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A REVIEW ON HERBAL SUNSCREEN POTENTIAL OF TULSI (OCIMUM SANCTUM) & DURVA (CYNODON DACTYLON)

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ABSTRACT

Ultraviolet (UV) radiation is one of the major environmental factors responsible for skin damage, premature aging, oxidative stress, inflammation, and skin cancer. Sunscreens are commonly used to protect the skin from harmful UV rays; however, synthetic sunscreen agents may produce adverse effects on the skin and environment. Therefore, herbal sunscreens have gained considerable attention due to their safety, antioxidant activity, and therapeutic benefits. Medicinal plants containing natural phytoconstituents such as flavonoids, phenolic compounds, and tannins are known to exhibit significant photoprotective properties. Tulsi (Ocimum sanctum) and Durva (Cynodon dactylon) are important medicinal plants widely used in traditional medicine. Tulsi contains bioactive compounds with antioxidant, anti-inflammatory, and free radical scavenging activities, while Durva possesses antioxidant and skin protective properties. These phytochemicals help in reducing UV-induced oxidative stress and maintaining skin health. The present review highlights the herbal sunscreen potential of Tulsi and Durva, focusing on their phytochemical constituents, antioxidant properties, and role in skin photoprotection. Based on various reported studies, both plants show promising potential for incorporation into herbal sunscreen formulations as natural and eco-friendly photoprotective agents.

KEYWORDS: Photoprotection, Antioxidant activity, Ultraviolet radiation, Skin protection.

1. INTRODUCTION

- **Solar radiation overview (UVA, UVB, UVC)**

a. Solar radiation is an essential component of the environment and plays a crucial role in various biological processes. However, prolonged exposure to ultraviolet (UV) radiation can adversely affect human skin and lead to several dermatological disorders. Ultraviolet radiation constitutes a small portion of the electromagnetic spectrum emitted by the sun and is classified into three categories based on wavelength: UVA (320–400 nm), UVB (280–320 nm), and UVC (100–280 nm). Each type of UV radiation exhibits distinct penetration characteristics and biological effects on the skin.[1,3]

b. Among the three categories, UVA radiation accounts for approximately 95% of the ultraviolet radiation reaching the Earth's surface. Due to its longer wavelength, UVA penetrates deeply into the dermal layer of the skin, where it induces oxidative stress and accelerates the degradation of collagen and elastin fibers. Continuous exposure to UVA radiation contributes significantly to photoaging, wrinkle formation, pigmentation disorders, and loss of skin elasticity. In addition, UVA stimulates the generation of reactive oxygen species (ROS), which damage cellular structures and promote premature aging of the skin.[1,5]

c. UVB radiation possesses a shorter wavelength but higher energy than UVA and primarily affects the epidermal layer of the skin. It is mainly responsible for erythema, sunburn, inflammation, and direct DNA damage. UVB-induced DNA mutations can alter normal cellular functions and increase the risk of skin carcinogenesis. Although UVB represents only a small proportion of the UV radiation reaching the Earth's surface, its biological impact on skin health is highly significant due to its ability to directly interact with cellular DNA.[2,6]

d. UVC radiation has the shortest wavelength and highest energy among all ultraviolet radiations. Fortunately, it is effectively absorbed by atmospheric oxygen and the ozone layer before reaching the Earth's surface. As a result, natural exposure to UVC is negligible under normal environmental conditions. Nevertheless, artificial sources of UVC radiation may pose potential health hazards if proper protective measures are not implemented.[3,5]

e. The combined effects of UVA and UVB radiation are responsible for a wide range of skin disorders, including oxidative stress, inflammation, immunosuppression, photoaging, and skin cancer. Therefore, adequate photoprotection through the use of effective sunscreen formulations is essential for minimizing ultraviolet-induced skin damage and maintaining overall skin health.[6,10]

- **Skin damage mechanisms: Photoaging, DNA damage, oxidative stress, skin cancer risk**

a. Ultraviolet radiation is considered one of the major environmental factors responsible for both acute and chronic skin damage. Repeated exposure to UV radiation disrupts normal cellular functions and initiates a series of biochemical and molecular changes that compromise skin integrity. The severity of skin damage depends on several factors, including duration of exposure, intensity of radiation, skin type, and individual susceptibility.[2,4,6]

b. One of the primary mechanisms underlying UV-induced skin damage is the excessive generation of reactive oxygen species (ROS). During exposure to ultraviolet radiation, ROS such as superoxide radicals, hydroxyl radicals, and hydrogen peroxide are produced in large quantities. These reactive molecules attack cellular proteins, lipids, and nucleic acids, leading to oxidative stress and impairment of normal physiological processes. Persistent oxidative stress contributes to cellular dysfunction, inflammation, and tissue injury.[1,3,6,7]

c. Lipid peroxidation is another significant consequence of ultraviolet exposure. ROS attack membrane lipids, resulting in the formation of lipid peroxides that compromise cell membrane integrity and function. Simultaneously, oxidative modification of proteins alters enzymatic activity and structural stability within skin tissues. These alterations collectively accelerate the aging process and impair the skin's natural defense mechanisms.[4,7,8]

d. DNA damage induced by ultraviolet radiation represents one of the most serious consequences of chronic sun exposure. UVB radiation directly interacts with DNA molecules and promotes the formation of cyclobutane pyrimidine dimers and other photoproducts, leading to mutations and genomic instability. UVA contributes indirectly to DNA damage through oxidative mechanisms. If these alterations are not adequately repaired, they may result in abnormal cell proliferation and ultimately increase the risk of melanoma and non-melanoma skin cancers.[5,8,9]

e. Ultraviolet radiation also stimulates inflammatory pathways and activates matrix metalloproteinases (MMPs), enzymes responsible for the degradation of collagen and extracellular matrix proteins. The destruction of these structural components reduces skin elasticity and promotes wrinkle formation, sagging, and other manifestations of photoaging. Additionally, prolonged UV exposure suppresses local immune responses, making the skin more susceptible to infections and reducing its ability to repair damaged tissues effectively.[4,6,9,10]

- **Limitations of synthetic sunscreens: Phototoxicity, Environmental concerns, skin Irritation**

a. Synthetic sunscreens are widely used for protection against harmful ultraviolet radiation and are considered an important component of modern skin care. These formulations typically contain chemical and physical UV filters that absorb, reflect, or scatter ultraviolet rays. Although synthetic sunscreens provide effective protection against sunburn and photodamage, concerns regarding their safety, stability, systemic absorption, and environmental impact have increased considerably in recent years.[11,15]

b. Several chemical sunscreen agents have been associated with adverse dermatological reactions, particularly in individuals with sensitive skin. Repeated application of certain UV filters may cause erythema, itching, irritation, allergic contact dermatitis, photosensitivity, and phototoxic reactions. Such adverse effects can reduce patient compliance and limit the long-term use of these products. The possibility of skin irritation becomes more significant when sunscreens are applied frequently or under conditions of prolonged sun exposure.[11,14]

c. Recent studies have also reported systemic absorption of some sunscreen ingredients following topical application. Certain chemical UV filters can penetrate the skin barrier and enter the bloodstream, raising concerns regarding their potential biological effects. Although the long-term health implications are still under investigation, some compounds have been suspected of exhibiting endocrine-disrupting activity and interfering with normal hormonal functions. These concerns have encouraged researchers to explore safer alternatives with improved biocompatibility.[12,14]

d. Apart from human health concerns, the environmental impact of synthetic sunscreens has become a major issue. Several commonly used UV filters have been detected in aquatic ecosystems and are associated with coral bleaching, disruption of marine biodiversity, and toxicity toward aquatic organisms. These compounds may accumulate in the environment and persist for extended periods, contributing to ecological imbalance. As a result, regulatory authorities and environmental organizations have increasingly emphasized the development of environmentally sustainable photoprotective products.[11,13,15]

e. Another limitation of synthetic sunscreens is their inability to provide complete protection against oxidative stress induced by ultraviolet radiation. While many UV filters effectively block or absorb UV rays, they often lack significant antioxidant activity. Consequently, additional antioxidants are frequently incorporated into formulations to neutralize reactive oxygen species and reduce oxidative damage. This limitation has further increased interest in medicinal plants that naturally possess both UV-absorbing and antioxidant properties.[15,19]

- **Rising interest in herbal photoprotective agents**

a. The increasing demand for safer, eco-friendly, and multifunctional skincare products has led to growing interest in herbal photoprotective agents. Medicinal plants have been utilized for centuries in traditional medicine for the treatment of various skin disorders and are now being explored extensively for their potential role in sunscreen formulations. Plant extracts contain numerous bioactive compounds capable of protecting the skin against ultraviolet-induced damage through multiple mechanisms.[15,20]

b. Herbal photoprotective agents are rich sources of flavonoids, polyphenols, tannins, phenolic acids, alkaloids, terpenoids, and other secondary metabolites. These phytochemicals possess strong antioxidant activity and effectively neutralize reactive oxygen species generated during UV exposure. By reducing oxidative stress, these compounds help protect cellular proteins, lipids, and DNA from damage, thereby minimizing the risk of photoaging and skin disorders.[16,20]

c. Many plant-derived compounds also exhibit intrinsic ultraviolet absorption properties. The conjugated aromatic structures present in flavonoids and phenolic compounds enable them to absorb UV radiation and reduce its penetration into deeper skin layers. In addition to UV absorption, these compounds possess anti-inflammatory activity that helps reduce erythema, swelling, and tissue damage associated with prolonged sun exposure. Such multifunctional properties make medicinal plants valuable candidates for photoprotective applications.[16,19]

d. Compared with synthetic sunscreen agents, herbal photoprotective compounds generally demonstrate better skin compatibility and lower irritation potential. Their natural origin and biocompatibility contribute to improved patient acceptance and reduced risk of adverse reactions. Furthermore, plant-based ingredients are biodegradable and environmentally friendly, making them attractive alternatives for sustainable sunscreen development.[15,18]

e. Numerous medicinal plants, including Tulsi (*Ocimum sanctum*), Durva (*Cynodon dactylon*), Aloe vera, Green Tea, Turmeric, and Neem, have shown promising photoprotective activity due to their antioxidant and UV-protective phytochemicals. The incorporation of such plant extracts into sunscreen formulations not only enhances UV protection but also provides additional therapeutic benefits such as anti-aging, antimicrobial, wound healing, and skin rejuvenating effects.[18,20]

2. Concept of Herbal Sunscreen

- **Defnition of sunscreen**

a. Sunscreens are topical preparations designed to protect the skin from the harmful effects of ultraviolet radiation by absorbing, reflecting, or scattering UV rays. Continuous exposure to sunlight without adequate protection can lead to sunburn, pigmentation, oxidative stress, photoaging, immunosuppression, and skin cancer. Consequently, the use of sunscreen products has become an essential component of preventive dermatology and skincare.[15,16]

b. Herbal sunscreens represent an emerging category of photoprotective products that utilize plant-derived bioactive compounds as active ingredients. Unlike conventional formulations that rely primarily on synthetic UV filters, herbal sunscreens incorporate medicinal plant extracts rich in flavonoids, polyphenols, phenolic acids, and other antioxidant phytochemicals. These natural constituents provide protection through both UV absorption and antioxidant defense mechanisms.[16,19]

c. The photoprotective activity of herbal sunscreens is largely attributed to the ability of plant phytochemicals to absorb ultraviolet radiation and neutralize free radicals generated during UV exposure. Flavonoids and phenolic compounds contain chromophoric structures capable of absorbing UV light, thereby reducing its penetration into the skin. Simultaneously, their antioxidant properties minimize oxidative stress and protect cellular components from UV-induced damage.[16,20]

d. An important advantage of herbal sunscreens is their multifunctional nature. In addition to photoprotection, many medicinal plant extracts exhibit anti-inflammatory, antimicrobial, wound healing, moisturizing, and anti-aging properties. These additional benefits contribute to overall skin health and enhance the therapeutic value of sunscreen formulations. Furthermore, herbal ingredients often demonstrate improved skin compatibility and lower toxicity compared with certain synthetic UV filters.[15,20]

e. The increasing interest in natural cosmetics and environmentally sustainable products has further accelerated research into herbal sunscreen formulations. The combination of safety, efficacy, antioxidant activity, and therapeutic benefits makes herbal sunscreens a promising alternative to conventional photoprotective products.[15,20]

- **SPF Concept**

a. un Protection Factor (SPF) is one of the most important parameters used to evaluate the effectiveness of sunscreen formulations. It indicates the ability of a sunscreen product to protect the skin against UVB-induced erythema and sunburn. SPF is defined as the ratio of the minimal erythemal dose on protected skin to that on unprotected skin under identical conditions of ultraviolet exposure.[24,25]

b. The SPF value provides an estimate of the level of protection offered by a sunscreen formulation. For example, an SPF 15 sunscreen theoretically allows an individual to remain in sunlight approximately fifteen times longer before developing erythema compared with unprotected skin. As the SPF value increases, the degree of protection against UVB radiation also increases. However, SPF primarily reflects protection against UVB and does not necessarily indicate complete protection against UVA radiation.[24,25]

c. In herbal sunscreen research, SPF evaluation plays a critical role in assessing the photoprotective potential of medicinal plant extracts. Flavonoids, polyphenols, and phenolic compounds contribute to SPF enhancement through their ability to absorb ultraviolet radiation and reduce oxidative stress. The concentration and composition of these phytochemicals significantly influence the SPF value of herbal formulations.[15,16,24]

d. SPF determination is commonly performed using spectrophotometric methods based on absorbance measurements in the UVB region, typically between 290 and 320 nm. This technique provides a rapid and reliable method for evaluating sunscreen efficacy during formulation development. In addition to SPF determination, antioxidant activity and UVA protection are often assessed to obtain a comprehensive understanding of photoprotective performance.[24,25]

e. The incorporation of medicinal plant extracts possessing strong antioxidant and UV-absorbing properties can significantly improve SPF values while providing additional protection against oxidative stress and photoaging. Therefore, SPF evaluation remains an essential parameter in the development and optimization of herbal sunscreen formulations.[15,16,24,25]

- **Mechanism of Photoprotection**

a. Photoprotection refers to the prevention or reduction of skin damage caused by ultraviolet radiation through physical, chemical, or biological mechanisms. Ultraviolet radiation generates excessive reactive oxygen species (ROS) within skin tissues, resulting in oxidative stress, inflammation, lipid peroxidation, collagen degradation, and DNA damage. These pathological changes ultimately contribute to premature aging, pigmentation disorders, and skin carcinogenesis. Therefore, effective photoprotective agents should not only block ultraviolet radiation but also prevent oxidative damage at the cellular level.[1,6,17,18]

b. One of the most important mechanisms of photoprotection is ultraviolet absorption. Many plant-derived phytochemicals, particularly flavonoids and phenolic compounds, contain conjugated aromatic ring structures capable of absorbing ultraviolet radiation. By absorbing harmful UV rays before they penetrate deeper skin layers, these compounds reduce direct cellular injury and minimize DNA damage. This mechanism significantly contributes to the sunscreen activity of herbal formulations.[16,18]

c. Another major photoprotective mechanism involves antioxidant defense. Exposure to ultraviolet radiation stimulates excessive production of reactive oxygen species such as superoxide radicals, hydroxyl radicals, and hydrogen peroxide. These reactive molecules attack cellular proteins, lipids, and nucleic acids, resulting in oxidative stress and tissue damage. Antioxidant phytochemicals present in medicinal plants neutralize these free radicals and prevent their harmful effects, thereby protecting skin cells from oxidative injury.[6,17,18,27]

d. Reduction of lipid peroxidation represents another important protective mechanism. Reactive oxygen species initiate oxidation of membrane lipids, leading to the formation of lipid peroxides that compromise membrane integrity and cellular function. Polyphenols and flavonoids inhibit lipid peroxidation by scavenging free radicals and stabilizing biological membranes. This protective effect helps preserve skin structure and reduces cellular damage associated with ultraviolet exposure.[17,18,26]

e. Protection against DNA damage is equally important in photoprotection. Ultraviolet radiation can induce mutations, chromosomal abnormalities, and genomic instability, which increase the risk of skin cancer. Natural antioxidants help minimize DNA damage by reducing oxidative stress and preventing the formation of reactive species that attack nucleic acids. Several plant-derived polyphenols have demonstrated the ability to enhance cellular defense mechanisms and support DNA protection against ultraviolet-induced injury.[6,17,27]

- **UV Absorption Potential**

a. Tulsi demonstrates considerable ultraviolet absorption potential because of its rich content of flavonoids, phenolic acids, eugenol, and other polyphenolic compounds. These phytochemicals possess conjugated aromatic structures capable of absorbing ultraviolet radiation within the UVA and UVB regions. By absorbing harmful UV rays before they penetrate deeper skin layers, these compounds reduce direct cellular injury and protect skin tissues from photodamage.[16,51,59]

b. The UV-absorbing capability of Tulsi contributes significantly to its photoprotective activity and supports its application in herbal sunscreen formulations. In addition to acting as natural UV filters, Tulsi phytochemicals provide antioxidant protection that further enhances overall sunscreen efficacy. These combined properties make Tulsi a promising botanical ingredient for broad-spectrum photoprotection.[16,51,59]

- **Antioxidant Activity**

a. Tulsi is widely recognized for its strong antioxidant activity, which is primarily attributed to the presence of flavonoids, polyphenols, rosmarinic acid, eugenol, and other phenolic constituents. These bioactive compounds effectively neutralize reactive oxygen species generated during ultraviolet exposure and prevent oxidative stress-induced cellular damage.[40,47,48,52]

b. Oxidative stress is a major contributor to premature skin aging, inflammation, pigmentation, and degradation of structural proteins. The antioxidant phytochemicals present in Tulsi help preserve cellular integrity, protect biomolecules from oxidation, and enhance the natural defense mechanisms of the skin. Consequently, antioxidant activity plays a crucial role in the photoprotective potential of Tulsi-based formulations.[40,47,48,52]

- **Free Radical Scavenging Activity**

a. Free radicals generated during ultraviolet exposure can initiate a cascade of oxidative reactions that damage proteins, lipids, and nucleic acids within skin tissues. Tulsi contains several phytochemicals capable of scavenging these free radicals and interrupting oxidative chain reactions before significant cellular injury occurs.[17,18,26,27]

b. Flavonoids and phenolic compounds donate hydrogen atoms or electrons to unstable free radicals, thereby converting them into more stable and less reactive species. This free radical scavenging activity reduces oxidative stress, prevents cellular dysfunction, and contributes significantly to skin protection against ultraviolet-induced damage. Such activity is particularly important in preventing photoaging and maintaining overall skin health.[17,18,26,27]

- **Anti-inflammatory Activity**

a. Inflammation is one of the primary biological responses triggered by excessive ultraviolet exposure. UV-induced oxidative stress stimulates the release of inflammatory mediators, resulting in erythema, edema, tissue injury, and discomfort. Tulsi possesses significant anti-inflammatory activity due to the presence of eugenol, ursolic acid, flavonoids, and phenolic compounds.[19,51,57]

b. These phytochemicals suppress inflammatory pathways and reduce the production of pro-inflammatory mediators responsible for tissue damage. By minimizing inflammation, Tulsi helps reduce redness, irritation, and swelling associated with ultraviolet exposure. The anti-inflammatory activity of Tulsi therefore complements its antioxidant and UV-protective properties, resulting in enhanced photoprotection.[19,51,57]

- **SPF Enhancement Potential**

a. Sun Protection Factor (SPF) is a critical parameter used to evaluate sunscreen efficacy against UVB radiation. The presence of UV-absorbing phytochemicals such as flavonoids and polyphenols contributes significantly to SPF enhancement in herbal sunscreen formulations. Tulsi extract contains several compounds capable of absorbing ultraviolet radiation and improving sunscreen performance.[15,16,18,19,24]

b. In addition to UV absorption, antioxidant phytochemicals reduce oxidative damage caused by UV exposure and provide supplementary protection beyond conventional sunscreen mechanisms. Therefore, incorporation of Tulsi extract into topical formulations may increase SPF values while simultaneously improving skin protection and formulation functionality.[15,16,18,19,24]

- **Role of Polyphenols in UV Scavenging**

a. Polyphenols represent one of the most important classes of bioactive compounds responsible for the photoprotective activity of Tulsi. These compounds exhibit strong antioxidant properties and efficiently neutralize reactive oxygen species generated during ultraviolet exposure. Their ability to scavenge free radicals reduces oxidative stress and protects cellular components from damage.[16–18,26,27]

b. Polyphenols also contribute to ultraviolet scavenging by reducing ROS-mediated cellular injury and suppressing inflammatory responses. Additionally, they help maintain collagen integrity and protect extracellular matrix components from degradation. These activities collectively contribute to the prevention of photoaging and enhancement of skin protection against environmental stressors.[16–18,26,27]

- **Inhibition of Reactive Oxygen Species (ROS)**

a. Reactive oxygen species play a central role in ultraviolet-induced skin damage. Excessive production of ROS disrupts cellular homeostasis and promotes oxidative injury to proteins, lipids, and DNA. Tulsi phytochemicals effectively inhibit ROS generation and neutralize already formed reactive species, thereby reducing oxidative stress within skin tissues.[1,6,17,18,27]

b. The reduction in ROS levels helps preserve normal cellular function, prevent inflammation, and minimize structural damage caused by ultraviolet radiation. Consequently, ROS inhibition is considered one of the most important mechanisms responsible for the photoprotective effects of Tulsi.[1,6,17,18,27]

- **Reduction of Lipid Peroxidation**

a. Lipid peroxidation is a major consequence of oxidative stress caused by ultraviolet radiation. Reactive oxygen species attack membrane lipids and initiate oxidative chain reactions that compromise membrane structure and function. Tulsi-derived polyphenols and flavonoids inhibit lipid peroxidation by scavenging free radicals and stabilizing biological membranes.[17,18,26]

b. By reducing lipid peroxidation, Tulsi helps preserve cellular integrity, maintain membrane function, and prevent further oxidative damage. This protective effect contributes significantly to skin preservation and reduction of photoaging-associated changes.[17,18,26]

- **Protection Against DNA Damage**

a. DNA damage is one of the most serious consequences of chronic ultraviolet exposure and is strongly associated with skin carcinogenesis. Ultraviolet radiation induces mutations, chromosomal abnormalities, and genomic instability through both direct and indirect mechanisms. Tulsi phytochemicals help protect DNA by reducing oxidative stress and minimizing the formation of reactive intermediates capable of damaging nucleic acids.[6,17,27]

b. The antioxidant and free radical scavenging activities of polyphenols, flavonoids, and phenolic compounds contribute significantly to genomic protection. By reducing DNA damage and supporting cellular defense mechanisms, Tulsi may help lower the risk of mutation formation and long-term photodamage associated with ultraviolet exposure.[6,17,27]

c. Continuous exposure to ultraviolet radiation can damage cellular DNA and induce mutations that may lead to premature aging and skin carcinogenesis. Bioactive compounds present in Tulsi, particularly flavonoids and polyphenols, help protect genetic material by reducing oxidative stress and preventing UV-induced cellular injury. These phytochemicals support the preservation of DNA integrity and enhance the skin's natural defense mechanisms against environmental damage. Consequently, Tulsi contributes to reducing the long-term harmful effects associated with ultraviolet exposure.[6,17,27]

- **Table 1: Mechanism of Herbal Photoprotection.**

Mechanism	Role in Photoprotection	Major Herbal Phytochemicals
UV Absorption	Absorbs harmful UVA/UVB radiation	Flavonoids, Phenolic compounds
Antioxidant Activity	Neutralizes oxidative Stress	Polyphenols, Rosmarinic acid
Free Radical Scavenging	Protects cells from ROS damage	Flavonoids, Eugenol
Anti-inflammatory action	Reduce Erythema and irritation	B-sitosterol, triterpenoids
DNA Protection	Prevents UV-induced mutation	Phenolic compounds
Anti-aging Effect	Prevents collagen drgradation	Anti-oxidants, Polyphenols

3. PLANT PROFILE – TULSI

- **Botanical Classification**

Tulsi (*Ocimum sanctum*), commonly known as Holy Basil, is an aromatic medicinal plant belonging to the family Lamiaceae. It is widely cultivated throughout India and various tropical and subtropical regions because of its remarkable medicinal value. In Ayurveda, Tulsi is regarded as one of the most sacred and therapeutically important medicinal herbs. The plant has been extensively studied owing to its diverse pharmacological activities and rich phytochemical composition.[53,55,57]

Table No. 2

Category	Classification
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Lamiales
Family	Lamiaceace
Genus	*Ocimum*
Species	*Ocimum Sanctum*

MORPHOLOGY

Tulsi is an erect, highly branched aromatic herb that usually grows to a height of 30–60 cm. The stem is quadrangular, hairy, and green to purplish in color. Leaves are simple, opposite, ovate, and slightly toothed, possessing a characteristic aromatic odor due to the presence of essential oils. The flowers are small, purplish or white, arranged in terminal racemes, while the fruits consist of small nutlets containing seeds. The plant thrives well in tropical and subtropical climates and is widely cultivated throughout India for its medicinal and religious significance.[53,55,57]

- **Traditional uses (ayurveda)**

a. Tulsi has been used for centuries in Ayurvedic and traditional healthcare systems for the treatment and prevention of various diseases. Different parts of the plant, including leaves, seeds, roots, and flowers, possess therapeutic properties and are utilized in numerous herbal remedies. Tulsi has traditionally been employed in the management of respiratory disorders, fever, cough, cold, bronchitis, skin infections, inflammatory conditions, digestive disturbances, and microbial diseases.[53,57]

b. In dermatological applications, Tulsi has been widely used for the treatment of wounds, acne, skin infections, insect bites, and inflammatory skin conditions. The paste or extract of Tulsi leaves is traditionally applied to affected areas to promote wound healing, reduce inflammation, and prevent microbial growth. Its antiseptic and antimicrobial properties contribute to the maintenance of healthy skin and protection against various dermatological disorders.[53,55,57]

c. Tulsi is also recognized as an adaptogenic herb capable of enhancing the body's resistance to physical, chemical, and environmental stress. It has been traditionally consumed to improve immunity, maintain overall well-being, and protect against oxidative stress-related disorders. The plant is considered beneficial for promoting longevity and supporting physiological balance.[53,57]

d. The therapeutic significance of Tulsi is largely attributed to its rich phytochemical composition, which provides antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory effects. These properties have contributed to its increasing incorporation into herbal cosmetics, dermatological preparations, and photoprotective formulations aimed at maintaining skin health and preventing ultraviolet-induced damage.[55–57]

- **Pharmacological activities relevant to sunscreen: Anti-oxidant, anti-inflammatory, anti-microbial, anti-aging**

a. Tulsi exhibits multiple pharmacological activities that support its application in sunscreen formulations. Its strong antioxidant activity enables effective scavenging of free radicals generated during ultraviolet exposure, thereby reducing oxidative stress and preventing cellular damage. The presence of flavonoids, phenolics, and essential oils contributes significantly to these protective effects.[16,19,51,57]

b. The anti-inflammatory properties of Tulsi help suppress inflammatory mediators produced during UV exposure and reduce erythema, swelling, and tissue injury. In addition, antimicrobial activity assists in maintaining skin hygiene and preventing microbial contamination in topical formulations. These combined effects improve the overall therapeutic value of sunscreen preparations containing Tulsi extract.[51,57]

c. Tulsi also demonstrates anti-aging potential through inhibition of oxidative stress and reduction of collagen degradation. By protecting structural proteins within the skin and minimizing free radical-mediated damage, the plant helps maintain skin elasticity and delay the appearance of wrinkles and other signs of photoaging. These multifunctional activities make Tulsi a valuable natural ingredient for advanced herbal sunscreen formulations.[16,19,51,57]

- **Tulsi Plant**

Fig. 1: (Ocimum Sanctum).

4. PHOTOPROTECTIVE ACTIVITY OF TULSI

- **Mechanism of Photoprotection**

a. Photoprotection refers to the prevention or reduction of skin damage caused by ultraviolet radiation through physical, chemical, or biological mechanisms. Ultraviolet radiation generates excessive reactive oxygen species (ROS) within skin tissues, resulting in oxidative stress, inflammation, lipid peroxidation, collagen degradation, and DNA damage. These pathological changes ultimately contribute to premature aging, pigmentation disorders, and skin carcinogenesis. Therefore, effective photoprotective agents should not only block ultraviolet radiation but also prevent oxidative damage at the cellular level.[1,6,17,18]

b. One of the most important mechanisms of photoprotection is ultraviolet absorption. Many plant-derived phytochemicals, particularly flavonoids and phenolic compounds, contain conjugated aromatic ring structures capable of absorbing ultraviolet radiation. By absorbing harmful UV rays before they penetrate deeper skin layers, these compounds reduce direct cellular injury and minimize DNA damage. This mechanism significantly contributes to the sunscreen activity of herbal formulations.[16–18]

c. Another major photoprotective mechanism involves antioxidant defense. Exposure to ultraviolet radiation stimulates excessive production of reactive oxygen species such as superoxide radicals, hydroxyl radicals, and hydrogen peroxide. These reactive molecules attack cellular proteins, lipids, and nucleic acids, resulting in oxidative stress and tissue damage. Antioxidant phytochemicals present in medicinal plants neutralize these free radicals and prevent their harmful effects, thereby protecting skin cells from oxidative injury.[6,17,18,27]

d. Reduction of lipid peroxidation represents another important protective mechanism. Reactive oxygen species initiate oxidation of membrane lipids, leading to the formation of lipid peroxides that compromise membrane integrity and cellular function. Polyphenols and flavonoids inhibit lipid peroxidation by scavenging free radicals and stabilizing biological membranes. This protective effect helps preserve skin structure and reduces cellular damage associated with ultraviolet exposure.[17,18,26]

- **UV absorption potential**

a. Tulsi exhibits considerable ultraviolet absorption potential owing to the presence of various bioactive phytochemicals, particularly flavonoids, phenolic compounds, rosmarinic acid, and eugenol. These compounds possess conjugated aromatic ring systems that enable them to absorb ultraviolet radiation across specific wavelength ranges. By absorbing a portion of incoming UVA and UVB radiation, these phytochemicals reduce the amount of harmful ultraviolet energy reaching deeper layers of the skin. This protective mechanism helps minimize direct cellular damage and lowers the risk of ultraviolet-induced skin disorders.[16,51,59]

b. The UV-absorbing property of Tulsi is particularly valuable because it provides a natural alternative to synthetic UV filters. Unlike conventional sunscreen agents that primarily function through absorption or reflection of UV radiation, Tulsi offers additional biological benefits through its antioxidant and anti-inflammatory activities. The combined effect of UV absorption and cellular protection contributes significantly to its overall photoprotective efficacy. Consequently, Tulsi has emerged as a promising botanical ingredient for incorporation into herbal sunscreen formulations designed to provide safe and effective skin protection.[16,51,59]

- **Antioxidant studies**

a. Antioxidant activity is one of the most i role in its photoprotective potential. Ultraviolet radiation stimulates excessive production of reactive oxygen species within skin tissues, leading to oxidative stress and damage to cellular components. Tulsi contains a rich variety of antioxidant phytochemicals including flavonoids, polyphenols, eugenol, rosmarinic acid, and other phenolic compounds that effectively neutralize these reactive molecules. By scavenging harmful oxidants, these constituents help maintain cellular integrity and protect the skin against environmental damage.[40,47,48,52]

b. The antioxidant constituents of Tulsi protect essential biomolecules such as proteins, lipids, and nucleic acids from oxidative injury. This protection is particularly important because oxidative stress contributes to collagen degradation, inflammation, pigmentation disorders, and premature skin aging. By reducing oxidative damage and enhancing the natural antioxidant defense system of the skin, Tulsi helps preserve skin elasticity and structural integrity. These protective effects support its application in herbal sunscreen and anti-aging formulations.[40,47,48,52]

c. Additionally, the antioxidant activity of Tulsi contributes to long-term skin health by minimizing cumulative oxidative damage caused by repeated ultraviolet exposure. Regular use of formulations containing antioxidant-rich plant extracts may therefore help delay photoaging and maintain healthier skin. The strong antioxidant potential of Tulsi is considered one of the primary reasons for its increasing utilization in dermatological and cosmetic preparations.[47,48,52]

- **SPF evaluation studies**

a. Sun Protection Factor (SPF) is one of the most important parameters used to evaluate the effectiveness of sunscreen formulations against UVB radiation. Higher SPF values indicate greater protection against sunburn and UV-induced skin damage. Natural plant extracts containing UV-absorbing compounds have gained considerable attention because they can enhance SPF while simultaneously providing additional therapeutic benefits.[15,16,18,19,24]

b. Tulsi contains flavonoids, polyphenols, and other phytochemicals capable of absorbing ultraviolet radiation and reducing its penetration into the skin. These compounds contribute directly to SPF enhancement when incorporated into topical formulations. The UV-absorbing capacity of Tulsi improves the overall performance of sunscreen products and helps strengthen photoprotection.[15,16,18,19,24]

c. Unlike many conventional sunscreen agents, Tulsi provides multifunctional benefits beyond simple UV absorption. Its antioxidant and anti-inflammatory activities offer additional protection against oxidative stress and inflammation associated with ultraviolet exposure. Consequently, incorporation of Tulsi extract into sunscreen formulations may improve SPF values while simultaneously enhancing overall skin health and protection.[15,16,18,19,24]

- **Polyphenol Role in UV scavenging**

a. Polyphenols are among the most important phytochemicals responsible for the photoprotective activity of Tulsi. These naturally occurring compounds exhibit strong antioxidant properties and play a critical role in neutralizing harmful reactive oxygen species generated during ultraviolet exposure. Their ability to scavenge reactive molecules helps reduce oxidative stress and prevent cellular damage.[16–18,26,27]

b. The polyphenolic compounds present in Tulsi protect various cellular structures, including proteins, lipids, and nucleic acids, from oxidative injury. In addition to their antioxidant effects, these compounds suppress inflammatory responses and contribute to the maintenance of skin integrity. Their multifunctional nature significantly enhances the protective capacity of Tulsi against UV-induced damage.[17,18,26,27]

c. Polyphenols also play an important role in preventing degradation of collagen and elastin fibers that are essential for maintaining skin elasticity and firmness. By protecting the extracellular matrix and reducing oxidative stress, these compounds help delay photoaging and preserve youthful skin appearance. Therefore, polyphenols are considered key contributors to the photoprotective efficacy of Tulsi.[16–18,26,27]

- **Explain mechanism: ROS inhibition, Lipid peroxidation reduction, DNA protection**

a. Reactive oxygen species are major mediators of ultraviolet-induced skin damage. Excessive UV exposure leads to overproduction of ROS, resulting in oxidative stress and disruption of normal cellular function. Elevated ROS levels damage proteins, lipids, DNA, and other essential cellular components, thereby accelerating skin aging and increasing susceptibility to various dermatological disorders.[1,6,17,18,27]

b. Tulsi contains several antioxidant phytochemicals that effectively inhibit the formation of reactive oxygen species and neutralize existing ROS molecules. Flavonoids, polyphenols, eugenol, and rosmarinic acid work together to reduce oxidative stress and protect skin cells from UV-induced injury. This mechanism plays a crucial role in maintaining cellular homeostasis and preserving skin health.[1,6,17,18,27]

c. The ability of Tulsi to inhibit ROS generation provides long-term protection against oxidative damage and helps prevent inflammatory responses associated with ultraviolet exposure. Consequently, ROS inhibition is regarded as one of the most important mechanisms underlying the photoprotective activity of Tulsi.[1,6,17,18,27]

- **Protection Against DNA Damage**

a. DNA damage is one of the most serious consequences of prolonged ultraviolet exposure. UV radiation can induce mutations, oxidative lesions, and structural alterations in genetic material, thereby increasing the risk of premature skin aging and skin cancer. Continuous DNA damage may impair normal cellular function and compromise genomic stability.[6,17,27]

b. Tulsi contains potent antioxidant phytochemicals that help protect cellular DNA from ultraviolet-induced injury. By reducing oxidative stress and neutralizing reactive oxygen species, these compounds minimize the formation of DNA-damaging molecules within skin cells. This protective action helps preserve the integrity of genetic material and supports normal cellular functioning.[6,17,27]

c. In addition to preventing oxidative DNA damage, Tulsi contributes to the maintenance of cellular defense mechanisms that protect against environmental stress. The ability to safeguard DNA from ultraviolet-induced injury represents a crucial aspect of its photoprotective activity and further supports its potential use in herbal sunscreen and dermatological formulations.[6,17,27]

5. PLANT PROFILE – DURVA (CYNODON DACTYLON)

- **Botanical Classification**

a. Durva (*Cynodon dactylon*), commonly known as Bermuda grass, is a perennial creeping grass belonging to the family Poaceae. It is one of the most widely distributed medicinal grasses found throughout tropical and subtropical regions of the world. In India, Durva occupies a significant place in traditional medicine and religious practices due to its diverse therapeutic applications. The plant exhibits remarkable adaptability and can thrive under a wide range of environmental conditions, including drought-prone areas and nutrient-deficient soils.[54,56,58]

b. For centuries, Durva has been utilized in Ayurvedic medicine for the treatment of wounds, bleeding disorders, inflammatory conditions, skin diseases, and various microbial infections. Scientific investigations have demonstrated that the plant contains numerous bioactive phytochemicals responsible for its antioxidant, antimicrobial, anti-inflammatory, and wound-healing properties. These pharmacological activities have generated considerable interest in the use of Durva for pharmaceutical, cosmetic, and dermatological applications.[54,56,58]

Table No. 3

Category	Classification
Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Order	Poales

Family	Poaceae
Genus	*Cynodon*
Species	*Cynodon dactylon*

- **Traditional medicinal uses**

a. Durva has been used extensively in Ayurveda and traditional systems of medicine because of its cooling, haemostatic, anti-inflammatory, antioxidant, and wound-healing properties. Various parts of the plant have been employed for the treatment of wounds, cuts, burns, bleeding disorders, urinary tract infections, gastrointestinal disturbances, and inflammatory diseases. Fresh Durva juice has traditionally been applied to wounds to control bleeding, accelerate tissue repair, and promote healing.[54,56,58]

b. In traditional dermatological applications, Durva has been used for the management of skin diseases, itching, rashes, eczema, allergic reactions, and minor infections. The soothing and anti-inflammatory nature of the plant helps reduce irritation and discomfort while supporting regeneration of damaged tissues. These properties have contributed to its widespread use in herbal skin-care preparations.[54,58]

c. Durva has also been employed in the treatment of fever, diabetes, respiratory disorders, digestive ailments, and microbial infections. Traditional practitioners have recommended the plant as a natural remedy for maintaining overall health and enhancing the body's defense mechanisms. The broad range of therapeutic applications reflects the presence of multiple biologically active constituents within the plant.[56–58]

d. The longstanding use of Durva for wound healing and skin protection is particularly relevant to modern photoprotective research. Its antioxidant and anti-inflammatory activities support its potential role in protecting the skin against environmental stressors, including ultraviolet radiation. Consequently, Durva has emerged as a promising natural ingredient for herbal cosmetic and sunscreen formulations.[54,56,58]

- **Chemical constituents**

a. Durva exhibits several pharmacological activities that support its application in sunscreen and skin-protective formulations. One of its most important properties is antioxidant activity, which helps neutralize reactive oxygen species generated during ultraviolet exposure. By reducing oxidative stress, Durva protects skin cells from damage and contributes to the maintenance of healthy skin.[18,19,56–58]

b. The plant also demonstrates significant anti-inflammatory activity. Bioactive constituents present in Durva suppress inflammatory pathways and reduce the production of mediators responsible for erythema, irritation, swelling, and tissue injury. This effect is particularly beneficial in minimizing skin damage caused by prolonged exposure to ultraviolet radiation.[18,19,56–58]

c. Another important pharmacological property of Durva is its wound-healing activity. The plant promotes tissue regeneration and accelerates repair processes by enhancing cellular proliferation and supporting restoration of damaged tissues. These effects may aid recovery from minor skin injuries and contribute to maintenance of skin integrity.[56–58]

- **Major phytochemicals: Flavonoids, Alkaloids, Triterpenoids, Phenolic compounds, Β-sitosterol**

a. Durva contains several biologically active phytochemicals that contribute to its medicinal and pharmacological properties. Major phytochemical constituents identified in the plant include flavonoids, alkaloids, triterpenoids, phenolic compounds, and β-sitosterol. These compounds are largely responsible for the antioxidant, anti-inflammatory, antimicrobial, and wound-healing activities exhibited by the plant.[56–58]

b. Among these constituents, flavonoids and phenolic compounds play a significant role in protecting cells against oxidative stress. These compounds possess strong antioxidant properties and effectively neutralize reactive oxygen species generated by environmental stressors such as ultraviolet radiation. Their free radical scavenging activity helps prevent oxidative damage to cellular proteins, lipids, and nucleic acids.[56–58]

c. Triterpenoids and β-sitosterol contribute to the anti-inflammatory and skin-protective properties of Durva. These phytochemicals help suppress inflammatory responses and support tissue repair processes, thereby promoting skin health. Alkaloids present in the plant also contribute to its therapeutic potential through various biological activities. The combined action of these phytochemicals provides a scientific basis for the traditional medicinal uses of Durva and supports its application in photoprotective and dermatological formulations.[56–58]

- **Durva Plant**

Fig. 2: (Cynodon Dactylon).

6. PHOTOPROTECTIVE ACTIVITY OF DURVA

- **Anti-inflammatory activity**

a. Inflammation is a common biological response to excessive ultraviolet exposure and is characterized by erythema, edema, irritation, and tissue damage. UV radiation stimulates the release of inflammatory mediators that contribute to skin discomfort and accelerate tissue injury. Therefore, suppression of inflammatory responses is an important aspect of photoprotection.[18,19,56–58]

b. Durva exhibits significant anti-inflammatory activity owing to the presence of flavonoids, triterpenoids, β-sitosterol, and phenolic compounds. These phytochemicals help regulate inflammatory pathways and reduce the production of pro-inflammatory mediators responsible for tissue damage. As a result, Durva helps alleviate redness, irritation, and swelling associated with ultraviolet exposure.[18,19,56–58]

c. In addition to reducing acute inflammation, Durva supports tissue repair and recovery following environmental stress. Its anti-inflammatory effects complement its antioxidant properties and contribute to comprehensive protection against UV-induced skin damage.[18,19,56–58]

- **Anti-oxidant capacity**

a. Antioxidant activity is one of the most important biological properties of Durva and plays a crucial role in protecting the skin from ultraviolet-induced damage. Exposure to UV radiation stimulates excessive production of reactive oxygen species, which can damage proteins, lipids, nucleic acids, and other cellular components. The flavonoids and phenolic compounds present in Durva effectively neutralize these reactive molecules and help maintain cellular homeostasis.[18,56–58]

b. The antioxidant phytochemicals of Durva protect skin tissues against oxidative stress and reduce the likelihood of cellular injury. By scavenging reactive oxygen species, these compounds help preserve membrane integrity, prevent degradation of structural proteins, and support normal physiological functions. Such effects are particularly beneficial in reducing UV-induced skin damage and delaying photoaging.[18,56–58]

c. Furthermore, antioxidant activity contributes to maintenance of skin elasticity and overall skin health. Regular incorporation of antioxidant-rich plant extracts such as Durva into topical formulations may provide long-term protection against environmental stressors and improve skin resilience.[18,56–58]

- **Free Radical Scavenging Activity**

a. Free radicals generated during ultraviolet exposure are highly reactive molecules capable of initiating oxidative chain reactions within skin tissues. These reactions lead to damage of proteins, lipids, and DNA, thereby contributing to premature aging and various dermatological disorders. Therefore, effective neutralization of free radicals is essential for maintaining healthy skin.[17,18,26,27]

b. Durva contains flavonoids and phenolic compounds that exhibit strong free radical scavenging activity. These phytochemicals donate electrons or hydrogen atoms to unstable free radicals, converting them into less reactive species and preventing further oxidative damage. Through this mechanism, Durva helps interrupt oxidative chain reactions and protect cellular structures from injury.[17,18,26,27]

c. The free radical scavenging activity of Durva contributes significantly to its photoprotective effects by reducing oxidative stress and preserving cellular integrity. This activity also helps protect collagen and elastin fibers from degradation, thereby supporting skin elasticity and reducing the appearance of photoaging.[17,18,26,27]

- **Possible UV filtering effects**

a. Polyphenols are among the most important phytochemicals responsible for the photoprotective activity of Durva. These compounds possess strong antioxidant properties and efficiently neutralize reactive oxygen species generated during ultraviolet exposure. Their ability to scavenge harmful radicals helps reduce oxidative stress and protect cellular structures from damage.[16–18,26,27]

b. In addition to their antioxidant activity, polyphenols inhibit inflammatory responses and protect biological membranes from oxidative injury. They also help preserve collagen and elastin fibers, thereby maintaining skin elasticity and reducing signs of photoaging.[17,18,26,27]

c. The multifunctional nature of polyphenols significantly enhances the photoprotective efficacy of Durva. Their combined antioxidant, anti-inflammatory, and UV-scavenging properties support the application of Durva extracts in sunscreen and dermatological formulations.[16–18,26,27]

- **Explain how flavonoids contribute to UV absorption**

a. Durva exhibits considerable ultraviolet absorption potential due to the presence of flavonoids, phenolic compounds, triterpenoids, and other bioactive phytochemicals. These compounds possess chromophoric structures capable of absorbing ultraviolet radiation and reducing its penetration into deeper layers of the skin. By acting as natural UV filters, they help minimize direct cellular exposure to harmful ultraviolet rays and reduce the risk of photodamage.[18,56–58]

b. The UV-absorbing ability of Durva contributes significantly to its photoprotective efficacy. By limiting the amount of ultraviolet radiation reaching viable skin cells, the plant helps reduce oxidative stress, inflammation, and structural damage associated with prolonged sun exposure. This protective mechanism supports the potential use of Durva extract in herbal sunscreen formulations.[18,56–58]

c. In addition to direct UV absorption, the antioxidant constituents present in Durva provide supplementary protection against ultraviolet-induced cellular injury. The combined action of UV filtering and antioxidant defense enhances the overall effectiveness of the plant as a natural photoprotective agent.[18,56–58]

7. COMPARATIVE PHOTOPROTECTIVE MECHANISM

Table 4.

Parameter	Tulsi (Ocimum Sanctum)	Durva (Cynodon Dactylon)
Major Compounds	Eugenol, Rosmarinic acid, Ursolic acid, Flavonoids, Phenolics.	Flavonoids, Alkaloids, Triterpenoids, Phenolics, β-sitosterol.
Anti-oxidant Strength	Strong antioxidant activity due to phenolics and eugenol.	Moderate to strong antioxidant activity due to flavonoids.
Anti-inflammatory activi	Significant anti-inflammatory effect.	Effective anti-inflammatory and wound healing activity.
UV absorption	Better UV absorption because of polyphenolic compounds.	Supportive UV filtering potential.
Skin healing role	Protects skin from oxidative stress and photoaging.	Promotes tissue repair and wound healing.
Photoprotective Mechanism	ROS inhibition, lipid peroxidation reduction, DNA protection.	Antioxidant defense and inflammatory reduction.

8. FORMULATION APPROACHES FOR HERBAL SUNSCREEN

a. The growing demand for safer and environmentally friendly photoprotective products has encouraged the development of herbal sunscreen formulations containing plant-derived bioactive compounds. Herbal sunscreens are designed to provide protection against ultraviolet radiation while simultaneously offering antioxidant, anti-inflammatory, and skin-nourishing benefits. The effectiveness of these formulations depends not only on the selection of active ingredients but also on the dosage form used for delivery.[15,19,24]

b. Various formulation approaches such as creams, gels, lotions, and advanced delivery systems have been investigated to improve the stability, efficacy, and user acceptability of herbal sunscreen products. Selection of an appropriate dosage form is essential to ensure uniform distribution of active constituents, enhanced skin retention, and optimal photoprotective performance.[15,19,24]

- **Creams based herbal Formulation**

a. Creams are among the most widely used topical dosage forms for sunscreen preparations because of their excellent spreadability, ease of application, and moisturizing properties. They are semisolid emulsions consisting of oil and water phases stabilized by suitable emulsifying agents. Depending on the formulation, creams may be oil-in-water (O/W) or water-in-oil (W/O) systems.[15,24]

b. Herbal sunscreen creams containing Tulsi and Durva extracts offer several advantages. The emulsion system facilitates uniform distribution of phytochemicals on the skin surface, thereby enhancing UV protection. In addition, creams provide an occlusive effect that helps maintain skin hydration and improves penetration of active constituents into the superficial layers of the skin.[15,24]

c. The incorporation of antioxidant-rich plant extracts into cream formulations further enhances photoprotective efficacy by reducing oxidative stress and inflammation associated with ultraviolet exposure. Creams also demonstrate good patient compliance due to their pleasant texture and cosmetic acceptability, making them suitable for routine sunscreen application.[15,24]

- **Gel Formulation**

a. Gels are semisolid systems in which active ingredients are dispersed within a three-dimensional polymeric network. They have gained considerable popularity in dermatological preparations because of their non-greasy nature, cooling sensation, and ease of application. Herbal sunscreen gels are particularly suitable for individuals with oily or acne-prone skin.[15,24]

b. Tulsi and Durva extracts can be effectively incorporated into gel formulations using gelling agents such as Carbopol. The gel matrix allows uniform dispersion of phytochemicals and facilitates controlled release of active constituents upon application. The transparent appearance and smooth consistency of gels also improve consumer acceptability.[15,24]

c. An additional advantage of gel formulations is their ability to provide rapid absorption without leaving an oily residue on the skin. This characteristic improves user comfort and encourages regular sunscreen use. The combination of photoprotective, antioxidant, and anti-inflammatory activities makes herbal gels a promising approach for modern sunscreen development.[15,24]

- **Nanoemulsion Systems**

a. Nanoemulsion systems represent advanced topical delivery approaches designed to improve the stability, penetration, and bioavailability of herbal sunscreen ingredients. These systems consist of extremely small droplets that increase surface area and facilitate more efficient delivery of active phytochemicals into the skin. As a result, nanoemulsions enhance photoprotective efficacy and improve overall sunscreen performance.[24,50]

b. Nanoemulsion-based formulations also help protect sensitive phytochemicals from degradation caused by environmental factors. Improved stability and enhanced antioxidant activity contribute to prolonged photoprotective effects. Because of these advantages, nanoemulsion technology has emerged as one of the most promising approaches for the development of next-generation herbal sunscreen products.[24,50]

- **Herbal lotions**

a. Herbal lotions are low-viscosity topical preparations that provide ease of application and excellent spreadability over large skin surfaces. Their lightweight consistency ensures uniform coverage and facilitates efficient delivery of antioxidant-rich phytochemicals to the skin. These characteristics make lotions particularly suitable for routine sunscreen application.[15,24]

b. In addition to good cosmetic acceptability, herbal lotion formulations exhibit significant antioxidant and ultraviolet protective effects. They improve topical coverage, enhance user comfort, and support daily photoprotection. Consequently, herbal lotions have become important dosage forms in cosmetic and sunscreen preparations containing medicinal plant extracts.[15,24]

- **Microencapsulation**

a. Microencapsulation is an advanced formulation technique in which active ingredients are enclosed within microscopic protective coatings. This approach has gained considerable attention in pharmaceutical and cosmetic research because it enhances stability, controls release, and protects sensitive compounds from degradation.[24,50]

b. Many phytochemicals present in herbal extracts are susceptible to oxidation, light-induced degradation, and environmental instability. Microencapsulation helps protect these bioactive compounds from external factors and improves their shelf life. The technology also allows sustained release of active ingredients, thereby prolonging their protective effects on the skin.[24,50]

c. In sunscreen formulations, microencapsulation may enhance the stability and efficacy of

Tulsi and Durva phytochemicals while minimizing degradation caused by sunlight and environmental exposure. This advanced delivery system offers significant potential for improving the performance of herbal photoprotective products and represents an important area of future research.[24,50]

- **Evaluation Parameters**

Evaluation of herbal sunscreen formulations is essential to ensure product quality, safety, stability, and effectiveness. Various physicochemical and performance-related parameters are assessed to determine whether the formulation provides adequate photoprotection and remains stable during storage. Proper evaluation also helps optimize formulation characteristics and improve product acceptability.[15,24]

1. Determination of Sun Protection Factor (SPF)

a. Sun Protection Factor (SPF) is the most important parameter used to evaluate the efficacy of sunscreen formulations against UVB radiation. It represents the ability of a product to protect the skin from erythema and sunburn induced by ultraviolet exposure. Higher SPF values indicate greater protective efficacy.[15,24]

b. SPF determination can be performed using in vitro or in vivo methods. In vitro methods involve spectrophotometric analysis of ultraviolet absorption, whereas in vivo methods assess the degree of protection provided to human skin under controlled conditions. Accurate SPF determination is essential for comparing formulations and establishing sunscreen performance.[15,24]

c. For herbal sunscreen formulations containing Tulsi and Durva extracts, SPF evaluation helps determine the contribution of plant-derived phytochemicals to overall photoprotection. This parameter serves as a key indicator of formulation effectiveness and product quality.[15,24]

2. pH Determination

a. The pH of a topical formulation is an important quality parameter because it influences skin compatibility, stability, and user comfort. Ideally, sunscreen formulations should possess a pH close to that of the skin to minimize irritation and maintain the natural skin barrier.[15,24]

b. pH measurement is generally carried out using a calibrated digital pH meter. Regular monitoring of pH during formulation development and stability studies helps ensure product consistency and detect any changes resulting from ingredient interactions or degradation.[15,24]

c. Appropriate pH values contribute to improved formulation stability and reduce the likelihood of skin irritation, thereby enhancing the overall safety and acceptability of herbal sunscreen products.[15,24]

3. Spreadability

a. Spreadability refers to the ease with which a formulation can be applied and distributed uniformly over the skin surface. It is an important characteristic because uniform coverage directly influences sunscreen performance and user satisfaction.[15,24]

b. Good spreadability ensures that active ingredients are evenly distributed across the skin, resulting in consistent photoprotection. Poor spreadability may lead to uneven application and reduced sunscreen efficacy. Therefore, this parameter is routinely evaluated during formulation development.[15,24]

c. Formulations with optimal spreadability are generally preferred because they improve ease of application, enhance consumer compliance, and contribute to better protective performance.[15,24]

4. Stability Studies

a. Stability studies are conducted to evaluate the ability of a formulation to maintain its physical, chemical, and microbiological properties during storage. These studies are essential for determining shelf life and ensuring consistent product performance throughout its intended period of use.[15,24]

b. Parameters commonly monitored during stability studies include appearance, color, odor, pH, viscosity, spreadability, and SPF value. Any significant changes in these characteristics may indicate formulation instability or degradation of active ingredients.[15,24]

c. For herbal sunscreen formulations, stability studies are particularly important because plant-derived phytochemicals may be susceptible to oxidation and environmental degradation. Proper stability assessment ensures the safety, efficacy, and quality of the final product.[15,24]

9. SAFETY & TOXOLOGICAL ASPECTS

Safety is a critical consideration in the development of sunscreen formulations because these products are intended for frequent and prolonged application on the skin. Herbal sunscreen formulations are generally considered safer than many synthetic alternatives due to the presence of naturally derived bioactive compounds. However, systematic safety evaluation remains necessary to ensure their suitability for topical use.[15,24]

- **Skin compatibility**

a. Skin compatibility refers to the ability of a topical formulation to remain in contact with the skin without producing undesirable reactions such as irritation, redness, itching, burning sensation, dryness, or allergic responses. Since sunscreen products are intended for frequent and repeated application, evaluation of skin compatibility is an essential step during formulation development.[15,24]

b. The compatibility of a sunscreen formulation depends on several factors including the nature of active ingredients, excipients, pH, formulation type, and concentration of bioactive constituents. Herbal ingredients generally demonstrate better compatibility with the skin because they contain naturally occurring compounds that often possess soothing and protective properties. Phytochemicals such as flavonoids and polyphenols not only provide photoprotection but may also contribute to maintenance of skin health and integrity.[15,24]

c. Tulsi contains eugenol, rosmarinic acid, and various flavonoids that exhibit antioxidant and anti-inflammatory activities, thereby helping reduce skin irritation and oxidative stress. Similarly, Durva contains flavonoids, phenolic compounds, triterpenoids, and β-sitosterol that support skin repair and protect against inflammatory damage. These properties suggest that formulations containing these plant extracts may be well tolerated by the skin when appropriately formulated.[16–19,56–58]

d. Assessment of skin compatibility is typically performed through patch testing and dermatological evaluation. Such studies help identify any adverse reactions and ensure that the formulation remains safe for long-term use. A product demonstrating good skin compatibility is more likely to achieve consumer acceptance and provide effective photoprotection without compromising skin health.[15,24]

- **Irritation studies**

a. Irritation studies are conducted to determine the potential of a formulation to produce adverse skin reactions following topical application. These studies play an important role in evaluating product safety and are often required before commercialization of sunscreen formulations. Parameters commonly assessed include erythema, edema, itching, burning sensation, scaling, and other visible signs of skin irritation.[15,24]

b. Exposure to certain chemical ingredients may cause irritation in sensitive individuals, particularly when products are used repeatedly over extended periods. Therefore, evaluation of irritation potential is necessary even for herbal formulations. Although plant-derived ingredients are generally associated with lower toxicity, inappropriate concentrations or interactions among formulation components may still produce undesirable effects.[15,24]

c. Herbal extracts such as Tulsi and Durva possess anti-inflammatory properties that may help reduce irritation and improve skin tolerance. The presence of antioxidant phytochemicals can further protect skin tissues against oxidative stress and inflammatory responses. These beneficial properties may contribute to the lower irritation potential often associated with herbal sunscreen formulations compared with certain synthetic products.[16–19,56–58]

d. Irritation studies provide valuable information regarding formulation safety and help optimize ingredient concentrations to minimize adverse reactions. Demonstration of low irritation potential enhances confidence in the suitability of the product for routine application and supports its use in sensitive skin populations.[15,24]

- **Natural vs synthetic safety comparison**

Table 05.

Parameter	**Natural Sunscreen**	**Synthetic Sunscreen**
Source	Derived from medicinal plants and natural phytochemicals	Prepared using chemical UV filters
Skin Compatibility	Generally more skin-friendly and soothing	May cause irritation or hypersensitivity in sensitive skin
hototoxicity Risk	Lower phototoxic and	Higher risk of phototoxicity and

	photoallergic reactions	photoallergic reactions
Anti-oxidant Activity	Strong antioxidant due to plant polyphenols	Limited antioxidant protection
Environmental Safety	More biodegradable and eco-friendly	Certain UV filters contribute to coral bleaching and aquatic toxicity
Long term safety	Considered safer for prolonged use	Concerns regarding endocrine disruption and chronic exposure
Stability	Phytochemicals may show stability issues	Generally more chemically stable
SPF Consistency	SPF may vary due to plant extract variability	More predictable SPF values

Sunscreen products can be broadly classified into natural and synthetic formulations depending on the origin of their active ingredients. Synthetic sunscreens typically contain chemical UV filters that absorb ultraviolet radiation and convert it into less harmful forms of energy. These agents are highly effective in preventing sunburn and UV-induced skin damage; however, some synthetic compounds have been associated with adverse effects such as skin irritation, allergic reactions, endocrine disruption concerns, and environmental impact.[15,24]

In contrast, natural sunscreen formulations utilize plant-derived bioactive compounds that provide photoprotection through multiple mechanisms. Flavonoids, polyphenols, phenolic compounds, and other phytochemicals absorb ultraviolet radiation, neutralize reactive oxygen species, reduce inflammation, and protect cellular structures from oxidative damage. As a result, herbal sunscreen products often provide broader biological protection than simple UV absorption alone.[16–19]

10. CHALLENGES IN HERBAL SUNSCREEN DEVELOPMENT

The increasing demand for herbal sunscreen products has encouraged extensive research on plant-derived photoprotective agents. Despite their numerous advantages, the development of effective herbal sunscreen formulations remains challenging due to several scientific, technological, and regulatory limitations. Factors such as variability in phytochemical composition, lack of standardization, instability of bioactive constituents, and regulatory complexities often hinder large-scale commercialization of herbal sunscreen products. Addressing these challenges is essential to ensure product quality, safety, efficacy, and consumer acceptance.[15,24]

- **Standardization issues**

a. Standardization is one of the most critical challenges associated with herbal formulations. Unlike synthetic compounds, medicinal plants contain complex mixtures of phytochemicals whose concentrations vary depending on geographical location, climatic conditions, soil composition, cultivation practices, harvesting season, and extraction techniques. Such variations may significantly influence the biological activity and photoprotective efficacy of plant extracts.[15,24]

b. The absence of standardized procedures for cultivation, collection, processing, and extraction can result in inconsistency in the quality of herbal raw materials. Consequently, different batches of the same plant extract may exhibit variations in antioxidant activity, UV absorption potential, and overall therapeutic effectiveness. This lack of uniformity poses difficulties in ensuring reproducible product performance.[15,24]

c. To overcome these issues, standardized cultivation practices, validated extraction methods, and comprehensive quality control measures should be implemented. Identification of marker compounds and phytochemical profiling using advanced analytical techniques can further improve consistency and reliability of herbal sunscreen formulations.[15,24]

- **Batch variability**

a. Batch-to-batch variability is closely related to the standardization problem and represents a major concern in herbal product development. Since medicinal plants are biological materials, variations in environmental and genetic factors can influence their phytochemical composition. These variations may result in differences in photoprotective activity and overall product efficacy between production batches.[15,24]

b. For example, fluctuations in the concentration of flavonoids, polyphenols, phenolic compounds, and triterpenoids may alter the antioxidant and UV-protective properties of plant extracts. Such inconsistencies can affect formulation performance and make it difficult to establish uniform product specifications.[15,24]

c. Implementation of Good Agricultural and Collection Practices (GACP), standardized processing techniques, and rigorous quality assurance programs can help minimize batch-to-batch variability. Continuous monitoring of phytochemical content is also essential for maintaining consistency and ensuring product quality.[15,24]

- **Stability of phytochemicals**

a. The stability of phytochemicals is another important challenge in the development of herbal sunscreen formulations. Many bioactive compounds present in medicinal plants are highly sensitive to environmental conditions such as temperature, light, oxygen, humidity, and pH changes. Exposure to these factors can result in degradation of active constituents and loss of biological activity.[15,24]

b. Flavonoids, polyphenols, and other antioxidant compounds are particularly susceptible to oxidation and photodegradation. Reduction in their concentration may decrease the antioxidant capacity and photoprotective efficacy of the final formulation. Consequently, maintaining phytochemical stability during manufacturing, storage, and use is essential for ensuring consistent sunscreen performance.[15,24]

c. Various pharmaceutical approaches have been investigated to improve phytochemical stability. Advanced delivery systems such as nanoemulsions, liposomes, nanoparticles, and microencapsulation technologies can protect sensitive compounds from degradation and enhance their shelf life. These technologies may significantly improve the effectiveness and commercial viability of herbal sunscreen products.[24,50]

- **Regulatory limitations and Clinical Trials**

a. Regulatory approval represents a significant challenge for herbal sunscreen products. Regulatory authorities require comprehensive evidence regarding safety, quality, efficacy, and stability before a product can be marketed. Generating such evidence often requires extensive laboratory investigations, toxicological evaluations, and clinical studies.[15,24]

b. Unlike synthetic drugs and cosmetics, herbal products frequently face difficulties due to variability in phytochemical composition and limited scientific documentation. The absence of universally harmonized guidelines for herbal sunscreen evaluation further complicates product registration and commercialization.[15,24]

c. Clinical validation of photoprotective activity is particularly important because laboratory findings may not always accurately predict performance under real-life conditions. Large-scale clinical studies are therefore required to confirm sunscreen efficacy and establish long-term safety. However, such studies are often expensive and time-consuming, creating additional barriers to product development.[15,24]

d. Despite these challenges, continued advances in analytical techniques, formulation technologies, and regulatory frameworks are expected to facilitate the successful development and commercialization of herbal sunscreen products in the future.[15,24]

11. FUTURE PERSPECTIVES

The growing awareness regarding the harmful effects of ultraviolet radiation and increasing demand for natural skincare products have created new opportunities for herbal sunscreen development. Recent advances in phytochemical research, nanotechnology, and cosmetic science have highlighted the potential of plant-derived photoprotective agents as safer alternatives to conventional sunscreen ingredients. Future research is expected to focus on improving formulation stability, enhancing SPF performance, increasing clinical validation, and developing environmentally sustainable sunscreen systems. These developments may contribute significantly to the commercialization and global acceptance of herbal sunscreen products.[15,19,24]

- **Nano-herbal sunscreen system**

a. Nano-herbal sunscreen systems represent one of the most promising advances in herbal photoprotection. The incorporation of medicinal plant extracts into nanoemulsions, nanoparticles, liposomes, and other nano-carrier systems can significantly improve the stability, bioavailability, and skin penetration of phytochemicals. These delivery systems protect sensitive bioactive compounds from degradation caused by environmental factors such as light, oxygen, and temperature, thereby maintaining their photoprotective activity for longer durations.[16,57,61,62,63]

b. Nano-sized carriers also enhance the solubility and controlled release of antioxidant compounds such as flavonoids and polyphenols. Improved retention of these phytochemicals on the skin surface contributes to enhanced SPF values, prolonged antioxidant protection, and better photostability. In addition, nano-herbal formulations may improve cosmetic acceptability by reducing greasiness and providing a more uniform protective layer on the skin.[16,57,61,62,63]

c. With continued advancements in nanotechnology, future herbal sunscreen formulations are expected to combine natural phytochemicals with sophisticated nano-delivery systems to achieve superior efficacy, safety, and consumer acceptance.[16,57,61,62,63]

- **Combination herbal SPF boosters**

a. The use of combination herbal systems is another promising strategy for enhancing sunscreen efficacy. Medicinal plants contain diverse bioactive compounds that often exhibit complementary biological activities. Combining multiple plant extracts rich in flavonoids, phenolic compounds, and polyphenols may result in synergistic antioxidant and photoprotective effects. Such combinations have the potential to improve SPF performance while simultaneously reducing oxidative stress and inflammation.[15,16,18,57,62]

b. Synergistic interactions among phytochemicals can enhance ultraviolet absorption, free radical scavenging activity, and protection against UV-induced cellular damage. Combination herbal SPF boosters may also provide additional anti-aging, anti-inflammatory, and skin-soothing benefits that contribute to comprehensive skin protection.[15,16,18,57,62]

c. Future research should focus on identifying optimal combinations of medicinal plants capable of providing broad-spectrum photoprotection with improved safety and effectiveness. Such formulations may reduce dependence on synthetic UV filters and support the development of multifunctional herbal sunscreen products.[15,16,18,57,62]

- **Green cosmetic trend**

a. The increasing popularity of green cosmetics has significantly influenced the future direction of sunscreen research. Consumers are becoming more aware of the potential environmental and health concerns associated with certain synthetic sunscreen agents, leading to increased demand for natural and eco-friendly alternatives. Herbal sunscreen formulations align closely with the principles of sustainability, biodegradability, and environmental compatibility.[12,18,57,60,62]

b. Plant-derived photoprotective compounds offer several advantages, including renewable sourcing, lower environmental toxicity, and improved biodegradability compared with many synthetic UV filters. In addition, herbal cosmetics are often perceived as safer and more compatible with sensitive skin. These factors have contributed to the growing market demand for natural photoprotective products.[12,18,57,60,62]

c. Future sunscreen development is expected to emphasize environmentally sustainable formulations that provide effective photoprotection while minimizing ecological impact. Consequently, green cosmetic trends are likely to play a major role in shaping the next generation of herbal sunscreen products.[12,18,57,60,62]

- **Clinical validation Need**

a. Despite the promising results reported for numerous herbal photoprotective agents, insufficient clinical validation remains a major limitation affecting their widespread acceptance. Most available evidence regarding herbal sunscreen efficacy is derived from laboratory studies and experimental models, whereas comparatively few well-designed human clinical trials have been conducted.[16,57,60,62]

b. Comprehensive clinical investigations are required to establish the long-term safety, efficacy, SPF enhancement potential, and dermatological compatibility of herbal sunscreen formulations. Standardized clinical protocols and multicenter studies will help generate reliable scientific evidence and facilitate regulatory approval.[16,57,60,62]

c. Future commercialization of herbal sunscreen products will depend heavily on rigorous clinical validation and toxicological assessment. Therefore, extensive human studies remain essential for confirming therapeutic reliability and strengthening confidence in plant-derived photoprotective agents.[16,57,60,62]

12. CONCLUSION

The present review highlighted the significant potential of medicinal plants in the development of safer and effective herbal sunscreen formulations. Tulsi (Ocimum sanctum) possesses strong antioxidant, anti-inflammatory, antimicrobial, and photoprotective activities because of the presence of bioactive phytochemicals such as eugenol, rosmarinic acid, ursolic acid, flavonoids, and phenolic compounds. These constituents help in scavenging reactive oxygen species, reducing lipid peroxidation, minimizing oxidative stress, and protecting skin cells from ultraviolet-induced damage. Various studies demonstrated that Tulsi exhibits considerable ultraviolet absorption potential and contributes effectively toward SPF enhancement and prevention of photoaging. Similarly, Durva (Cynodon dactylon) exhibits remarkable anti-inflammatory, antioxidant, wound healing, and skin protective properties due to the presence of flavonoids, alkaloids, triterpenoids, β-sitosterol, and phenolic compounds. The plant plays a supportive role in reducing skin inflammation, promoting tissue repair, and minimizing oxidative damage caused by ultraviolet radiation. Durva also contributes to skin soothing and healing activities, which are beneficial in herbal sunscreen formulations intended for long-term dermatological protection. The review further emphasized that combination herbal photoprotective systems containing Tulsi and Durva may provide synergistic antioxidant and skin protective effects with improved safety and biocompatibility compared to synthetic sunscreen agents. In addition, increasing interest in green cosmetics, nano-herbal delivery systems, and multifunctional plant-derived SPF boosters indicates promising future prospects for herbal sunscreen development. However, several challenges including phytochemical variability, standardization issues, stability concerns, regulatory limitations, and lack of large-scale clinical trials still remain significant barriers in commercialization of herbal sunscreen products. Therefore, further research focusing on advanced formulation strategies, standardized evaluation protocols, and comprehensive clinical validation is essential for establishing scientifically reliable, stable, and effective herbal sunscreen formulations for future dermatological and cosmetic applications.

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