogenesis of various age-related skin conditions (25). Specific compounds found in eggplant, such as amides and phenylpropanoids, contribute to its strong antioxidant and radical-scavenging activities, which in turn mitigate oxidative stress, a known trigger for inflammation (3). Phenylpropanoid derivatives like neochlorogenic acid have demonstrated substantial antioxidant activity and contribute to eggplant's ability to mitigate oxidative stress (3).

Eggplant extracts have shown the ability to suppress inflammatory pathways associated with aging. For instance, fermented eggplant peel extracts (BEPs) have been shown to inhibit the activity of mitogen-activated protein kinases (MAPKs), specifically suppressing the phosphorylation of ERK, p38, and JNK (6). MAPK pathways are crucial signaling cascades involved in cellular responses to stress, including inflammation and aging (6). By inhibiting these pathways, BEPs can effectively reduce inflammatory responses in the skin. Additionally, aqueous extracts of *Solanum melongena* have been reported to inhibit PAR-2 agonist-induced inflammation, which can contribute to atherosclerosis (15,23,24,26). In vivo studies in animal models have confirmed the anti-inflammatory effects of eggplant extracts (5,19). Methanolic extracts of S. melongena demonstrated significant inhibitory effects on acetic acid-induced increases in capillary permeability, indicating a strong anti-inflammatory activity (19). Furthermore, an aqueous extract of *Solanum melongena* leaves showed anti-inflammatory activity in experimental animals, supporting its traditional use for inflammatory ailments (5). The reduction in malondialdehyde (MDA) and lipid peroxidation 4-hydroxynonenal (LPO-4HNE) levels, coupled with increased superoxide dismutase (SOD) activity in aflatoxin B1-induced rats treated with eggplant skin extract, further demonstrates its protective effect against oxidative stress and associated inflammation (3). This dual action of antioxidant and anti-inflammatory properties makes purple eggplant skin a promising candidate for improving skin health in the context of aging and postmenopause.

Table 1 - Phytochemical profile and properties in purple eggplant skin.

Phytochemical Class	Specific Compounds	Properties/Activities
Anthocyanins	Delphinidin-type anthocyanins (main component), Nasunin, Total Monomeric Anthocyanin (TMA)	**Coloration:** Primary pigments responsible for the reddish to black-purple color of eggplant peels. Potential application as natural industrial colorants. **Potent Antioxidant Activity:** Protect cells from free radical damage and oxidative stress. Nasunin shows specific antioxidant activity. Contributes to the overall antioxidant capacity of eggplant peel extracts. Capable of scavenging free radicals, inhibiting hydroxyl radical formation, and chelating ferrous iron. **Anticancer/Antitumor Properties:** Induce apoptosis in leukemia cells, inhibit tumor growth, and exhibit both in vitro and in vivo anticancer activity against liver cancer. **Cardioprotective:** High anthocyanin intake is linked to reduced risk of cardiovascular diseases, myocardial infarction, stroke, and other heart conditions. **Anti-inflammatory:** Eggplant extracts exhibit anti-inflammatory effects by suppressing inflammatory responses. Anthocyanins also contribute to bone health through osteoimmunological activity. **Skin Health & Wound Healing:** Fermented eggplant peel extracts promote wound healing, reduce ROS levels, restore mitochondrial function, and improve skin health by downregulating MMP1 and upregulating collagen I. **Biosynthesis:** Anthocyanin biosynthesis involves genes such as CHS, CHI, F3H, DFR, and ANS. Early activation of the phenylpropanoid pathway is responsible for anthocyanin accumulation and purple coloration.
Phenolic Compounds (general)	Chlorogenic acid (major, 2.86%), Total Phenolic Content (TPC)	**High Content:** Purple eggplant peel extracts are rich in phenolics. Levels increase in a concentration-dependent manner, usually expressed as chlorogenic acid equivalents. **Antioxidant Activity:** Phenolics significantly contribute to antioxidant capacity, protecting against oxidative stress with high radical-scavenging activity. **Anti-inflammatory:** Methanolic extract shows a significant inhibitory effect on inflammation.
Flavonoids (general)	Kaempferol, Tannins, Total Flavonoid Content (TFC)	**High Content:** Ethyl acetate extract of eggplant peel contains flavonoids. Levels increase with concentration. Flavonoids are the largest group of plant phenolics.

Phytochemical Class	Specific Compounds	Properties/Activities
		Potent Antioxidant Activity: Major contributors to radical scavenging and protection against ROS. **Disease Prevention:** Associated with lower risk of stroke, lung cancer, cardiovascular disease, diabetes, and other chronic conditions.
Kaempferol	–	**Anticancer Potential:** Molecular studies show strong binding affinity of kaempferol with cancer embryonic antigen (CEA), suggesting potential anticancer applications.
Tannins	–	Found in ethyl acetate extracts of eggplant peel; contribute to antioxidant activity.
Alkaloids	General glycoalkaloids	Present in eggplant peel extracts. Contribute to antioxidant activity. Glycoalkaloids (e.g., alpha-solanine) can inhibit invasion of prostate cancer cells.
Saponins	General saponins	Present in eggplant peel extracts; contribute to antioxidant activity.
Phenylpropanoids	–	**Biosynthesis:** Accumulate in eggplant fruits. Early phenylpropanoid biosynthesis is involved in anthocyanin accumulation.

Effects on the Extracellular Matrix in Postmenopausal Skin Improvement

The extracellular matrix (ECM) is a crucial component of the dermis, providing structural support, elasticity, and strength to the skin (6). In postmenopausal women, hormonal changes, particularly the decline in estrogen, contribute to the degradation of ECM components, leading to visible signs of aging such such as wrinkles and sagging skin (10). Purple eggplant skin extracts hold promise for improving postmenopausal skin by positively influencing ECM remodeling through both stimulating synthesis and inhibiting degradation.

Collagen and elastin are the primary structural proteins within the ECM, synthesized predominantly by fibroblasts in the dermal layer (6). Collagen, particularly Type I collagen, provides tensile strength, while elastin confers elasticity and recoil properties to the skin (6). Studies have begun to reveal the potential of eggplant extracts in promoting the synthesis of these vital proteins. Fermented eggplant peel extracts (BEPs) have been shown to upregulate collagen I (COL1) expression in UVB-damaged hairless mice (6). This is a significant finding as UVB radiation is a major extrinsic factor that damages skin and leads to collagen degradation (6). The ability of BEPs to enhance COL1 production suggests a mechanism by which these extracts could help restore and maintain the structural integrity of the dermis, counteracting the age-related decline in collagen synthesis. While the direct mechanism of fibroblast stimulation is not explicitly detailed in the provided sources, the increase in COL1 expression implies a positive effect on fibroblast activity, as fibroblasts are the primary producers of collagen.

The overall health benefits of plant-derived compounds, including flavonoids and phenolic compounds, which are abundant in eggplant, have been linked to anti-aging activities in human dermal fibroblasts (6,25). These compounds, particularly polyphenols, have molecular mechanisms that promote anti-aging effects in aged human dermal fibroblasts (25). This general observation supports the notion that eggplant's rich phytochemical profile could stimulate fibroblasts indirectly, leading to enhanced ECM component production. Improving skin elasticity and strength is a direct benefit of maintaining healthy collagen and elastin levels (6).

In parallel with stimulating synthesis, inhibiting the enzymatic degradation of ECM components is equally crucial for maintaining skin integrity. Matrix metalloproteinases (MMPs) are a family of enzymes responsible for the breakdown of various ECM proteins, including collagen and elastin (6). Elevated MMP activity is a hallmark of aged and photodamaged skin, as these enzymes degrade existing collagen and elastin fibers, leading to wrinkle formation and loss of elasticity (6).

Fermented eggplant peel extracts (BEPs) have been shown to downregulate matrix metalloproteinase 1 (MMP1) expression in UVB-damaged hairless mice (6). MMP1, also known as collagenase-1, is a key enzyme responsible for initiating the degradation of Type I collagen (6). By reducing MMP1 expression, BEPs effectively protect collagen from enzymatic breakdown, thereby preserving the structural framework of the dermis. The activation of MMPs is often triggered by reactive oxygen species (ROS) that are generated by external stimuli such as UV radiation (6). The antioxidant properties of purple eggplant skin extracts, discussed earlier, would therefore indirectly contribute to MMP inhibition by reducing the upstream oxidative stress signals that activate these enzymes (6). This dual action – promoting collagen synthesis and inhibiting its degradation – underscores the significant potential of purple eggplant skin extracts in improving and maintaining the ECM in postmenopausal skin, leading to enhanced firmness and elasticity.

Skin Hydration and Barrier Function in Postmenopausal Skin Improvement

Maintaining adequate skin hydration and a robust barrier function is essential for overall skin health and becomes particularly challenging for postmenopausal women due to hormonal changes [Nijhawan2014]. While direct detailed studies explicitly on purple eggplant skin extract's role in improving water retention and strengthening epidermal lipids in postmenopausal women are not extensively detailed in the provided sources, strong indirect evidence and general principles derived from its known properties suggest a significant potential.

The epidermal layer serves as the primary physical barrier, preventing water loss (transepidermal water loss, TEWL) and protecting against environmental damage (6). Lipids in the epidermal layer play a critical role in maintaining this barrier function (6). The decline in estrogen during menopause can compromise this barrier, leading to increased dryness and sensitivity (10).

The antioxidant properties of purple eggplant skin extracts are highly relevant to maintaining skin hydration and barrier function. Oxidative stress, caused by free radicals and reactive oxygen species (ROS), can damage cellular membranes and lipids, including those critical for the epidermal barrier (3,6,12). By effectively neutralizing these free radicals and suppressing oxidative damage, the phenolic compounds and anthocyanins in eggplant skin can indirectly protect the integrity of the epidermal lipid matrix (3,6,12). This preservation of lipid structure is fundamental for preventing excessive water loss and maintaining skin hydration. For instance, fermented eggplant peel extracts (BEPs) effectively suppressed ROS production and improved mitochondrial dysfunction, which are factors that disrupt energy homeostasis and exacerbate oxidative stress, collectively compromising skin's structural integrity (6).

Furthermore, the anti-inflammatory properties of eggplant extracts contribute to a healthy skin barrier. Chronic low-grade inflammation, often associated with aging and oxidative stress, can disrupt the delicate balance of the epidermal turnover and lipid synthesis (6,25). By reducing inflammation, purple eggplant skin extracts can foster a more stable and functional epidermal environment, supporting the natural processes that build and maintain the skin barrier (3,19).

While the sources discuss the general benefits of polyphenols and plant-based foods for skin health and anti-aging (25), explicit mentions of direct effects on water retention or strengthening of epidermal lipids by purple eggplant skin extract are not prominent. However, given that flavonoids, saponins, and other bioactive compounds are present in the extract (8,9), it is plausible that some of these molecules could interact with skin cells and lipids to enhance water-binding capacity or fortify the intercellular lipid lamellae, similar to other plant-derived ingredients known in dermatology (27). For instance, certain plant-based ingredients in personal care products are acknowledged for supporting skin health (25).

Future research should specifically investigate these aspects, perhaps by measuring transepidermal water loss (TEWL), evaluating lipid composition, and assessing water-binding capacities in skin models or clinical trials using purple eggplant skin extracts. Nonetheless, the well-established antioxidant and anti-inflammatory actions of purple eggplant skin extracts provide a strong theoretical basis for their indirect, yet significant, contribution to improved skin hydration and a strengthened skin barrier function in postmenopausal women.

Photoprotective Role in Postmenopausal Skin Improvement

Ultraviolet (UV) radiation, comprising UVA and UVB, is a primary extrinsic factor contributing to skin aging, a process known as photoaging (6,10). UV exposure generates reactive oxygen species (ROS), which initiate a cascade of detrimental changes, including DNA damage, inflammation, and the degradation of extracellular matrix (ECM) components like collagen (6). Purple eggplant skin, rich in antioxidants and anti-inflammatory compounds, demonstrates significant potential in offering photoprotection against these harmful effects.

The mechanism of UV-induced skin damage involves the generation of ROS, which then activate mitogen-activated protein kinases (MAPKs) (6). These activated MAPKs subsequently lead to the increased secretion of matrix metalloproteinases (MMPs), which are enzymes responsible for the degradation of collagen and other ECM components, resulting in loss of skin elasticity and wrinkle formation (6). Furthermore, mitochondrial dysfunction, a critical regulator of cellular energy metabolism, is exacerbated by oxidative stress, further compromising skin integrity (6).

Purple eggplant skin extracts have been investigated for their ability to counteract these processes, particularly against UVB-induced damage. Fermented eggplant peel extracts (BEPs) have shown enhanced antioxidant and protective effects against UVB-induced skin damage (6). Specifically, BEPs demonstrated significant capacity to mitigate UVB-induced damage in hairless mice models (6).

Key aspects of the photoprotective role of BEPs can be understood through their multifaceted biological activities. First, BEPs effectively reduced ROS levels in human dermal fibroblasts (HDFs) damaged by hydrogen peroxide (H2O2), an important mechanism since ROS act as the initial triggers of UV-induced cellular damage (6). This direct scavenging activity highlights their importance in mitigating oxidative stress. In addition, BEPs were found to suppress the phosphorylation of ERK, p38, and JNK, which are central components of the MAPK signaling pathways activated by UV radiation (6). By inhibiting these pathways, BEPs prevent the downstream activation of MMPs, thereby reducing collagen degradation. Complementing this effect, dietary supplementation of BEPs in UVB-induced hairless mice downregulated matrix metalloproteinase 1 (MMP1) expression while simultaneously upregulating collagen I (COL1) (6). This dual action of protecting existing collagen from breakdown and promoting new collagen synthesis plays a crucial role in maintaining and restoring skin structure in the face of photodamage. Furthermore, the antioxidant activity of eggplant extracts against DPPH and ABTS radicals demonstrates their protective capacity against lipid peroxidation, a damaging process in which free radicals attack membrane lipids, compromising cellular integrity under UV exposure (3). Finally, nasunin, an anthocyanin found in eggplant peels, has shown anti-angiogenic activity (7,15,24). Although not a direct UV filter, its modulation of vascular responses may contribute to photoprotection by alleviating UV-induced inflammation and tissue damage in the skin.

Overall, the studies suggest that purple eggplant skin, especially in its bio-converted form, holds significant potential as a protective agent for mitigating UVB-induced damage and promoting skin health (6). Its rich profile of phenolic compounds and anthocyanins works synergistically to scavenge free radicals, suppress inflammatory signaling, and regulate ECM remodeling, thereby offering comprehensive photoprotection. Further research would be beneficial to explore its full spectrum of protection against UVA and its efficacy in human clinical settings.

In Vitro and In Vivo Studies

Extensive research conducted through both in vitro cell culture experiments and in vivo animal models has highlighted the diverse pharmacological activities of purple eggplant skin extracts, particularly in relation to skin health and anti-aging. In vitro studies have consistently demonstrated the strong antioxidant potential of these extracts. For instance, the ethyl acetate extract of *Solanum melongena* peel showed significant antioxidant activity, even outperforming standard antioxidants such as ascorbic acid and gallic acid in phosphomolybdenum and DPPH assays (8). Methanol extracts of purple eggplant varieties also exhibited effective ROS scavenging, with small purple-colored varieties displaying superior DPPH activity compared to standards (23). Similarly, flavonoid-rich extracts obtained through supercritical fluid extraction demonstrated promising concentration-dependent antiradical activity (24). Beyond antioxidant effects, eggplant extracts have also been shown to exert anti-inflammatory actions, as ethanol extracts of eggplant stalks suppressed oxidative and inflammatory responses in macrophage RAW 264.7 cells (16), while aqueous extracts inhibited PAR-2 agonist-induced inflammation (15,23,24,26). Additional benefits have been observed in wound healing, where fermented eggplant peel extracts (BEPs) enhanced recovery in H2O2-damaged human dermal fibroblasts by reducing ROS levels and restoring mitochondrial function (6). Furthermore, anticancer potential has been reported, with ethyl acetate peel extracts inducing apoptotic death in MCF-7 breast cancer cells and showing cytotoxic effects across multiple cancer cell lines, supported by molecular docking studies indicating kaempferol as a promising therapeutic agent (8,22).

In vivo animal models provide further evidence of these pharmacological properties. In aflatoxin B1-induced rats, ethanol extracts of eggplant skin reduced malondialdehyde (MDA) and lipid peroxidation markers while enhancing superoxide dismutase (SOD) activity, with the optimal protective dose identified as 600 mg/kg body weight (3). In UVB-exposed hairless mice, dietary supplementation with BEPs reduced MMP1 expression and increased collagen I levels, showing greater efficacy than non-fermented extracts (6). Hepatoprotective and anticancer activities were also confirmed in rats with CCl4-induced hepatocellular carcinoma, where methanol extracts reduced α-fetoprotein (AFP) levels, restored liver function markers, and improved histopathological outcomes (22). Antioxidant capacity of eggplant varieties was further correlated with hepatoprotective effects (14,15). Moreover, anti-inflammatory activity was observed in carrageenan-induced paw edema models and acetic acid-induced capillary permeability tests (5,19). Beyond skin and liver protection, eggplant extracts demonstrated anti-hemorrhoidal effects in rat models and cardioprotective properties in both raw and cooked forms (14,15,19). Extracts of eggplant also have been shown to possess cardioprotective properties in raw and cooked forms (14,15,28).

Taken together, these findings strongly suggest the therapeutic potential of purple eggplant skin extracts for human health, especially in addressing oxidative stress-related conditions and skin aging. In vitro studies elucidate key molecular mechanisms, including ROS scavenging, MAPK pathway inhibition, and MMP downregulation, while in vivo evidence underscores systemic efficacy in reducing oxidative stress markers, enhancing antioxidant enzyme activity, and protecting against UV-induced collagen degradation (3,6). However, it must be emphasized that animal models cannot fully replicate the complexity of human physiology, including differences in metabolism, pharmacokinetics, and genetic variability (8,29). Therefore, while preclinical studies provide a strong scientific foundation, rigorous human clinical trials remain necessary to establish the efficacy, safety, optimal dosing, and long-term impact of purple eggplant skin extracts, particularly in postmenopausal women (8,29).

Clinical Study Data

While the existing in vitro and in vivo studies provide compelling evidence for the antioxidant, anti-inflammatory, and protective properties of purple eggplant skin extracts, the direct clinical study data specifically on its benefits for improving skin health in postmenopausal women remains limited in the provided sources. This highlights a significant gap in the current research landscape, necessitating more focused human trials.

One human study mentioned relates to the traditional use of eggplant peduncles. Aqueous extracts from *Solanum melongena* L. peduncles were investigated for their beneficial effects in periodontal diseases (26). In a double-blind study, twenty volunteer patients with periodontal diseases were given peduncle extracts as a mouthwash solution for three months, against a placebo (26). The results indicated that the peduncle extracts significantly improved the antioxidant activity and glutathione levels of saliva in patients and clinically ameliorated pocket depth and bleeding index (26).

The study by Diab2011 demonstrates several methodological strengths that enhance its credibility and relevance to human health research. Conducted in a double-blind fashion, it minimized bias from both participants and investigators regarding treatment assignment and outcome evaluation. The inclusion of a placebo group provided a valid baseline for comparison, ensuring that observed effects could be attributed to the intervention rather than psychological or non-specific influences. Furthermore, the use of objective biochemical markers, such as total antioxidant activity and glutathione levels in saliva, offered quantifiable and reliable measures of antioxidant status. Clinical endpoints, including pocket depth and bleeding index, provided direct evidence of therapeutic benefit in periodontal health. The three-month duration of the study also allowed for the observation of sustained treatment effects, rather than short-term or transient outcomes (26).

Despite these strengths, several weaknesses limit the study's relevance to skin health in postmenopausal women. The most notable issue is its focus on periodontal disease rather than skin-related outcomes, meaning that the findings, while indicative of systemic antioxidant and anti-inflammatory activity, cannot be directly extrapolated to dermal physiology. Moreover, the participants were not specifically identified as postmenopausal women, an important demographic for this review, since hormonal changes after menopause significantly influence skin aging processes. Another limitation lies in the choice of extract: the study employed peduncle extracts instead of purple eggplant skin extracts, which are the subject of this review and may differ in phytochemical composition and efficacy. Finally, the relatively small sample size of only twenty participants restricts the statistical power of the study and reduces the generalizability of its findings to broader populations (26).

Other sources allude to the broader context of plant-derived compounds and human health. Polyphenols from fruits and vegetables are generally recognized for their protective actions against chronic diseases, with epidemiological studies correlating flavonoid intake with reduced incidence of cardiovascular disease, diabetes, and cancer (12). Natural phenolic antioxidants are considered health-promoting substances that warrant investigation at a fundamental scientific level (13). Dietary interventions with natural antioxidants are relevant for preventing chronic diseases caused by oxidative stress (3,12). Moreover, healthy lifestyle factors, including nutrition and diet, are increasingly recognized for their role in improving skin well-being and anti-aging (25). Phytoestrogens and phytochemicals are specifically mentioned as influencing skin health (25). Some plant seed oils are also discussed for their use in dermatology and benefits for menopausal symptoms (30). However, these are general discussions about natural compounds and lifestyle rather than specific clinical trials on purple eggplant skin extracts for postmenopausal skin health.

Conclusion regarding clinical data: The current literature, as provided, indicates a dearth of targeted human clinical trials specifically investigating the efficacy and safety of purple eggplant skin extracts for improving skin health in postmenopausal women. While the periodontal study offers valuable insights into the systemic antioxidant and anti-inflammatory potential of eggplant derivatives in humans, it does not directly address the nuanced changes in postmenopausal skin (26). The robust in vitro and in vivo data strongly suggest a promising therapeutic avenue, but robust clinical evidence, employing well-designed, randomized, placebo-controlled trials with adequate sample sizes in postmenopausal women, is critically needed. Such future studies should focus on specific skin health markers such as collagen density, elasticity, hydration, wrinkle depth, and transepidermal water loss, alongside safety profiles, to conclusively establish the clinical potential of purple eggplant skin extracts in this demographic.

Conclusion

Purple eggplant skin is a potent source of bioactive compounds with strong antioxidant, anti-inflammatory, extracellular matrix–modulating, and photoprotective properties. These activities help reduce oxidative stress, suppress inflammation, promote collagen synthesis while preventing its breakdown, support skin barrier integrity, and protect against UV-induced damage. Collectively, the evidence highlights its promising potential for improving skin health and counteracting aging, particularly in postmenopausal women.

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