

A Review of Herbal Photoprotective Agents: From Traditional Knowledge to Modern Sunscreen Formulations

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Abstract

Continuous exposure of skin to UV rays leads to tanning, premature aging, sunburn, pigmentation, and skin cancer. Sunscreens are widely used to protect the skin from these harmful stimuli. However, sunscreen components may interfere with other health concerns like irritation, itching, allergic reactions, and distinct environmental damage. This major concern initiated the introduction of herbal photoprotective agents, which are eco-friendly, safer for use, and rich in antioxidants (preventing free radicals). Since ancient times, people began depending on plant sources due to their potent biochemical properties, natural defense, and their truly favorable healing mechanisms. India has a rich history of Ayurveda and herbal remedies, which aids even the formulation of sunscreens. The presence of flavonoids, tannins, phenolic compounds, essential oils, and other phytochemicals of plants has shown potent photoprotective activity. Phytochemicals, like polyphenols, flavonoids, alkaloids, tannins, and terpenoids, have demonstrated their significant ability to reduce or prevent inflammation, UV-induced oxidative stress, hyperpigmentation, photoaging, and carcinogenesis. This review traces the journey from traditional knowledge and ethnobotanical uses of sun-protective botanicals to contemporary approaches for isolating, characterizing, and formulating their active constituents into modern sunscreen products. Studies have reported that various Indian plants can reduce UV-induced oxidative stress and prevent cellular damage or death. Including UV protection, these plants also possess anti-aging, repair skin damage, reduce inflammation, and enhance collagen synthesis (maintaining elasticity of skin, arteries, and organs). This review highlights various Indian herbal photoprotective agents, phytochemicals involved, mechanisms of action (in vivo and in vitro), available herbal formulations, and their potential role in contemporary formulations.

Keywords: Antioxidants, herbal formulations, Indian herbals, integumentary system, photoprotective agents, sunscreen

INTRODUCTION

Skin is a complex and large organ, essential for maintaining fluid loss and tissue homeostasis, defense mechanisms, acting as a barrier, absorption, stabilizing temperature, relaying sensory inputs, and repairs.

The skin is composed of three distinct layers: the epidermis on the outermost surface, the dermis beneath it, and the hypodermis, which forms the innermost layer. The outer layer is subdivided into five types: stratum corneum (contains corneocytes), stratum lucidum (dead keratinocytes, eleidin, and clear intracellular proteins), stratum granulosum (cysteine-histidine rich granules and keratin filaments), stratum spinosum/prickle cell layer (desmosomes present; tightly packed keratinocytes), and stratum basale (contains basal keratinocytes, lymphocytes, melanocytes, and Langerhans cells). Beneath the dermis (two layers: reticular and papillary; transport of nutrients, hair follicles, glands) and hypodermis [1].

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In the United States, cutaneous malignant melanoma is the fifth leading diagnosed cancer. Family history, continuous exposure to UV rays, immunosuppression, radiation, and others lead to skin cancers [2]. Studies suggest that using sunscreen can intercept the formation of skin neoplasms. UV rays can mutate the epidermal layer, leading to uncontrolled malignant or non-malignant cellular development [3]. UVB (ultraviolet radiation emitted by the sun) rays have both benefits and risks to the skin. High UVB absorption by 7-dehydrocholesterol results in the synthesis of vitamin D, yet it can also lead to DNA mutations. Studies showed that vitamin D metabolites can enhance the apoptosis of carcinomatous cells, prevent angiogenesis, and stop proliferation to reduce the prognosis of skin cancers [4]. Types of Skin Cancer are given in Figure 1.

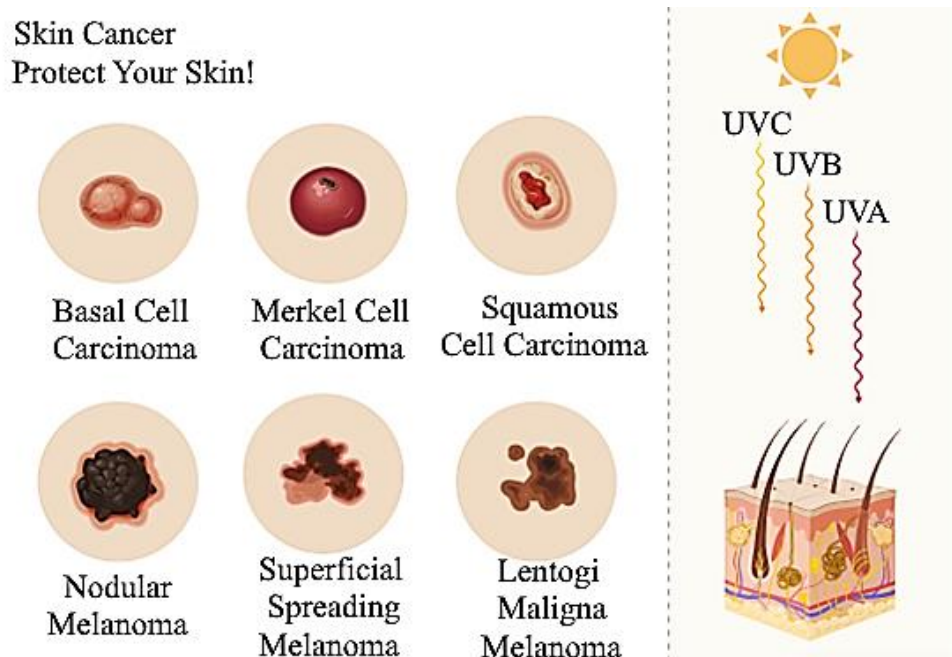


Figure 1. Types of skin cancers.

METHODS OF DATA COLLECTIONS

Various e-databases, like PubMed, Springer, Google Scholar, and Scopus sources, were utilized for this study with relevant keywords. All the studies were analyzed and screened to identify major gaps and systematic studies done yet.

Herbal Phytochemicals

Herbal phytochemicals and their formulations have a promising application to prevent skin cancer. These phytochemical molecules can act against UV radiation by working as a potential absorbance of UV rays and antioxidants. These molecules have fewer side effects than modern available formulations [5]. Most anti-ultraviolet extracts show antioxidant activity, which is essential for photoprotective activity (Table 1). Photoprotective Herbs Numerous analytical methods have already been employed to assess the antioxidant activity of plant extracts. It helps to evaluate the elimination of ROS (Reactive Oxygen Species), DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)), PCL (photo-chemiluminescence), FRAP (ferric reducing antioxidant potential), and ORAC (Oxygen Radical Absorbance Capacity) and others [6]. Octyl methoxycinnamate (OMC) is present in cinnamon plants and is widely used in the formulation of sunscreens. Studies on human cell lines resulted in the inhibition of cyclobutane pyrimidine dimer formation. Also, studies revealed significant changes reported in few gene expressions, and the expression of p53 can also alter [7]. Photoprotectant compounds are highly effective in reducing UV radiation effects on the skin; however, many sun filters, particularly organic ones, can cause allergies. As a result, there is ongoing research into formulations that include plant extracts, which may offer a safer alternative [8].

Table 1. Photoprotective herbal.

Name of the plant	Phytochemicals	References
<i>Achillea biebersteinii</i> Afan.	Hydro glycolic fruit extract of plant has flavonoids, phenolic acids and coumaroyl quinic acid isomers.	[9]
<i>Vitis vinifera</i> L.	Flavonoid enriched extract revealed from Hydro alcoholic peel & fruit.	[10]
<i>Achillea millefolium</i> yarrow	Hydro glycolic fruit extract has polyphenols, which showed potent photoprotective activity.	[9]
<i>Silybum marianum</i> L.	Seed extract has Silymarin, Flavonolignans.	[11]
<i>Disterigma alaternoides</i>	Acetone leaf extract revealed various anthocyanins.	[12]
<i>Juglans regia</i> L.	Methanolic male flower extract revealed fatty acids and flavonoids.	[13]
<i>Calea fruticosa</i>	n- hexane, ethyl acetate, and ethanol aerial leaf reveals terpenoids, coumarins, flavanol, sesquiterpenic lactone, quercetin, and cichoriin are the major phytochemicals, which possess antiproliferative and photoprotective activities.	[14]
<i>Hesperomeles ferruginea</i>	Acidulated acetone extracts given Total anthocyanins & total phenols.	[15]
<i>Angelica pubescens</i>	Osthole, eugenol & α - bisabolol has potent anti UVB radiation.	[16]
<i>theaflavin</i>	Antityrosinase activity & antioxidation.	[17]
<i>Moringa oleifera</i>	Rutin, Quercetin, Ellagic acid, Chlorogenic acid and Ferulic acid.	[18]
<i>Disterigma alaternoides</i>	Quercetin & rutin possess antiradical capacity & antioxidant activity.	[19]

Herbal Substances as Absorbents of UV

Plants can protect against UV damage in several ways. One important way is by absorbing harmful UV rays and releasing them as less harmful energy. Herbal extracts contain many natural compounds that can absorb both visible and UV light of different wavelengths [20]. UV light can generate ROS, which damage skin cells. The antioxidant properties of herbal substances play a significant role in protecting against this damage. Compounds, such as phenols, flavonoids, phytoalexins, phenolic acids, cyanidin-3-glycoside, anthocyanins, hydrolyzable tannins, soy isoflavones, gamma-oryzanol, inositol, and fatty acids, act as powerful natural antioxidants that help neutralize these harmful ROS [21]. Methanolic extract (70%) of *E. angustifolia* leaves possesses various phytochemicals like phenolic compounds, polyphenols, and flavonoids [22]. These phytochemicals reported potent sun-protective capacity. Hippophae rhamnoides oil (HRO), sesame oil, aqua, xanthan gum, parabens, and other components with extract have formulated potent herbal sunscreens [23].

Nanocarriers for Enhancing the UV Protection of Sunscreens

Nanocarrier and microcarrier systems can prevent skin penetration and enhance the photoprotective potential of actives [24]. Nanocarriers constitute a viable strategy for enhancing sunscreen formulation, physicochemical properties, and photoprotective effects. This offers solutions regarding efficacy and UV filter safety in cosmetic applications [25]. Solid lipid nanoparticles (SLNs) have advanced characters as compared to conventional carrier systems (liposomes and emulsions). SLNs can release drugs in a controlled manner. The occlusive property of SLNs overcomes conventional sunscreen disadvantages. SLNs can achieve occlusion without paraffin and other greasy oil presence; it is smooth and flexible. Newer approaches in the future may lead to even better delivery [26].

Mechanism of UV-Induced Damage

According to wavelength, UV components of sunlight are classified into UVC (ultraviolet C; 100–290 nm), UVB (ultraviolet B; 290–320 nm), and UVA (ultraviolet A; 320–400 nm) (Figure 2). UVC rarely contacts skin because the ozone layer blocks it. But 90% of UVC and 5% of UVB penetrate the ozone layer, which is responsible for UVR. UV radiation can lead to dermal photodamage via various pathways like DNA damage, oxidative stress, inflammation, and unprogrammed cell death. Precisely 80% of skin aging and wrinkles account for ROS [27].

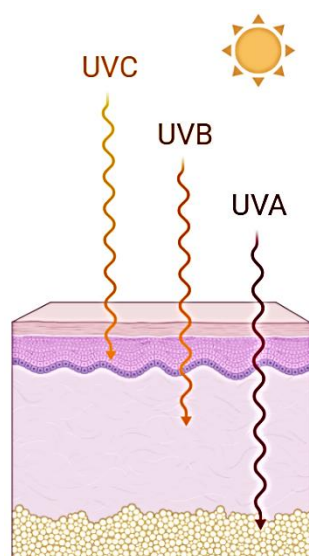


Figure 2. UV rays (UVC, UVB and UVA) and its depth on skin.

UVA indirectly damages DNA through a photosensitization reaction, leading to the formation of 8-hydroxyguanine (8-OHdG). Reactive oxygen species (ROS) activate mitogen-activated protein kinases (MAPKs) and nuclear factor kappa B (NF- κ B). These pathways can increase levels of matrix metalloproteinases (MMPs) in the skin. MMPs degrade collagen and elastin, which are essential for maintaining skin elasticity and integrity. Between 50% and 80% of erythema is associated with UVA radiation. UVB rays are responsible for sunburn and can convert light energy into chemical signals. UVB often leads to the development of thymine dimers (distinctive indicators of UVB) which leading to form cyclobutene pyrimidine dimers (CPDs) and 6-4PPs (6-4 photoproducts). Accumulation of these results in skin cancer, which is considered a high risk to QoL.

Gene therapy offers a significant reduction in skin cancer. AI and MLP algorithms started resolving the screening difficulties of skin cancer. FDA-approved DermaSensor and ESS (Elastic Scattering Spectroscopy) can detect skin cancer, and it is an accurate diagnostic method in real time [28].

Salvia miltiorrhiza is a dicotyledonous medicinal plant, rich in active compounds like tanshinone I, tanshinone II, danshensu, and SAB (salvianolic acid B). These biocompounds exhibit antifibrotic, antioxidant, and anti-inflammatory medicinal properties. Abundant phenolic compounds from the leaves and roots can neutralize ROS, reduce melanin accumulation, and mitigate allergic skin responses. DSU and SAB may regulate melanin synthesis via inhibiting tyrosinase in B16 melanoma cells [29].

Medicinal plants exhibit a promising application for the inhibition of photoaging and suggesting significant cosmetic applications and therapeutic benefits. Multiple molecular pathways of herbal extracts were demonstrated by various preclinical studies and can inhibit pathways like MAPK/AP-1 signaling cascade (stopping MMPase expression), Nrf2/Keap1 (enhancing antioxidant defense), downregulation of NF- κ B (mitigating inflammation), TGF- β /Smad (promoting collagen synthesis), and extracellular matrix repair [30].

RESEARCH STUDIES

Research involving smaller groups has been conducted, but long-term clinical or preclinical studies are quite limited, especially in this area. For instance, *Polypodium leucotomos* extract (PLE) was given orally to 22 subjects to explore its molecular and photobiologic effects. The findings are promising, indicating that PLE could serve as a helpful supplement to reduce the harmful photobiologic impacts of UVB radiation, as noted [31]. Exactly 60 days of continuous consumption of *Polypodium leucotomos* (Fitzpatrick skin types I to IV) by healthy subjects (placebo-controlled study) reported safe and effective

reduction of the damaging effect of UV radiation [32]. Epicatechin derivatives from green tea are highly chemotherapeutic. Continuous topical application (human subjects) of green tea polyphenols and (-)-epigallocatechin-3-gallate (EGCG) resulted in the inhibition of UVB-induced erythema, oxidative stress, and infiltration of inflammatory leukocytes [33].

CONCLUSION

This review study highlights the photoprotective phytochemicals which promise the bridge between traditional and modern dermatological science. Phytochemicals, like polyphenols, flavonoids, alkaloids, tannins, and terpenoids, have demonstrated their significant ability to reduce or prevent inflammation, UV-induced oxidative stress, hyperpigmentation, photoaging, and carcinogenesis. Various herbals have been demonstrated in this study with their active constituents and mechanism of photoprotection through antioxidant, anti-inflammatory, DNA protective, and enzyme inhibitory mechanisms. Liposomes, SLNs, NLC, phytosomes, and nanoemulsion-like advanced delivery systems can enhance skin permeability, stability, and efficacy which may improve the potency of sun care formulations in the future.

Also, preclinical, and few clinical study reports of formulations have been included. Insufficient clinical applications study and mechanistic understandings are still gaps in this study. Establishment of safety considerations, regulatory, and quality control guidelines, and environmental impacts from herbal formulations have limited studies so far.

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