

Review Article

Plant-based active photoprotectants for sunscreens

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Abstract

Excessive exposure to the sun's radiation is the major exogenous mediator of skin damage, which accelerates skin ageing and increases the risk of developing skin cancer. Compounds with photoprotectant activity are extremely useful for decreasing the effect of ultraviolet (UV) radiation on the skin; however, numerous sun filters, especially organic sunscreens, are allergenic. Therefore, the development of formulations containing plant extracts, which may be potentially safer, is extensively being explored. Plant-based cosmetics are commonly used to avoid skin ageing because they contain antioxidant agents that minimize free radical activity, and numerous studies have investigated the skin-protectant effects of related plant species. In addition to their antioxidant properties, plant-based cosmetics protect the skin against solar radiation because they contain polyphenols such as flavonoids and carotenoids. Therefore, this study aims to present a review of plant species commonly used in sunscreens to protect the skin against damage due to sunlight exposure.

Résumé

L'exposition excessive au rayonnement du soleil est le principal médiateur exogène de dommages à la peau, ce qui accélère le vieillissement de la peau et augmente le risque de développer un cancer de la peau. Les composés ayant une activité photo-protectrice sont extrêmement utiles pour réduire l'effet du rayonnement ultraviolet (UV) sur la peau; Toutefois, de nombreux filtres solaires, en particulier les filtres solaires organiques, sont allergisantes. Par conséquent, le développement de formulations contenant des extraits de plantes, qui peuvent être potentiellement plus sûres, est largement explorée. Des cosmétiques à base de plantes sont couramment utilisés pour éviter le vieillissement de la peau, car ils contiennent des agents antioxydants qui réduisent l'activité des radicaux libres, et de nombreuses études ont étudié les effets protecteurs des espèces de plantes apparentées. En plus de leurs propriétés antioxydantes, les cosmétiques à base de plantes protègent la peau contre le rayonnement solaire, car ils contiennent des polyphénols tels que les flavonoïdes et les caroténoïdes. Par conséquent, cette

étude vise à présenter un examen des espèces végétales couramment utilisées dans les écrans solaires pour protéger la peau contre les dommages dus à l'exposition au soleil.

Introduction

Sunscreens are topical products used to protect the skin against damage caused by ultraviolet (UV) rays. The deleterious effects of UV solar radiation on the skin, which include irreversible skin aging and dermal pathologies, are cumulative, irreversible and currently a major health concern [1]. Solar radiation is capable of producing biochemical and physiological changes including alterations in collagen and elastic fibres, loss of subcutaneous adipose tissue and photocarcinogenic changes [2, 3]. Sunscreens not only protect against skin cancer but they also prevent the development of other solar radiation-mediated skin conditions such as ageing, wrinkle formation, undesired pigmentation and collagen loss [4, 5]. The use of sunscreens in regions with high solar radiation levels is an effective precautionary measure against developing these problems [1].

New compounds, especially from plant materials, with the ability to absorb or block UV radiation have been extensively researched for development as products for protecting the skin against harmful solar radiation. Therefore, we aimed to perform a comprehensive literature review of plant compounds that are reported to protect the skin against solar radiation when incorporated into topical formulations.

Sunlight and UV rays

Sunlight is the portion of the electromagnetic radiation emitted by the sun that consists mainly of infrared (IR), visible and UV light. UV radiation can be divided into three categories, UVC, UVB and UVA, based on the wavelength ranges of 200–280, 280–315 and 315–400 nm, respectively [6].

The health benefits attributed to UV radiation include stimulation of vitamin D3 (cholecalciferol) production, which is involved in bone metabolism and immune system functions. Furthermore, UV radiation is used to treat certain skin diseases such as psoriasis and vitiligo. Regular exposure to UV radiation constitutes phototherapy, which can be combined with drugs that increase sensitivity to radiation to improve the symptoms of certain skin diseases [7–11]. However, according to Klug *et al.* [12], the main cause of

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skin cancer is the exposure to UV radiation, which occurs when this radiation penetrates the ozone layer [13] with an increased potential to induce skin cancer [4].

UVA radiation can induce various biological responses, ranging from erythema to photoageing [14, 15] because the solar UV spectrum component penetrates the dermis to reach the subcutaneous tissue, and affects both the epidermal and dermal skin components [16]. Furthermore, the generation of reactive oxygen species (ROS) including singlet oxygen, hydroxyl radical, superoxide anion and hydrogen peroxide, as well as the release of 'free' iron, leads to significant levels of oxidative stress [17, 18].

The singlet oxygen radical is currently the focus of increasing attention because of its involvement in the mediation of sun damage to the skin. This oxygen species may be the species that is most abundantly produced following exposure of the skin to solar radiation. Molecules that are capable of absorbing UVB and UVA radiation, which either occurs naturally in the skin (tryptophan or riboflavin) or reaches the skin from exogenous sources (via the use of some UV filters), can transfer the acquired energy from the UV photons to oxygen absorption. It is through this process that the molecules generate the reactive chemical singlet oxygen species [19]. Singlet oxygen radicals react instantaneously with neighbouring molecules and disturb the orderly cellular structure and the extracellular matrix [20].

Reactive oxygen species produced by UVA exert a variety of harmful effects including oxidation of nucleic acids, proteins and membrane lipids [21]. Keratinocytes contain high levels of antioxidants such as glutathione and various enzymes that are involved in antioxidant defence, including superoxide dismutase and catalase [22]. Nevertheless, the generation of high levels of ROS by UVA can overwhelm the body's natural defence to oxidative damage and, thereby, lead to extensive cellular damage and eventual cell death either by apoptosis or by necrosis [16, 17, 21].

The shorter wavelength of UVB radiation (290–320 nm) enables it to also have the propensity to induce pigmentation, but the resulting higher energy is mainly responsible for skin sunburns [23]. Although UVC radiation has some desirable properties such as germicidal activity, reports suggest that this radiation can be harmful to the skin because of its potential mutagenic and carcinogenic activity [24]. Studies on the effects of the increasing damage to the ozone layer have stimulated major concerns in the scientific community. Moreover, few studies have reported the levels of UVC radiation that currently cross the ozone layer, which is why currently available sunscreens on the market are not effective against UVC rays [25]. Ultimately, protection against solar UV-induced oxidative damage to the human skin depends on avoiding excessive sunlight exposure and the use of sunscreens.

Sunscreen – types of sun filters

The first reported use of a sunscreen was in the US in 1928, with the commercial introduction of an emulsion containing benzyl salicylate and benzyl cinnamate. In the early 1930s, a product containing 10% salol (phenyl salicylate) appeared on the Australian market. In 1936 in France, a chemist named E. Schueller introduced the first commercial sunscreen product. In the US, lotions containing quinine oleate and quinine bisulphate first appeared in 1935. *p*-Aminobenzoic acid (PABA) was first patented in 1943, leading the way for the incorporation of several *p*-aminobenzoate derivatives in sunscreen formulations. During World War II, red petrolatum was used by the US military, which led to the extensive

use of both physical and organic UV filters after the war ended. The US military specifications issued on 10 July 1951 listed approved sunscreen compounds and their recommended concentrations as glyceryl PABA, 3%; escapol 75A, 5%; 2-ethylhexyl salicylate, sunarome WMO, 5%; digalloyl trioleate, 3%; homomenthyl salicylate, 8%; and dipropylene glycol salicylate, 4% [26].

In Brazil, the organic UV filters permitted by the Agência Nacional de Vigilância Sanitária (ANVISA), which is the Brazilian Health Surveillance Agency, are PABA, cinnamates, salicylates, benzimidazoles, benzylidene derivatives and benzophenone [27, 28]. These filters possess structures that absorb harmful UV rays and convert them into low-energy radiation, which is considered relatively safe. Therefore, organic UV filters absorb harmful energy and transform it into a non-aggressive form before transmitting it to the skin [29].

Inorganic UV filters are classified as physical filters because their skin protection mechanism against solar radiation involves physical phenomena such as scattering and reflection of UV radiation [5, 13, 30–32]. The most frequently used inorganic UV filters are titanium dioxide (TiO₂) and zinc oxide (ZnO) which function well at reflecting light; however, they tend to be opaque and white on the skin and consequently are unacceptable for cosmetic use. Cosmetic acceptability of metal-oxide sunscreens requires the particle size of TiO₂, ZnO and other similar products (such as alumina, ceria and zirconia) to be approximately 20–50 nm. These oxides have been formulated as nanometric-sized particles, which decreases the reflection of visible radiation and, thereby, produces less white colouration when applied to the skin, and confers additional beneficial and efficacious photoprotection [25, 33, 34]. According to Balogh *et al.* [35], although sunscreens present several advantages, they also have numerous safety challenges that need to be overcome [7, 36].

Benzophenone-3 (oxybenzone) is a major cause of allergic reactions, especially contact dermatitis. PABA and benzophenone-10 are not commonly used currently because their continuous application can induce skin irritation [7, 37, 38]. Systemic absorption and chronic toxicity following sunscreen use are rarely reported. However, research on commonly used sunscreens is necessary [7, 39]. Therefore, research on the use of natural ingredients is steadily increasing, with the aim of minimizing the occurrence of skin irritation associated with sunscreens.

Plant compounds in sunscreens

The term 'phytocosmetic' (*phyto* and *kosmein*, in Greek) is used to refer to plant extracts and/or oils having cosmetic properties [40].

Antioxidants are commonly used in cosmetic formulations to prevent skin ageing. Most of these formulations currently contain at least one substance with antioxidant properties [20, 41]. Recently published studies have reported the beneficial effects of plant-derived antioxidant compounds, especially carotenoids and flavonoids, in sunscreens because they protect against sun damage. Compounds with aromatic rings can absorb UV rays, especially UVA and UVB at a wavelength range of 200–400 nm [42]. Therefore, phenolic compounds such as flavonoids may be used as sun filters.

According to the Agência Nacional de Vigilância Sanitária (ANVISA) guidelines, a sunscreen should have a sun protection factor (SPF) equal to or greater than 6 [43]. According to the US Food and Drug Administration (FDA) recommendations, to be considered as a sunscreen, a formulation should have an SPF value

higher than 2. However, to ensure adequate protection and minimize the risks of skin damage, the FDA recommends the regular use of sunscreens with an SPF value of 15 or higher, combined with other protective measures [44]. Therefore, a large number of natural compounds are currently being studied to determine whether they fulfil this requirement and can be classified as 'green sunscreens'.

Flavonoids are the most studied class of compounds with sun-protectant properties. They are a class of polyphenolic compounds (Fig. 1) synthesized by plants via the phenylpropanoid metabolic pathway and have been the subject of considerable scientific and therapeutic interest [45]. Quercetin (3,4'-dihydroxyflavonol) and rutin (quercetin-3-O- β -rutinoside) are the most widely studied flavonoids (Fig. 2). Since 1990, several therapeutic properties of flavonoids, mainly quercetin, which is the main flavonoid present in the human diet, have been studied. Flavonoids not only have antioxidant and anticarcinogenic potential, but they also protect the renal, cardiovascular and hepatic systems [46–49].

Flavonoids are present in fruits such as strawberries, grapefruits and apples; vegetables; and beverages such as tea and red wine. Among the vegetables commonly consumed in Brazil, onion, kale, broccoli and rocket are the main sources of flavonoids, which contain high levels of quercetin. Flavonoid levels of food are determined genetically; however, they are also influenced by factors such as season, climate, soil composition, stage of plant maturity, food preparation method, processing and storage [50, 51]. The presence of aromatic rings in the molecular structure of flavonoid confers them with the ability to absorb UV radiation between 200 and 400 nm, which makes them suitable for use as sunscreen agents.

Rutin and quercetin are the most studied plant compounds with protective effects against the solar radiation used in sunscreens. Using an *in vitro* method, Choquenot *et al.* [52] investigated the properties of these compounds and determined their effects on both SPF and UVA (PF-UVA) values when combined with inorganic UV filters in topically applied sunscreen formulations (oil-in-water, O/W emulsion). The spectral activities obtained for rutin and quercetin in this study were very similar, and absorption peaks were observed at 373 and 341 nm, respectively. For each substance, the influence of concentration on their effectiveness in the UVB and UVA range was studied. Three different combinations were investigated using the same percentage of each ingredient (10% w/w): (i) only flavonoids, (ii) flavonoids in combination with TiO₂ and (iii) flavonoids in combination with ZnO. Each combination was assessed for additive and synergistic effects, as well as potential incompatibilities. Transmission values for SPF and PF-UVA from 290–400 and 320–400 nm, respectively, were measured using a spectrophotometer equipped with an integrating sphere. The two

substances behaved similarly. When incorporated in O/W emulsions at a concentration of 10% (w/w), rutin and quercetin showed SPF values that were similar to those of homosalate, a standard ingredient in sunscreens. These compounds also provided a non-negligible level of photoprotection in the UVA range. When combined with TiO₂, the substances exhibited an SPF of approximately 30 [52]. Thus, flavonoids combined with physical filters enhance SPF levels synergistically.

Similarly, published studies by Velasco *et al.* [53] describe the development and *in vitro* efficacy evaluation of sunscreens containing rutin with or without UVA (benzophenone-3) and UVB (ethylhexyl methoxycinnamate) filters. The different formulations were evaluated *in vitro* using reflectance spectrophotometry with an integrated sphere to determine parameters such as the SPF, critical wavelength and UVA/UVB ratio. The photoprotective efficacy of rutin (0.1% w/w) was found to be dependent on the concentration and the presence of UVA and UVB filters. Owing to the synergistic effect, the SPF increased from 7.34 ± 0.24 to 9.97 ± 0.18 , when a minimum concentration of the flavonoid was combined with the filters. Furthermore, the photoprotective property of rutin was also observed in combination with UVA and UVB filters. Additionally, the isolated flavonoid provided superior UVA protection to that provided by the formulation without the UV filters [53]. While the usefulness of isolated flavonoids is currently being investigated, the data obtained from studies conducted on plants containing flavonoids are quite interesting.

Ginkgo biloba and green tea (*Camellia sinensis*) are widely used in antioxidant-containing natural products due to their ability to scavenge free radicals. The antioxidant properties of extracts of these plants are mainly due to the abundance of flavonoids [54, 55]. *G. biloba* extracts, which are rich in flavonoids (rutin, quercetin, kaempferol and isorhamnetin), biflavones and terpene trilactones, are widely used for their anti-inflammatory and vasodilatory effects [56–58]. Green tea leaf extracts contain lipids, minerals (manganese and potassium), organic acids, terpenes, alkaloids (caffeine, theophylline and theobromine), phenolic acids (caffeic, chlorogenic and gallic acids), flavonoid glycosides (kaempferol, quercetin and myricetin) and anthocyanidins [59].

The antioxidant properties of *G. biloba* and green tea have made them a focus of studies to determine their possible application as alternatives to conventional sunscreens. The photoprotective effect of the extracts of these plants alone or incorporated in emulsions was evaluated by applying them to the dorsal skin of hairless mice before UVA/B irradiation. After 20 h, the skin was assessed for barrier damage, erythema, histological alterations and sunburn cell formation. The results showed that only the formulations supplemented with the plant extracts protected the skin against UV-induced damage. The formulations containing *G. biloba* totally protected the skin barrier function against UV-induced radiation damage (skin barrier damage and erythema) and were more effective than those containing green tea. Therefore, the photoprotective effects may not be due to the UV-absorbing properties of UV filters, but due to biological effects induced following the application of the formulations containing *Ginkgo biloba* extracts. However, formulations containing a combination of both plants extracts were suggested to provide substantial photoprotection because they each protected against different aspects of skin damage [60].

Propolis is a resinous mixture collected from tree buds, sap flows, and other botanical sources by honeybees. It is basically composed of resin and balsam (55%), wax (30%), essential oils (10%), pollen

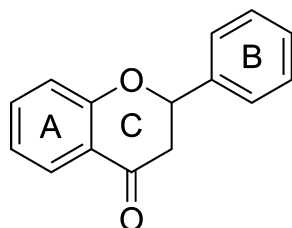


Figure 1 Basic molecular structure of flavonoids.

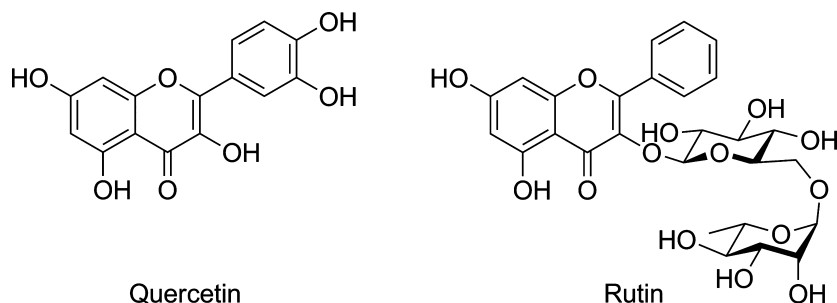


Figure 2 Molecular structures of quercetin and rutin.

(5%) and close to 100 other tree substrates such as flavonoids, terpenoids, amino acids and phenylpropanoids [61–63]. Propolis is rich in polyphenols and, therefore, Nascimento *et al.* [63] evaluated the *in vitro* photoprotective activity of commercial formulations containing two different types of propolis, green and red, using ethanol and propylene as extraction solvents. The ethanol extracts (1%) of the green and red propolis were incorporated into topical formulations containing carbomer polymers and two commercial sun filters, namely phenylbenzimidazole sulfonic acid and 2-hydroxy-4-methoxybenzophenone-5-sulfonic acid. Transmission levels of the SPF were measured using a spectrophotometer. The results indicated synergism between the formulations, which showed SPF values of 5.8 and 3.8 for the green and red propolis extract (8% each) formulations, respectively. Following their incorporation into the sunscreen formulations, the photoprotective analysis revealed that the extracts intensified the sunscreen protective factor [64].

Carotenoids, such as β -carotene, lutein and lycopene (Fig. 3), are natural lipophilic pigments that are widely distributed in nature and have diverse biological functions and health benefits and

include substances such as antioxidants, hormonal precursors, dyes and components essential to photosynthesis. These substances are tetraterpenes and are responsible for the red, yellow and orange colouration of fruits, vegetables, roots, flowers, fish, invertebrates and birds [65–67].

These compounds are known to be potential antioxidants and can prevent free radicals from attacking different molecules including those of the skin tissue. Lycopene, in particular, may be the most effective against the singlet oxygen radical, which is potentially the most dangerous ROS generated in the skin following sunlight exposure to sunlight [20]. Therefore, the skin-protective effects of carotenoids have encouraged their widespread study as potential photoprotective agents.

Buriti palm tree (*Mauritia flexuosa*) oil is rich in carotenoids and has been frequently used in the production of cosmetics. Buriti oil contains approximately 1.7 mg of total carotenoids g^{-1} . Furthermore, β -carotene is the major carotenoid and represents 90% of the total carotenoid content of most substances [68, 69].

Zanatta *et al.* [18] investigated whether topical creams and lotions formulated with Buriti oil and commercial surfactants

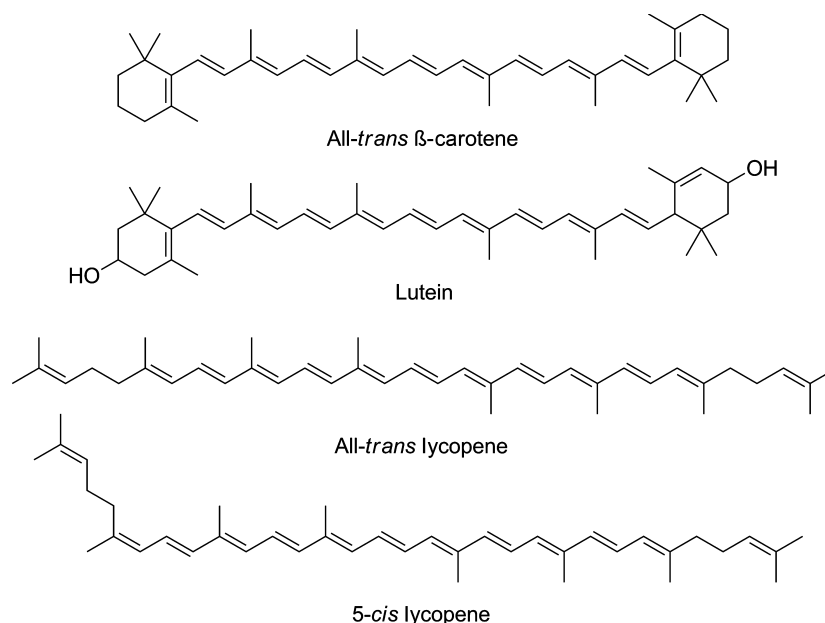


Figure 3 Structure of carotenoids.

exerted photoprotective effects against UVA and UVB irradiation. Human keratinocyte cells and mouse embryonic fibroblast cells were treated with the formulations in two stages consisting (i) prior to and after a 30-min exposure to UVA plus UVB radiation and (ii) prior to and after a 60-min exposure to UVA radiation. The mouse fibroblasts treated with the formulation containing the plain oil showed higher viability than the untreated control cells did following irradiation with UVA plus UVB. The formulation containing the plain oil did not cause phototoxic damage to the cells (especially keratinocytes). Additionally, the product reduced, at least in part, the damage caused by UV radiation. Further investigation suggested a synergistic effect between α -tocopherol and carotenoids, leading to a pro-oxidant activity.

Zanatta *et al.* [18] concluded that Buriti oil emulsions formulated with Steareth-2[®] in combination with Cetareth-5[®] or Cetareth-20[®] in the presence or absence of α -tocopherol were not able to reduce the damages caused by UVA and UVB radiation. However, at the concentration used, the combination of the antioxidants and carotenoids present in the Buriti oil might have exerted a pro-oxidant effect on the cells exposed to UV radiation. Therefore, Buriti oil emulsions may be considered as potential vehicles for transporting antioxidant precursors and may be used as adjuvants in sun protection formulations due to their effectiveness against UVA/UVB radiation. Moreover, they should be re-evaluated in combination with organic UV filters to investigate whether their antioxidant effects can enhance the photoprotection compared to the organic filters alone.

The dry extract of *Malpighia glabra* L. (acerola) has also been studied as a potential sunscreen agent due to the presence of flavonoids and carotenoids in the fruit [70–72]. Souza *et al.* [73] assessed the *in vitro* antioxidant and photoprotective activities of dry acerola extract incorporated into O/W emulsions in the presence or absence of a chemical sunscreen. The emulsion containing extracts of acerola showed absorption in the UVB region with maximum absorbance at 290 nm. Acerola showed a clear antioxidant activity at the concentration used in the formulation; however, it did not exhibit an SPF ≥ 2 and, thus, cannot be considered as a fruit with photoprotective potential. The acerola extract emulsion was combined with the organic filters, 2-ethylhexyl p-methoxycinnamate (5%) and 2-hydroxy-4-methoxybenzophenone (3%), and the resulting formulations synergistically protected the skin against UV irradiation-induced damage. Therefore, acerola may be useful as an adjuvant in sunscreen formulations [73].

Açaí (*Euterpe oleracea* Mart.), a native palm of the Amazon region, contains essential nutrients and anthocyanins, which are a class of polyphenols with reported antioxidant properties [74–77]. An açaí extract was investigated by Daher *et al.* [78] to determine its photoprotective activity in O/W emulsions. In this study, the emulsion containing açaí glycolic extract showed a PF-UVA of 14.97, a 1.69 SPF/PF-UVA ratio and a critical wavelength of 378 nm. Therefore, this emulsion may be considered a sunscreen with UVA and UVB protectant effects, according to Brazilian legislation and the European Cosmetics Association.

Lipid nanocarriers with rice bran and raspberry seed oil incorporated into cosmetic formulations were developed by Niculae *et al.* [79] who evaluated their photoprotective capacity. The lipid nanocarriers, which contained large amounts of vegetable oils, were incorporated into creams containing 3.5% UV filters (butylmethoxydibenzoylmethane [BMDBM] and octocrylene [OCT]). The results indicated that both sunscreens exhibited improved photoprotection, reflected as a 91% and 93% increased protection against

UVA and UVB rays, respectively. The determination of the release mechanisms of both UV filters from the same lipid nanocarrier after 24 h revealed that a slow release of BMDBM (less than 4%) and OCT (17.5%) occurred via Fick's diffusion process. The study demonstrated a synergistic effect between plant extracts (rice bran and raspberry seed oil) and organic filters. This study is a milestone in both nanotechnology and skin cosmetology that will lead to the development of safer cosmetic formulations with antioxidant and photoprotective properties. Furthermore, an effective co-release of active ingredients can be achieved because of the high nano-structured vegetable oil content combined with a low amount of synthetic UV filters in the same carrier system.

Another study highlighting the synergistic effect between plants and organic filters was performed with green coffee oil [80], which contains polyphenols that are responsible for the photoprotective potential of the formulation. According to Chiari *et al.* [80], green coffee oil in combination with the synthetic sunscreen ethylhexylmethoxycinnamate showed a 20% increase in SPF. Therefore, data from this study suggest that this vegetable oil is a potential natural sunscreen product that could be used in formulations to improve the efficiency of skin damage protection.

Garcinia brasiliensis epicarp extract was also investigated for potential photoprotective activity based on its polyphenolic compound content. Figueiredo *et al.* [81] determined the *in vitro* and *in vivo* photoprotective/photochemopreventive potential of this plant, and their results showed that the extract had great potential for use as a sunscreen combined with UV filters in topical formulations. The *in vitro* studies using fibroblasts showed that the photoprotective properties of the formulation containing *G. brasiliensis* were similar to those of a commercial sunscreen with SPF-15. The *in vivo* results demonstrated that the formulation decreased UVB-induced damage such as reduced endogenous glutathione depletion, increased myeloperoxidase activity and secretion of cytokines interleukin (IL)-1 β and tumour necrosis factor (TNF)- α .

Jarzycka *et al.* [82] investigated the *in vitro* photoprotective activity and photostability of sunscreen formulations containing *Helichrysum arenarium*, *Sambucus nigra* and *Crataegus monogyna* extracts. These plants are rich in phenolic compounds including flavonoids [81]. The aim of this study was to determine the photoprotective efficacy of formulations before and after exposure to UV radiation using polymethylacrylate (PMMA) plates. The results showed *in vitro* SPF values in the range of 6.00–9.88 for the individual plant extracts. However, the emulsions containing a mixture of plant extract showed *in vitro* SPF, and PF-UVA values that were higher; for *H. arenarium* and *C. monogyna*, values were 19.51 and 16.58; for *C. monogyna* and *S. nigra*, 18.21 and 7.54; and for *S. nigra* and *H. arenarium*, 16.94 and 11.57, respectively. Therefore, the data presented suggest that the formulations' photoprotective activity against UVA and UVB was significantly reinforced when the formulations contained extract combinations [82].

The photostability study was performed by subjecting the formulations to UV radiation at an intensity of 650 W m⁻² within 2 h, following global solar radiation intensity (290–400 nm), according to the guidelines of the International Commission on Illumination (CIE) [83, 84]. The results showed that the tested emulsions exhibited excellent photostability, especially in the UVA region, regardless of the UV irradiation intensity. The authors concluded that the addition of polyphenolic compounds to sunscreen formulations is a promising strategy for the development of broad-spectrum sunscreen products with enhanced efficacy and safety.

Herbal oils used in cosmetics such as olive, coconut, castor, almond, mustard, chaulmoogra and sesame also have *in vitro* sun protection factor determinate. In a study conducted by Kaur and Saraf [85], herbal oils of various manufacturers purchased from local pharmacies were prepared by dilution in an ethanol and water solution (40 : 60), and then their absorbance values were determined at 290–320 nm using a UV–visible spectrophotometer. The *in vitro* SPF values for the olive and coconut oil were approximately 8; castor oil, approximately 6; almond oil, approximately 5; mustard oil and chaulmoogra oil, approximately 3; and sesame oil, approximately 2. Their conclusion was that olive and coconut oils had the best SPF values, a finding that will be helpful in the selection of fixed oil for sunscreen formulations.

Furthermore, the presence of flavonoids in some plant species has encouraged the evaluation of their potential photoprotective activity, including *Moringa oleifera* L. [86], *Achillea millefolium* L. (seed oil) [87] and several other species from the Savanna region of Brazil, including *Apocynaceae*, *Lythraceae* and *Oxalidaceae* [88]. According to Korac and Khambholja [89], the incorporation of herbs into formulations such as sunscreens is commonly being explored, and the traditional use of plants as medication or for beautification has become the basis for numerous research studies and for making new advances in cosmetics. However, under the current conditions and plant extract concentrations used, these extracts are not capable of providing SPF values above 6 and, therefore, cannot be described as natural sunscreen agents according to the ANVISA guidelines [43].

Besides studies on plants, other natural materials such as mycosporines [90], lignin [91] and green algae such as *Klebsormid-*

ium fluitans [92, 93] were also analysed for their potential photoprotective activity and have become natural-based sun filters for sunscreens.

Conclusions

Sunscreen use is essential to combat skin damage, and therefore, numerous studies are being conducted, aimed at developing new formulations that are safe and efficacious. Additionally, scientists are exploring natural compounds of plant origin that are capable of absorbing UV radiation and possess photoprotective activity. Polyphenols, especially flavonoids, have been widely explored for radiation absorptive properties. Furthermore, carotenoids are currently being analysed for potential antioxidant activity. Studies on açai and the combination of *H. arenarium*, *C. monogyna* and *S. nigra* demonstrated one of the highest SPF values. However, although numerous studies have demonstrated that the use of these plant compounds improved the SPF values and efficacy of commercial UV filters, the research into and discovery of new sunscreens that contain plant compounds, which can protect the skin effectively, according to ANVISA and FDA guidelines, is still necessary.

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