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A Comprehensive Review of Natural Sunscreens: Efficacy, Safety, and Environmental Impact

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ABSTRACT

The growing demand for safer, eco-friendly, and sustainable skincare products has led to increasing interest in herbal and natural sunscreen formulations. These sunscreens incorporate botanical ingredients with inherent ultraviolet (UV) protective properties, such as *Aloe vera*, *Camellia sinensis* (green tea), *Curcuma longa* (turmeric), and *Ocimum sanctum* (tulsi), offering photoprotection through antioxidant, anti-inflammatory, and UV-absorbing mechanisms. Preparation methods typically involve solvent extraction and formulation into emulsions, gels, or creams. Compared to synthetic sunscreens, herbal formulations provide advantages such as biocompatibility, reduced risk of skin irritation, and environmental safety. However, challenges persist in achieving consistent sun protection factor (SPF), ensuring stability, and navigating regulatory standards. Regulatory frameworks, including those from the FDA and EMA, often focus on physical blockers like zinc oxide and titanium dioxide, with limited provisions for herbal actives. Despite these limitations, natural sunscreens represent a promising avenue for future photoprotective innovations, provided their efficacy and safety are rigorously validated.

Keywords: Natural Sunscreens, Efficacy, Safety, and Environmental Impact

INTRODUCTION

According to the FDA and the EU Cosmetic Regulation, cosmetics are substances applied to the body—especially the skin, hair, nails, and lips—to cleanse, beautify, or promote attractiveness without affecting the body's structure or functions (Alnuqaydan AM et al., 2024). This broad category includes skincare products, makeup, lotions, perfumes, hair care items, toothpaste, and deodorants. Used for thousands of years across various cultures, cosmetics have evolved from simple natural ingredients to sophisticated formulations developed through modern science (Khan AD et al., 2019). Beyond enhancing appearance, cosmetics also contribute to personal hygiene, skin health, and self-care. For students, they offer a means of self-expression, boost confidence, and support readiness for professional environments where appearance can play a significant role (KI Martin et al., 2011).

The skin is the largest organ of the body and has **three main layers** as shown in the Figure 1.

1. **Epidermis**
This is the outermost layer of the skin. It acts like a shield, protecting the body from dirt, germs, and harmful sunlight. It also gives skin its color because it contains a pigment called melanin.

2. **Dermis**
This is the middle layer under the epidermis. It's where you find important stuff like blood vessels, sweat glands, hair follicles, and nerve endings. The dermis helps the skin feel things like touch, pain, and temperature.

3. **Hypodermis (or Subcutaneous Layer)**
This is the deepest layer of the skin. It's mostly made up of fat and connective tissue, which helps insulate the body and protect muscles and organs underneath. HYousef et al ., 2024

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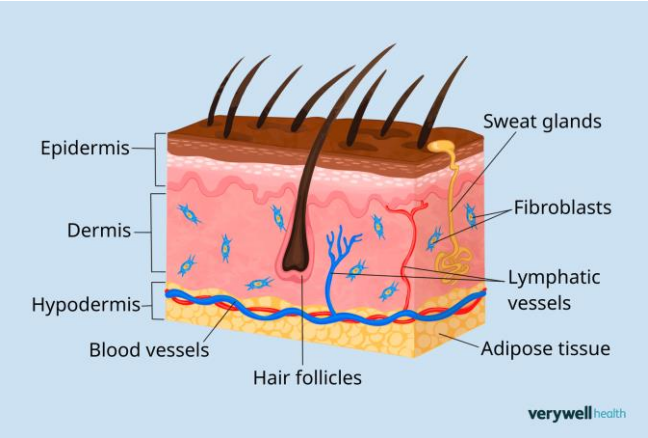

Figure 1: Structure of Skin

Herbal Sunscreen:

Herbal sunscreen is a type of sun protection cream made mainly from natural plant-based ingredients like aloe vera, turmeric, green tea, or neem. These ingredients help protect the skin from harmful UV rays while also providing soothing, anti-inflammatory, and antioxidant benefits. Donglikar MM et al., 2017

Herbal sunscreens use minerals, essential oils, and botanical extracts that have anti-inflammatory, antioxidant, and UV-absorbing qualities in place of artificial chemicals. Aloe vera, green tea, licorice, turmeric, sandalwood, and chamomile are examples of common herbal components. People looking for natural and holistic skincare solutions favour these products because they promise to provide broad-spectrum protection while being kind to the skin and the environment. Mansuri R et al., 2021

Objectives:

 UV Protection: Herbal sunscreens provide effective protection against harmful UV-A and UV-B rays using natural, plant-based compounds. Liyan Li et al., 2022

 Gentle on Skin: Formulations are designed to reduce the risk of skin irritation and allergic reactions, making them suitable for sensitive skin.

 Eco-Friendly: They utilize biodegradable and environmentally friendly ingredients that are safe for aquatic ecosystems, including coral reefs.

 Skin Benefits: Enriched with antioxidant and anti-inflammatory herbal extracts, these sunscreens help nourish, soothe, and protect the skin.

 Natural Alternative: Offer a chemical-free option for sun protection, appealing to consumers seeking holistic and natural skincare solutions.

 Sustainability-Oriented: Support eco-conscious beauty trends by promoting sustainable and plant-based skincare practices. Geoffrey K et al., 2019

Advantages and Disadvantages

Table 1: Advantages and Disadvantages of Herbal Sunscreen

Advantages	Disadvantages
• **Skin-Friendly Formulation**: Contain plant-based ingredients that are less likely to irritate the skin or cause allergic reactions. • **Nourishing Extracts**: Often include beneficial botanical extracts like aloe vera, green tea, turmeric, and chamomile with anti-inflammatory and antioxidant properties. • **Environmental Benefits**: Many are reef-safe and biodegradable, minimizing environmental impact. • **Ethical Appeal**: Frequently vegan and cruelty-free, aligning with consumer values around ethical and holistic skincare. • **Chemical-Free**: Serve as a natural alternative to chemical-laden sunscreens, attracting health-conscious users. Shah Y et al., 2023	Lower **SPF Protection**: Often offer less SPF coverage compared to conventional sunscreens. Frequent **Reapplication**: May require more frequent reapplication, especially in water or strong sunlight. White **Cast Issues**: Mineral components like zinc oxide can leave a visible white cast, particularly on darker skin tones. Shorter **Shelf Life**: Lack of strong synthetic preservatives can reduce shelf life and product stability. Inconsistent **Performance**: Effectiveness may vary between brands due to differences in ingredient quality and formulation. Resende DI et al., 2022

Benefits of Sunscreen:

Protects against UV radiation: Shields the skin from harmful UVA and UVB rays.

Reduces skin cancer risk: Regular use lowers the chances of developing skin cancer.

Prevents sunburn: Minimizes the likelihood of painful sunburns.

Slows signs of aging: Helps prevent early aging signs such as fine lines, wrinkles, and hyper pigmentation.

Maintains even skin tone: Prevents dark spots and discoloration caused by sun exposure.

Soothes sensitive skin: Protects sensitive or hypersensitive skin from sun-induced flare-ups and irritation.

Preserves skin proteins: Helps retain essential proteins like collagen, elastin, and keratin for healthy skin structure.

Supports long-term skin health: Daily use—whether mineral-based or chemical-based promotes overall skin wellness. Burnett ME et al., 2011

TYPES OF SUNSCREEN:

Sunscreen is a product that helps protect the skin from the harmful effects of UV radiation (mainly UVB and UVA), preventing sunburn, premature aging, and skin cancer. It does this by either absorbing, reflecting, or scattering UV rays. Maier T et al., 2005

Table 2: Types of sunscreen and their properties

Type of Sunscreen	Definition	MOA	Common Ingredients
Chemical sunscreen	Sunscreens that use organic (carbon-based) compounds to absorb UV radiation and convert it into heat.	Absorbs UV rays and turns them into heat.	- Avobenzone - Octinoxate - Oxybenzone - Octocrylene
Physical (Mineral) sunscreen	Sunscreens made with natural minerals that sit on the skin's surface and reflect or scatter UV radiation.	Reflects and scatters UV rays.	- Zinc oxide - Titanium dioxide

Herbal (Natural) sunscreen	Sunscreens made from plant-based extracts that provide natural UV protection, often with antioxidant properties.	Provides natural UV protection by absorbing and neutralizing UV rays.	- Aloe vera - Green tea extract - Licorice extract - Raspberry seed oil - Carrot seed oil

SPF [Sun Protection Factor]

SPF (Sun Protection Factor) is a measure of how well a sunscreen protects the skin from sunburn caused by UVB rays.
It indicates how much longer a person can stay in the sun without getting burned compared to having no protection.

- UVB (B for Burning)

→ These rays mainly cause sunburn.
→ They damage the top layers of your skin.
→ UVB is the main cause of skin cancers too.

- UVA (A for Aging)

→ These rays go deeper into your skin.
→ They cause wrinkles, tanning, and aging signs.
→ UVA also plays a role in skin cancer, but it's more about long-term damage.

Both UVA and UVB come from the sun and can harm your skin, just in different ways. That's why many sunscreens say "broad-spectrum" — it means they protect against both types. Schulz J et l.,2002

The SPF number indicates how much protection a sunscreen offers against UVB rays, which are the main cause of sunburn. For example, a sunscreen with SPF 15 blocks about 93% of UVB rays, while SPF 30 blocks around 97%. An SPF 50 sunscreen provides 98% protection, and an SPF 100 blocks about 99% of UVB rays. While higher SPF numbers provide slightly more protection, it's important to note that no sunscreen can block 100% of UVB rays. Regular reapplication is also key to maintaining effective protection. Rantika N et al., 2024

Natural Sunscreen

Natural sunscreen defined as a sunscreen formulation that primarily uses naturally derived ingredients to protect the skin from UV radiation. These products typically rely on physical blockers such as zinc oxide and titanium dioxide, which sit on the skin's surface to reflect and scatter UV rays. Additionally, they may contain plant-based extracts such as aloe vera, green tea, and raspberry seed oil, which offer antioxidant benefits and support the skin's natural defense mechanisms. Unlike chemical sunscreens, natural sunscreens generally avoid synthetic ingredients and chemicals, making them a preferred choice for those seeking non-toxic, hypoallergenic, and environmentally friendly alternatives. Schulz J et al., 2002

Uses of natural sunscreens in short points:

1. **Sun Protection** – Shields skin from harmful UV rays (UVB and UVA).
2. **Sensitive Skin** – Ideal for individuals with sensitive or allergic skin.
3. **Environmental Protection** – Reef-safe and eco-friendly, without harmful chemicals.
4. **Daily Protection** – Suitable for everyday use to prevent skin aging and damage.
5. **Moisturization** – Often includes hydrating ingredients like aloe vera and vitamin E. Rantika N et al.,2024

Table 3: Advantages and Disadvantages of Natural Sunscreen

Advantages	Dis-advantages
Broad-Spectrum Protection: Natural sunscreens, especially those with zinc oxide or titanium dioxide, provide broad-spectrum protection against both UVA (aging) and UVB (burning) rays, offering effective sun protection.	Lower SPF: Some natural sunscreens may offer lower SPF ratings compared to chemical sunscreens, though this can vary. Higher SPF natural sunscreens are available, but they may be harder to find.
Reef-Safe: Many natural sunscreens are made with mineral-based ingredients and are considered reef-safe, meaning they don't contain harmful chemicals that can damage coral reefs and marine life.	Greasy or Oily Feel: Some natural sunscreens may feel greasy or heavy on the skin, especially those containing oils or butters, which might not be ideal for people with oily or acne-prone skin.
No Synthetic Chemicals: Natural sunscreens tend to avoid synthetic chemicals like oxybenzone, octinoxate, and other potential endocrine disruptors, appealing to those who prefer clean beauty or eco-friendly products.	Shorter Wear Time: Natural sunscreens may not stay on the skin as long as chemical sunscreens, meaning they might need to be reapplied more frequently, especially after swimming or sweating.
Moisturizing Ingredients: Many natural sunscreens include ingredients like aloe vera, green tea extract, and vitamin E, which provide additional moisturizing and antioxidant benefits for the skin. Kadawla M et al.,2022	Potential for Inconsistent Protection: While natural sunscreens can provide effective sun protection, not all natural ingredients are as well-tested or as effective as chemical sunscreens, meaning the level of protection might not be as consistent. Donglikar MM et al.,2022

Sunscreen has several important applications

1. Prevents Sunburn

- The primary purpose of sunscreen is to protect the skin from harmful UV radiation. By blocking or absorbing UV rays, sunscreen prevents sunburns, which can cause redness, pain, and peeling.

2. Reduces Risk of Skin Cancer

- Regular use of sunscreen helps reduce the risk of developing skin cancers, such as melanoma, basal cell carcinoma, and squamous cell carcinoma, which are often caused by prolonged UV exposure. Sunscreen acts as a barrier to harmful UV radiation that can damage skin cells and DNA.

3. Prevents Premature Aging (Photoaging)

- Sunscreen helps to prevent these signs of premature aging by protecting the skin from UV damage.

4. Reduces Hyperpigmentation

- Sunscreen helps in reducing and preventing the worsening of skin pigmentation issues such as melasma, sunspots, and age spots. Sunscreen helps to keep this under control.

5. Protects Sensitive Skin

- For individuals with sensitive skin, conditions like rosacea or eczema can worsen with sun exposure. Sunscreen helps protect these delicate skin types from irritation and flare-ups caused by UV rays.

6. Helps With Post-Procedure Care

- After dermatological procedures like chemical peels, laser treatments, or microdermabrasion, the skin is often more sensitive to UV radiation.

7. Prevents Skin Inflammation

- Chronic sun exposure can lead to inflammation of the skin, exacerbating conditions like acne or psoriasis. Sunscreen helps reduce this inflammation by protecting the skin from UV-induced irritation.

8. Sun Protection During Outdoor Activities

- Sunscreen ensures long-lasting protection while you're active in the sun, particularly if you sweat or come into contact with water. Water-resistant sunscreens help keep your skin protected under these conditions.

9. Protection in Winter and Altitudes

- Even in cold weather, UV rays can be harmful, especially in snowy conditions or at higher altitudes. Snow reflects UV radiation, increasing exposure, while higher altitudes mean stronger UV rays. Sunscreen helps in these scenarios to prevent damage. Morabito K et al.,2011.

Method of preparation

Types of Sunscreen Preparation Methods

1. Emulsion-Based Technique (Water-in-Oil or Oil-in-Water)
The most popular technique for making natural sunscreen is this one. It entails combining a water phase (including hydrosols, humectants, and herbal extracts) with an oil phase (containing oils, waxes, and UV filters like zinc oxide or titanium dioxide). To create a stable cream or lotion, the stages are heated independently and then emulsified while being constantly stirred.
• Oil-in-Water (O/W): Better for everyday usage, non-greasy, and lighter in texture.
• Water-in-Oil (W/O): Perfect for outdoor or sporting applications, this substance is thicker and more water-resistant.

2. Anhydrous (Water-Free) Formulation

These sunscreens are made entirely of oils, butters, waxes, and powdered UV filters; no water is added. This kind of preparation produces solid lotions, balms, or sticks that are very stable, have a longer shelf life, and are perfect for use on delicate skin or when traveling. Arianto A et al ., 2018

3. Formulation Based on Gel
Aloe vera gel or other natural thickeners (such as xanthan gum or guar gum) are utilized to make a light, moisturizing solution in gel-based sunscreens. These frequently contain hydrosols or herbal infusions and are perfect for skin types that are prone to oiliness or acne. Geoffrey K et al ., 2019

4. Mist or Spray Compositions
Spray sunscreens are made with a water-alcohol basis or light oils (such fractionated coconut oil) for a rapid and simple application. Although they might have a lesser SPF or water resistance than creams, these need the UV filters to be properly emulsified and dispersed to guarantee equal coverage. Chavda VP et al ., 2023

5. Nano and Micronized Formulations
Certain sophisticated natural sunscreens may contain non-nano or micronized zinc oxide or titanium dioxide particles for improved spreadability and aesthetic appeal (lessening the white cast). Although these particles are specifically chosen to stay on the skin's surface rather than penetrate it, the safety and regulatory approval of this technique are frequently contested. Darmawan MA et al ., 2022

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Some herbs used for Herbal Sunscreens

1. GUAVA LEAF

Figure 2: Guava Leaf

- High in Antioxidants: High amounts of vitamin C, flavonoids, and polyphenols found in guavas in figure 2 aid in scavenging UV-generated free radicals. These antioxidants guard against photoaging and oxidative stress in skin cells.

- Organic UV-Absorbing Substances: Phenolic chemicals in guava leaves and fruit extracts have been found in studies to have the ability to absorb UV radiation, offering a natural kind of sun protection. Using guava extract in topical formulations has shown moderate sun protection factor (SPF) activity.

- Properties That Reduce Inflammation: Quercetin and ellagic acid, two bioactive substances found in guava, lessen inflammation brought on by UV radiation.This aids in calming skin that has been burnt or inflamed.

- Safe and Natural: As a plant-based ingredient, guava extract is considered non-toxic, biodegradable, and eco-friendly, aligning with the demand for herbal and reef-safe sunscreens. D Dewage et al., 2022

2. MANJISTHA

Figure 3: MANJISTHA *(Rubia cardifolia)*

- Packed with Antioxidants: Anthraquinones, flavonoids, and tannins found in manjistha in figure 3 have strong anti-free radical properties. These antioxidants shield skin cells from photoaging and oxidative damage brought on by UV radiation.

- UV-Absorbing Substances: Manjistha has phytoconstituents such purpurin and rubiadin that have demonstrated the ability to absorb UV radiation, making it a natural photoprotective agent.

- Reduction of Inflammation: In Ayurveda, manjistha is prized for its blood-purifying and anti-inflammatory qualities. When used topically, it can help reduce sun-induced skin irritation and inflammation.

- Skin Healing and Brightening: Manjistha has long been used to treat pimples, acne, and hyperpigmentation. It may also help promote even skin tone and lessen dark spots caused by UV rays. It is appropriate for skin restoration following sun exposure since it promotes collagen renewal and wound healing.

- Natural and non-toxic: Manjistha is a plant-based, non-toxic, biodegradable product that is appropriate for sensitive skin and fits in with the holistic and eco-conscious skincare movement. Indira S et al.,2022

3. TURMERIC

Figure 4: Turmeric

- High Level of Antioxidant Activity: Curcumin, a potent antioxidant that counteracts free radicals produced by UV exposure, is abundant in turmeric as in figure 4. Aids in preventing oxidative stress-induced skin cell damage, fine wrinkles, and photoaging.

- Organic UV Defence: Curcumin is a good option for natural SPF formulations because of its UV-absorbing qualities, especially in the UV-B spectrum. According to studies, adding turmeric extracts to herbal sunscreen bases raises the SPF value.

- Reduction of Inflammation: Additionally, curcumin has strong anti-inflammatory properties that help lessen sunburn's redness, swelling, and irritation. Aids in the quicker healing and calming of sun-damaged skin.

- Skin Healing and Brightening: used in Ayurveda for centuries to create an even skin tone, lessen imperfections, and diminish hyperpigmentation. Antimicrobial Characteristics: Turmeric can help prevent infections on sun-exposed skin because of its antibacterial and antifungal properties.

- Non-toxic and natural: It is eco-friendly, reef-safe, and perfect for skin that is sensitive or prone to allergies because it is biodegradable and safe for the skin. Gharbavi M et al ., 2018

4. LEMON PEEL

Figure 5: Lemon peel

- Packed with Vitamin C and Flavonoids: Vitamin C (ascorbic acid), flavonoids, and citric acid—all of which have potent antioxidant qualities—are abundant in lemon peel as in figure 5. These substances lower the chance of photoaging by shielding the skin from oxidative stress brought on by UV rays.

- Potential for UV Absorption: When combined with other botanical components, the natural phenolic compounds found in lemon peel extract have the ability to absorb UV rays and provide modest sunblock.

- Skin Toning and Brightening; the skin is brightened, sunspots are faded, and UV-induced hyperpigmentation is lessened thanks to the high vitamin C concentration.

- Astringent and Antibacterial Properties: Because of its inherent astringent and antibacterial qualities, lemon peel extract is beneficial for oily or acne-prone skin, especially after sun exposure.

- Sustainable Ingredient: Lemon peel is a plant-based, biodegradable by-product that is frequently derived from food industry waste and works well in environmentally friendly and sustainable sunscreen formulas. Sharma A et al.,2018

5. MORINGA

Figure 6: Moringa

- High Level of Antioxidants: Vitamins C, E, flavonoids, and polyphenols are abundant in moringa leaves and seeds shown in figure 6. By scavenging free radicals generated by UV exposure, these antioxidants help stop oxidative skin damage and photoaging.
- Organic UV Defense; Phenolic chemicals found in moringa extract have been demonstrated to absorb UV radiation, which helps to increase the SPF of sunscreen formulations.
- Benefits of Anti-Inflammation: Moringa contains bioactive substances including kaempferol and quercetin that lower inflammation, treat sunburns, and shield the skin from UV ray damage.
- Skin Repair and Nourishing: It is well known that moringa promotes the synthesis of collagen, which helps to repair and supplify the skin. Additionally, it includes oleic acid, which aids in protecting and moisturizing the skin barrier.
- Effects of Antimicrobials and Detoxification: Because of its antibacterial, antifungal, and detoxifying qualities, moringa is a good choice for preserving skin health in challenging environmental circumstances.
- Sustainable and Green: Moringa is perfect for sustainable, biodegradable skin care formulations since it grows quickly and is environmentally benign. Tran TPA et al.,2024

Evaluation Parameters

1. Color Identification
Small amount of the test compound were set up in diffuse daylight against a white background in order to evaluate its color. After that, the color was visually assessed and noted appropriately. Mosa FA et al.,2019

2. Evaluation of Odor
a small amount of sample was let to stand in a watch glass with a diameter of 5cm for 15min Following this time, the air above the sample was repeatedly and slowly inhaled. While the nature of the odor was defined as aromatic, fruity, musky, moldy, or rotten, the intensity of the odor was rated as either non-existent, weak, distinct, or strong. I Solai et al., 2023

3. Evaluation of Spreadability
Spreadability was evaluated using a subjective sensory assessment. Volunteers assessed the product's tactile sensation using this method. It represents the true perception of how quickly the substance distributes on the skin, even though it does not offer exact numerical data. Kale S et al.,2010

4. Solubility
Using the British Pharmacopoeia (BP) 2013 descriptive words, solubility was evaluated by measuring the volume of solvent (in millilitres) needed to dissolve one gram of the substance. Smaoui S et al.,2017

5. Calculating the Sun Protection Factor (SPF)
An indicator of sunscreen effectiveness, the SPF is determined by using:
SPF = MED on skin that is protected MED on skin that is not
SPF = MED on exposed skin MED on shielded skin

The least amount of UV radiation that results in a minor reddening of the skin is known as the "Medimal Erythema Dose." Better protection against sunburn is indicated by a higher SPF.

Mansur et al. (1979) suggested the following spectrophotometric equation for in vitro SPF analysis:

$$SPF = CF \times \sum_{290}^{320} EE(\lambda) \times I(\lambda) \times Abs(\lambda)$$

Where:

- CF (Correction Factor) = 10
- EE(λ) = Erythemal Effect
- I(λ) = Solar Intensity
- Abs(λ) = Absorbance at wavelength λ

EE × I Values by Wavelength Indira S et al., 2023

CONCLUSION

In conclusion, as consumers look for safer, more environmentally responsible, and more skin-friendly substitutes for traditional sun protection products, herbal and natural sunscreens are growing in popularity. In addition to offering moderate UV protection, these sunscreens—formulated with plant-based components like turmeric, guava, manjistha, moringa, and lemon peel—also exhibit anti-inflammatory and antioxidant properties. Their benefits, such as being biodegradable, reef-safe, and suitable for sensitive skin, make them attractive to those who favor a holistic approach to skincare. However, current limitations include variability in SPF efficacy, lack of regulatory standardization, and challenges in ensuring consistent formulation stability. Future research should focus on clinical validation of SPF claims, standardizing extraction and formulation processes, and improving the photostability of natural ingredients. As scientific evidence grows and regulatory frameworks evolve, herbal sunscreens have the potential to become both a reliable and sustainable alternative in the field of dermatological protection.

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