

**SUNSCREENS: CLASSIFICATION, MECHANISM, FORMULATION,  
EVALUATION AND EMERGING TRENDS**

**Yasir Yousuf Lone\*<sup>1</sup>, Firoz Ahmed<sup>2</sup>, Tanya Sharma<sup>3</sup>, Dhananjay Mistry<sup>4</sup>, Noorul Huda<sup>5</sup>,  
Kamalesh Mistry<sup>6</sup>**

<sup>1</sup>Research Scholar, Faculty of Pharmaceutical Science, Mewar University, Gangrar,  
Chittorgarh 312901, Rajasthan, India.

<sup>2</sup>Associate Professor, Department of Pharmacy, Faculty of Pharmaceutical Science, Mewar  
University, Gangrar, Chittorgarh 312901, Rajasthan, India.

<sup>3</sup>Assistant Professor, Department of Pharmacy, Faculty of Pharmaceutical Science, Mewar  
University, Gangrar, Chittorgarh 312901, Rajasthan, India.

<sup>4</sup>Lecturer, Department of Pharmacy, Faculty of Pharmaceutical Science, Mewar University,  
Gangrar, Chittorgarh 312901, Rajasthan, India.

<sup>5</sup>Assistant Professor, Department of Pharmacy, Faculty of Pharmaceutical Science, Mewar  
University, Gangrar, Chittorgarh 312901, Rajasthan, India.

<sup>6</sup>Assistant professor, Dept. Of pharmaceutical Analysis, Nityananda college of pharmacy  
Balasore Odisha India - 756060

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**\*Corresponding Author: Yasir Yousuf Lone**

Research Scholar, Faculty of Pharmaceutical Science, Mewar University, Gangrar, Chittorgarh 312901, Rajasthan,  
India.

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**ABSTRACT**

Sunscreens are essential dermatological and cosmetic preparations developed to protect the skin from the harmful effects of ultraviolet (UV) radiation. Continuous exposure to UV radiation can lead to acute and chronic skin damage, including erythema, pigmentation, premature aging, immunosuppression, and carcinogenesis. Sunscreens function by absorbing, reflecting, or scattering UV rays, thereby minimizing their penetration into the skin. This review manuscript provides a comprehensive discussion of ultraviolet radiation, classification of sunscreens, mechanisms of action, formulation strategies, evaluation techniques, regulatory considerations, safety concerns, and recent advancements such as nanotechnology and herbal photoprotective agents. With increasing awareness regarding skin health and

environmental sustainability, sunscreen formulations have undergone significant improvements in safety, efficacy, and consumer acceptability.

**KEYWORD:** Sunscreens, Ultraviolet Radiation, Sun Protection Factor (SPF), Photoprotection, Nanotechnology in Sunscreens.

## 1. INTRODUCTION

Sunlight is one of the most important environmental factors influencing human health, playing a vital role in vitamin D synthesis and maintaining circadian rhythm. However, excessive exposure to sunlight, particularly ultraviolet radiation, has detrimental effects on the skin. Ultraviolet radiation is divided into three regions based on wavelength: UVC (200–290 nm), which is completely absorbed by the ozone layer; UVB (290–320 nm), which is responsible for sunburn and direct DNA damage; and UVA (320–400 nm), which penetrates deeper into the dermis and contributes to photoaging and oxidative stress. Prolonged exposure to UV radiation results in cumulative skin damage, including hyperpigmentation, loss of elasticity, wrinkles, and an increased risk of skin cancer. Therefore, the use of sunscreens has become an essential preventive strategy in modern dermatology.

## 2. Historical Background

The concept of sun protection dates back to ancient civilizations, where natural substances such as plant extracts, oils, and minerals were used to protect the skin from sunlight. Egyptians used rice bran and jasmine extracts, while Greeks applied olive oil for photoprotection. The development of modern sunscreens began in the early 20th century, with the introduction of the first commercial sunscreen in 1928. Subsequent decades saw the development of para-aminobenzoic acid (PABA)-based formulations, followed by broad-spectrum sunscreens in the 1980s and nanotechnology-based products in recent years. These advancements reflect the growing understanding of photobiology and the increasing demand for effective sun protection.

## 3. Classification of Sunscreens

Sunscreens are broadly classified based on the nature of UV filters, spectrum of protection, and dosage form. Based on the nature of UV filters, they are divided into organic (chemical) and inorganic (physical) sunscreens. Organic sunscreens, such as avobenzone, octinoxate, oxybenzone, and octocrylene, function by absorbing UV radiation and converting it into heat energy. These formulations are cosmetically elegant and transparent but may cause skin

irritation and photodegradation in some cases. In contrast, inorganic sunscreens, including zinc oxide and titanium dioxide, act by reflecting and scattering UV radiation. They provide broad-spectrum protection with minimal irritation but may leave a white residue on the skin, which has been reduced with the use of nanoparticles.

Based on the spectrum of protection, sunscreens are categorized as UVB blockers, UVA blockers, and broad-spectrum sunscreens that protect against both types of radiation. Based on dosage forms, sunscreens are available as creams, lotions, gels, sprays, sticks, and powders. Creams are suitable for dry skin, gels for oily skin, and sprays and sticks for convenience and ease of application.

#### **4. Mechanism of Action**

Sunscreens protect the skin through multiple mechanisms, including absorption, reflection, and scattering of ultraviolet radiation. Organic sunscreens absorb UV rays and dissipate the absorbed energy as heat, thereby preventing damage to skin cells. Physical sunscreens form a protective barrier on the skin surface, reflecting and scattering UV radiation away from the skin. Additionally, many modern formulations contain antioxidants that neutralize free radicals generated by UV exposure, thereby reducing oxidative stress and cellular damage.

#### **5. Skin and UV Interaction**

Human skin consists of three primary layers: the epidermis, dermis, and hypodermis. UVB radiation primarily affects the epidermis, causing sunburn and direct DNA damage, while UVA radiation penetrates deeper into the dermis, leading to collagen degradation and premature aging. DNA damage occurs through both direct absorption of UVB radiation and indirect mechanisms involving reactive oxygen species generated by UVA radiation. These processes contribute to mutations, cellular dysfunction, and the development of skin cancers.

#### **6. Formulation Aspects**

Sunscreen formulations consist of a combination of active and inactive ingredients designed to ensure efficacy, stability, and user acceptability. Active ingredients include UV filters, while inactive components such as emollients, emulsifiers, preservatives, antioxidants, fragrances, and colorants enhance the formulation's performance and aesthetic appeal. Sunscreens are typically formulated as oil-in-water or water-in-oil emulsions, gels, or sprays, depending on the desired characteristics. An ideal sunscreen should provide broad-spectrum protection, be photostable, non-toxic, water-resistant, and easy to apply.

## **7. Sun Protection Factor (SPF)**

Sun Protection Factor (SPF) is a measure of a sunscreen's ability to protect against UVB radiation. It is defined as the ratio of the minimal erythema dose (MED) of protected skin to that of unprotected skin. For example, SPF 15 blocks approximately 93% of UVB radiation, SPF 30 blocks 97%, and SPF 50 blocks 98%. Although higher SPF values provide greater protection, no sunscreen can block 100% of UV radiation, and proper application and reapplication are essential for effective protection.

## **8. Evaluation of Sunscreens**

The evaluation of sunscreens involves both in vitro and in vivo methods. In vitro techniques include UV spectrophotometry and diffuse reflectance spectroscopy, which assess the absorption and reflection of UV radiation. In vivo methods involve determining the minimal erythema dose on human subjects. Stability testing is also conducted to evaluate the formulation's resistance to heat, light, and environmental conditions, ensuring product safety and efficacy throughout its shelf life.

## **9. Safety and Toxicity Concerns**

Despite their widespread use, sunscreens may cause adverse effects such as allergic reactions, contact dermatitis, and acne. Some chemical UV filters have been associated with potential endocrine disruption, although this remains a topic of debate. Environmental concerns have also been raised, as certain sunscreen ingredients may contribute to coral reef damage and marine toxicity. These issues have led to increased interest in safer and eco-friendly alternatives.

## **10. Regulatory Aspects**

Sunscreens are regulated differently across the world. In the United States, they are classified as over-the-counter drugs and regulated by the FDA, while in Europe they are considered cosmetic products. In India, sunscreens are regulated under the Central Drugs Standard Control Organization (CDSCO) and Bureau of Indian Standards (BIS). Regulatory guidelines ensure product safety, efficacy, and proper labeling, including SPF value, usage instructions, and water resistance claims.

## **11. Herbal and Natural Sunscreens**

Natural and herbal sunscreens have gained popularity due to their perceived safety and environmental benefits. Plant-based ingredients such as Aloe vera, green tea polyphenols,

turmeric, and sandalwood exhibit antioxidant and anti-inflammatory properties that provide photoprotection. These agents are often used in combination with conventional UV filters to enhance efficacy.

## **12. Nanotechnology in Sunscreens**

Nanotechnology has revolutionized sunscreen formulations by improving transparency, stability, and UV protection. Nanoparticles of zinc oxide and titanium dioxide provide effective broad-spectrum protection without leaving a visible white residue. However, concerns regarding the safety and environmental impact of nanoparticles are still under investigation.

## **13. Advanced Delivery Systems**

Advanced delivery systems such as liposomes, solid lipid nanoparticles, nanoemulsions, and microencapsulation techniques have been developed to enhance the performance of sunscreens. These systems improve the stability, skin penetration, and controlled release of active ingredients, resulting in better protection and longer-lasting effects.

## **14. Photoaging and Skin Cancer Prevention**

Photoaging is characterized by wrinkles, pigmentation, and loss of skin elasticity due to prolonged UV exposure. Regular use of sunscreen significantly delays these effects and helps maintain healthy skin. Sunscreens also play a critical role in preventing skin cancers, including basal cell carcinoma, squamous cell carcinoma, and melanoma, by reducing DNA damage and mutagenesis.

## **15. Environmental Impact and Future Trends**

The environmental impact of sunscreens has become an important consideration in recent years. Certain chemical UV filters have been implicated in coral bleaching and marine toxicity, leading to the development of eco-friendly and biodegradable formulations. Emerging trends in sunscreen technology include hybrid formulations, DNA repair enzymes, smart sunscreens, and AI-based skin analysis tools. Future research is focused on developing safer, more effective, and sustainable sunscreen products.

## **16. CONCLUSION**

Sunscreens are indispensable in modern skincare, providing essential protection against harmful ultraviolet radiation. Advances in formulation science, nanotechnology, and natural

product research have significantly improved their efficacy and safety. Regular use of broad-spectrum sunscreen, along with other protective measures, is crucial for preventing skin damage, photoaging, and skin cancer. Continued research and innovation will further enhance the role of sunscreens in promoting skin health and environmental sustainability.

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