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EXPLORING THE POTENTIAL OF LIPID COMPOUNDS FROM SEAWEEDS IN ENHANCING SUN PROTECTING FACTOR (SPF) : A LITERATURE REVIEW

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ABSTRAK
Rumput laut merupakan sumber alami senyawa bioaktif dengan potensi fotoprotektif, termasuk senyawa berbasis lipid termasuk lipid polar maupun non polar seperti asam lemak, karotenoid, sterol, steroid, dan triterpenoid. Kelompok senyawa ini dapat menyerap radiasi ultraviolet (UV), dan menetralkan radikal bebas, sehingga dapat melindungi kulit dari paparan sinar matahari dan mencegah terjadinya berbagai bentuk permasalahan kulit seperti penuaan dini (photoaging), hiperpegentasi, sunburn hingga kanker kulit. Tinjauan pustaka ini bertujuan untuk mengevaluasi potensi senyawa lipid dari berbagai spesies rumput laut dalam meningkatkan aktivitas Sun Protection Factor (SPF). Metode narrative review digunakan pada artikel review ini dengan menganalisis berbagai artikel penelitian yang memenuhi kriteria inklusi, yaitu diterbitkan antara tahun 2015 dan 2025, berasal dari jurnal terakreditasi SINTA atau terindeks Scopus, serta ditulis dalam bahasa Indonesia atau bahasa Inggris. Artikel yang tidak mencantumkan data uji SPF secara jelas, tidak meneliti senyawa lipid, atau hanya membahas metabolit lain seperti polisakarida dan protein dieksklusi dari tinjauan ini. Hasil review menunjukkan bahwa senyawa lipid seperti asam lemak (EPA, DHA), fucoxanthin, steroid, gliserol, dan terpenoid dari rumput laut menunjukkan aktivitas fotoprotektif yang menjanjikan, terutama saat diekstraksi menggunakan pelarut non-polar seperti n-heksan. Artikel ini berfokus pada potensi lipid dari rumput laut sebagai bahan aktif dalam formulasi tabir surya alami.

**Kata kunci : ** fotoprotektif, rumput laut, senyawa turunan lipid, SPF

ABSTRACT
Seaweeds are natural sources of bioactive compounds with photoprotective potential, including lipid-derivative compounds including polar and non-polar lipids such as fatty acids, carotenoids, sterols, steroids, and triterpenoids. These compounds can absorb ultraviolet (UV) radiation, and neutralize free radicals, thus protecting the skin from sun exposure and preventing various forms of skin problems such as premature aging (photoaging), hyperpigmentation, sunburn and skin cancer. This literature review aims to evaluate the potential of lipid-derivative compounds from various seaweed species in enhancing Sun Protection Factor (SPF) activity. The narrative review method was used in this review article by analyzing various research articles that met the inclusion criteria, namely published between 2015 and 2025, originating from SINTA accredited or Scopus indexed journals, and written in Indonesian or English. Articles were excluded if they did not clearly report SPF test results, did not study lipid-derivative compounds, or focused solely on other metabolites such as polysaccharides and proteins. The review findings indicate that lipid-derivative compounds such as fatty acids (EPA, DHA), fucoxanthin, steroids, glycerol, and terpenoids from seaweeds exhibit promising photoprotective activity, especially when extracted using non-polar solvents like n-hexane. This review highlights the potential of seaweed-derived lipids compounds as active ingredients in natural sunscreen formulations.

***Keywords* : ** *lipid derivative compounds, photoprotective, seaweed, SPF*

INTRODUCTION

Ultraviolet (UV) radiation from sunlight is a major environmental factor that damages the skin, causing photoaging, hyperpigmentation, and an increased risk of skin cancer. To protect

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the skin from these harmful UV rays, the use of sunscreen products is crucial. Sunscreen is a product in various formulations containing sun protection agents—substances or materials that shield the skin from UV radiation by absorbing, scattering, and reflecting UV rays, which are highly dangerous due to their high energy and carcinogenic properties (Sander et al., 2020; Saucedo et al., 2020). The primary measure of sunscreen ingredient efficacy is the Sun Protection Factor (SPF), which indicates how well a substance can absorb or block UV radiation, particularly UVB (290–320 nm) and partially UVA (320–400 nm) wavelengths (Kalasariya et al., 2022; Morais et al., 2020).

There is an increasing interest in sunscreen use has increased in recent years (Gitin et al., 2023), particularly toward natural sunscreens due to their perceived safety and environmental friendliness (Thomas et al., 2024). One natural resource with significant potential for development as a natural sunscreen is seaweed. Seaweeds contain diverse promising bioactive compounds, especially lipid-derived molecules such as fatty acids, carotenoids (including fucoxanthin), sterols (e.g., fucosterol), steroids, and triterpenoids. These compounds have demonstrated significant photoprotective properties (Cian et al., 2015; Hamed et al., 2015). They can absorb UV radiation, neutralize free radicals, and stabilize cellular membranes against oxidative stress, thereby aiding in skin protection (Achmadi & Arisandi, 2021)..

The identification of natural materials with photoprotective potential is conducted through various in vitro and in vivo methods (Lee et al., 2023). In vitro SPF testing via UV-Visible spectrophotometry is now a common approach due to its effectiveness, rapid results, and ethical advantages compared to in vivo testing. SPF outcomes are influenced by multiple factors, including the nature of active compounds, extraction techniques, solvent polarity, and sample concentration (Natarajan et al., 2025). This review aims to evaluate the photoprotective capabilities of seaweed-derived lipid compounds and explore the factors influencing their SPF performance, emphasizing their potential as natural ingredients for sunscreen formulations. A comprehensive figure describing this review article can be seen in (figure 1).

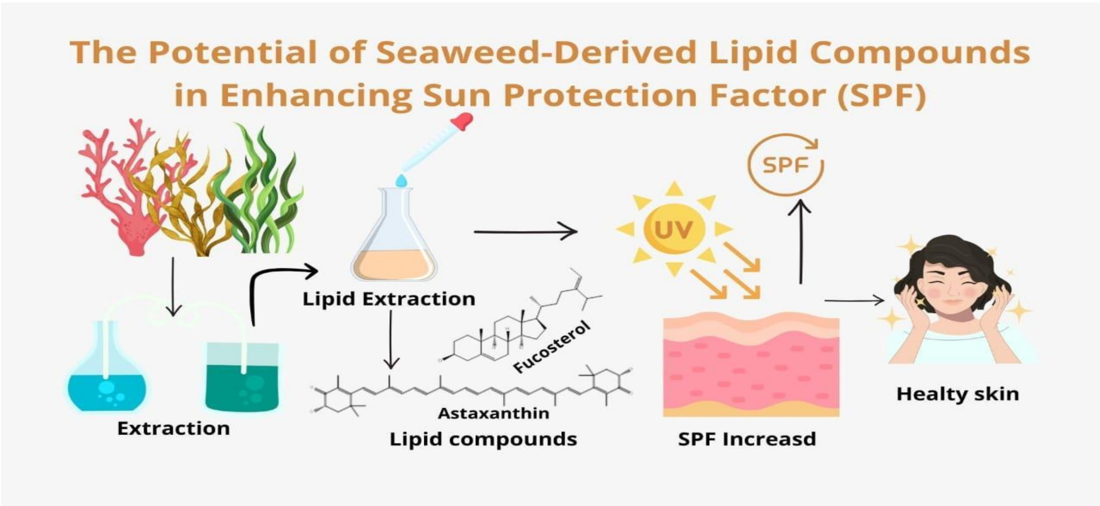

Figure 1. Comprehensive Figure Summarising The Review Article

METODE

The methodology used to construct this review article could be seen in (figure 2).

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Problem Identification

Potential of lipid-derivate compounds from seaweeds as photoprotective agents

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Literature Search

Databases: Google Scholar, PubMed, ScienceDirect.

Keywords: **"***SPF test of seaweed", "bioactive lipids from seaweed"*, "*SPF test of seaweed*", *"seaweed lipid UV protection"*, *"brown algae lipid sunscreen activity"*, and *"marine algae lipid compounds skin protection"*, *"bioactive lipids from seaweed for cosmetics"*, and *"seaweed lipid profile and photoprotective properties"*, and "*Lipid compounds in seaweed with photoprotective activity*".

Publication years: 2015-2025

Languages: English & Indonesian

↓

Article Selection

Inclusion:

Articles published in peer-reviewed journals

SPF studies in seaweeds

Discussion of lipid-derivate compounds from seaweed

Articles with accessible full-text

Exclusion:

Review articles or non-original studies

Discussion SPF of other metabolites (polysaccharides/proteins)

Discussion SPF from non-seaweed sources

No SPF data

↓

Article Analysis

Types of lipid-derivative compounds

Extraction methods

Solvents used

Resulting SPF activity

Figure 2. Flowchart of the Literature Review Methodology

RESULT

Table 1. Summary of Photoprotective Activity and SPF Values of Seaweed Extracts Containing Lipid-Derivative Compounds

Lipid Derivative Compound	Seaweed Source	Sample Location	Photoprotective Activity/ SPF Value	Extraction Method	Reference
Carotenoids and fatty acids	*Sargassum wightii, Turbinaria ornata*	Mandapam Coast, Tamil Nadu, India	SPF increased up to 18.75 for combined extract formulation	Maceration using 70% ethanol	(Natarajan et al., 2025)
Fucosterol & Glyserol	*Sargassum horneri*	Jeju Island, South Korea	Shown to stabilize membranes and reduce UVB-induced damage	Ultrasonication with ethanol	(Kirindage et al., 2024)

Triterpenoids & Steroids	*Turbinaria conoides*	Not specified	SPF value of 5,2 (n-heksana extracts), 13,3 (etil asetat extracts), 16,7 (methanol)	Multistage maceration with n-hexane, ethyl acetate, methanol	(Yanuarti, Rini Nurjanah. Anwar, Effionora .Pratama, 2017)
Steroids	*Eucheuma cottonii*	Punaga Village, South Sulawesi.	SPF value of 1,02 in extracts, categorized as maximum protection	Maceration with ethanol 96%	(Sami et al., 2021)
Terpenoids	*Sargassum polycystum*	Punaga Village, South Sulawesi.	SPF value of 2,41 in extracts, categorized as minimum protection	Maceration with ethanol 96%	(Sami et al., 2021)
Steroids & Fucosterol	*Caulerpa racemosa*	Punaga Village, South Sulawesi.	SPF value of 22,59 in extracts, categorized as ultra protection	Maceration with ethanol 96%	(Sami et al., 2021)
Fucoxanthin	*Sargassum sp*	Poteran, Madura	SPF value of 32,63 (etil asetat extracts), 23,71 (metanol extracts), 25,22 (n-heksana extracts)	Maceration with Methanol, ethyl acetate, n-hexane	(Kasitowati et al., 2021)
Fucoxanthin, fatty acids (EPA, DHA)	*Undaria pinnatifida, Sargassum, Laminaria*	Not specified	Suggested antioxidant and anti-UV effects	Organic solvents, supercritical CO_2	(Hamed et al., 2015)
Triterpenoids	*Eucheuma cottonii*	Not specified	SPF value of 14,37 in cream formulation, categorized as minimum protection	Maceration with water	(Surya et al., 2021)
Triterpenoids	*Eucheuma cottonii*	Not specified	SPF value of 5,22 in extracts, categorized as medium protection	Maceration with ethanol 50%	(Ramdani, Yuyun, A. Dwi Ananto, 2021)
Triterpenoids	*Eucheuma cottonii*	Not specified	SPF value of 6,01 in lotion formulation, categorized as extra protection	Maceration with ethanol 50%	(Ramdani, Yuyun, A. Dwi Ananto, 2021)
Fucoxanthin	*Sargassum sp*	Talango Island, Sumenep, Madura	Potential sunscreen candidate with SPF index (2-4) in cream formulation	Ethanol extraction	(Sari et al., 2019)
Fucoxanthin & Steroids	*Padina sp*	Perairan Aceh	SPF value Up to 9,08, categorized as maximum protection	DMSO pre-treatment + Acetone 80% + Column chromatography	(Abdullah et al., 2021)
Fucoxanthin & Steroids	*Sargassum sp*	Perairan Aceh	SPF value Up to 17.23, categorized as ultra protection	DMSO pre-treatment + Acetone 80% + Column chromatography	(Abdullah et al., 2021)

Based on the category of protection effectiveness of compounds as sunscreens according to the FDA (Hayah, 2023), SPF values of 2-4 are categorized as minimal protection, SPF values

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of 4-6 are classified as moderate protection, SPF values of 6-8 are classified as extra protection, SPF values of 8-15 are classified as maximum protection, and SPF values of ≥15 are classified as ultra protection.

Table 2. Summary of Existing Pharmaceutical Formulas That Contain Lipid-Derivative Compounds As Photoprotective Agents

Lipid-Derived Compound	Formulation	Photoprotective Role	Reference
Vitamin E (Tocopherol)	Sunscreen emulsion, nano emulsion, cream	Powerful antioxidant, scavenges UV-induced ROS, stabilizes cell membranes	(Crous et al., 2024)
Vitamin E (Tocopherol)	Sunscreens, Anti-aging creams	Neutralizes UV-induced free radicals	(Hunt et al., 2021)
Squalane	Mineral sunscreens, moisturizers	Antioxidant, reinforces skin barrier.	(Milani & Sparavigna, 2017)
Co-enzyme Q10 (Ubiquinone)	Facial cream, liposomal gel	Mitochondrial antioxidant, protects against UV-induced oxidative stress	(Nwanodi, 2018)
Ceramides	Barrier repair creams, moisturizers	Strengthens skin barrier, maintains hydration, protects against chronic UV damage	(Gęgotek et al., 2021)
Glycolipid (MGDG,DGDG,SQDG) & fosfolipid (PL)	Sunscreen nano emulsions	Protects skin from UV damage	(Lopes et al., 2021)
Omega-3 Fatty Acids (EPA, DHA)	Topical creams, oral supplements	Reduces UV-induced erythema, improves skin barrier function	(Nwanodi, 2018)

The table above summarizes lipid-derived compounds (such as Vitamin E, Squalane, Ceramides, and Omega-3) used in pharmaceutical formulations as photoprotective agents. Each compound is listed alongside its formulation type (creams, nano emulsions, moisturizers), skin-protective roles (antioxidant, membrane stabilization, skin barrier enhancement), and supporting references from various studies. This information demonstrates the diversity of lipid compounds applicable in cosmetic and pharmaceutical products, while also underscoring the potential of seaweed as a natural source of photoprotective compounds.

DISCUSSION

Classification of Seaweeds

Seaweed is a group of photosynthetic macroalgae widely distributed in marine and freshwater environments (Dolorosa et al., 2017). These organisms have a variety of applications, including in medical, food supplements, fertilizer, and livestock products (Sami et al., 2021;Kasitowati et al., 2021). Seaweeds are known to have a significant variation in their content of protein, minerals, lipids, and fiber (Sami et al., 2021). Based on the dominant pigments in their chloroplasts, seaweeds are classified into two primary kingdoms: Chromista (brown seaweed) and Plantae (green and red seaweed) (Dolorosa et al.,2017). Globally, over more than 200 species of seaweed have been identified, consisting of 32 species of green seaweed, 64 species of brown seaweed, and 125 species of red seaweed (Surya et al., 2021;Ramdani et al., 2021). The image of various types of seaweed species could be seen in (figure 3).

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Figure 3. Seaweed species images: (a) ***Fucus vesiculosus*** **(P); (b)—*Undaria pinnatifida* (P); *c)—Schizymenia dubyi* (R); (d)—*Ulva linza* (C); (e)—*Bryopsis plumosa* (C); (f)—*Laminaria digitata* (P); (g)—*Palmaria palmata* (R); (h)—*Himanthalia elongata* (P); (i)—*Porphyra umbilicalis* (R); (j)—*Jania rubens* (R); (k)—*Gracilaria gracilis* (R); (l)—*Ceramium virgatum* (R); (m)—*Kappaphycus alvarezii* (R); (n)—*Ulva lactuca* (C); (o)—*Ascophyllum nodosum* (P); (p)—*Eucheuma denticulatum (R);* C—*Chlorophyta;* R—*Rhodophyta;* P—*Phaeophyceae*; Scale = 1 cm, all figures were obtained from Kalasariya et al (Kalasariya et al., 2022)**

Green Seaweed (*Chlorophyta*)

Green seaweed contains chloroplasts with chlorophyll a and b, which give them their characteristic green .These seaweeds store starch in plastids as a food reserve. As of 2020, approximately 2,200 species of green seaweed have been documented (Sami et al., 2021). In 2019, green seaweed accounted for about 16.70 megatons, representing roughly 0.048% of global seaweed production. Most green seaweed thrive in both marine and freshwater ecosystems; however, some can also be found growing on rocks, trees, or soil (Abdullah et al., 2021). Common genera of green seaweed include *Ulva*, *Codium*, *Chaetomorpha*, and *Cladophora*. Among these species, *Ulva* is the most widely distributed, especially in brackish water environments, such as estuaries (Sami et al., 2021). It is rich in proteins, minerals, and vitamins and has been explored for its nutraceutical potential (Morais et al., 2020).

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Red Seaweed (*Rhodophyta*)

Red seaweed are distinguished by the pigments phycoerythrin and phycocyanin, which give them their red colour. Their cell walls typically contain carrageenan and agarose cellulose (Sari et al., 2019). Red seaweed are considered nutritionally valuable due to their high protein content, which can reach up to 47%, this is higher than that of green or brown seaweed (Sami et al., 2021;Crous et al., 2024). Red seaweed are also rich in both water-soluble vitamins (such as B and C) and fat-soluble vitamins (such as provitamin A carotenoids). These carotenoids, including zeaxanthin and lutein, not only contribute to its colorisation, but are also known as potentantioxidants (Sami et al., 2021). Currently, approximately 6,500 species of red seaweed have been identified. Common genera include *Porphyra*, *Gracilaria*, *Eucheuma/Kappaphycus* (Abdullah et al., 2021).

Brown Seaweed (*Phaeophyceae*)

Brown seaweed contain xanthophyll pigments, primarily fucoxanthin, which causes it to have brown colour (Abdullah et al., 2021). This seaweed group comprises of approximately 20 classes and over 1,800 species, representing approximately 66% of all seaweed. The global production of brown seaweed has increased significantly from 13 megatons in 1950 to 16.4 gigatons in 2019, it’s an average annual growth rate of 10.9%, surpassing the 7.9% growth rate of overall aquaculture (Hunt et al., 2021). Brown seaweed are a prominent source of omega-3 and omega-6 fatty acids (Hamed et al., 2015). The most common genera include *Sargassum*, *Turbinaria*, *Dyctyota*, *Padina*, *Hormophysa*, *Hydroclathrus* (Achmadi & Arisandi, 2021). Among these, *Sargassum* is noted for its high content of polyphenolic compounds such as fucol, fucophlorethol, fucodiphloroethol, and G-ergosterol, which contribute significantly to its antioxidant activity (Morais et al., 2020).

Classification of Lipid-Derivative Compounds Found in Seaweeds

Lipid-derivative compounds in seaweeds refer to a broad group of bioactive molecules derived from lipids. These compounds include fatty acids, sterols, carotenoids, glycolipids, phospholipids, and triterpenoids, many of which possess potent biological activities such as antioxidant, anti-inflammatory, and photoprotective effects. Seaweeds are rich in these lipid-derivative compounds. The lipid-derivative compounds in seaweeds can be classified based on their chemical structures and physiological functions. Recent studies have identified several key classes. First, fatty acids, including both saturated and unsaturated types such as *eicosapentaenoic acid* (EPA) and d*ocosahexaenoic acid* (DHA), are commonly found in seaweeds and are recognized for their anti-inflammatory activity and potential to prevent UV-induced skin damage (Kalasariya et al., 2022;Morais et al., 2020). Second, sterols such as *fucosterol*, which are abundant in brown seaweed, exhibit potent antioxidant, anti-inflammatory, and photoprotective effects, particularly in modulating oxidative stress and UV-related inflammation (Morais et al., 2020;Cian et al., 2015).

Third, carotenoids like *fucoxanthin*, *β-carotene*, *lutein*, and *astaxanthin* are present in high concentrations in brown and red seaweed. These compounds act as natural antioxidants and protect skin by absorbing UV light and neutralizing free radicals (Morais et al., 2020;Cian et al., 2015). Fourth, glycolipids and phospholipids that types of polar lipids, play important roles in maintaining cellular membrane integrity and have been studied for their bioactivity in topical skincare and sunscreen formulations (Kalasariya et al., 2022;Cian et al., 2015). Lastly, steroid and triterpenoid derivatives are secondary metabolites with known anti-inflammatory and antioxidant effects, partly due to their ability to regulate molecular pathways such as MAPK and Nrf2, which are critical in cellular response to oxidative stress (Cian et al., 2015). The structures of lipid-derivative compounds found in seaweeds can be seen in (figure 4).

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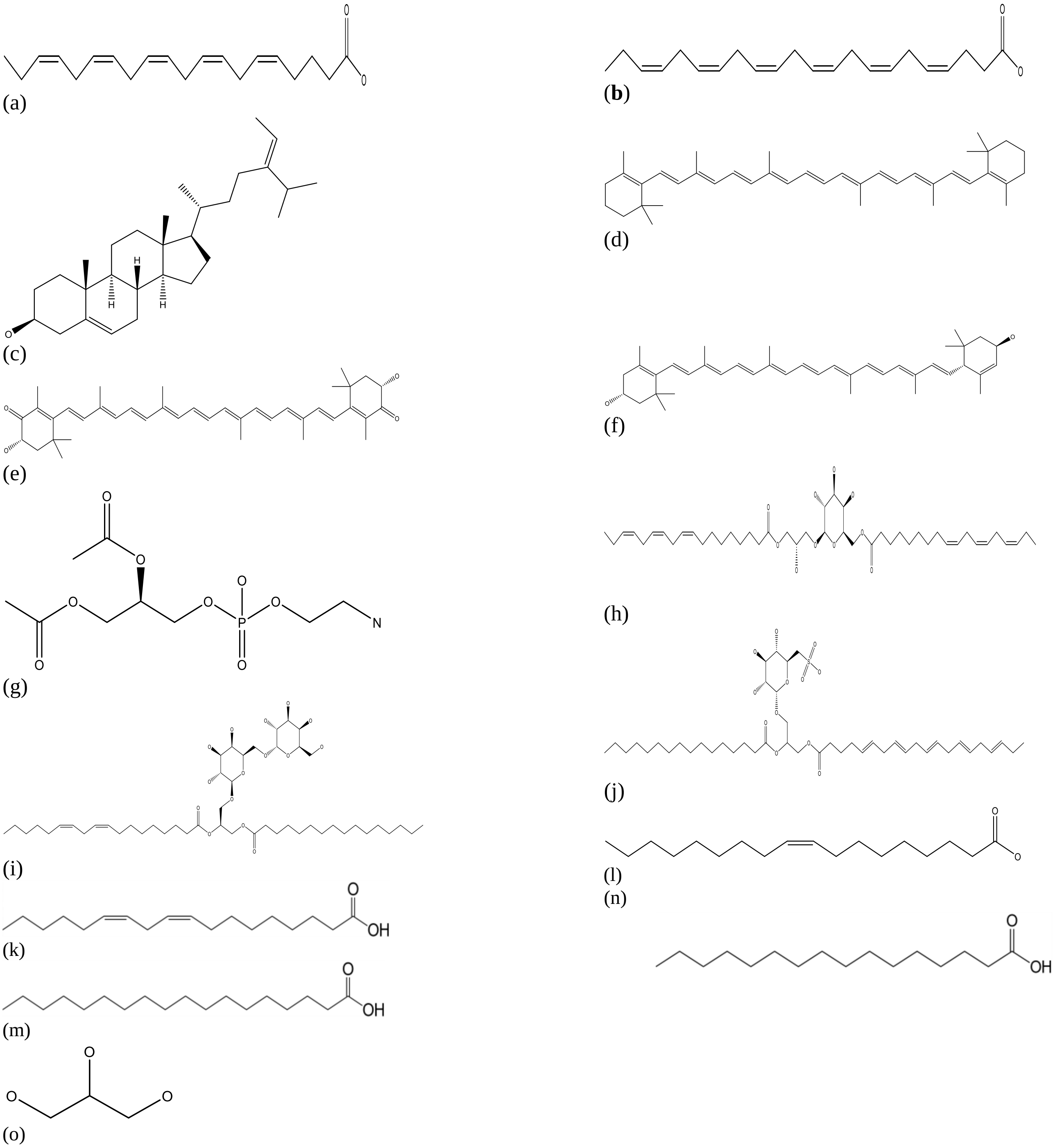

Figure 4. This is a figure of lipid-derivative compounds structure (a) ***Eicosapentaenoic Acid*****, (b)** ***Docosahexaenoic Acid*****, (c)** ***Fucosterol*****, (d)** ***β-carotene*****, (e)** ***Astaxanthin*****, (f)** ***Glycolipids (Monogalactosyldiacylglycerol*****), (g)** ***Phospholipids (Phosphatidylethanolamine*****), h)** ***Glycolipids (Monogalactosyldiacylglycerol*****), (i)** ***Glycolipids (Digalactosyldiacylglycerol*****), (j)** ***Glycolipids (Sulfoquinovosyldiacylglycerol*****, (k)** ***Linoleic acid*****, (l)** ***oleic acid*****, (m)** ***steroic acid*****, (n)** ***palmitic acid*****, (o)** ***glycerol***

Existing Pharmaceutical Formulas That Contain Lipid-Derivative Compounds As Photoprotective Agents

Lipid derivatives have been extensively integrated into various pharmaceutical and cosmetic formulations to enhance photoprotective efficacy through synergistic mechanisms. Their ability to stabilise skin barrier structures, act as antioxidants, and interact with UV filters makes these compounds act as key components in modern formulations (Crous et al., 2024;Hunt et al., 2021;Milani & Sparavigna, 2017). Examples of their implementation include

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incorporating Vitamin E (Tocopherol) into sunscreen emulsions, nano emulsions, and anti-aging creams, where it functions as an antioxidant that neutralizes UV-induced free radicals. Squalane is commonly used in mineral sunscreens and moisturizers to reinforce the skin barrier. Co-enzyme Q10, with its mitochondrial antioxidant properties, is formulated in facial creams and liposomal gels to combat oxidative stress triggered by UV exposure. Omega-3 fatty acids (EPA and DHA) are utilized in topical creams and oral supplements to reduce UV-induced erythema and enhance skin barrier function. Additionally, ceramides are included in barrier repair creams and moisturizers to maintain skin hydration and provide long-term protection against chronic UV damage (table 2).

Factors affecting SPF Value of Seaweed Lipid-Derivative Compounds and Products

Based on Table 1 and Table 2, various studies have reported the Sun Protection Factor (SPF) values of seaweed extracts and formulations containing lipid-derivative compounds. Among the tested species, brown seaweeds are the most frequently studied due to their rich content of lipid-based bioactive compounds, such as fucoxanthin, fucosterol, and triterpenoids, which are believed to play a central role in photoprotection (Saini et al., 2021;Chen et al., 2025). The reported SPF values vary significantly across different studies, influenced not only by the seaweed species but also by differences in their biochemical composition, particularly the presence and concentration of these lipid compounds (Nkurunziza et al., 2025). Other technical factors such as the method of extraction, type of solvent used, form of the tested preparation, and test concentration also considerably impact the SPF values obtained.

For instance, studies by Dharmawan, Ulfa and Kasitowati (Kalasariya et al., 2022;Putri et al., 2022), used similar brown seaweed samples, yet reported different SPF values. These discrepancies likely reflect variations in extraction techniques, solvents, or formulation parameters. Therefore, understanding these influencing factors is essential in optimizing the extraction and application of lipid compounds from seaweed for use in natural sunscreen products. The following discussion will provide detail descriptions on six key aspects affecting the difference in SPF value between seaweeds: (a) the types of lipid-based bioactive compounds identified, (b) the seaweed species used, (c) the solvents used, (d) the extraction methods applied, and (e) the forms of dosage tested and the effect of concentration on SPF values.

Bioactive Compounds

Several lipid compounds found in brown seaweed, such as fucoxanthin, fucosterol, and triterpenoids, have been widely reported to have potential as natural active ingredients in sunscreen products. These compounds contain chromophoric groups that can absorb ultraviolet (UV) light, both at UVA and UVB wavelengths. Fucoxanthin, which is a xanthophyll-type carotenoid and is widely found in the genera *Sargassum, Padina*, and *Turbinaria*, is known to have potent antioxidant and anti-inflammatory activities. Several studies have shown that fucoxanthin can reduce oxidative stress due to UVB exposure by suppressing the expression of Cyclooxygenase-2 (COX-2) and increasing the activity of Nrf2, a critical transcription factor in the cell's defence mechanism against oxidation (Kirindage et al., 2024; Sutedjo et al., 2016; Prasedya et al., 2021). In addition, this compound also affects the MAPK signalling pathway, which plays a role in preventing cell damage due to UV light.

Fucosterol, as a type of marine sterol found abundantly in Padina and Hizikia fusiformis, also has the ability to protect skin tissue from the negative effects of UVB rays. The mechanisms include decreasing the expression of MMP-1 and IL-6, as well as increasing the production of type I collagen and TGF-β1 which are important in maintaining skin structure and preventing premature aging (Meinita et al., 2021; Hwang et al., 2014). In addition, triterpenoids which also come from brown seaweed contribute to maintaining the integrity of the skin's protective layer and preventing oxidative degradation caused by UV rays. In general, these lipid compounds work through several mechanisms, ranging from direct absorption of UV radiation, scavenging free radicals (ROS), to regulating inflammatory pathways and protecting collagen structures (Freitas et al., 2020;Sami et al., 2021)

Type of Seaweed Tested

Among the three major groups of seaweeds brown (Phaeophyta), red (Rhodophyta), and green (Chlorophyta) brown seaweeds are the most widely studied in relation to photoprotective lipid compounds. This is also due to their naturally high content of lipophilic bioactive compounds, including fucoxanthin, fucosterol, and various triterpenoids, which are rarely found in significant amounts in red or green seaweeds (Sami et al., 2021) (Kasitowati et al., 2021; Arsianti et al., 2016). Brown seaweed species such as *Sargassum*, *Padina*, *Turbinaria*, and *Hormophysa* have consistently shown promising SPF values in various studies. For example, *Sargassum horneri* and *Padina boergesenii* have been reported to exhibit SPF values above 15, often categorized as high protection, due to their fucoxanthin-rich extracts (Zavella, 2018;Kim et al., 2012). Other brown seaweed such as *Hormophysa triquetra* and *Turbinaria conoides* have also demonstrated antioxidant and UV-absorbing capabilities linked to their lipid content (Yanuarti et al.,2017;Wikanta et al., 2017). In contrast, red and green seaweeds may possess different classes of bioactive compounds, such as polysaccharides or polyphenols, but their lipid profile is generally less prominent (Meinita et al., 2021). Therefore, brown seaweeds remain the most relevant source in the search for lipid-based photoprotective agents.

Type of Solvent

The type of solvent used in the extraction process plays a critical role in determining the yield and selectivity of lipid-based bioactive compounds from seaweeds. Different solvents vary in polarity, affecting their ability to extract specific classes of compounds. For lipid-targeted extractions, moderately polar solvents like ethanol and ethyl acetate, as well as nonpolar solvents such as n-hexane, are commonly employed (Achmadi & Arisandi, 2021). The effect of solvent type on the yield produced is quite significant. This is demonstrated in a study by Pranomo et al., (2020) which reported that the yield of polar lipid extract from Spirulina platensis microseaweed using water as a solvent was 1.25%, much smaller than the yield obtained using chloroform-methanol solvent, which was 4.27%.

Studies have shown that ethyl acetate and ethanol 80–96% are effective in extracting fucoxanthin and fucosterol from brown seaweeds such as *Padina* and *Sargassum*. For instance, Septiani (Zavella, 2018), reported that ethyl acetate fractions of *Padina boergesenii* yielded significant SPF values, attributed to the high lipid content of the extract. Similarly, Abdullah et al., (2021)demonstrated that 80% acetone was superior in extracting fucoxanthin from *Sargassum sp.*, which resulted in high photoprotective activity. While ethanol is often favoured due to its lower toxicity and ease of use, the choice of solvent must be tailored to the desired compound. Nonpolar solvents like n-hexane are more selective for sterols and long-chain lipids but may be less effective for fucoxanthin (Saini et al., 2021). Therefore, understanding the solubility behaviour of each target lipid is essential to optimize extraction for maximum SPF potential.

Extraction Method

The extraction method is very important in determining the success of obtaining lipid compounds from seaweed, especially if the compound is sensitive to heat such as fucoxanthin. Several examples of techniques or extraction methods commonly used in research are maceration, soxhlation, and ultrasound-assisted extraction (UAE). Maceration is an extraction method that is carried out without heating, so it is safer to use to extract lipid compounds that

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are easily damaged by heat. Research from, (Arsa & Achmad, 2020)shows that this method is effective in extracting fucoxanthin and fucosterol from *Sargassum* and *Padina*, with a fairly high SPF value. This process is also more simple and does not damage the structure of the active compound.

Meanwhile, soxhletation involves the continuous use of heat, so it is more suitable for extracting more stable lipid compounds such as fucosterol. However, this method is less recommended for fucoxanthin because excessive heat can cause degradation of its molecular structure (Kirindage et al., 2024). Another method that is starting to be widely used is ultrasound-assisted extraction (UAE), which works by utilizing ultrasonic waves to speed up the extraction process. Although the extraction time is shorter, its effectiveness is highly dependent on the duration and settings of the tool. Agusman et al in (2022) stated that UAE can increase the recovery of triterpenoid and sterol compounds if the extraction time is set optimally.

The effect of the extraction method on the yield is also significant. This was demonstrated in a study by Escorsim et al /kwhich reported that lipid extraction from the microalga *Acutodesmus obliquus* using the Soxhlet method with an ethanol:hexane (1:2) mixture resulted in a yield of 92%. This value is notably higher compared to the yield obtained using the ultrasound-assisted extraction method, which was only 59% . In general, the selection of extraction methods needs to be adjusted to the type of lipid compound targeted. For temperature-sensitive compounds such as fucoxanthin, maceration is the most recommended method, while for more stable lipids, soxhlet or UAE can be alternatives (Achmadi & Arisandi, 2021).

Test Dosage Form and Concentration

The tested preparation form has a significant effect on changes in SPF value. Most studies show that direct testing of extracts provides a higher SPF value when compared to extracts that have been formulated into certain forms, such as cream or lotion. The research conducted by Ramdani and Surya (2021) showed that there was a reduction in the SPF value of seaweed extract after being formulated into a preparation. This was due to the reduced concentration of extracts added to the preparation. The extract added was too small therefore also causing a reduction in SPF value. In addition, excipients or additional ingredients in the preparation formula may also effect the extract's activity by inhibiting the release of active compounds in the extract. This also causes a decrease in the activity of the resulting preparation (Prasedya et al., 2021).

Various studies on SPF assessments showed that higher concentrations also results in a higher SPF value. This shows the effect of tested concentration on increasing or decreasing the SPF value of a tested sample. Research by Surya et al (2021), shows higher amount of extract used can result in an increase its SPF value. In a research conducted on the *Sargassum sp*. SPF assessment, it was shown that an increase in concentration from 500 ppm to 4000 ppm, also caused an increase in SPF from 6.39 to 38.64 (Kalasariya et al., 2022).

CONCLUSIONS

This article review emphasizes the significant potential of lipid compounds from seaweed as active ingredients in natural sunscreens. Compounds such as fucoxanthin, fucosterol, and triterpenoids effectively protect against sun exposure by absorbing ultraviolet (UV) rays and reducing free radicals. The review indicates that extraction methods and solvent types considerably affect SPF values. Additionally, the species of seaweed chosen and the product format play crucial roles in skin protection effectiveness. Thus, lipid compounds derived from seaweeds can serve as a safe and eco-friendly option for skin defence. Nevertheless, further research is essential to understand their mechanisms and enhance product formulations for better real-world effectiveness

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