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# PHARMACOLOGICAL POTENTIALS, ECOLOGICAL IMPACTS, AND DEVELOPMENT OF TERRESTRIAL AND MARINE-DERIVED NATURAL PRODUCTS-BASED TOPICAL SUNSCREENS

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## ABSTRAK

Radiasi ultraviolet (UV) dapat menyebabkan kulit terbakar, penuaan dini, dan meningkatkan risiko kanker kulit. Tabir surya membantu melindungi kulit, tetapi beberapa filter UV sintetis dikaitkan dengan isu kesehatan dan lingkungan. Sejumlah literatur melaporkan masalah medis berkaitan dengan penggunaan agen tabir surya sintetis, seperti iritasi kulit, gangguan hormonal, fotosensitivitas, serta kekhawatiran terkait inhalasi pada tabir surya semprot atau bubuk. Literatur lain juga melaporkan isu ekologis yang relevan, baik pada ekosistem laut, seperti pemutihan terumbu karang dan gangguan pada mikrobioma biota perairan, maupun pada ekosistem terestrial, seperti toksisitas tanah dan gangguan pertumbuhan tanaman. Isu-isu ini mendorong dilakukannya tinjauan terfokus terhadap karya-karya terkini mengenai tabir surya topikal berbasis bahan alam sebagai alternatif. Tinjauan naratif ini merangkum studi-studi terbaru mengenai produk alam asal terestrial dan laut sebagai bahan untuk tabir surya topikal. Artikel ditelusuri melalui Google Scholar, ScienceDirect, SpringerLink, dan PubMed, dengan waktu publikasi 2016 hingga Januari 2026. Literatur yang ditinjau membahas klasifikasi tabir surya, bahan alam dengan potensi fotoprotektif serta efek menutrisi kulit, serta pertimbangan kesehatan manusia dan aspek ekologis. Secara umum, banyak bahan alam menunjukkan potensi sebagai bahan tambahan tabir surya dan dapat memberikan manfaat tambahan berupa aktivitas antioksidan serta efek menutrisi kulit. Namun, kapasitas fotoprotektif dan stabilitasnya dapat bervariasi bergantung pada formulasi dan konsentrasi, sementara data jangka panjang terkait keamanan, efektivitas, dan kelayakan ekonomi bahan alam sebagai agen aktif tabir surya masih terbatas. Penelitian lanjutan mengenai formulasi, pengawetan, uji keamanan, serta dampak lingkungan masih diperlukan untuk mendukung pengembangan tabir surya berbasis bahan alam yang efektif dan ramah lingkungan.

**Kata kunci**: bahan alam, filter UV, formulasi tabir surya, fotoproteksi

## ABSTRACT

Ultraviolet (UV) radiation can cause sunburn, premature skin aging, and increase skin cancer risk. Sunscreens help protect the skin, but some synthetic UV filters are associated with both health and environmental concerns. Some literature has reported medical problems associated with the use of synthetic sunscreen agents, such as skin irritation, hormonal disruption, photosensitivity, and specific inhalation concerns for spray/powder sunscreens. Other literature has also reported relevant ecological issues, both to the marine ecosystem, such as coral reef bleaching and disturbance to the microbiome of aquatic life, and to the terrestrial ecosystem, such as soil toxicity and disrupted plant growth. These issues prompt a focused review of recent works on nature-based topical sunscreens as a viable alternative. This narrative review summarizes recent studies on terrestrial and marine natural products as ingredients for topical sunscreens. Articles were retrieved from Google Scholar, ScienceDirect, SpringerLink, and PubMed for publications from 2016 to January 2026. The reviewed literature discusses sunscreen classification, natural ingredients with photoprotective and skin-nourishing effects, as well as human-health and ecological considerations. Overall, many natural ingredients show potential as sunscreen additives and may provide antioxidant and skin-nourishing benefits. However, their photoprotective capacity and stability can vary with formulation and concentration, and long-term data associated with the safety, efficacy, and economic viability of natural ingredients as active sunscreen agents are still limited. Further studies on formulation, preservation, safety testing, and environmental impacts are needed to support the development of effective and eco-friendly nature-based sunscreens.

**Keywords**: natural products, photoprotection, sunscreen formulation, UV filter

## INTRODUCTION

Sunlight is essential for life, but it also contains ultraviolet (UV) radiation that can harm the skin. In the sources summarized in this review, UV exposure is associated with sunburn, premature skin aging, and an increased risk of skin cancer (Geoffrey *et al*., 2019; Gabros *et al*., 2023). Ultraviolet radiation is commonly grouped into UVC, UVB, and UVA, with the ozone layer absorbing almost all of UVC, most of UVB, but only a small amount of UVA. UVA penetrates deeper into the dermis and promotes reactive oxygen species (ROS) formation that contributes to indirect DNA damage, whereas UVB is reported as the main cause of sunburn, penetrates into the epidermis, and is closely associated with nonmelanoma skin cancer. UVC is the most harmful type, but it is largely blocked by the atmosphere (Gabros *et al*., 2023; Tang *et al*., 2024). Sunscreens are defined as substances that protect the skin from solar UV radiation by absorbing, reflecting, scattering, or otherwise deflecting UV photons (Parrado *et al*., 2021; Hau, 2024). Sunscreen performance is commonly measured using the sun protection factor (SPF), which mainly reflects UVB protection, and the protection grade of UVA (PA), which relates to UVA protection (Chavda *et al*., 2023; Aswini *et al*., 2024).

Sunscreen use is discussed as particularly important for people who spend long periods outdoors, including outdoor sports participants and tourists in low-latitude areas with intense sunlight, because UV exposure can be more frequent and prolonged (Geoffrey *et al*., 2019; Zafren, 2020). In that context, broad-spectrum sunscreen together with other protective measures such as photoprotective clothing is recommended, and SPF values of at least 30 are repeatedly mentioned as a practical baseline for exposed skin (Geoffrey *et al*., 2019; Zafren, 2020). Some studies also note that long duration outdoors can still lead to inadequate UV protection even while using sunscreen, which motivates attention to product selection and correct application method (Geoffrey *et al*., 2019; Aswini *et al*., 2024).

Based on active ingredients, sunscreens are commonly grouped into organic filters, inorganic (mineral) filters, nature-based filters, and hybrid filters (Chavda *et al*., 2023; A. Sharma & M. Sharma, 2023). Organic filters mainly work by absorbing high-energy UV photons, with examples including avobenzone, octisalate, and octocrylene (Bhattacharjee *et al*., 2021; Chavda *et al*., 2023). Inorganic filters commonly work by reflecting and scattering UV rays, with titanium dioxide and zinc oxide as examples (Geoffrey *et al*., 2019; Bhattacharjee *et al*., 2021). Nature-based filters are defined as plant extracts or other natural materials with UV-blocking properties and antioxidant activity, including the ability to help neutralize ROS produced by UVA (Bhattacharjee *et al*., 2021; Aswini *et al*., 2024). The reviewed literature also highlights that efficacy can vary across natural materials and formulations, and protection may be insufficient for prolonged exposure without careful formulation and adequate active levels (Bhattacharjee *et al*., 2021; Li *et al*., 2023). Hybrid sunscreens are defined as a combination of organic and inorganic filters to improve sun protection while reducing the disadvantages of each category (Ngoc *et al*., 2019; Ballestín & Bartolomé, 2023).

Sunscreens can also be grouped by formulation type, with different products being delivered in the form of creams, lotions, gels, sprays, sticks, or powders, with each form having different texture, spreadability, and convenience factors (Teplitz *et al*., 2018; Aswini *et al*., 2024). For example, creams are reported to be thicker and often used for dry skin, lotions are lighter and spread well, gels are fast-absorbing and non-greasy, and sprays, sticks, or powders are practical options that can support reapplication (Karimah *et al*., 2023; Aswini *et al*., 2024).

The reviewed literature explains that filters can differ in action mechanism and stability under sunlight. Mineral sunscreens work mainly by physical reflection and scattering, while organic sunscreens work mainly by absorption, converting UV energy to heat (Geoffrey *et al*., 2019; Bhattacharjee *et al*., 2021). Photostability is treated as important because some filters can dissipate absorbed energy and return to a low-energy state, while others can degrade or become photoreactive and produce ROS (Ahmad *et al*., 2016; Bhattacharjee *et al*., 2021). The reviewed sources also highlight health and safety concerns such as irritation and sensitization, and they note that sprays and powders raise inhalation considerations, particularly when mineral filters are involved (Teplitz *et al*., 2018; Bhattacharjee *et al*., 2021). Environmental concerns are emphasized as well, including discussion of coral bleaching or marine toxicity linked to some chemical sunscreens and microbiome disturbance in aquatic organisms after exposure to commercial sunscreen formulations (Chatzigianni *et al*., 2022; Bellec *et al*., 2024).

In response to these concerns, many studies have presented alternative nature-based topical sunscreens that use terrestrial or marine natural products as active components, with the goal of providing UV protection together with added skin benefits such as antioxidant and anti-inflammatory effects, while also minimizing the hazard factors that may be present in conventional synthetic sunscreen agents (Sabrina *et al*., 2022; Aswini *et al*., 2024). The literature summarized in this review describes candidates from both terrestrial materials and marine organisms, including the much-discussed algae sources with UV-absorbing or UVA-protective properties (Prasedya *et al*., 2019; Rosic & Thornber, 2023). At the same time, many studies have reported the limitations faced in using nature-derived compounds as sunscreen active agents, including varied efficacy depending on formulation and concentration, and stability and shelf-life challenges related to degradation and microbial contamination during preparation and storage (Pandey *et al*., 2023; Ansari *et al*., 2024). Some sources also report allergic reactions to specific natural ingredients and emphasize that safety evaluation may require approaches such as patch and irritation testing (Bose *et al*., 2023; Dutta *et al*., 2024). Accordingly, this narrative review synthesizes recent findings on the pharmacological potentials, ecological impacts, and development of terrestrial- and marine-derived natural products-based topical sunscreens, summarizing classifications, comparing reported benefits and limitations with synthetic sunscreens, and outlining development considerations as implied in the reviewed sources (Chavda *et al*., 2023; Thomas *et al*., 2024).

## MATERIALS AND METHODS

### Materials

Literature records were retrieved from Google Scholar, ScienceDirect, SpringerLink, and PubMed. The scope was limited to publications from 2016 to January 2026. The review focused on terrestrial- and marine-derived natural products for topical sunscreen use. The discussion emphasized pharmacological potentials, ecological impacts, and development aspects such as formulation, stability, and standardization.

### Instruments

A computer with internet access was used to search the databases. A reference manager (Mendeley) was used to store and organize citations. Word-processing software (Microsoft Word) was used to draft and revise the manuscript. Spreadsheet software (Microsoft Excel) was used to extract key information from the reviewed literature.

### Methods

This study was prepared as a structured narrative review. Searches were conducted in Google Scholar, ScienceDirect, Springer Nature Link (formerly known as SpringerLink), and PubMed for publications from 2016 to January 2026 using combinations of keywords and synonyms with Boolean operators, for example: (“natural product” OR botanical OR marine OR algae OR seaweed) AND (sunscreen OR “UV filter” OR photoprotection OR SPF) AND (topical OR cream OR lotion OR formulation), with additional terms related to safety and the environment (e.g., ecotoxicity, reef safe, coral bleaching, aquatic toxicity, soil toxicity). Inclusion criteria comprised peer-reviewed journal articles (and authoritative scientific sources when relevant) that reported active agent candidates, photoprotective mechanisms (direct UV absorption and/or antioxidant/anti-inflammatory support), performance endpoints (e.g., in vitro/in vivo SPF, UV absorbance, UVA/UVB coverage), safety data, and/or environmental outcomes. Exclusion criteria included studies not addressing topical sunscreen usage and publications with insufficient reporting of methods or outcomes for meaningful comparison. Titles and abstracts were screened to identify papers that discuss the pharmacological potentials, ecological impacts, and development of terrestrial- and marine-derived natural products for topical sunscreens (formulation, standardization, and safety assessment). Full texts were then reviewed, and key information was summarized, specifically those pertaining to the biological source (organism/plant part), major compound class, extraction or formulation approach, photoprotection testing methods, supportive bioactivities, photostability/stability issues, and reported toxicological or ecotoxicological findings.

## RESULT AND DISCUSSION

### Classification and Performance Attributes of Topical Sunscreens

Topical sunscreens are substances that protect the skin from harmful solar UV radiation by absorbing, reflecting, scattering, or otherwise deflecting UV photons (Parrado *et al*., 2021). Sunscreens help prevent sunburn, reduce skin cancer risk, and minimize premature skin aging (Gabros *et al*., 2023). The protection level of a sunscreen is commonly measured using SPF (UVB protection) and PA rating (UVA protection) (Chavda *et al*., 2023). Based on active ingredients, sunscreens are commonly grouped into organic filters, inorganic (mineral) filters, nature-based agents, and hybrid products (Chavda *et al*., 2023; A. Sharma & M. Sharma, 2023). Organic filters work by absorbing high-energy UV photons (Mota *et al*., 2020). Inorganic filters mainly scatter and reflect UV rays; common examples include titanium dioxide and zinc oxide, which are considered broad-spectrum, although they may leave a white residue and can feel heavier on the skin (Ngoc *et al*., 2019; Bhattacharjee *et al*., 2021). Nature-based agents use plant extracts with UV-blocking properties and often provide additional antioxidant benefits, but their efficacy can vary and may be insufficient for prolonged exposure (Li *et al*., 2023). Interest in nature-based sunscreens has grown with awareness of environmental damage from synthetic sunscreens (Thomas *et al*., 2024). Hybrid sunscreens combine organic and inorganic components to improve protection while reducing drawbacks, and they can work through both absorption and reflection/scattering (Ngoc *et al*., 2019; Ballestín & Bartolomé, 2023).

Table 1. Classification of Sunscreen Products

| Class of sunscreen | Representative active compounds (examples) | Dominant mechanism | Typical advantages | Common limitations/risks |
|---|---|---|---|---|
| Organic agents | e.g., avobenzone, octisalate, octocrylene | Absorb high-energy UV photons | Effective sun protection | May cause skin irritation; linked to potential hormonal disruption; some synthetic UV filters are reported to be susceptible to photodegradation. |
| Inorganic (mineral) agents | titanium dioxide, zinc oxide | Scatter and reflect UV rays | Broad-spectrum coverage across the UV range; not absorbed through the skin and less likely to cause irritation | May leave a white residue and feel heavier/greasier; inorganic sunscreens are not recommended in spray or powder form due to inhalation concerns. |
| Hybrid agents | Organic and inorganic combinations | Absorb, reflect, and scatter light | Combine organic and inorganic UV agents to enhance SPF and provide broad-spectrum protection while minimizing the downsides of each category | Formulation using hybrid agents still does not completely eliminate the risks and limitations of both the organic and inorganic agents. |
| Natural (nature-based) agents | Plant extracts with UV-blocking properties | UV blocking and antioxidant support | Often less irritating; antioxidant properties inherent in some natural agents can help neutralize ROS produced by UVA and provide additional skin-nourishing effects | Efficacy can vary and may not provide sufficient protection from prolonged sun exposure; demand has increased due to the growing awareness of environmental damage caused by synthetic sunscreens. |

*Source*: (Teplitz *et al*., 2018; Jesus *et al*., 2022).

In terms of product form, sunscreens are commonly sold as creams and lotions, and they are also available as gels, sprays, sticks, and powders (Geoffrey *et al*., 2019). Creams are thicker and suitable for dry skin, while lotions are lighter and spread well (Aswini *et al*., 2024). Gels are absorbed quickly and can leave a matte, non-greasy finish that suits oily or acne-prone skin (Aswini *et al*., 2024). Sprays are convenient for large or hard-to-reach areas, and sticks are practical for small areas around the face. Both forms are easy to carry and use (Teplitz *et al*., 2018; Aswini *et al*., 2024). Powdered sunscreens can provide a matte finish and can be reapplied over makeup during the day. The formulation type of a sunscreen can affect both its usage considerations and its commercial value (Karimah *et al*., 2023; Aswini *et al*., 2024).

Sunscreens can also be classified by their mechanism of action. Physical sunscreens mainly work by reflecting and scattering UV rays, while chemical sunscreens mainly work by absorbing UV energy and converting it into heat (Geoffrey *et al*., 2019; Bhattacharjee *et al*., 2021). These filters also vary in photostability. Stable filters can dissipate absorbed energy and return to their original state, whereas less stable filters may degrade or become photoreactive under sunlight, potentially producing reactive oxygen species (ROS) (Ahmad *et al*., 2016; Bhattacharjee *et al*., 2021).

**Photoprotective Mechanisms Relevant to Natural Products**

Natural ingredients discussed for sunscreens can support photoprotection in two main ways. Some compounds can absorb UV radiation, whereas other terrestrial and marine extracts mainly help by providing antioxidant or anti-inflammatory activity that can reduce ROS formed after UV exposure (Li *et al*., 2023; Aswini *et al*., 2024). Because the UV protection from nature-based ingredients can vary, these materials are commonly formulated carefully and may be combined with other sunscreen agents to reach adequate protection levels (Li *et al*., 2023; Maliyil *et al*., 2023).

**Terrestrial-derived Natural Products**

Many terrestrial plants have been used as traditional remedies, and recent studies report that some botanical extracts have potential as sunscreen additives, especially those with antioxidant and anti-inflammatory activity (Prasanth *et al*., 2020; Li *et al*., 2023). Several botanicals have been reported to show SPF-related activity and antioxidant potential. Green tea (*Camellia sinensis*) contains polyphenols, particularly catechins, and has been discussed for photoprotective effects through antioxidant activity (Bhattacharya & Sherje, 2020; Aswini *et al*., 2024). Turmeric (*Curcuma longa*) contains curcumin and other secondary metabolites and is discussed for antioxidant, anti-inflammatory, and photoprotective properties (Liu *et al*., 2018; Nurhasnawati *et al*., 2024).

Aloe vera (*Aloe barbadensis* Miller; *Aloe chinensis* Baker) is well known for soothing and moisturizing effects and has been discussed for providing some UV protection and improving the effect of other sunscreen agents (Hendrawati *et al*., 2020; Tayal *et al*., 2024). Licorice (*Glycyrrhiza glabra*) contains glycyrrhizin and other compounds that have been discussed for UV absorption and antioxidant activity. Some components are also reported to affect melanin formation (Aswini *et al*., 2024; Gurjar *et al*., 2024). Some candidates come from plant by-products that are often treated as waste, such as rambutan peel or mango kernel. Rambutan (*Nephelium lappaceum*) peel is reported to contain photoprotective compounds such as flavonoids and tannins, and rambutan leaves have been reported to show SPF values (Mota *et al*., 2020; Na'ima, 2022). Mango (*Mangifera indica*) kernel fat and phenolic extracts show antioxidant and UV-absorbing potential, and mango leaf extract has been reported to show photoprotective activity with high SPF values (Melo *et al*., 2019; Ameliana *et al*., 2023).

Other examples discussed include cucumber, tomato, and rosehip seed oil. Cucumber (*Cucumis sativus*) extract contains antioxidants (cucurbitacins, vitamin C) and caffeic acid, and cucumber seed oil has been reported to show UV absorption (Wang *et al*., 2022; Tayal *et al*., 2024). Tomato (*Solanum lycopersicum*) is a source of lycopene, which has been discussed for antioxidant effects that may help reduce UV-induced oxidative stress and skin aging (Aswini *et al*., 2024; Tayal *et al*., 2024). Rosehip (*Rosa rubiginosa*) seed oil has been found to exhibit anti-inflammatory and photoprotective properties, while also containing a significant amount of vitamin C, making it a great candidate for the development of skincare formulations (Kayath *et al*., 2019; Porumb *et al*., 2024). Overall, terrestrial natural products are discussed mainly as added ingredients that can support sunscreen performance through antioxidant and anti-inflammatory effects, but the level of protection can vary depending on the formulation and concentration (Li *et al*., 2023; Maliyil *et al*., 2023).

**Marine-derived natural products**

Oceans cover much of the earth and contain many organisms that are sources of natural products (Dutta *et al*., 2023). Many marine organisms in the photic zone are exposed to strong sunlight, making them gradually adapt by producing photoprotective molecules such as mycosporine-like amino acids (MAAs) or ovothiols (Luccarini *et al*., 2023; Yamamoto *et al*., 2023). MAAs are widely discussed as photoprotective compounds in marine organisms and are considered among the strongest UVA-absorbing compounds found in nature (Luccarini *et al*., 2023; Peng *et al*., 2023). Macroalgae are also reported as sources of anti-inflammatory, antioxidant, and photoprotective agents, including MAAs (Prasedya *et al*., 2019; Rosic & Thornber, 2023).

Macroalgae (seaweeds) include green (Chlorophyta), brown (Phaeophyceae), and red (Rhodophyta) algae (Sami *et al*., 2021). Brown algae can produce phlorotannins, and many macroalgae can also produce other UV-absorbing compounds, such as phenolic compounds and chromophore groups reported from *Caulerpa racemosa* (Ersalina *et al*., 2020; Meng *et al*., 2021). Several Microalgae species (*Coelastrella rubescens*; *Enallax coelastroides*; *Scotiella chlorelloidea*; *Ankistrodesmus spiralis*; *Chlorella sorokiniana*) have been reported as rich sources of MAAs (Santiesteban-Romero *et al*., 2022). Microalgae can also produce astaxanthin, which is commonly produced by *Haematococcus pluvialis*, and *Spirulina platensis* has been reported to show UV protection related to antioxidant pigments (Pratama *et al*., 2020; Dutta *et al*., 2023; Nemani *et al*., 2024). Other than algae, marine faunas have also been shown to exhibit potential UV-protective capacity. Sea urchin (*Paracentrotus lividus*) eggs contain ovothiols that have been suggested to show UVA-protecting behavior similar to MAAs (Luccarini *et al*., 2023; Peng *et al*., 2023). Other work reported that body parts of sea urchin (*Diadema savignyi*) contain anti-inflammatory and antioxidant substances such as polyphenols (Chaithanya *et al*., 2023; Luccarini *et al*., 2023).

Table 2. Representative Natural Products with Photoprotective Potential

| Source category | Example material | Representative active compounds (examples) | Proposed photoprotective roles | Development notes |
|---|---|---|---|---|
| Terrestrial botanicals | Green tea (*Camellia sinensis*) | Catechins (polyphenols) | SPF and antioxidant potential; reported protection against UV effects through neutralization of free radicals and reduced oxidative stress. | |
| Terrestrial botanicals | Licorice (*Glycyrrhiza glabra*) | Glycyrrhizin; licochalcone A; glabridin; glaciridin | Natural UV-absorbing properties; topical glycyrrhizin is described as capable of forming a protective layer that intercepts and absorbs part of incoming UV radiation; antioxidant activity and prevention of melanin synthesis are also reported. | |
| Agricultural by-products | Rambutan peel/leaves (*Nephelium lappaceum*) | Flavonoids; tannins | The peel is reported to contain substances with photoprotective potential (including | Reported as a ‘waste’ ingredient source in this review. |

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| | | | flavonoids and tannins), and the leaf extract is reported to show SPF value. | |
| Agricultural by-products | Mango kernel/leaves (*Mangifera indica*) | Mango kernel fat (oleic and stearic); phenolics (gallic acid); flavonoids (leaves) | Antioxidant properties and UV-absorbing capacity are reported for kernel extracts, and leaves are reported to show photoprotective activity with high SPF values. | Reported as a 'waste' ingredient source in this review. |
| Produce-derived | Tomato (*Solanum lycopersicum*) | Lycopene (carotenoid) | Lycopene is described as a powerful antioxidant with photoprotective benefits, reported to neutralize free radicals generated by UV exposure, reduce oxidative stress, and help prevent UV-induced skin damage and skin aging. | |
| Produce-derived | Turmeric (*Curcuma longa*) | Curcumin; flavonoids; phenols | Curcumin is described as having antioxidant, anti-inflammatory, and photoprotective properties that help shield the skin from UV-induced damage; flavonoids and phenols are also described as having antioxidant potential for sun protection products. | |
| Marine macroalgae | Red algae (e.g., *Devaleraea inkyuleei*, *Gracilaria* spp.) | Mycosporine-like amino acids (MAAs) | Marine organisms are described as producing photoprotective molecules such as MAAs; MAAs are described as strong UVA-absorbing compounds in nature. | Macroalgae are described as abundant and having potential for commercial utilization of bloom biomass. |

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|---|---|---|---|---|
| Marine macroalgae | Brown algae (e.g., *Sargassum* spp.) | Phlorotannins | Macroalgae are described as sources of anti-inflammatory, antioxidant, and photoprotective agents; brown algae are described as producing phlorotannins as UV-absorbing compounds. | Macroalgae are described as abundant and having potential for commercial utilization of bloom biomass. |
| Marine microalgae | *Haematococcus pluvialis* | Astaxanthin | Astaxanthin is described as a UV-protecting agent; microalgae are described as containing UV-protection agents capable of neutralizing free radicals and protecting skin against UV damage. | Astaxanthin is described as most commonly produced by the microalga *Haematococcus pluvialis*. |
| Marine invertebrates | Sea urchin eggs and body parts (*Paracentrotus lividus* or *Diadema savignyi*) | Ovothiols; polyphenols | Ovothiols in sea urchin (*Paracentrotus lividus*) eggs are reported to have possible UVA-protecting properties resembling MAAs; other sea urchin (*Diadema savignyi*) body parts are reported to contain anti-inflammatory and antioxidant substances such as polyphenols. | |

**Health Considerations**

Synthetic sunscreens are effective against UV rays, but some studies report health concerns. Synthetic UV filters can undergo photodegradation, which may generate ROS and lead to cytotoxic or genotoxic effects (Bhattacharjee *et al*., 2021; Serpone, 2021). Materials such as para-aminobenzoic acid (PABA) and its derivatives have been linked to photoallergy and photosensitivity on the skin (Bhattacharjee *et al*., 2021; Serpone, 2021). Sunscreen formulation types can also affect the risk factors. One study reported that it is not recommended for inorganic sunscreens to be made as sprays or powders, because inhalation of titanium dioxide or zinc oxide may cause unexpected issues to the respiratory system (Bhattacharjee *et al*., 2021; Ballestín & Bartolomé, 2023).

In comparison, nature-based sunscreens are discussed as promising alternatives because their natural ingredients often include antioxidant and anti-inflammatory properties that can support skin protection and reduce oxidative stress from UV exposure (Bhattacharjee *et al*., 2021; Aswini *et al*., 2024). Nature-based sunscreens are also reported to show fewer side effects and better compatibility across skin types than some synthetic formulations (Bhattacharjee *et al*., 2021; Gabros *et al*., 2023). However, allergic reactions to specific natural ingredients have been reported. Because there are fewer studies on adverse reactions for nature-based sunscreens than for synthetic sunscreens, additional safety assessment, such as patch testing and irritation testing, has been recommended (Bose *et al*., 2023; Dutta *et al*., 2024). Stability and microbial quality are also key concerns for natural formulations. Natural products can be affected by microbial contamination and degradation during preparation and storage, which can lead to loss of active constituents and, in some cases, toxic metabolites (Pandey *et al*., 2023; Ansari *et al*., 2024).

**Ecological Considerations**

Some studies have linked the use of chemical sunscreens containing oxybenzone or octinoxate with coral bleaching and marine toxicity (Sirois, 2019; Thomas *et al*., 2024). Other work reported that exposure to synthetic sunscreen can disturb the skin and gut microbiome of aquatic life (Bellec *et al*., 2024; Thomas *et al*., 2024). Compared to aquatic ecosystems, less research has been conducted on terrestrial impacts. One study reported that inorganic sunscreen waste containing titanium dioxide or zinc oxide may contribute to toxicity in soil organisms after mixing with rainwater or nearby puddles (Labille *et al*., 2020; Ballestín & Bartolomé, 2023). Another study reported that wastewater contaminated with organic sunscreens containing avobenzone can reduce plant growth when used for irrigation or fertilization (Labille *et al*., 2020; Beijora *et al*., 2024). In contrast, nature-based sunscreens are generally discussed as more biodegradable and less harmful to aquatic and terrestrial life than synthetic sunscreens, but ecotoxicological testing is still recommended (Banti & Hadjikakou, 2021; Aswini *et al*., 2024). In addition, some materials treated as “waste” (e.g., rambutan peel, mango kernel) or “pests” (e.g., bloom-forming macroalgae) are discussed as potential sources of sunscreen ingredients that could also bring environmental and economic benefits when used appropriately (Mota *et al*., 2020; Joniver *et al*., 2021).

Table 3. Summary of Health and Ecological Considerations Relevant to Sunscreen Ingredients

| Assessment domain | Conventional UV filters (general considerations) | Nature-based candidates (general considerations) | Considerations for the development of nature-based sunscreen agents |
|---|---|---|---|
| Photostability and stability | Some synthetic UV filters have photostability limits and can photodegrade over time. The review describes photodegradation as potentially generating ROS with undesirable biological effects, including cytotoxic and genotoxic outcomes. | Nature-based ingredients are described as potentially helpful because many provide antioxidant activity. The review also notes that protection can vary with formulation and concentration, and that natural compounds may degrade during preparation and storage or be affected by microbial contamination. | The review highlights stability and shelf life as key issues for nature-based sunscreens. It notes that degradation and microbial contamination during preparation and storage can reduce active constituents and affect protective quality. |
| Skin tolerability | Conventional sunscreens are described as effective but associated with irritation concerns, and some ingredients have been linked to potential hormonal disruption. The review also reports photoallergy and photosensitivity for PABA and its | Nature-based sunscreens are described as potentially gentler and may reduce irritation and allergies when formulated correctly. However, allergic reactions to specific natural ingredients are reported, and adverse reactions are described | The review recommends patch testing and irritation testing to assess skin compatibility and safety. It also highlights a need for longer-term allergy and toxicity testing to better compare risks between nature-based and synthetic products. |

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| | derivatives. | as less extensively studied than in synthetic sunscreens. | |
| Formulation and exposure route | The review describes common dosage forms such as creams, lotions, gels, sprays, sticks, and powders. It notes that inorganic sunscreens are not recommended as sprays or powders because inhalation of titanium dioxide or zinc oxide can cause unexpected medical issues to the lungs. | Nature-based sunscreens are discussed in the same dosage forms, and the review links forms to use needs. It describes creams for dry skin, gels for oily or acne-prone skin, sprays for large or hard-to-reach areas, sticks for spot use, and powders for reapplication over makeup. | The review notes that efficacy can vary with formulation method and active concentration, so dosage-form choice can affect protection. It also provides a specific caution to avoid spray or powder forms for inorganic mineral filters due to inhalation concerns. |
| Aquatic impact | The review links some chemical filters, including oxybenzone and octinoxate, to coral bleaching and marine ecosystem damage and reports marine toxicity concerns. It also reports disturbance of the skin and gut microbiome of aquatic life after exposure to synthetic sunscreen. | Nature-based sunscreens are described as generally more biodegradable and less harmful to aquatic life than synthetic sunscreens. The review also states that more ecotoxicological testing is recommended and mentions the Brine Shrimp Lethality Test (BSLT) as an example approach. | The review calls for additional studies and toxicity testing to assess the environmental impacts of nature-based formulations, ideally with the involvement of environmental specialists. It emphasizes that environmental testing is needed to support conclusions about reduced harm. |
| Terrestrial impact | The review notes fewer studies on terrestrial impacts and reports that inorganic sunscreens containing titanium dioxide or zinc oxide can contribute to soil toxicity. It also describes potential toxicity to plants and soil organisms through runoff and reports reduced plant growth from wastewater contaminated with organic sunscreens containing avobenzone. | Nature-based sunscreens are described as generally less harmful to terrestrial life, but the review emphasizes that clearer evidence is still needed to support broad conclusions. It notes that the extent of terrestrial effects remains uncertain. | The review presents terrestrial impact as an area for further study, especially for disposal and runoff pathways. It recommends more studies and toxicity testing to clarify environmental effects across ecosystems. |
| Sourcing and development potential | Conventional sunscreens are described as commonly based on synthetic chemical filters, and concerns about health and environmental harm are presented as motivations for alternatives. The | The review highlights that some natural ingredients can be abundant and relatively inexpensive and can include materials described as "waste" (e.g., mango kernel, rambutan peel). It also | The review describes the use of "waste" and "pest" materials as having potential economic and environmental benefits, while noting this is presented as theoretical. It also emphasizes the |

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| | review discusses these concerns alongside the rising demand for more eco-friendly products. | discusses “harmful pest” sources such as bloom-forming macroalgae and notes that marine-derived candidates are promising but less studied than many terrestrial options. | need for continued research and innovation to address remaining challenges in efficacy, stability, and standards. |

**Development Priorities and Future Research Directions**

Overall, this literature review suggests that both health and ecological aspects should be considered together when developing and evaluating sunscreen ingredients, and more testing is needed before strong safety claims can be made. Nature-based sunscreens are indeed promising, but it is still far from being able to entirely replace conventional sunscreens, and recent trends are more inclined to see nature-derived products only as secondary ingredients that may add benefits to a sunscreen product. Ideally, future development should focus on finding the best sunscreen formulation based on the photoprotective efficacy, economic viability, health safety, and environmental safety factors.

Marine-derived ingredients have strong potential but are less studied than many terrestrial ingredients, so further work on marine candidates could hopefully lead to a breakthrough and improve the existing formulations. Future development could also include the use of materials treated as “waste” (rambutan peel, mango kernel) or “harmful pests” (bloom-forming macroalgae), with more focus on the potential local economic and environmental benefits.

Future studies should also focus on the long-term efficacy, safety, and economic viability of nature-based sunscreens, as the current data are still quite limited. More long-term allergy and toxicity testing is needed to better compare the risks of nature-based and synthetic sunscreens. More environmental testing, preferably with environmental specialists, is also needed to be able to objectively assess the environmental impact of nature-based sunscreen formulations when compared to conventional sunscreens. Furthermore, natural ingredients can easily degrade over time and may be affected by microbial contamination during preparation and storage, making them not as economically viable as the conventional synthetic sunscreen agents, hence necessitating more studies pertaining to the preservation methods to maintain their stability and shelf life.

**Limitations of This Review**

This review was prepared as a structured narrative review, so the selection and synthesis of studies relied on the search strategy, screening decisions, and interpretation made by the author. The literature search was limited to Google Scholar, ScienceDirect, SpringerLink, and PubMed within the 2016 to January 2026 publication window, so relevant studies indexed elsewhere or published outside this period may not have been captured. The included studies also differed in their aims and reported outcomes, which limits direct comparisons across natural products and formulations. In addition, this review did not conduct a formal systematic review protocol, quantitative synthesis, or standardized risk-of-bias assessment, so the conclusions are presented as a qualitative summary of the available literature. It does not substitute for a full systematic review with meta-analysis, which would require complete documentation of search strings, screening outcomes, and risk-of-bias assessment across all included records.

This review also has several limitations that should be considered when interpreting its synthesis. First, sunscreen research uses heterogeneous experimental models, ranging from spectrophotometric estimates of SPF to cell-based oxidative-stress assays and, less commonly, standardized in vivo testing. As a result, direct quantitative comparison across studies is often not possible without access to raw data and harmonized protocols. Second, many natural-product studies evaluate crude extracts with limited chemical characterization; therefore, some reported effects may depend on batch-specific compositions rather than reproducible marker compounds. Third, safety and ecotoxicology data remain sparse for several emerging candidates, and the absence of evidence should not be interpreted as evidence of safety. Finally, local availability and sustainability of candidate sources can differ substantially by region, so development priorities may need to be tailored to local supply chains and regulatory contexts.

## CONCLUSION

Awareness of sunscreen use has increased, and concerns about the environmental effects of synthetic sunscreens have led to an increased interest in nature-based sunscreens. Evidence discussed in this review indicates that terrestrial and marine natural products show potential as ingredients for topical sunscreen development. Sunscreens can be classified by ingredients (organic, inorganic, hybrid, or nature-based), product forms (creams, lotions, gels, sprays, sticks, and powders), and action mechanisms (absorbing or reflecting). Nature-based sunscreens may provide UV protection together with additional skin benefits and are generally discussed as more biodegradable and less harmful to aquatic life, although more testing is still needed. At the same time, their efficacy can vary with formulation and concentration, and natural ingredients may degrade during preparation and storage, which can affect stability and public acceptance. Continued research on formulation, stability, safety testing, and environmental assessment is needed to support the development of effective, safe, and eco-friendly topical sunscreens.

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