

Chapter

Plant-Based Sunscreens: Innovations and New Formulations

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Abstract

This book chapter corresponds with the modern trends that aim to include natural plant compounds and vegetal extracts in dermocosmetics and cosmeceuticals. Today, there is an increased tendency to obtain new cosmetic formulations that are eco-friendly, non-toxic, hypoallergenic, and possess antioxidant and anti-inflammatory effects. In this perspective, the main purpose of this chapter is to review the applications and limitations of some natural compounds and vegetal extracts (*Aloe vera*, *Maurititia flexuosa*, *Elaeagnus angustifolia*, *Punica granatum*, *Daucus carota*, *Cocos nucifera*, and others) in skin photoprotection and to present the latest topical formulations based on plants developed to increase their effectiveness.

Keywords: sunscreen, UV radiation, natural compounds from plants, vegetal extracts, modern formulations

1. Introduction

Sun exposure plays a significant role in human health, offering both benefits and risks. Moderate sun exposure is the primary natural source of vitamin D synthesis, which is crucial for bone health and immune function. Sunlight increases melanogenesis, which acts as a natural sunscreen and has an anti-inflammatory effect in some cutaneous conditions such as acne, psoriasis, and eczema. It is also linked to improved mood and circadian rhythm regulation [1, 2]. However, the positive effects are outweighed by the risks associated with prolonged or unprotected exposure to ultraviolet (UV) radiation.

The sun emits three types of UV radiation: UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm). Although UVC radiation has the highest energy in the UV spectrum and is the most harmful to human DNA, inducing carcinogenesis, it is largely absorbed by the Earth's ozone layer and does not reach the surface [3]. About 90–99% of UVA and 1–10% of UVB rays reach the Earth's surface, having a substantial impact on skin and overall health [1]. UVB rays are only capable of reaching the epidermis and are primarily responsible for sunburns, as they damage the DNA in epidermal cells, triggering inflammation and redness. UVA rays are able to penetrate deep into the dermis and accelerate the breakdown of collagen and elastin fibers, leading to premature aging, wrinkles, and loss of skin elasticity. They cause photoaging, immunosuppression, and skin cancer [3]. Chronic exposure to both UVA and UVB radiation increases the risk of skin cancers, including basal cell carcinoma,

squamous cell carcinoma, and the more aggressive melanoma. UV radiation causes DNA mutations, oxidative stress, and immune suppression, all of which contribute to carcinogenesis [4].

Overexposure can cause hyperpigmentation issues such as melasma and age spots and can damage the skin microbiome, reducing host immunity. UV rays can also harm the eyes, contributing to cataracts and macular degeneration. Excessive UV exposure may suppress the immune system, reducing the skin's ability to combat infections and increasing susceptibility to diseases. It can also exacerbate autoimmune conditions like lupus and increase oxidative stress in tissues, potentially accelerating aging and chronic disease development [2].

In recent years, other types of radiation with less energy, have been shown to possess deleterious effects on human health, such as blue light, near-infrared radiation, and long UVA. Near-infrared radiation is involved in photoaging along with UVA radiation [5]. Exposure to blue light from smartphones, computers, tablets, and electronic devices in general greatly contributes to extrinsic skin aging. Blue light penetrates up to 1 mm into the dermis and induces the formation of free radicals, resulting in DNA damage, hyperpigmentation, skin aging, and deregulation of the circadian rhythm [6].

To mitigate the harmful effects of UV radiation, sunscreens are formulated with UV filters that either absorb, reflect, or scatter harmful rays. UV filters are broadly classified into organic (chemical) and inorganic (physical) filters. Organic UV filters absorb UV radiation and convert it into heat through a photochemical reaction, preventing the rays from penetrating the skin. These filters are composed of aromatic compounds that contain conjugated double bonds, which allow them to absorb specific UV wavelengths. Since UVB causes immediate and serious sunburn, most organic UV filters protect against UVB rays, and only a few can protect against UVA rays [1]. Because each filter has a limited spectral band of absorption, in order to achieve broad-spectrum protection, they are mainly used in combination, with the maximum additive concentration ranging from 2 to 20% in the EU, USA, China, and Japan [7].

Inorganic filters, also known as mineral filters, act by reflecting and scattering UV radiation away from the skin. They are composed of non-toxic, naturally occurring minerals (zinc oxide, titanium dioxide) and are generally considered safer and more environmentally friendly. Inorganic filters offer broader coverage by blocking both UVB and UVA radiations and are more photostable. They are less likely to cause allergic reactions or irritation by penetrating only up to the dermis layer, making them ideal for sensitive skin types. The disadvantage of giving a white appearance to the skin on application may be overcome by incorporating these filters in microparticles and nanoparticles [8, 9].

Organic UV filters may cause skin irritation, allergic, and photoallergic contact dermatitis. They are lipophilic molecules that may be absorbed and accumulated in the adipose tissue, leading to systemic effects (endocrine-disrupting effects, cytotoxicity, neurotoxicity, and behavioral changes). Some compounds are unstable under exposure to ultraviolet radiation and may trigger phototoxic reactions, adding extra oxidative damage to skin cells [2, 10]. To mitigate this effect, different antioxidants (retinol, ascorbic acid, and tocopherol) have been included in sunscreen formulations [8]. Another disadvantage of conventional UV filters is the harmful effect on ecosystems, which negatively impacts the human body [4].

The demand for natural, safe, and sustainable alternatives to synthetic UV filters has driven significant interest in plant-based compounds and extracts for sunscreen formulations. These natural ingredients provide protection against ultraviolet (UV)

radiation while often offering additional skin benefits, such as antioxidant and anti-inflammatory properties [2]. Some plant compounds contain chromophores that absorb UV radiation and convert it into harmless heat, similar to synthetic chemical filters. Plant compounds with aromatic rings usually show a broad absorption spectrum with a wavelength range of 200–400 nm [1].

Antioxidants present in plant extracts neutralize reactive oxygen species (ROS), mitigating the oxidative stress induced by UV radiation. Moreover, plant-derived compounds often possess anti-inflammatory properties that soothe the skin and reduce erythema (sunburn). Notable natural compounds that can be used in sunscreen formulations are polyphenols (epigallocatechin gallate from green tea; proanthocyanidins from grape seed; flavonoids like apigenin, quercetin, rutin, kaempferol; phenolic acids, such as ferulic acid and caffeic acid), carotenoids (beta-carotene, lycopene, and lutein), seed oils (shea butter, cocoa butter, jojoba oil, rosehip oil, and grapeseed oil), volatile oils (chamomile, lavender), and alkaloids (sanguinarine, piperine, and caffeine) [2, 11].

This chapter presents an overall profile of the plant extracts or compounds with UV-filter activity, their main biological effects, their mechanisms of anti-UV activity, and modern nano-formulations that can increase their activity. The review is based on articles published in the last 5 years, retrieved by searches of the following electronic databases: Web of Science, Pubmed, Google Scholar, Elsevier, and Wiley. Only articles including plant extracts or natural compounds from plant sources were selected. The following keywords were used: sunscreen, SPF, sun protection factor, and UV filter. All keywords were searched individually and in combination.

2. Plant-based UV protection agents in sunscreens

One of the primary benefits of plant extracts and compounds as UV filters is their natural ability to absorb and reflect harmful UV radiation. These phytochemicals work by either absorbing UV rays or acting as physical barriers to reduce the penetration of harmful radiation into the skin. Plant-based UV filters are often rich in antioxidants, which play a vital role in neutralizing free radicals caused by UV exposure, thereby helping to prevent skin aging and cellular damage [12]. These antioxidants can protect the skin from oxidative stress and inflammation, reducing the risk of sunburn, premature aging, and skin cancer. Unlike synthetic chemicals, plant extracts provide a more holistic form of protection by not only shielding the skin from UV damage but also supporting its recovery and regeneration [2].

One of the major concerns with conventional sunscreens is their use of potentially harmful synthetic chemicals, such as oxybenzone, avobenzone, and parabens. These chemicals can sometimes cause skin irritation, allergies, or hormonal disruptions [7]. In contrast, plant-based sunscreens are typically less likely to cause such adverse reactions. The natural origin of these compounds makes them more suitable for individuals with sensitive skin or those seeking to avoid exposure to harsh synthetic substances. For example, aloe gel is widely known for its soothing and anti-inflammatory properties, making it ideal for calming sunburned or irritated skin [13].

Another significant advantage of using plant extracts as sunscreens is their sustainability and minimal environmental impact. Many chemical-based sunscreens, particularly those containing oxybenzone and octinoxate, have been shown to harm marine life by contributing to coral reef degradation. Plant-based sunscreens, on the other hand, are biodegradable and typically have less harmful effects on the environment, making them a better option for eco-conscious consumers [14].

Plant name/natural compound	Type of extract and plant parts used	Mechanism of action	Formulations	Ref.
<i>Agave americana</i> var. <i>americana</i> (Aa) <i>A. americana</i> var. <i>marginata</i> (Am)	Ethanol extract of leaves	Aa extract: SPF of 9.95; Am extract: SPF of 5.84; phytosome formulations with Aa extract had SPF activity of 9.96–13.3 (with 40 mg extract and 60 mg soy lecithin)	Formulations with phytosomes (with 20–40 mg dry ethanolic extract)	[15]
<i>Aloe vera</i>	<i>Aloe vera</i> -loaded solid liquid nanoparticles	<i>In vitro</i> SPF value of 16.9 ± 2.44 ; <i>in vivo</i> SPF value of 14.81 ± 3.81	Solid lipid nanoparticles	[16]
<i>Astragalus monspessulanus</i>	Ethanol extract	SPF of 38.55 ± 0.85 due to antioxidant activity	—	[17]
<i>Baccharis antioquiensis</i>	Polyphenol extracts from the leaves, in different solvents (ethanol, methanol, hexane, dichloromethane, ethyl acetate)	Highest SPF value (21.9 ± 3.3) was obtained for the methanolic extract	Oil-in-water (O/W) emulsions of the extracts alone or mixed	[18]
<i>Buddleja salina</i> (the false olive)	Ethanol extract from leaves and stem	Antioxidant, antiproliferative activity against human dermal fibroblasts; SPF value of 16.1 and UVA protection factor (UVAPF) values of 6.45	O/W emulsion	[19]
Calceolarioside (CAL), myconoside (MYC), and <i>Haberlea rhodopensis</i> methanol extract (HRE)	Isolated from the leaves of <i>Haberlea rhodopensis</i>	HRE, MYC, and CAL significantly reduced intracellular ROS formation in UVR-exposed HaCaT cells; modulation of redox homeostasis; CAL is a potent natural NRF2 activator	—	[20]
<i>Calea fruticosa</i>	N-hexane, ethyl acetate, and ethanol aerial parts extracts	Highest SPF value (9.665) was obtained for the ethanolic extract (0.1 mg/mL) due to coumarin content and its antioxidant activity Extracts showed synergistic action on the sunscreen	Sunscreen UVA-UVB 5% Pemulen TR-1 gel mixed with the extracts	[21]
<i>Carpobrotus edulis</i>	Aqueous leaf extract	Photoprotective activity (absorption in UV region)	Oil in cream emulsion	[22]
Catechins	Isolated from <i>Uncaria gambir</i> leaves	Antioxidant properties SPF 16	O/W emulsion with <i>Cera alba</i> , tween 80, cetyl alcohol, and stearyl alcohol	[23]
<i>Cistus ladanifer</i>	Labdanum resin	Antiaging Anti-inflammatory activity due to its flavonoid fraction		[24]

Plant name/natural compound	Type of extract and plant parts used	Mechanism of action	Formulations	Ref.
<i>Cocos nucifera</i>	Ethanollic husk fiber extract	Photoprotection due to phenolic compounds	Emulsions of various concentrations of extract 5–20% in lanette base	[25]
<i>Cocos nucifera</i>	Dark and light-colored lignin from coconut husk	Light-colored lignin exhibits a higher level of UV absorption; Addition of 4% lignin into a commercial sunscreen led to nearly a twofold increase in SPF and UVAPF value	Combinations with plain cream and SPF cream (with various concentrations of lignin of both types)	[26]
<i>Cyperus rotundus</i> (nutsedge)	Aqueous extract of tubers	Antioxidant SPF 5.794	—	[27]
<i>Calendula officinalis</i> , <i>Daucus carota</i> , <i>Solanum lycopersicum</i> , <i>Humulus lupulus</i>	Marigold petals, carrot roots, tomato fruits, and hop cones (water/ water and propylene glycol/oil extracts)	Antioxidant due to phenolic content; SPF determined by spectrophotometric method (hop water extract SPF 21)	—	[28]
<i>Curcuma longa</i> , <i>Daucus carota</i> , <i>Camellia sinensis</i> , <i>Aloe vera</i> , <i>Cera flava</i> , <i>Cocos nucifera</i>	Turmeric powder, carrot seeds, green tea extract, aloe gel, beeswax, coconut oil	Photoprotection due to compounds with antioxidant activity; SPF values of 33.43 and 33.50	Coconut oil-based sunscreens	[13]
<i>Daucus carota</i>	Carrot extract	Carrot extract was as effective as SPF 15 in preventing apoptosis of mouse fibroblasts exposed to UVB; an antioxidant	—	[29]
<i>Daucus carota</i>	Carrot seed oil	SPF value of 0.1 for the <i>in vitro</i> determination and 2.5 for the <i>in vivo</i> determination	—	[30]
Gamma-oryzanol, <i>Daucus carota</i> , <i>Vitellaria paradoxa</i> , <i>Cera flava</i>	Gamma-oryzanol-loaded NLCs, nanosized UV filters, carrot seed oil, shea butter, beeswax	SPF = 34 due to the presence of both inorganic and organic UV filters, the potent antioxidant gamma-oryzanol, and natural oils, with synergistic effects	Topical xanthan gum nanogel	[31]
<i>Daucus carota</i>	Carrot root extract, carrot seed oil, sunflower oil, canola oil, beta-carotene, tocopheryl acetate	Photoprotection from blue light: in the 415–455 nm wavelength range associated with oxidative stress, Carotolino (0.4%) reduced blue light by 97%	Lipophilic complex (Carotolino)	[32]
<i>Dalbergia sissoo</i>	Leaves aqueous extract, fruits aqueous extract, bark aqueous extract	Leaves and fruit extracts have moderate SPF; bark extract has shown SPF value (39.38) higher than positive control (33.76); antioxidant, DNA protection, and anti-proliferative activity	Gel formulations with 1 mg/ml extract	[33]

Plant name/natural compound	Type of extract and plant parts used	Mechanism of action	Formulations	Ref.
Dihydroquercetin (DHQ) Quercetin (Q) Beta-carotene (β C)	—	Emulsion with 0.5% DHQ and 2% β C has SPF 5.19, emulsion with 0.5% DHQ has SPF 4.65, and emulsion with 0.5% Q has SPF 3.35	Fast inverted oil-in-water emulsion/ SWitch-Oil-Phase (SWOP) emulsions	[34]
<i>Elaeagnus angustifolia</i>	70% methanolic extract of leaves (EAPE)	SPF values of formulations with 2–8% EAPE was in the range of 6.37 ± 0.14 to 21.05 ± 0.85	Emulgel (emulsion type O/W) with EAPE, sesame oil, and sea buckthorn oil	[35]
<i>Elaeocarpus floribundus</i>	N-hexane, ethyl acetate, and methanol leaf extracts	Antioxidant activity; SPF values of methanol extract were 45.470, 44.791, 43.754, 38.861, and 21.102 for 1000, 800, 600, 400, and 200 μ g/mL, respectively	—	[36]
Epigallocatechin gallate	Isolated from green tea leaves	Antioxidant activity protects fibroblasts from oxidative-stress damage; broad-spectrum UV absorption and lower UV transmittance than commercial sunscreens with SPF 15 and 30	Formulations with 10 wt% EA NPs (epigallocatechin gallate/aminobenzoic acid nanoparticles)	[37]
<i>Erica australis</i>	Aqueous extract of flower	Antioxidant activity: Flower extracts showed a negligible SPF value (0.18). The elaborated sunscreen creams presented an SPF of 5.8	O/W emulsion	[38]
<i>Helichrysum odoratissimum</i>	The ethanolic extract of leaves and stem	Antioxidant, antiproliferative activity against human dermal fibroblasts; SPF value of 16.0 and UVAPF values of 6.47	O/W emulsion	[19]
Lignin obtained from <i>Kenaf</i> stalks (<i>Hibiscus cammabinus</i>)	Light-color lignin	2% lignin nanospheres added to SPF 30 sunscreen increased SPF value to 67.88; 4% lignin nanosphere added to SPF 10 sunscreen increased SPF to 27.84	Lignin nanospheres added to commercial sunscreen lotion of SPF 10 and 30	[39]
<i>Moringa concanensis</i>	Hexane, chloroform, methanol, and ethyl acetate stem bark extracts	Photoprotection due to antioxidant activity; SPF value of 10.50 ± 0.23 for the chloroform extract	—	[40]
<i>Nephelium lappaceum</i> (rambutan)	The ethanolic extract of fruit peel	Addition of rambutan total phenolics (at concentrations of 0.25%, 0.50%, and 1.00%) to organic sunscreens, resulting in an increase of SPF values of 23.5, 49.6, and 134.9%	Cream emulsions	[41]

Plant name/natural compound	Type of extract and plant parts used	Mechanism of action	Formulations	Ref.
<i>Oncosiphon suffruticosum</i>	Essential oil from the fresh aerial parts	SPF value of 2.299 photoprotection due to antioxidant activity	—	[42]
<i>Opuntia ficus-indica</i> (prickly pear)	Seed pomace extracts (a by-product of seed oil extraction)	SPF value of 8.36 ± 0.53 ; photoprotection due to antioxidant activity	Oil-in-water emulsions	[43]
<i>Orbignya phalerata</i> (babassu)	Lipophilic extract of seeds	SPF of 35.5 ± 3.0 , photostable after 6 h of radiation and non-cytotoxic to fibroblast cells	Oil-in-water nanoemulsion containing babassu lipophilic extract and low concentrations of organic sunscreens	[44]
P-coumaric acid	—	SPF value of 36 ± 0.2 and UVAPF value of 16 ± 0.4 ; significant reduction of UV-A induced oxidative stress biomarkers; enhanced permeation	P-coumaric acid-phospholipid complex-loaded gel	[45]
<i>Pluchea discoloridis</i> , <i>Lawsonia inermis</i> , <i>Aloe vera</i> , <i>Eucalyptus camaldulensis</i>	90% methanolic extract of leaves	Antioxidant activity: Extracts (1 mg/ml) had SPF values of 18.79 ± 2.01 , 19.97 ± 0.78 , 18.85 ± 1.10 , and 17.97 ± 1.24 , respectively	—	[46]
<i>Psidium guajava</i>	Ethanollic fruit extract	Photoprotection due to the flavonoid and tannin content improved the photoprotection of an organic filter formulation with 134% (SPF 8.1)	Cream with guava-fruit extract and 2-ethyl-hexyl methoxycinnamate	[47]
<i>Punica granatum</i>	Polyphenol enriched fraction (PEF) of pomegranate peel	Antioxidant activity; SPF value of 7.5; UV-A1/total UV value of 0.94	Water-in-oil emulsions with 5% zinc oxide-PEF nanoparticles	[48]
<i>Punica granatum</i>	Pomegranate seed oil	Cell DNA protection against UVB-induced damage	Pomegranate seed oil nanoemulsion with pomegranate peel polyphenol-rich extract encapsulation	[11]
Rutin	—	Reduced skin erythema, increased UVA radiation photoprotection	Gelatin nanostructures	[49]
<i>Salsola foetida</i>	Methanolic extract of dried aerial parts	SPF values of 21.3 ± 0.03 due to high content of phenols, flavonoids (anthocyanins), and antioxidant and anti-inflammatory effect	—	[50]
<i>Schinus terebinthifolius</i>	Ethanollic fruit peel extract (STPE) and ethanollic whole fruit extract (STWFE)	SPF values of 20.15–26.82 for STPE and 5.08–16.41 for STWFE; SPF values of emulsion extracts varied between 1.25 and 32.40 for STPE and 0.52 and 41.58 for STWFE	Emulsion of STPE or STWFE of 5% or 10% concentration in Lanette base	[51]

Plant name/natural compound	Type of extract and plant parts used	Mechanism of action	Formulations	Ref.
<i>Spondias purpurea</i>	70% v/v ethanolic extract of stem bark	SPF value for the extract (14.37 at 0.2 mg/mL and 26.16 at 2 mg/mL); SPF values of the formulations obtained in 0.2 mg mL ⁻¹ (0.495–2.27) and 2.0 mg mL ⁻¹ (2.29–15.87); antioxidant activity due to phenolic content	Formulations with different concentrations (0.2–10% ethanolic extract of stem bark)	[52]
<i>Stenochlaena palustris</i> (kelakai)	70% ethanolic extract of root	SPF value of 9.816; erythema transmission percentage of 9.591%; pigmentation transmission percentage of 16.779%	0.5% microemulsion (with 0.1% extract) incorporated into a gel form	[53]

Table 1.
Plants and natural compounds with photoprotective activity.

Some plant compounds, such as the polyphenols found in red algae and certain fruits, provide broad-spectrum protection against both UVA and UVB rays. By using plant-based sunscreens, consumers benefit from natural compounds that can offer protection across the full spectrum of UV radiation. Their antioxidant properties, non-toxic nature, and broad-spectrum protection make them a valuable option for consumers looking to protect their skin from harmful UV rays while also promoting overall skin health [1]. **Table 1** lists plants and phytocompounds that have been investigated as active sunscreen ingredients in the last 5 years.

Despite their advantages, natural compounds used in sunscreens face certain challenges: lower SPF, stability issues, variability in efficacy, skin penetration, cost and scalability, and regulatory approval. Most natural extracts provide moderate sun protection factors, often insufficient for high-performance sunscreens. As a result, they are typically combined with synthetic filters to meet regulatory standards for sun protection [54].

Many natural compounds degrade rapidly under prolonged UV exposure, reducing their effectiveness over time. Stabilizing these ingredients often requires advanced formulation techniques or the addition of synthetic stabilizers, which may reduce their appeal as “natural” products [54].

The photoprotective efficacy of plant-based ingredients can vary significantly depending on factors such as plant species, extraction method, and formulation. This variability poses challenges for standardization and consistent performance. In addition, some natural UV filters struggle to penetrate the skin adequately to provide effective protection, limiting their functionality in topical applications. **Also**, the extraction and purification of high-quality natural compounds can be expensive and resource-intensive, making it difficult to scale production for commercial use [55].

Regulatory frameworks for sunscreen products often require rigorous testing of efficacy and safety. There are no natural compounds approved as UV filters in the European Union or USA [14]. Many natural extracts lack the extensive scientific validation needed to obtain approval, delaying their adoption in mainstream sunscreen products.

3. Enhanced sunscreen formulations

Plant extracts and isolated plant compounds have been included over time in various classic formulations (emulsions, microemulsions, conventional gels, creams) or modern ones with the aim of increasing their stability, their ability to spread and penetrate the skin, and improving their organoleptic appearance, but also to make them as easy to apply as possible and as attractive as possible for those who use them.

The development of new eco-friendly formulations from renewable sources represents an increased concern in obtaining cosmeceuticals. Classical sunscreen formulations predominantly consist of popular emulsion-based products, such as creams, gel creams, and lotions. Water-in-oil (w/o) emulsions are often favored for sunscreens due to their ability to deliver high SPF and excellent water resistance. However, w/o emulsions typically contain a higher oil-to-water ratio, resulting in a greasy texture and heavier feel, which can make them less appealing compared to oil-in-water (o/w) emulsions. To address this, fast-inverting o/w emulsions, also known as Switch-Oil-Phase (SWOP) emulsions, have been developed. These emulsions invert into w/o emulsions upon application, forming a lipophilic, water-resistant layer on the skin, making them particularly suitable for sun protection products. Thus, Radava Martić et al. tested the antioxidant activity and UV absorption of several SWOP emulsions added with dihydroquercetin and β -carotene [34]. The SPF of SWOP emulsion that consisted of combining dihydroquercetin and β -carotene was the highest (5.19), likely due to the combined effect of both active ingredients. While β -carotene is not a conventional UV absorber, it may protect dihydroquercetin from oxidation through its antioxidant properties, thereby enhancing dihydroquercetin's UV absorbance. In contrast, the SPF of the emulsion base S was minimal. These results highlight the good photoprotective potential of the selected antioxidants when combined with a promising cosmetic carrier like the SWOP emulsion [34].

Isolated constituents from the crude plant extracts have demonstrated greater photoprotection capacity compared to the extract. It is the case of two phenylethanoid glycosides (calceolarioside and myconoside), isolated from *Haberlea rhodopensis* leaves. These compounds could be used in photoprotective formulations, given their ability to reduce UVA/UVB-induced ROS production, results observed in an in vitro photoaging model in human keratinocytes. It appears that calceolarioside is a potent NRF2 activator; meanwhile, myconoside stimulates PGC-1 α and TGF-1 β /SMAD/Wnt signaling pathways [20].

The association of coconut oil with *Aloe vera* gel, turmeric, green tea, and carrot seed led to a more improved formula, with a protection factor of 33.47. The topical preparation presented a good safety profile for topical application without mutagenic effects, irritation, or erythema. In addition, it proved to be homogeneous, uniform, stable, and presented *in vitro* a good antioxidant activity [13].

But there are also cases where the addition of a plant extract to a commercial UV filter with a known protection factor does not result in an improvement in SPF, possibly due to the lack of synergism between the components. Rodrigues et al. managed to identify a large number of compounds in the stem bark extract of *Spondias purpurea* (phenolic acids, tannins, flavonoids and derivatives, and benzophenones), which explained the high antioxidant activity. Also, the SPF value of the extract was higher (26.16) than that of octyl methoxycinnamate (SPF 21.84), a substance known for its photoprotective effect. Unexpectedly, in the formulation that combined the two, a

decrease in SPF by 9 units (17.16) was detected. However, plant extracts are valuable sources of compounds that can prevent cellular degradation following exposure to UV radiation, thus contributing to greater skin protection [52].

3.1 Oil-in-water emulsions

Oil-in-water emulsions (O/W) are frequently used in cosmeceuticals and have high potential for several industrial areas (pharmaceuticals, cosmetics, and food). In the cosmetics industry, water-in-oil emulsions are used in creams and lotions, providing a hydrating effect and helping deliver moisture deep into the skin. These emulsions are particularly effective in creating products that offer long-lasting moisture without feeling greasy, and plant extracts can be easily included in such formulations [56].

An emulgel containing different concentrations of *Elaeagnus angustifolia* purified extract from leaves (2, 4, 6, 8%) proved to have good stability for 8 weeks in temperature variations between 4 and 40°C. The preliminary tests regarding stability led to the conclusion that the best concentration was 6%, and this formulation had colorless effects on the skin. The sun protective factor (SPF) for this new emulsion O/W was spectrophotometrically detected, and its value of 16.03 makes this species a good, natural candidate as an alternative to synthetic substances, thus reducing adverse reactions [35]. According to the European Cosmetic Regulation 1223/2009, the protection categories based on the SPF results (*in vitro* or *in vivo* tests) are the following: measured SPF 6–14.9 (low protection), SPF 15–29.9 (medium protection), and SPF 30–59.9 (high protection) [57].

Buddleja salina and *Helichrysum odoratissimum* are another two plants with antioxidant activity and antiproliferative effects against skin cancer lines. The ethanolic extracts of leaves and stems of these species were incorporated in two O/W emulsions, to which was also added titanium dioxide (Solaveil™ XT-100), in order to obtain an SPF of 15. The ethanolic plant extracts were added in an amount of 6.0 mg/mL in each formulation and represented 10% of the ingredients. The good results obtained in the *in vivo* skin irritation tests on female volunteers (18–65 years old), but also the test on the human dermal fibroblast cell line, which attests to non-mutagenicity, correlated with an SPF of approximately 16 and UVAPF (UVA protection factor) of 6.45 for *B. salina* and 6.47 for *H. odoratissimum*, making the two plants valuable sources of natural ingredients added to products with a photoprotective effect [19].

3.2 Microemulsions

Microemulsions are also used in the cosmetics industry to improve skin penetration. They are thermodynamically stable mixtures of oil, water, and surfactants, characterized by their nanoscale droplet size [58].

The 70% ethanolic extract of roots of *Stenochlaena palustris* with a high content of flavonoids, alkaloids, and saponins have proven their efficiency in terms of UV protection of the skin when incorporated into a microemulsion gel. In addition, the gel formulated with sodium carboxymethyl cellulose and propylene glycol was classified as “sunblock” in the tests regarding evaluation of erythema transmission percentage and pigmentation transmission percentage [53].

3.3 Nanostructures

The increasing awareness of the need for effective sun protection has driven innovation in sunscreen formulations, with nanostructures emerging as a game-changing

technology. Nanostructured systems, such as nanoparticles, liposomes, and nanoemulsions, have transformed sunscreen development, particularly with plant-based compounds and extracts as active ingredients. These advanced formulations offer enhanced UV protection, stability, and environmental sustainability [59]. Nanostructures protect delicate plant compounds, like polyphenols and flavonoids, from degradation by light, oxygen, or heat, ensuring prolonged efficacy [4]. Liposomes and solid lipid nanoparticles transport active compounds like curcumin or resveratrol deeper into the skin, providing sustained protection and reducing the need for frequent reapplication [10]. Phytochemicals serve as safer, biodegradable alternatives to synthetic UV filters, minimizing environmental and health risks. Nanostructured formulations create lightweight, transparent, and non-greasy sunscreens, masking odors and textures of plant extracts for a better user experience [8]. These systems combine UV protection with skin benefits like hydration, antiaging, and anti-inflammatory effects, addressing diverse consumer needs. Efficient use of natural resources and biodegradable ingredients reduces the ecological footprint of sunscreens, especially in marine environments [60].

Advanced research in the field of dermatocosmetics has led to the development of formulations with phytosomes to improve the absorption of molecules into the skin. One such study conducted on ethanolic extract from *Agave americana* leaves showed that with increasing concentration of plant extract in phytosomes, an increase in SPF was also observed. In order to obtain phytosomes, varying concentrations of soy lecithin (50–70 mg), plant extract (20–40 mg), and 10 mg cholesterol, all dissolved in dichloromethane, were used. The formulated samples exhibited *in vitro* SPF values, ranging from 3.86 (control) to 9.96 (formulation with 20 mg extract), 12.2 (formulation with 30 mg extract), and 13.3 (formulation with 40 mg extract) [15].

Also, oil-in-water nanoemulsions prepared by ultrasound have been developed with the aim of increasing the solubility and stability of lipophilic substances or extracts. One such example is *Orbignya phalerata* lipophilic extract from seeds with a high content of saturated fatty acids (lauric acid 52.64% and myristic acid 15.42%), phenolic compounds, and tocopherols, which was incorporated into an oil-in-water nanoemulsion along with 4 substances known for their photoprotective effect. The authors of the study observed an increase in SPF from 28.6 (in the case of the preparation with benzophenone-3, diethylamino hydroxybenzoyl hexyl benzoate, octocrylene, and octyl methoxycinnamate) to 35.5 when babassu lipophilic extract was added. Although the formulation that included only the plant extract presented SPF < 2, it seems that the synergism of action between the components led to a more efficient photoprotective preparation, due to the plant compounds with antioxidant effect [44].

Reis-Mansur et al. proposed preparing some oil-in-water nanoemulsions with 3% buriti oil (*Mauritia flexuosa*) and 10% concentrated dry extract of *Aloe vera* spray-dried. The formulation named NE-A19, to which they added two synthetic filters (octyl methoxycinnamate and ethylhexyl methoxycrylene), proved to have satisfactory organoleptic properties, good stability, no phase separation and was safe for administration. Moreover, the SPF value was 49 [61].

Yingren Liu et al. produced lignin nanospheres for further use in cosmetic sunscreen formulations. The extracted stabilized lignin was dissolved in a gamma-valerolactone solution to achieve a concentration of 0.4 mg/mL. The resulting lignin solution was transferred into a dialysis bag and dialyzed at room temperature for 48 hours. Following this, the extracted lignin was vacuum-dried, and the lignin

nanospheres were obtained. The morphology and particle size of the lignin nanospheres were measured by scanning electron microscope and a zeta potential tester. Lignin usually has a darker color, but the one obtained by this group of researchers has a lighter color, making it easier to use in cosmetic formulations [39].

P-coumaric acid is a hydroxycinnamic acid widely distributed in plants (fruits, beans, potatoes, tea) that has antioxidant and anti-inflammatory activity, inhibiting UV-B radiation and melanogenesis in cell line culture, but also having a UV-A protective effect. Unfortunately, it lacks the capacity to penetrate the deeper layers of the skin for a longer period of time. In this perspective, Biswas et al. have formulated a complexation of a p-coumaric acid with phospholipid hydrogenated soybean phosphatidylcholine in order to increase its permeability to the skin and its stability. This complex was incorporated in a gel base (carbopol 940) and tested by spectrophotometric methods to determine its SPF value, UV-A protection factor, and photo-stability. The gel met all the conditions for topical application, and the incorporation of coumaric acid in a complex increased the penetration capacity into the skin by almost 6 times. In addition, this formulation has a high capacity to protect the skin from UV radiation: SPF 35.5 and UVAPF 16.2 [45].

Rutin, a therapeutically active flavonoid, has been shown to possess a wide range of pharmacological activities, including anti-inflammatory, antimicrobial, and anticancer. However, its poor aqueous solubility, low membrane permeability, and bioavailability limit its therapeutic applications. In order to increase the penetration of the ingredient into deeper layers of the skin and its benefits in photoprotective formulations, rutin was frequently associated with nanostructures (ethosome, gelatin nanocapsules, phytosome, nanocrystal, chitosan/tripolyphosphate nanoparticles). The encapsulation of rutin into gelatin nanostructures and association with three known UV filters (ethylhexyl dimethyl PABA, ethylhexyl methoxycinnamate, and butyl methoxydibenzoylmethane) increased the *in vitro* value of SPF due to a possible synergistic effect among constituents [49].

Gamma-oryzanol (GO) is a plant-derived natural antioxidant composed of a mixture of more than ten phytosterol ferulates. Its antioxidant activity is considered to be up to 10 times stronger than that of vitamin E in rice bran. Beyond its potent antioxidant properties, gamma-oryzanol offers potential skin-protective benefits, including UV light absorption, intrinsic sun protection factor (SPF)-boosting capabilities, and reported antiaging effects. Badalkhani et al. developed a topical nanogel containing gamma-oryzanol-loaded nanostructured lipid carriers (NLCs) and nanosized UV filters (TiO₂ and methylene bis-benzotriazolyl tetramethylbutylphenol). This involved partially replacing UV filters by incorporating and maximizing the amount of the powerful plant-derived antioxidant (gamma-oryzanol) in the formulations. The findings indicate that encapsulating GO into the NLCs did not result in an increase in particle size, instability, or a reduction in the uniformity of the nanoparticles. Thus, the formulation retained its desirable properties. The optimized nanosystem showed long-term stability and high photoprotection capacity (SPF = 34), along with no sensitization or skin irritation [31].

Aloe vera-loaded solid lipid nanoparticles formulated by Rodrigues et al. using glyceryl monostearate (300 mg) as a lipid and 100 mg aloe powder did not cause skin irritation or sensitization reactions in *in vivo* tests performed on Wistar albino rats. In addition, both *in vitro* and *in vivo* SPF tests showed good skin protection against UV light exposure (SPF = 16.9, respectively 14.81) [16].

The association of a plant such as *aloe vera* which has demonstrated photoprotection, with other plant extracts can lead to the development and innovation of much

improved formulations. This is also the case of *Crocus sativus* (safranal)-loaded solid lipid nanoparticles (SLN), which were incorporated into a cream with aloe vera gel and almond oil. This product demonstrated good stability and excellent rheological properties, having an SPF of 9.22 [62].

4. Conclusions

Natural compounds and plant extracts offer promising alternatives to synthetic UV filters, combining photoprotection with additional skin benefits. Ingredients such as polyphenols, flavonoids, carotenoids, and oils have demonstrated efficacy in absorbing UV radiation, neutralizing oxidative stress, and reducing inflammation. However, challenges such as lower SPF values and stability issues must be addressed to optimize their use in commercial sunscreens. Continued research and innovation are essential to harness the full potential of these natural solutions.

The development of modern instrumental analysis methods and those assessing the biological activity of plant extracts and natural compounds has led to the creation of eco-friendly formulations in the cosmetics industry, offering multiple benefits for users. Innovations in dermatocosmetic formulations represent a significant step forward, especially as they have demonstrated the absence of adverse reactions, good skin tolerability, and additional effects in protecting the skin barrier against the harmful effects of UV radiation due to their antioxidant and anti-inflammatory properties. The development of sunscreen products based on plant extracts, either alone or in combination with synthetic substances known as UV filters, is continuously growing. Progress in this field supports consumers by offering sustainable products derived either from raw materials that are by-products of the wood industry or from renewable sources.

Nanostructured formulations represent a significant advancement in sunscreen technology, particularly when harnessing the power of plant-based compounds and extracts. By improving stability, enhancing delivery, reducing chemical load, and providing multifunctional benefits, these systems offer a superior alternative to traditional formulations. As consumer preference shifts toward safer, more sustainable products, nanostructured sunscreens incorporating natural compounds are poised to become the future of sun protection.

Conflict of interest

The authors declare no conflict of interest.

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References

- [1] Li L, Chong L, Huang T, Ma Y, et al. Natural products and extracts from plants as natural UV filters for sunscreens: A review. *Animal Models and Experimental Medicine*. 2023;**6**(3):183-195. DOI: 10.1002/ame2.12295
- [2] Verma A, Zanoletti A, Kareem KY, Adelodun B, et al. Skin protection from solar ultraviolet radiation using natural compounds: A review. *Environmental Chemistry Letters*. 2024;**22**:273-295. DOI: 10.1007/s10311-023-01649-4
- [3] Abou-Dahech M, Boddu SHS, Bachu RD, Babu RJ, et al. A mini-review on limitations associated with UV filters. *Arabian Journal of Chemistry*. 2022;**15**(11):104212. DOI: 10.1016/j.arabjc.2022.104212
- [4] Fonseca M, Rehman M, Soares R, Fonte P. The impact of flavonoid-loaded nanoparticles in the UV protection and safety profile of topical sunscreens. *Biomolecules*. 2023;**13**(3):493. DOI: 10.3390/biom13030493
- [5] Gracia-Cazaña T, Aguilera J, Navarro-Bielsa A, González S, Lim HW, Gilaberte Y. New trends on personalized sunscreens. *Photodermatology, Photoimmunology & Photomedicine*. 2024;**40**(3):e12967. DOI: 10.1111/phpp.12967
- [6] Ferreira L, Torres B, Hameed H, Vieira ACF, et al. Updated insights of active cosmetic ingredients against blue light: *In vivo* and *in vitro* evidence. *Journal of Drug Delivery Science and Technology*. 2024;**101**(B):106306. DOI: 10.1016/j.jddst.2024.106306
- [7] Huang Y, Law J, Lam T, Leung K. Risks of organic UV filters: A review of environmental and human health concern studies. *Science of the Total Environment*. 2021;**755**(1):142486. DOI: 10.1016/j.scitotenv.2020.142486
- [8] Santos A, Marto J, Chá-Chá R, Martins AM, et al. Nanotechnology-based sunscreens - a review. *Materials Today Chemistry*. 2022;**23**:100709. DOI: 10.1016/j.mtchem.2021.100709
- [9] Mascarenhas-Melo F, Mathur A, Murugappan S, Sharma A, et al. Inorganic nanoparticles in dermopharmaceutical and cosmetic products: Properties, formulation development, toxicity, and regulatory issues. *European Journal of Pharmaceutics and Biopharmaceutics*. 2023;**192**:25-40. DOI: 10.1016/j.ejpb.2023.09.011
- [10] Júnior JADC, Mendonça Santos A, Santos Oliveira AM, Santos AB, et al. Use of nanotechnology applied to sunscreens: Technological prospection based on patents. *Journal of Drug Delivery Science and Technology*. 2024;**91**:105245. DOI: 10.1016/j.jddst.2023.105245
- [11] Chu CC, Nyam KL. Application of seed oils and its bioactive compounds in sunscreen formulations. *Journal of the American Oil Chemists' Society*. 2021;**98**:713-726. DOI: 10.1002/aocs.12491
- [12] Mansuri R, Diwan A, Kumar H, Dangwal K, Yadav D. Potential of natural compounds as sunscreen agents. *Pharmacognosy Reviews*. 2021;**15**(29):47-56. DOI: 10.5530/phrev.2021.15.5
- [13] Tiwari R, Singh I, Gupta M, Singh LP, et al. Formulation and evaluation of herbal sunscreens: An assessment towards skin protection from ultraviolet radiation. *Pharmacophore*.

2023;**13**(3):41-49. DOI: 10.51847/svzLRFMP5F

[14] Milutinov J, Pavlović N, Ćirin D, Atanacković Krstonošić M, Krstonošić V. The potential of natural compounds in UV protection products. *Molecules*. 2024;**29**(22):5409. DOI: 10.3390/molecules29225409

[15] Vaghela H, Mbatia B, Calvin A, Sania F, et al. Formulation of phytosomes with sun protection factor using *Agave americana* ethanolic extract. *Journal of Biologically Active Products from Nature*. 2024;**14**:238-250. DOI: 10.1080/22311866.2024.2335153

[16] Rodrigues LR, Jose J. Exploring the photo protective potential of solid lipid nanoparticle-based sunscreen cream containing *Aloe vera*. *Environmental Science and Pollution Research International*. 2020;**27**(17):20876-20888. DOI: 10.1007/s11356-020-08543-4

[17] Benslama O, Lekmine S, Mansouri N. Phytochemical constituents of *Astragalus monspessulanus* and integrative analysis for its antioxidant, photoprotective, and antityrosinase activities: Experimental and computational investigation. *European Journal of Integrative Medicine*. 2023;**60**:102247. DOI: 10.1016/j.eujim.2023.102247

[18] Monsalve-Bustamante YA, López Figueroa F, Vega J, Rodrigues Moreira B, et al. Holistic photoprotection, broad spectrum (UVA-UVB), and biological effective protection factors (BEPFs) from *Baccharis antioquiensis* hydrolysates polyphenols. *Plants*. 2023;**12**(5):979. DOI: 10.3390/plants12050979

[19] Twilley D, Moodley D, Rolfes H, Moodley I, McGawd L, et al. Ethanolic extracts of south African plants, *Buddleja saligna* wild. and *Helichrysum odoratissimum* (L.) sweet, as

multifunctional ingredients in sunscreen formulations. *South African Journal of Botany*. 2021;**137**:171-182. DOI: 10.1016/j.sajb.2020.10.010

[20] Stoykova ID, Koycheva IK, Binev BK, Mihaylova LV, et al. Myconoside and calceolarioside E restrain UV-induced skin photoaging by activating NRF2-mediated defense mechanisms. *International Journal of Molecular Sciences*. 2024;**25**:2441. DOI: 10.3390/ijms25042441

[21] Seregheti TMQ, Pinto APR, da Goncalves CM, dos Antunes SA, et al. Antiproliferative and photoprotective activities of the extracts and compounds from *Calea fruticosa*. *Brazilian Journal of Medical and Biological Research*. 2020;**53**(9):e9375. DOI: 10.1590/1414-431X20209375

[22] Lassoued MA, Ben Fatma NH, Romdhane MH, Faidi A, et al. Photoprotective potential of a Tunisian halophyte plant *Carpobrotus edulis* L. *European Journal of Integrative Medicine*. 2021;**42**(1):101286. DOI: 10.1016/j.eujim.2021.101286

[23] Mita SR, Husni P, Putriana NA, Maharani R, et al. A recent update on the potential use of catechins in cosmeceuticals. *Cosmetics*. 2024;**11**:23. DOI: 10.3390/cosmetics11010023

[24] Frazão DF, Martins-Gomes C, Steck JL, Keller J, et al. Labdanum resin from *Cistus ladanifer* L.: A natural and sustainable ingredient for skin care cosmetics with relevant cosmeceutical bioactivities. *Plants (Basel)*. 2022;**11**:1477. DOI: 10.3390/plants11111477

[25] Oliveira MBS, Valentim IB, Santos TR, Xavier JA, et al. Photoprotective and antiglycation activities of non-toxic *Cocos nucifera* Linn. (Arecaceae) husk fiber ethanol

extract and its phenol chemical composition. *Industrial Crops and Products*. 2021;**162**:113246. DOI: 10.1016/j.indcrop.2021.113246

[26] van Duy N, Tsygankov PY, Menshutina NV. Facile lignin extraction and application as natural UV blockers in cosmetic formulations. *Chemical Engineering*. 2024;**8**:69. DOI: 10.3390/chemengineering8040069

[27] Ben Ali A, Chouikh A, Haddad L. *Cyperus rotundus* tubers resin from Algeria: A promising source of natural antioxidants, anti-inflammatory, and photoprotective compounds. *Ovidius University Annals of Chemistry*. 2023;**34**:132-139. DOI: 10.2478/auoc-2023-0017

[28] Kurzawa M, Wilczynska E, Brudzynska P, Sionkowska A. Total phenolic content, antioxidant capacity and UV radiation protection properties of marigold (*Calendula officinalis*), carrot (*Daucus carota*), tomato (*Solanum lycopersicum*) and hop (*Humulus lupulus*) extracts. *Cosmetics*. 2022;**9**:134. DOI: 10.3390/cosmetics9060134

[29] Satriyasa BK, Widiyanti IGA, Fajar Manuaba IBG. The potential of carrot extract as a sunscreen to prevent apoptosis in white mice (*Mus musculus*) fibroblast cell cultures exposed to UVB light. *Bali Medical Journal*. 2022;**11**(2):527-530. DOI: 10.15562/bmj.v11i2.3460

[30] Ácsóvá A, Hojerová J, Janotková L, Bendová H, et al. The real UVB photoprotective efficacy of vegetable oils: *In vitro* and *in vivo* studies. *Photochemical & Photobiological Sciences*. 2021;**20**:139-151. DOI: 10.1007/s43630-020-00009-3

[31] Badalkhani O, Pires PC, Mohammadi M, Babaie S, et al. Nanogel

containing gamma-oryzanol-loaded nanostructured lipid carriers and TiO₂/MBBT: A synergistic nanotechnological approach of potent natural antioxidants and nanosized UV filters for skin protection. *Pharmaceuticals*. 2023;**16**:670. DOI: 10.3390/ph16050670

[32] Martiniaková S, Hojerová J, Turányiová Z, Dvoranová D, et al. Reducing the impact of artificial blue light on the skin: A spectroscopic study. *Acta Chimica Slovenica*. 2024;**17**(1):55-62. DOI: 10.2478/acs-2024-0007

[33] Shagufta Y, Promila G. Cosmeceutical and anticancer potential of aqueous extracts of *Dalbergia sissoo* Roxb. aerial parts. *Journal of Herbal Medicine*. 2021;**29**:100456. DOI: 10.1016/j.hermed.2021.100456

[34] Martić R, Kotur-Stevuljević J, Malenović A, Ušjak L, et al. Fast inverted photoprotective o/w emulsions loaded with dihydroquercetin and β-carotene: An innovative approach to *in vitro* assessment of antioxidant activity in a bioenvironment. *Natural Product Communications*. 2022;**17**:1-12. DOI: 10.1177/1934578X221112811

[35] Ahmady A, Amini MH, Zhakfar AM, Babak G, Sediqi MN. Sun protective potential and physical stability of herbal sunscreen developed from Afghan medicinal plants. *Turkish Journal of Pharmaceutical Sciences*. 2020;**17**:285-292. DOI: 10.4274/tjps.galenos.2019.15428

[36] Utami R, Syahputra R, Dona R, Fadhli H, et al. Total flavonoid content and *in vitro* study on the sunscreen activity of extracts of leaves of *Elaeocarpus floribundus* blume. *Pharmacy Education*. 2023;**23**:118-121. DOI: 10.46542/pe.2023.232.118121

[37] Chen X, Yi Z, Chen G, Ma X, Tong Q, Tang L, et al. Engineered fabrication

- of EGCG-UV absorber conjugated nano-assemblies for antioxidative sunscreens with broad-band absorption. *Colloids and Surfaces. B, Biointerfaces*. 2022;**220**:112912. DOI: 10.1016/j.colsurfb.2022.112912
- [38] López-Hortas L, Conde E, Falqué E, Domínguez H, Torres MD. Antioxidant capacity of the extracts from flowers of *Erica australis* L.: Comparison between microwave hydro diffusion and gravity (MHG) and distillation extraction techniques - formulation of sunscreen creams. *Industrial Crops and Products*. 2020;**145**:112079. DOI: 10.1016/j.indcrop.2019.112079
- [39] Yingren L, Xing-Xiang J, Zhongjian T, Hairui J, et al. A cascade valorization of Kenaf stalk for the preparation of lignin sunscreens and papermaking. *International Journal of Biological Macromolecules*. 2023;**230**:123122. DOI: 10.1016/j.ijbiomac.2022.123122
- [40] Santhanam R, Karunakaran T, Sowndhararajan K, Zulkifli MF, et al. Photoprotective potential, cytotoxicity, and UPLC-QTOF/MS analysis on bioactive solvent fractions of *Moringa concanensis* Nimmo bark. *eCAM*. 2022;**2022**:3781189. DOI: 10.1155/2022/3781189
- [41] Mota MD, da Boa Morte AN, Silva LCRCE, Chinalia FA. Sunscreen protection factor enhancement through supplementation with Rambutan (*Nephelium lappaceum* L) ethanolic extract. *Journal of Photochemistry and Photobiology. B*. 2020;**205**:111837. DOI: 10.1016/j.jphotobiol.2020.111837
- [42] Adewinogo SO, Sharma R, Africa CJ, Marnewick JL, et al. Chemical composition and cosmeceutical potential of the essential oil of *Oncosiphon suffruticosum* (L.) Källersjö. *Plants*. 2021;**10**:1315. DOI: 10.3390/plants10071315
- [43] Ferreira RM, Flórez-Fernández N, Silva AS, Saraiva JA, et al. *Opuntia ficus-indica* seed pomace extracts with high UV-screening ability in a circular economy approach for body lotions with solar protection. *Journal of Industrial and Engineering Chemistry*. 2024;**130**:456-467. DOI: 10.1016/j.jiec.2023.09.052
- [44] Vieira IRS, Lima Nunes Silva A, Castro N, Pinto C, et al. Development and characterization of photoprotective nanoemulsions containing Babassu (*Orbignya phalerata* Mart.) lipophilic extract. *Brazilian Journal of Pharmaceutical Sciences*. 2023;**59**:e23011. DOI: 10.1590/s2175-97902023e23011
- [45] Biswas S, Mukherjee PK, Kar A, Bannerjee S, et al. Enhanced permeability and photoprotective potential of optimized p-coumaric acid-phospholipid complex loaded gel against UVA mediated oxidative stress. *Journal of Photochemistry and Photobiology. B*. 2021;**221**:112246. DOI: 10.1016/j.jphotobiol.2021.112246
- [46] Mohamed A, Sorour W. Assessment of photoprotective, antioxidant and anti-skin cancer activities of leaf extracts of certain medicinal plants. *Egyptian Journal of Botany*. 2020;**60**:749-762. DOI: 10.21608/ejbo.2020.26982.1480
- [47] Mota MD, Costa RYS, Guedes AAS, Silva LCRCE, Chinalia FA. Guava-fruit extract can improve the UV-protection efficiency of synthetic filters in sun cream formulations. *Journal of Photochemistry and Photobiology. B*. 2019;**201**:111639. DOI: 10.1016/j.jphotobiol.2019.111639
- [48] Kokabi M, Ebrahimi SN. Polyphenol enriched extract of pomegranate peel; a

novel precursor for the nbiosynthesis of zinc oxide nanoparticles and application in sunscreens. *Pharmaceutical Sciences*. 2021;**27**(1):102-110. DOI: 10.34172/PS.2020.56

[49] Ariede MB, Gomez Junior WA, Cândido TM, de Aguiar MMGB, et al. Would rutin be a feasible strategy for environmental-friendly photoprotective samples? A review from stability to skin permeability and efficacy in sunscreen systems. *Cosmetics*. 2024;**11**:141. DOI: 10.3390/cosmetics11040141

[50] Gheraissa N, Elkhaila Chems A, Cherrada N, Benamor B, et al. Exploring the phytochemical and biological properties of *Salsola foetida*: A promising wild plant from southeastern Algeria. *International Journal of Food Properties*. 2024;**27**(1):584-601. DOI: 10.1080/10942912.2024.2339248

[51] Oliveira MBS, Valentim IB, Rocha TS, Santosc JC, et al. *Schinus terebenthifolius* Raddi extracts: From sunscreen activity toward protection of the placenta to Zika virus infection, new uses for a well-known medicinal plant. *Industrial Crops and Products*. 2020;**152**:112503. DOI: 10.1016/j.indcrop.2020.112503

[52] Rodrigues F, Giffony P, Santos S, Guedes J, et al. *Spondias purpurea* L. stem bark extract: Antioxidant and *in vitro* photoprotective activities. *Journal of the Brazilian Chemical Society*. 2021;**32**:1918-1930. DOI: 21577/0103-5053.20210082

[53] ForestryanaD, RamadhanH, MaulidaP. The photoprotective effectiveness of microemulsion gel made from an ethanol extract of kelakai root (*Stenochlaena palustris* (Brum. f) Bedd.). *Pharmacy Education*. 2024;**24**:134-143. DOI: 10.46542/pe.2024.246.134143

[54] He H, Li A, Li S, Tang J, Li L, Xiong L. Natural components in

sunscreens: Topical formulations with sun protection factor (SPF). *Biomedicine & Pharmacotherapy*. 2021;**134**:111161. DOI: 10.1016/j.biopha.2020.111161

[55] Shah Y, Mewada R. Recent advances in sunscreen agents and their formulations: A review. *International Journal of Pharmaceutical Chemistry and Analysis*. 2022;**9**(4):141-150. DOI: 10.18231/j.ijpca.2022.027

[56] Fresneda M, Trujillo-Cayado L, García C, Alfaro-Rodriguez MC, Muñoz J. Production of more sustainable emulsions formulated with eco-friendly materials. *Journal of Cleaner Production*. 2020;**243**:118661. DOI: 10.1016/j.jclepro.2019.118661

[57] Sunscreen Products Regulations in Europe [Internet]. 2024. Available from: <https://taobe.consulting/european-regulations-sunscreen-products/> [Accessed: January 10, 2025]

[58] Suhail N, Alzahrani K, Basha J, Kizilbash N, et al. Microemulsion: Unique properties, pharmacological applications, and targeted drug delivery. *Frontiers in Nanotechnology*. 2021;**3**:754889. DOI: 10.3389/fnano.2021.754889

[59] Xenakis A, Galani E, Papadimitriou V, Chatzidaki MD. Soft nanostructures for sun protection formulations. *Current Opinion in Colloid & Interface Science*. 2024;**71**:101803. DOI: 10.1016/j.cocis.2024.101803

[60] Chavda VP, Acharya D, Hala V, Daware S, Vora LK. Sunscreens: A comprehensive review with the application of nanotechnology. *Journal of Drug Delivery Science and Technology*. 2023;**86**:104720. DOI: 10.1016/j.jddst.2023.104720

[61] Reis-Mansur MCPP, Firmino Gomes CC, Nigro F, Ricci-Júnior E,

de Freitas ZMF, Dos Santos EP.
Nanotechnology as a tool for optimizing
topical photoprotective formulations
containing Buriti oil (*Mauritia
flexuosa*) and dry *Aloe vera* extracts:
Stability and cytotoxicity evaluations.
Pharmaceuticals (Basel). 2023;**16**(2):292.
DOI: 10.3390/ph16020292

[62] Sanju N, Vineet M, Kumud M.
Development and evaluation of a broad
spectrum polyherbal sunscreen
formulation using solid lipid
nanoparticles of safranal. Journal of
Cosmetic Dermatology. 2022;**21**(10):
4433-4446. DOI: 10.1111/jocd.14777