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A Review: Formulation and Evolution of Sunscreen

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Abstract: ***Sunscreens are vital skincare items used to shield the skin from ultraviolet (UV) radiation's damaging effects. They are essential in avoiding skin cancer, sunburn, and early ageing. According to their active components and mode of action, sunscreens are often divided into two categories: chemical (organic) and physical (mineral). The creation of broad-spectrum, photos table, and aesthetically pleasing sunscreens has been made possible by advancements in formulation technology. Their effectiveness and safety are guaranteed by evaluation techniques including SPF, PPD, and photo stability testing. To guarantee product quality, regulatory agencies such as the FDA, EU, and CDSCO offer stringent criteria. Research on sustainable and customized sunscreen solutions has been fuelled by growing consumer awareness, environmental concerns, and desire in herbal and reef-safe substitutes.***

Keywords: ***Sunscreen, UV radiation, SPF, UVA/UVB protection, physical sunscreen, chemical sunscreen, photo stability, nanotechnology, herbal sunscreen, reef-safe, regulatory guidelines, formulation, consumer awareness, antioxidant, personalized skincare.***

I. INTRODUCTION

Life requires exposure to sunshine because it helps produce vitamin D and preserves circadian rhythm. However, excessive and unprotected exposure to ultraviolet (UV) radiation can seriously harm the skin, increasing the chance of developing melanoma and non-melanoma skin cancers as well as disorders like sunburn, photo aging, and hyperpigmentation. Given these dangers, using sunscreen has emerged as a commonly advised and successful preventative strategy to protect the skin from damaging UV rays[1-2].

Depending on its active components, sunscreen—also referred to as sunblock or sun cream—is a topical preparation that either reflects or absorbs UV rays.

It acts as a barrier to shield the skin from damaging rays that can result in both immediate and long-term skin damage. The worldwide sunscreen market has grown significantly due to increased knowledge of skincare and the prevalence of UV-related illnesses. It has expanded into a variety of formulations, including creams, gels, lotions, sprays, and sticks, each of which is customized to suit a distinct skin type and preference. UVA (320–400 nm), UVB (290–320 nm), and UVC (100–290 nm) photons make up the majority of the UV spectrum[3-4].

UVA and UVB enter the skin to varying depths and cause different types of skin damage, but UVC is primarily absorbed by the Earth's ozone layer and does not reach the surface. While UVB is the main cause of sunburn and has a major role in the development of skin cancer, UVA is linked to photo aging and long-term skin deterioration. In order to protect the skin from both UVA and UVB rays, contemporary sunscreens are made to provide broad-spectrum protection[5].

Physical (inorganic) and chemical (organic) sunscreens are the two main categories into which sunscreens are often divided according to their composition and method of action. Physical sunscreens that reflect or scatter UV radiation include zinc oxide and titanium dioxide. Because of their low risk for irritation, they are frequently suggested for sensitive skin. Conversely, chemical sunscreens use chemicals like oxybenzone, octinoxate, and avobenzone to absorb UV rays and transform them into heat. To improve stability and protection, both kinds can be applied alone or in combination.

A commonly accepted metric for assessing how well a sunscreen blocks UVB rays is the Sun Protection Factor (SPF). While no sunscreen can completely filter UV rays, higher SPF ratings provide better protection[6].

Despite the well-established advantages of sunscreens, many customers do not use them correctly or regularly, sometimes as a result of ignorance or worries about the safety of the ingredients. The environmental effects of some chemical sunscreen chemicals on marine ecosystems, particularly coral reefs, have also been the subject of recent research. As a result, some places have developed reef-safe alternatives and restrictions.The goal of this study is to present a thorough analysis of sunscreen formulations, classifications, and modes of action, important components, assessment techniques, regulatory issues, and new developments, including the function of natural and herbal sunscreens. Additionally, consumer behaviours, safety, effectiveness, and the future course of sunscreen development in dermatological and cosmetic sciences will be emphasized[7-8].

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II. TYPES OF UV RADIATION

A skincare product called sunscreen is intended to protect the skin from the damaging effects of ultraviolet (UV) radiation that the sun emits. UVA and UVB rays are the two primary forms of UV radiation that have an impact on the skin[9]. deepest layer of skin, the dermis, is deeply penetrated by UVA photons, which have a longer wavelength. Premature skin ageing, which includes wrinkles, fine lines, and age spots, is mostly their fault. Skin malignancies can also develop as a result of prolonged exposure to UVA radiation. Conversely, UVB rays have a shorter wavelength and primarily damage the epidermis, the skin's outermost layer. These rays contribute significantly to the development of skin cancer and are the main cause of sunburn[10].

UV rays are either absorbed, reflected, or scattered by sunscreens. Sunscreens come in two primary varieties: chemical and physical (mineral). Zinc oxide and titanium dioxide are examples of active mineral compounds used in physical sunscreens that physically block UV radiation by sitting on top of the skin. Organic substances like oxybenzone, avobenzone, or octinoxate, which are found in chemical sunscreens, absorb UV rays and transform them into innocuous heat[11].

Broad-spectrum sunscreens are advised for efficient skin protection since they provide defence against both UVA and UVB radiation. A vital component of everyday skincare, sunscreen with an SPF (Sun Protection Factor) of at least 30 helps prevent sunburn, lowers the risk of skin cancer, and delays the onset of ageing[12].

III. CLASSIFICATION OF SUNSCREENS

Sunscreens are categorized according to their formulation, protective range, and mode of action. Sunscreens fall into two main categories: chemical (organic) and physical (inorganic)[13].

Physical sunscreens, sometimes referred to as mineral sunscreens, are made using natural mineral components such as titanium dioxide and zinc oxide. These substances reflect or disperse UV rays while remaining on the skin's surface. They offer broad-spectrum defence against UVA and UVB radiation and start working as soon as they are applied[14].

Chemical sunscreens: These include organic substances that absorb UV photons and transform them into innocuous heat, such as oxybenzone, avobenzone, octinoxate, and octocrylene. Formulations sometimes contain many components for broad-spectrum coverage since each chemical agent targets distinct wavelengths. Broad-spectrum sunscreens: These formulations offer complete defence against UVA and UVB rays by combining chemical and physical ingredients. It is advised to use them every day to avoid skin cancer and photo aging.

Water-resistant sunscreens are specially designed to be effective for a certain amount of time in the water (often 40 to 80 minutes), making them perfect for swimming or perspiration[15].

IV. MECHANISM OF ACTION

Sunscreens use two primary methods to shield the skin from damaging ultraviolet (UV) rays: absorption and reflection/scattering. Chemical sunscreens use chemical substances like octinoxate and avobenzone to absorb UV rays and transform the energy into innocuous heat. Physical sunscreens, on the other hand, contain particles like titanium dioxide or zinc oxide that rest on the skin's surface and scatter or reflect UV radiation away from the skin. For broad-spectrum protection, several contemporary formulations combine the two methods. Sunscreens help prevent sunburn, premature ageing, skin cancer, and other photo damage by blocking or neutralizing UV light[16-20].

A. Ingredients Used in Sunscreens:

Active chemicals included in sunscreens offer defence against ultraviolet (UV) rays. These can be roughly divided into two categories: chemical (organic) and physical (mineral) filters[21-25].

Physical components consist of:

Oxide of zinc

Dioxide of titanium

These reflect or disperse UVA and UVB rays when they rest on the skin's surface. They provide instant protection and are kind to delicate skin.

Among the chemical components are:

Avobenzone is a UVA ray protector.

Oxybenzone absorbs certain UVA and UVB rays.

The main absorbers of UVB radiation include Octinoxate, Octisalate, Homosalate, and Octocrylene.

UV rays are absorbed by these substances and transformed into heat. Chemical sunscreens are easier to apply and have a more refined appearance.

To improve skin benefits, stability, and user experience, sunscreens also contain emollients, preservatives, scents, and antioxidants (such as vitamin E or green tea extract). Multiple agents are used in broad-spectrum sunscreens to provide total UVA and UVB protection[26-30].

V. FORMULATION OF SUNSCREENS

Active chemicals and basic ingredients are carefully blended during the sunscreen formulation process to provide stability, efficient UV protection, and aesthetic acceptance. Avobenzone, octinoxate, and oxybenzone are examples of chemical (organic) UV filters, whereas physical (mineral) UV filters include zinc oxide and titanium dioxide.

These active ingredients are added to an appropriate foundation, often an oil-in-water (O/W) emulsion, which gives it a non-greasy feel and good spreadability. To preserve consistency, skin moisture, and product stability, the base contains emollients, thickeners, preservatives, emulsifiers, and humectants.

To shield skin from oxidative stress, antioxidants such as vitamin E, niacinamide, or green tea extract are frequently applied. For increased consumer appeal, fragrances, colorants, and skin-soothing ingredients like panthenol or aloe vera may be added[31-32].

VI. EVALUATION OF SUNSCREENS

1) *Sun Protection Factor (SPF) Test*
- Definition: Measures protection against UVB radiation, indicating how long sunscreen prevents sunburn compared to unprotected skin.
- Standard Range:
  - SPF 15: Blocks ~93% UVB
  - SPF 30: Blocks ~97% UVB
  - SPF 50: Blocks ~98% UVB

2) *Persistent Pigment Darkening (PPD) Test*
- Definition: Evaluates protection against UVA radiation by measuring skin tanning or darkening.
- Standard Range:
  - PPD ≥ 8 is considered good UVA protection.

3) *Boots Star Rating System*
- Definition: Compares UVA protection to UVB protection, represented by stars (1 to 5).
- Standard Range:
  - 4-5 stars = High UVA protection relative to SPF.

4) *Water Resistance Test*
- Definition: Assesses sunscreen's ability to maintain SPF after water exposure.
- Standard Range:
  - Water-resistant: Maintains SPF after 40 minutes in water
  - Very water-resistant: Maintains SPF after 80 minutes in water

5) *Photo stability Test*
- Definition: Evaluates the stability of sunscreen ingredients upon UV exposure.
- Standard Range:
  - Active ingredients should not degrade significantly under UV exposure.

6) *In-vitro Transmittance Test*
- Definition: Measures UV absorption or reflection through a film of sunscreen on a substrate.
- Standard Range: Depends on SPF claim; must meet ISO or FDA standards for UV absorption curves[33-35]

VII. REGULATORY ASPECTS

1) Depending on the nation, sunscreens are either regulated as cosmetics or over-the-counter (OTC) medications. The FDA in the US categorizes sunscreens as over-the-counter medications and mandates adherence to monograph requirements, which include effectiveness testing, SPF labelling, and Authorised active ingredients.
2) Sunscreens are regarded as cosmetics in the EU and are subject to EU Cosmetic Regulation (EC) No 1223/2009, which guarantees product safety, ingredient disclosure, and UVA/UVB protection.

3) Sunscreens are governed by cosmetic norms set out by the CDSCO in India. Stability, safety, and efficacy data must be provided by manufacturers worldwide. Statements such as "broad-spectrum," "water-resistant," or SPF ratings need to be supported by standardized laboratories[36-37].

A. *Side Effects and Safety Concerns:*

Particularly in sensitive people, certain sunscreens might result in acne, allergic reactions, or skin irritation. Chemical components such as oxybenzone have sparked worries about their effects on the environment and hormones. Although they may leave a white cast, physical sunscreens are usually safer. For safety, always use broad-spectrum, non-comedogenic formulas that have been evaluated by dermatologists[38-39].

B. *Recent Advances in Sunscreens:*

The goals of recent advancements in sunscreen technology are to improve environmental safety, user experience, and efficacy. Chemical and mineral filters are used in hybrid sunscreens to provide broad-spectrum protection and enhanced aesthetic appeal. Improvements in chromophore chemicals and formulations based on nanoparticles have produced sunscreens with improved photo stability and UV protection. Furthermore, new formulations include radiative cooling technology, which helps reduce skin temperature and protects the skin from UV radiation, improving comfort while exposed to the sun. These advancements seek to accommodate customer preferences and environmental concerns while offering complete sun protection[40-41].

C. *Consumer Awareness and Usage Patterns:*

According to studies, even though a large number of consumers understand the value of sun protection, real sunscreen use varies. According to a poll, 79% of Americans have been sunburnt, yet just 20% of them wear sunscreen every day. It is used 100% of the time in the summer, 75% in the spring, 57% in the autumn and 46% in the winter. Despite knowledge of the dangers of skin cancer, few people regularly use it. Furthermore, 27% of respondents choose sunscreens that are reef-safe, which reflects rising environmental concerns. These trends show how important it is to improve public awareness of regular, year-round sun protection measures[42-43].

D. *Role of Herbal Sunscreens:*

Herbal sunscreens minimize the negative effects of synthetic chemicals while shielding the skin from damaging UV rays by using natural components. Aloe vera, green tea, turmeric, sandalwood, and liquorice are examples of plant-based extracts that have anti-inflammatory, antioxidant, and UV-absorbing qualities. These components aid in reducing sun-induced skin damage, calming inflammation, and neutralizing free radicals. Customers with sensitive skin or those looking for chemical-free, environmentally responsible options like herbal sunscreens. When used in conjunction with physical filters such as zinc oxide, they frequently offer broad-spectrum protection. Because of their environmental friendliness, safety, and skin-benefitting properties, herbal sunscreens are becoming more and more popular as interest in natural skincare grows[44].

VIII. FUTURE SCOPE

1) Advanced Nanotechnology Formulations- Development of Nano-sized UV filters for enhanced skin penetration, transparency, and broad-spectrum protection without leaving a white cast.
2) Eco-Friendly and Reef-Safe Ingredients-Rising demand for biodegradable, non-toxic sunscreens that do not harm marine ecosystems, promoting sustainable formulations.
3) Herbal and Bioactive-Based Sunscreens-Increased research on plant-derived UV protectants with antioxidant and healing properties for safer, natural alternatives.
4) Smart Sunscreens and Wearable UV Sensors-Integration of technology to monitor UV exposure and signal when reapplication is needed, improving compliance.
5) Personalized Sunscreen Products- Customized formulations based on individual skin type, tone, and UV sensitivity, using AI and dermatological data[45].

IX. CONCLUSION

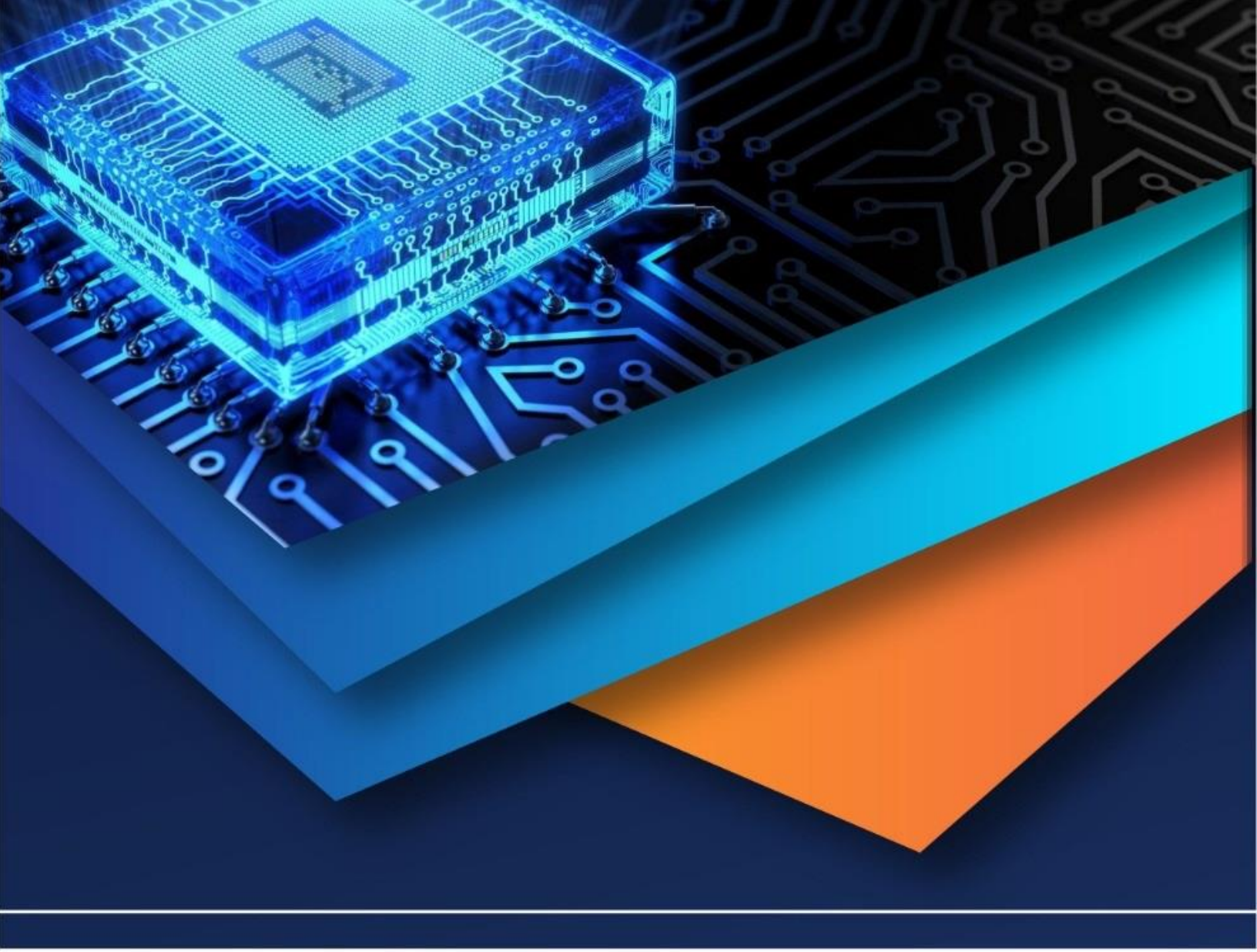
Sunscreens continue to be an essential component of dermatological and cosmetic treatment because they provide vital defence against UV-induced cancer and skin damage.

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There is a noticeable trend towards safer, more effective, and ecologically friendly sunscreen products as skin health becomes more widely recognized. There are advantages to both chemical and physical sunscreens, and more recent hybrid formulas provide well-rounded protection. In order to verify efficacy, evaluation techniques including SPF, PPD, and photo stability testing are essential. Regulatory frameworks use uniform ingredient and labelling guidelines to guarantee consumer safety. A more individualized and sustainable future is suggested by recent advancements in nanotechnology, bioactive plant extracts, and smart sunscreen technologies. Because to their minimal side effects and natural effectiveness, herbal sunscreens are becoming more and more popular. The market will probably change as research progresses and technology and biotechnology are included into sunscreen creation. Customized, high-performing, environmentally friendly sunscreen formulas that accommodate a range of skin types and lifestyles worldwide are the way of the future.

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