Review Article

Application of seed oils and its bioactive compounds in sunscreen formulations

Chee Chin Chu, Kar Lin Nyam*

Department of Food Science and Nutrition, Faculty of Applied Sciences,

UCSI University, 56000 Kuala Lumpur, Malaysia

*Correspondence: Kar Lin Nyam; Email: nyamkl@ucsiuniversity.edu.my

Abstract

The photoprotective skincare products are in high demand to meet the consumer market with concern on skin health. Seed oils are commonly used as ingredients in many cosmetic products due to their natural antioxidants and now being increasingly recognised for their effects on skin health and photoprotection. This article briefly reviews the application of seed oils in sunscreen development focusing on the antioxidants that contribute to photoprotection, thus preventing UV-induced erythema and photoaging. The addition of seed oils that contain specific natural bioactive compounds were discussed in the review. Besides that, seed oils acting in molecular pathways that benefit in photoprotection were also summarized. Seed oils (pomegranate seed oil, castor oil, cocoa butter, jojoba oil, rosehip oil, grapeseed oil, kenaf seed oil and pumpkin seed oil) utilization have high potential to act as natural UV filters and at the same time help in skin repairing. The seed oils contributed beneficial properties to the sunscreen formulation by their synergistic effect with antioxidants, antiaging properties, anti-inflammatory effect, and potential hormetic effect. The finding of specific bioactive compound from seed oils provide better understanding on the contribution of seed oils in sunscreen formulation.

Keywords: Seed oil, photoprotection, antiaging, antioxidants, anti-inflammation

1. Introduction

Aging is a gradual and continuous degradation of the structural integrity and physiological functions in human body. The process of skin aging has been divided into two categories, which are intrinsic and extrinsic aging (Thring et al., 2009). Intrinsic skin aging is resulted from the changing of skin elasticity from time to time. On the other hand, extrinsic skin aging is more likely to be triggered by UV exposure, which is known as photoaging that accounts for about 80 % of skin aging (Kwon et al., 2019). UV radiation consists of UV-A, -B, and -C that differ in their wavelength, posing degree of side effects on skin. UVA and UVB radiation elevate the alteration of skin connective tissue via the formation of reactive oxygen species (ROS), lipid peroxides, and degradation of cell contents and enzymes. While UVC with the longest wavelength is absorbed by the ozone layer and will not reach the earth. The UV-induced free radicals promote harmful effect on human skin that trigger the process of aging by activating DNA damage and formation of inflammatory cytokines to damage the extracellular matrix (ECM) (Kwon et al., 2019). Besides that, UV radiation also promotes collagen and elastin degradation while inhibits their formation, leading to the formation of wrinkles (Leccia et al., 2019). This leads to the loss of skin elasticity.

Photoprotective products protect the skin by preventing and minimizing the damaging effects of UV radiation. Sunscreen is an important part of a complete UV protection strategy. According to the recommendation of the Skin Cancer Foundation, regular daily use of sunscreen before going outdoor is crucial to decrease the risk of skin cancers. Sunscreen is categorised into physical and chemical sunscreen. Physical sunscreen consists of mineral titanium dioxide and/or zinc oxide. The physical sunscreen blocks and scatters the UV radiation before they penetrate the skin. While for chemical sunscreen, it contains chemical UV filters like avobenzone and octocrylene to absorb UV radiation before they damage the skin. However, all active ingredients in sunscreen are chemically derived.

Nowadays, the use of natural ingredients in sunscreen formulation has gained significant attention as they are supplied with antioxidants with beneficial properties (Radice et al., 2016). Seed oils contain phytochemicals were proven in reducing the amount of synthetic chemicals (Lacatusu et al., 2014; Chu et al., 2019) and play crucial roles in antiaging and skin repair pathways (Kwon et al., 2019). The utilization of seed oil in sunscreen formulation is important to fulfil consumers' needs to maintain healthy youth while providing adequate protection against harmful UV radiation. This review focuses on the provision of sunscreen fortified with seed oils and their role in photoprotection and skin health contribution. The present review highlighted potential seed oils in sunscreen development with specific natural bioactive compounds benefit in photoprotection, anti-inflammation and anti-photoaging.

2. Potential seed oils in sunscreen development

Vegetable oils have played important roles in the composition of cosmetics, act as emollients and vehicles to carry other active substances (Yara-Varon et al., 2017). Seed oil is a vegetable oil extracted from the seed by pressing and/or solvent extraction. Cosmetic formulations with seed oils are designed to protect the skin against exogenous or endogenous damages. The incorporation of seed oils in cosmetic products is crucial to provide moisturizing effect by forming a skin barrier to prevent water loss (Sarkar et al., 2017). Also, seed oils showed antiaging effects by supplying bioactive compounds that nourish the skin (Lin et al., 2017). There are some skincare and personal care products with seed oils added, including skincare lotions and creams, bath products, facial makeup, personal cleanliness, sunscreen, and other skincare products. The application of seed oils was found to promote hydration and prevent transdermal water loss, normalize the sebaceous glands, and enhance UV protection to prevent photoaging (Lin et al., 2017; Michalak & Kiełtyka-Dadasiewicz, 2018). There were several types of seed oil discussed in this article that showed significant unsaturated fatty acids (Table 1), tocol content (Table 2), and phytosterols (Table 3). The seed oils found to contribute in the major molecular pathway to protect the skin against oxidative stress by UV radiation were also summarized in Table 4. Therefore, the utilization of seed oils with alternative medication effects are promising in sunscreen formulation by providing additional beneficial properties in skin beauty.

2.1. Pomegranate seed oil

Pomegranate (*Punica granatum* L.) is an important fruit crop that is extensively cultivated in Asia, North Africa, the Mediterranean, and the Middle East and became popular due to its nutritious properties. The seed contained 17.5-35.1 % oil, which is light with a thin consistency (Çavdar et al., 2017). The seed oil contained high amount of unsaturated fatty acids, mainly isomer punicic acid (75.2-82.3 %) as shown in Table 1 (Boroushaki et al., 2016). The total unsaturated fatty acid content including punicic acid reported in the study of Çavdar et al. (2017) was higher than in the papers of Melo et al. (2016) and Khoddami et al. (2014). The differences in pomegranate seed lipid profile might be related to the differences of cultivar, environmental growth conditions, and its ripening stage (Çavdar et al., 2017). Punicic acid is an omega-5 fatty acid which is known as trichosanic acid. It is an isomer of conjugated α-linolenic acid with structural similarities to conjugated linoleic acid. Punicic acid has increasingly attracted scientific interest and gained wide attention for their therapeutic potential due to its several potential health benefits, including antioxidant, antidiabetic, neurodegenerative prevention, and serum lipid-lowering activities (Melo et al. 2014; Mirmiran et al., 2016; Shabbir et al. 2017).

Apart from the unique lipid composition of pomegranate seed oil, it was found to have high amount of skin beneficial tocopherols such as α and γ-tocopherol and phytosterols such as β-sitosterol, campesterol, stigmasterol as shown in Table 2 and Table 3 (Melo et al., 2016). The phytochemical composition of pomegranate seed oil and their nutraceutical effects made it an attractive ingredient in the cosmetic application (Khoddami et al., 2014; Boroushaki et al., 2016). According to previous studies, pomegranate seed oil has been reported to have skin beneficial effects in epidermal tissue regeneration and UV protection enhancement (Zarfeshany et al., 2014; Montenegro & Santagati, 2019). The study from Baccarin et al. (2015) suggested the effect of cell DNA protection against UVB-induced damage exhibited by pomegranate seed oil nanoemulsion with pomegranate peel polyphenol-rich extract encapsulation. In addition, Afaq et al. (2009) reported the photo-chemopreventive effects of pomegranate derivatives, including juice, extract, and oil that inhibited UVB-mediated DNA and protein damage tested in human skin model. The results suggested the effect of pomegranate derivatives against UVB-mediated damages to human skin (Afaq et al. 2009). Besides that, pomegranate extract was found to have a protective effect in the normal human epidermal keratinocytes cell line against UVB-induced oxidative stress and able to downregulate the expression of biomarkers for photoaging (Zaid et al. 2007). Therefore, the nutraceutical properties of pomegranate suggested it could be a useful supplement in a sunscreen formulation.

2.2. Castor oil

Castor oil obtained from castor (*Ricinus communis* L.) plant. Castor oil is the major industrial crop in India but it also cultivated in Brazil, China, Africa, and South America (Patel et al., 2016). The seeds contain 34.6-56.6 % oil, which is viscous and pale yellow. The oil yields vary according to the plant variety and the solvent extraction (Sbihi et al., 2018). The study from Sbihi et al. (2018) reported the seed oil yield and phytosterol content were higher in ethanolic extraction and higher tocol content in hexane extraction. As stated in Table 1, castor oil is rich in high content of unsaturated fatty acid, mostly ricinoleic acid ranged from 75.8 to 94.6 % (Ndiaye et al., 2006; Patel et al., 2016; Sbihi et al., 2018). Ricinoleic acid is a hydroxy monounsaturated fatty acid that is widely applied in the chemical industry. It shows antimicrobial effect and prevents the growth of virus (Prasad & Rao, 2017). Ricinoleic acid acts as a humectant to provide skin moisturizing effect and improves various skin conditions such as rough skin (Patel et al., 2016). Besides, ricinoleic acid also used as skin-conditioning agents, emulsion stabilisers, and surfactants in cosmetics (Patel et al., 2016). With high ricinoleic acid, castor oil and the hydrogenated castor oil and/or its esters are produced and applied in automobiles, cosmetic, hair, and skincare as emollient and are useful for cleansing and conditioning the skin (Patel et al., 2016).

Furthermore, it was found to have high amount of phytosterols, tocopherol, and tocotrienol. According to the industry reports from the Food and Drug Administration (FDA) 2002, castor oil was applied in 769 cosmetic products and its hydrogenated oil was used in 202 cosmetic products (Johnson, 2007). Topical application of castor oil showed significant effect in improving the signs and symptoms in patients with chronic inflammation of the eyelid tissues and ocular surface (Muntz et al., 2020). With high ricinoleic acid and bioactive compounds with proven anti-inflammatory, antimicrobial, and moisturizing properties in castor oil, thus contributed to the improvement of the sign of ocular surface diseases (Muntz et al., 2020). Besides that, Shobha, et al. (2018) reported the utilization of castor seed extract to synthesize zinc oxide nanoparticle with distinctive anticancer, antibacterial, and antioxidant activity. This show the potential of castor plant in sunscreen development as zinc oxide is one of the FDA approved sunscreen mineral UV filter.

2.3. Cocoa butter

Cocoa (*Theobroma cacao* L.) is the main source to make chocolate. Cocoa butter is the creamy fat extracted from the cocoa bean. It is widely used as a base to produce functional foods and skincare products. Table 1 showed the yield and fatty acid composition of cocoa butter which made up mainly of palmitic, stearic, and oleic acids. Cocoa butter is a source of natural antioxidant which is widely utilised as an emollient in cosmetic formulations (Scapagnini et al., 2014). It is a common active ingredient in lotions, creams, and lip balms. According to Scapagnini et al. (2014), the lipid of the cocoa butter benefits skin health through dry skin alleviation and skin elasticity improvement. Besides that, it also plays an important role in the pro-inflammatory cytokines downregulation thus result in its anti-inflammatory effect (Scapagnini et al., 2014).

Cocoa contains bioactive compounds and polyphenols that function in inhibiting lipid peroxidation and combating against ROS (Heinrich et al., 2006; Scapagnini et al., 2014). Topical application of cocoa butter increases dermal antioxidant capacity and protects the epidermis from oxidative stress and exogenous ROS which leads to antiaging properties (Scapagnini et al., 2014). Based on the study from Heinrich et al. (2006), topical application and oral intake of cocoa polyphenols, especially flavanols provide effective photoprotection and anti-inflammation. Thus, it acts as a promising ingredient for further dermatological applications, ranging from skincare regimen to photoprotection and photoaging prevention.

2.4. Jojoba oil

Jojoba (*Simmondsia chinensis*) is a desert shrub in the Sonoran desert and Baja California regions of North America. The oil yield of jojoba seed is 48.7-54.6 %, which is in color- and odor-free. Jojoba oil is a liquid wax ester which is similar to the sebum produced by the human sebaceous gland (Matsumoto et al., 2019). It is suitable to be used as a natural emollient to moisturize and soothe the skin. Jojoba oil is resistant to oxidation and rancidity (Calka & Pawlica, 2019) and thus, can be used as a carrier oil for essential oil and active substances that susceptible to degradation. With soothing and moisturizing effects, jojoba oil not only applied as a humectant meanwhile also maintain the skin moisture (Calka & Pawlica, 2019).

From the study conducted by Habashy et al. (2005), topical application of jojoba oil was found to be effective in the reduction of edema in animal models with significant anti-inflammatory properties. The oil revealed a significant anti-inflammatory, antioxidative, and antibacterial properties. Besides that, *in vitro* wound healing effects of jojoba oil were studied on human keratinocytes and human dermal fibroblasts that showed skin repair properties (Ranzato et al. 2011). In addition, *in vivo* study from Matsumoto et al. (2019) with mice models reported the beneficial properties of topical application of jojoba oil through transdermal delivery that can increase the level of serum non-esterified fatty acid. The study from Matsumoto et al. (2019) thus, concluded the beneficial effect of jojoba oil in enhancing liver lipolysis and reducing the skin fatty acid trafficking. Apart from that, the addition of jojoba oil was found to enhance the viscosity and stability of lubricants at high temperature which is suitable to be utilized as a cosmetic ingredient (Alvarez & Rodríguez, 2000). Also, a pilot study from Meier et al. (2012) with the application of jojoba oil in clay facial mask preparation was found preliminary evidence of jojoba oil in the treatment of lesioned skin, mild acne vulgaris, and improvement of overall skin condition. Floratech, a company that produces and markets botanical-derived ingredients for personal care and cosmetic industry has patented a lipid complex (L22®) produced from jojoba oil/macadamia seed oil esters, squalene, phytosteryl macadamiate, phytosterols, and tocopherol. L22® was claimed to be able to balance the changes of skin lipid components due to aging to maintain the same balance as present on a healthy 22-year-old skin condition (Floratech, 2019). Besides that, the company also formulated a day cream with sunscreen active by using L22® (formula L044) with the proven of skin moisturization synergy observed when combining with Floraesters® K-20W Jojoba and glycerin (Floratech, 2019). Overall, jojoba oil is useful in the preparation of future skincare products with the lipid structure similar to human serum and its bioactive compounds is an adding value to sunscreen formulation to reduce the effect of UV-induced inflammation and free radical scavenging production.

2.5. Rosehip oil

The fruit of rosehip (*Rosa canina* L.) has been used as a herbal medicine for 2,000 years (Winther et al. 2016). There are many studies suggested the plant contains health-promoting properties. As shown in Table 1, the oil extracted from rosehip seed contains high amount of polyunsaturated fatty acids followed by monounsaturated fatty acid (Szentmihalyi et al., 2002; Marmol et al., 2017; Kulaitienė et al., 2020). With the high content of polyunsaturated fatty acid, it acts as a potential source to prevent obesity and hyperlipidaemia. Besides, rosehip oil also contains high phytosterols (β-sitosterol, stigmastenol, and campesterol) and tocopherols (Ilyasoglu, 2014; Grajzer et al., 2015). The findings from Ilyasoglu (2014) and Grajzer et al. (2015) indicated the presence of bioactive compounds as good sources of phytonutrients in rosehip seed and seed oil. Rosehip oil with phytonutrients showed therapeutic effects on the skin. The presence of tocopherols such as γ- and δ-tocopherol were found to exhibit effective anti-inflammatory, cytotoxic, and anti-mutagenic effect in the human body (Grajzer et al., 2015).

Moreover, rosehip oil was found to have high amount of carotene pigment up to 107.7 mg/kg (Grajzer et al., 2015). The presence of carotenoid in rosehip oil provides skin moisturizing properties and promotes skin cell regeneration to improve skin flexibility and permeability. Overall, rosehip oil was rich in polyunsaturated fatty acids, phytosterols, and tocopherols which could be proposed as an ingredient in cosmetic formulations that aid in reducing the signs of photoaging and prevent sunburn (Marmol et al., 2017).

2.6. Grapeseed oil

Grapeseed oil is extracted from the seeds of grape (*Vitis vinifera* L.). Grapeseed is a by-product of winemaking and contains 8-12 % oil (Garavaglia et al., 2016). There is a growing interest in grapeseed consumption and application worldwide due to its nutritional value. The high antioxidant potential of the oil benefits in modulating the antioxidant enzyme expression, protecting against cellular oxidative damage, anti-atherosclerotic, anti-inflammation, and some cancers (Puiggros et al., 2005; Perez et al., 2015). The lipid composition of grapeseed oil consisted majority of polyunsaturated fatty acid followed by monounsaturated fatty acid (Table 1) (Garavaglia et al., 2016). Due to its high content of unsaturated fatty acids, dietary consumption of grapeseed oil showed health-promoting effects in the prevention of cardiovascular diseases, diabetes, and obesity.

Grapeseed oil is common in the cosmetic industry as a raw material with softening, soothing, antioxidant. and moisturizing effect. The oil with high unsaturated fatty acids and antioxidants can be used in the therapy of psoriasis and skin chafe. Grapeseed oil showed a high amount of omega-6 fatty acid that can prevent excessive water loss by forming a protective barrier on the skin (Lin et al., 2017). Apart from that, with the high amount of vitamin E, grapeseed oil is effective in aging prevention (Soto et al., 2015) benefits skin health (Bail et al., 2018; Glampedaki & Dutschk, 2014). Besides that, grapeseed oil also provides phenolic components like flavonoids, carotenoids, phenolic acids and tannins (Puiggros et al., 2005; Perez et al., 2015) which are capable in improving UV protection and epidermal antioxidant activity to delay premature aging and photoaging (Lorencini et al., 2014). Therefore, grapeseed oil is suitable to be used in sunscreen formulation with added ability to delay skin aging.

2.7. Kenaf seed oil

Kenaf (*Hibiscus cannabinus*) is a plant that received attention worldwide for its commercial value as fiber applications. It is used in the production of twine, rope, pulp and paper (Cheng et al., 2016). Kenaf seed is a by-product of kenaf, which is found to have a high content of kenaf seed oil. The fatty acid composition of kenaf seed oil was shown in Table 1. At the same time, it also consists of tocopherols, phytosterols, and polyphenols (Cheong et al., 2017; Nyam et al., 2009; Omenna et al., 2017). It was proven to have high nutritional value and significant antioxidant activity that showed nutraceutical properties to promote good health (Cheong et al., 2017; Ryu et al., 2017).

The utilization of kenaf seed oil was proven to provide antioxidant activity to the formulation and exhibit synergistic effects (Chu et al., 2019; Chu & Nyam, 2020). According to the previous studies from Chu et al. (2019) and Lee et al. (2019), KSO was utilized as a renewable source and potential ingredient to produce an innovative sunscreen formulation. The utilization of kenaf seed oil in the lipid phase of nanostructured lipid carrier for UV filter encapsulation was found to exhibit synergistic effect to boost up the photoprotective properties of the formulation (Chu et al. 2019). Meanwhile, Chu & Nyam (2020) showed the potential of kenaf seed oil application in cosmetic cream formulation fortified with palm-based vitamin E with adding value to the antioxidant activity. Moreover, Chu et al. (2021) reported the enhancement of photoprotection in term of the SPF value and UVA/UVB ratio of the photoprotective prototype developed from kenaf seed oil and tocopherol. Therefore, besides being an edible oil, kenaf seed oil can be applied in skincare and sunscreen formulation with additional skin beneficial properties.

2.8. Pumpkin seed oil

Pumpkin (*Cucurbita sp.*) belongs to the family Cucurbitaceae. The seeds, skins, and leaves of the pumpkin plant are used as functional food or traditional medicines (Ramak & Mahboubi, 2018). Among several species of pumpkin, *Cucurbita pepo, Cucurbita maxima* and *Cucurbita moschata* are cultivated extensively worldwide. Pumpkin is a valuable vegetable primarily due to its high carotenoid content and minerals with the low glycemic index (Dar et al., 2017). Pumpkin seed oil is a dark greenish oil which is extracted from the seeds by pressing or solvent extraction. From Table 1, the seed oil contains high amount of unsaturated fatty acids. The unsaturated fatty acids in the oil predominant with oleic, linoleic, and palmitic acids. Besides, it also rich in phytosterols, tocopherols, and squalene (Nyam et al., 2009; Naziri et al. 2015). It was proven to have pharmacological activities in anti-diabetic, anti-fungal, anti-bacterial, anti-inflammation, and antioxidant effects (Bardaa et al., 2016).

High bioactive compounds in pumpkin seed oil could provide high protection against oxidative stress (Rezig et al., 2012) and photoprotection benefit, and anti-inflammation (Bardaa et al., 2016). In addition, both Bardaa et al. (2016) and Rabrenovic et al. (2014) confirmed the prevalence of α- and γ-tocopherol, phytosterols, and squalene content in the seed oil that made it suitable to be used in topical application with medicinal proposes. The study from Bardaa et al. (2016) showed significant wound healing effect of pumpkin seed oil in animal assays through topical application. Apart from that, Chu et al. (2020) reported pumpkin seed oil in nanostructured lipid carrier development for sunscreen formulation development demonstrated the presence of synergistic effect between pumpkin seed oil and synthetic UV filters. Pumpkin seed oil showed the effect in boosting the UV protection of a sunscreen formulation (Chu et al., 2020). Overall, pumpkin seed oil with unique fatty acid composition and high squalene content would be recommended in the nutritional, UV protection, and medicinal purposes.

3. Non-prescription over-the-counter (OTC) sunscreen drug and the role of seed oil in sunscreen

In the United States, sunscreen active ingredients are regulated by the U.S. Food and Drug Administration (FDA) and pre-market registration is needed for sunscreen products. The sunscreen active ingredients are recognised as non-prescription over-the-counter (OTC) drug and the sunscreen with UV filters are regulated under Sunscreen Drug Products for Over-the-Counter Human Use Monograph (21 CFR part 310, 352, 700) and The Sunscreen Innovation Act to review on the safety and efficiency of the active ingredients (Federal Register, 2019). However, in 2019, the FDA published a proposed update to the current sunscreen regulation and highlighted the concerns on the safety and efficiency of the approved active ingredients. Among the 16 approved UV filters, only 2 are proposed to be safe and effective to use and 2 are classified as non-safe (FDA, 2019). Due to the concern on the safety of synthetic UV filters in sunscreen that lead to growing demand for natural cosmetic ingredients. Hence, plant seed oils show high potential to be added to sunscreen formulation. The unique fatty acid composition and bioactive compounds in seed oil add value to the topical photoprotection formulation through two different pathways, which are function as an antioxidant to scavenge the UV-induced free radicals and/or act as a UV filter to absorb the harmful UV radiation from damaging the skin. The application of seed oils contributed to synergistic effect to the sunscreen formulation, exhibit antiaging and anti-inflammation as well as act as potential natural hormetins.

3.1. Synergistic effect with antioxidants

The presence of natural antioxidants from seed oil may be a promising option to enhance sunscreen photostability, decrease skin damage caused by UV radiation (Baccarin et al., 2015), and improve SPF value of the formulation without introducing additional UV active ingredients (Afonso et al., 2014). The bioactive compounds such as carotenoids and phenolic compounds are found to be able to absorb UV radiation that showed potential synergistic effect with UV filters. Carotenoids are potent natural antioxidants and play important roles to protect the plants from UV damage. According to Darvin et al. (2011), the presence of carotenoids (α-, γ-, β-carotene, lutein, zeaxanthin, lycopene) and their isomers in human skin can protect against oxidation. Due to the photoprotective role of carotenoids in plants, they are applied as natural photoprotective agents in the treatment of human photosensitivity, particularly mediated by porphyrins (Anstey, 2002). Stahl & Sies (2012) reported the effect of β-carotene and lycopene dietary intake that provide protection against UV-induced skin damage in humans. Mezzomo & Ferreira (2016) reported the function of carotenoids to absorb harmful UV radiation and act as UV filters to protect the skin against photodamage. Carotenoids like phytoene and phytofluene are precursor molecules of unsaturated carotenoids contribute photoprotective effects with their absorption UVA and UVB spectra, respectively (Melendez-Martinez, 2007). Due to the spectral properties in light absorption (UVB and UVA range), they are expected to have skin beneficial properties by their natural photoprotective effects (Fiedor & Burda, 2014). Moreover, the previous study also suggested β-carotene supplementation protect against photodamage caused by visible and infrared radiations in a time-dependent manner (Melendez-Martinez, 2007; 2019).

Apart from that, phenolic compounds also play vital roles in photoprotection. The findings from Nichols & Katiyar, (2010) indicated the ability of tea polyphenols and pro-anthocyanidins from grapeseeds in absorbing mainly in UVB and part of the UVA and UVC wavelength. Moreover, Agati et al. (2013) reported the effect of flavonoids such as quercetin and quercetin derivatives in UVB spectrum absorption activity. Therefore, antioxidants with potential UV absorbing activity may be promising to be added in sunscreen formulation to boost up the effect of UV filters. According to the previous studies, the findings indicated the adding value of antioxidants in sunscreen development to enhance the photoprotective properties while maintaining antioxidant capacity (Lacatusu et al., 2014; Chu et al., 2019; Chu et al. 2020; Chu et al., 2021). Also, Chu et al. (2019) and Badea et al. (2016) claimed the synergistic interaction that occurred among the sunscreen active compounds with different seed oils to boost up the photoprotection. Hence, by applying renewable plant-based resources such as seed oils, they showed the ability to manifest self-antioxidative properties and have advantages by replacing a considerable amount of synthetic UV filters (Niculae et al., 2014). The combination of biomedical featured seed oils with the unique properties of lipid nanoparticles was found to be effective in producing a sunscreen formulation that demonstrated the additional skin beneficial properties from the natural bioactive compounds (Lacatusu et al., 2014; Baccarin et al., 2015; Chu et al., 2019; Badea et al., 2016; Niculae et al., 2014). Therefore, the addition of seed oils showed the advantages in terms of minimizing the side effects of synthetic ingredients with the presence of synergistic effect.

3.2. Antiaging

Premature skin aging is caused by UV radiation that damage the skin connective tissue. The exposure of UV radiation initiates the production of ROS and cellular mechanism that damages skin connective tissue and finally lead to photoaging (Figure 1). UV radiation triggers the mitogen-activated protein kinase (MAPK) pathway. The activated kinases upregulate expression and functional activation of the nuclear transcription factor, AP-1, which then stimulates transcription of genes for matrix-degrading enzymes such as matrix metalloproteinase (MMP) -1, -2, -3, -9 and -12 (Kwon et al., 2019; Freitas-Rodríguez et al., 2017). Moreover, transcription factor AP-1 also causes skin aging through transforming growth factor (TGF)-β1 pathway inhibition followed by collagen gene expression (Kwon et al., 2019). UV radiation triggers the production of ROS which will be quenched by the antioxidant defences in the skin. If the antioxidant defence is overwhelmed that will cause oxidative stress to damage skin cells and alter their gene expression. At last, it will lead to photoaging and finally promoting skin cancers. Thus, topical application of antioxidant not only to introduce the antioxidant compounds, in addition to direct chemical interference with free radicals generated and thus interfere with UV-induced gene expression by multiple pathways.

Seed oils with high antioxidants protect skin from oxidative stress and implement cellular antioxidant level to promote skin health (Thring et al., 2009; Lin et al., 2017). Seed oils are found in rich with carotenoids, phenolic compounds, phytosterols, and vitamin E which play important roles in quenching the UV-induced ROS to prevent premature aging. Fiedor & Burda (2014) reported the mechanism of carotenoids associated with epidermal and dermal damage. Carotenoids show excellent singlet oxygen quenching and ROS scavenging properties (Fiedor & Burda, 2014). Carotenoids act as antioxidants that provide radical scavenging effect, inhibit lipid peroxidation, and protect the skin against ROS generated by UV radiation (Mezzomo & Ferreira, 2016). Besides, they also found in inhibiting UV-induced gene by downregulating the expression of metalloproteases which are responsible for premature aging as well as modulate photoimmune system (Mezzomo & Ferreira, 2016). According to Melendez-Martinez (2007), carotenoids triggered keratinocyte proliferation, epidermal differentiation, and reduced inflammation that benefit skin health. Overall, the reduction of the sign of photoaging (wrinkling, pigmentation, dryness, and loss of skin elasticity) is closely associated with the beneficial role of carotenoids on the skin.

Besides that, the findings from Nichols & Katiyar, (2010) indicated the ability of tea polyphenols and pro-anthocyanidins from grapeseeds in preventing UV-induced inflammation, DNA damage, and oxidative stress which contributed to the antiaging effect. Vitamin E with high antioxidant activity showed potential protection against UV-induced skin photodamage (Krol et al., 2000). From Thiele et al. (2006), topical application of vitamin E up to 1 % is considered safe and effective to improve the level of skin vitamin E. According to Krol et al. (2000), topical application of α-tocopherol was found to inhibit the formation of cyclobutane pyrimidine photoproducts in the animal model. Vitamin E protects the skin from various deleterious effects mainly contributed to lipid peroxidation interacts with enzymatic and nonenzymatic pathways of other antioxidant systems and acts as a free-radical scavenger (Anstey, 2002; Ribeiro et al., 2015). The study from Maalouf et al. (2002) indicated topical application of vitamin E protects against UVB-induced skin damage and photoaging. In addition, the application of vitamin E on human keratinocyte cell line was found to demonstrate some degree of protection against cell death after UVB irradiation (Maalouf et al., 2002). On the other hand, vitamin E is a free radical scavenger that not only to combat the free radicals produced from UV radiation but also act as a moisture barrier to the skin that decelerates the aging process in return (Pinto et al., 2018; Muthukumarasamy & Ideris. 2016). The study from Rekik et al. (2016) reported the beneficial properties from the combination of polyphenols, carotenoids, vitamin E, and phytosterols in anti-inflammation and antiaging by protecting the skin against free radicals and ensuring the stability and integrity of the skin.

3.3. Anti-inflammation

UV radiation that causes inflammation has been well documented clinically and histologically (Hruza & Pentland, 1993). Acute exposure of UV radiation results in sunburn, followed by tanning and epidermal thickening. Meanwhile, chronic exposure can induce skin aging and skin cancers. UV-induced inflammation also known as UV-induced erythema. It is caused by UV radiation which triggers chemical reactions occurring in the skin. It activates the transcription of pro-inflammatory cytokines such as IL-1 and IL-6 which lead to sunburn or inflammation (Lin et al., 2017). The inflammatory cytokines contribute to tissue repair and infection control. However, they also activate keratinocytes and immune cells to damage the skin tissue through ROS production. ROS triggers MAPK pathway as indicated in Figure 1 to cause the degradation of ECM which leads to skin aging. Therefore, the intensity of inflammation resolution is critical to limit normal skin tissue damage. Topical application of seed oils with mono- and polyunsaturated fatty acids may influence the inflammatory responses. Due to its high composition of unsaturated fatty acids and antioxidants, seed oils contain relatively high protection against inflammation and oxidative stress. According to the literatures, pomegranate seed, rosehip, grapeseed, kenaf seed oil, and pumpkin seed oil were found to prevent inflammation and contributed to wound healing effect (Lin et al., 2017; Nyam et al. 2015; Bardaa et al., 2016; Rekik et al., 2016). Besides that, pumpkin seed oil with relatively high squalene content is beneficial to skin health (Nyam et al. 2009). Squalene is resistant to peroxidation to function as a ROS quencher, protect skin lipid peroxidation against the exposure to UV radiation, and other sources of oxidative damage (Huang et al., 2009). It functions in enhancing regeneration, nourishment, and protection of human skin as well as in skin treatment from cracks, eczema, dermatitis, rashes, and so forth (Muller et al., 2007). The presence of bioactive compounds and unique fatty acid composition in seed oils are valuable in skin health to prevent UV-induced inflammation.

3.4. Natural hormetin

Hormesis is a biphasic dose response to an agent in which a low dose will cause beneficial effects and a high dose will lead to toxic effects (Mattson 2009). In the biological and medicinal field, hormesis is a phenomenon in which the cell and organism response to the induction of mild stress (Mattson 2009). The examples of mild stress induction can be from exercises, dietary intake, and phytonutrient exposure that results in cellular signalling pathways to mediate hormetic responses. The application of seed oils could be a novel biological hormetin in the cosmetic formulation due to their effect of certain phytochemicals in hormesis. The presence of high content of bioactive compounds in the seed oil exhibit direct free radical scavenging properties and responsible for the health benefits. However, according to Mattson (2009) and Rattan (2015), the presence of some phytonutrients such as polyphenols, flavonoids, and curcumin exert advantages in activating adaptive stress response signalling pathways, leading to the production growth factors for cellular regeneration, cytoprotective protein production, and protein repair.

Hormesis induced by mild stress benefit in aging due to the function to maintain and repair the cells and proteins in the body (Rattan, 2004). Aging is caused by the failure of cellular maintenance. Therefore, Rattan (2004) suggested the application of mild stress to trigger hormesis could be a promising approach for modulating aging by mediating several stress-induced gene expression to improve the cellular function. The previous study from Rattan et al. (2012) showed beneficial effects of Chinese herb Sanchi (*Panax notoginseng*) extract in skin health due to the production of stress-induced proteins involved in protein repair and removal of abnormal proteins. Besides that, the clinical evaluation on Sanchi extract also indicated significant positive effects against facial wrinkles and other symptoms of facial skin aging (Rattan et al. 2012). The application of natural hormetins from seed oil could be a promising approach to aging intervention. Seed oil can act as a free radical scavenging agent to protect the skin against harmful UV radiation and at the same time trigger hormetic responses to benefit skin health. Unfortunately, a more complete research should be carried out in order to define the complete pathway of hormesis triggered by seed oils.

4. Conclusion

The review of seed oils in sunscreen development is valuable in the growing market of natural cosmetics. Seed oils as sources of unsaturated fatty acids and bioactive compounds play crucial roles in photoaging prevention. Numerous scientific studies have confirmed the beneficial effects of seed oils on exhibiting synergistic effect with synthetic UV active ingredients to improve skin health. The phytonutrients of seed oils play crucial roles to boost up the photoprotection, promote skin health by their antioxidative activities, protect the skin from UV-induced erythema, and trigger hormetic responses for protein repair. Therefore, seed oils are beneficial in delaying aging process through antioxidant replenishment and skin cell regeneration. Future studies should be conducted to verify the cellular pathway and molecular mechanisms in dermatological treatments by the application of seed oils suggested from pomegranate, castor, cocoa butter, jojoba, rosehip, grapeseed, kenaf, and pumpkin in sunscreen products. Besides that, hormesis induced by seed oils and their beneficial effects in UV protection should be defined. In principle, phytonutrients from plant seed oils can be a propitious therapeutical strategy to develop novel cosmetic formulations.

Acknowledgements

This work has been supported by the Ministry of Higher Education via the Fundamental Research Grant Scheme (FRGS/1/2018/WAB01/UCSI/02/1).

Conflict of interest

The authors declare no conflict of interest.

References

Agati, G., Bruneti, C., Ferdinando, M. D., Ferrini, F., Pollastri, S., & Tattini, M. (2013) Functional roles of flavonoids in photoprotection: New evidence, lessons from the past. Plant Physiology and Biochemistry, **72:**35-54.

Afonso, S., Horita, K., Silva, J. P. S., Almeida, I. F., Amaral, M. H., Lobao, P. A., Costa, P. C., Miranda, M. S., Silva, J. C. G. E., & Lobo, J. M. S. (2014). Photodegradation of avobenzone: Stabilization effect of antioxidants. Journal of Photochemistry and Photobiology B: Biology, **140:**36-40.

Anstey, A. V. (2002). Systemic photoprotection with α-tocopherol (vitamin E) and β-carotene. Clinical and Experimental Dermatology, **27:**170-176.

Afaq, F., Zaid, M. A., Khan, N., Dreher, M., & Mukhtar, H. (2019). Protective effect of pomegranate derived products on UVB-mediated damage in human reconstituted skin. Experimental Dermatology, **18:**553-561.

Al-Okbi, S. Y., Mohamed, D. A., Kandil, E., Abo-Zeid, M. A., Mohammed, S. E., & Ahmed, E. K. (2017). Anti-inflammatory activity of two varieties of pumpkin seed oil in an adjuvant arthritis model in rats. Grasas y Aceites, **68:**e180.

Alvarez, R. A. M. & Rodríguez, G. M. L. (2000). Lipids in pharmaceutical and cosmetic preparations. Grasas y Aceites, **51:**74-96.

Agarwal, S., Arya, D., & Khan, S. (2018). Comparative fatty acid and trace elemental analysis identified the best raw material of jojoba (*Simmondsia chinensis*) for commercial applications. Annals of Agricultural Sciences, **63:**37–45.

Badea, G., Badea, N., Brasoveanu, L. I., Mihaila, M., Stan, R., Istrati, D., Balacic, T., & Lacatusu, I. (2016). Naringenin improves the sunscreen performance of vegetable nanocarriers. New Journal of Chemistry, **41:**480-492.

Boroushaki, M. T., Mollazadeh, H., & Afshari, A. R. (2016). Pomegranate seed oil: A comprehensive review on its therapeutic effects. International Journal of Pharmaceutical Sciences and Research, **7:**430-442.

Bail, S., Stuebiger, G., Krist, S., Unterweger, H., & Buchbauer, G. (2008). Characterisation of various grape seed oils by volatile compounds, triacylglycerol composition, total phenols and antioxidant capacity. Food Chemistry, **108:**1122-1132.

Bardaa, S., Ben Halima, N., Aloui, F., Ben Mansour, R., Jabeur, H., Bouaziz, M., Sahnoun, Z. (2016). Oil from pumpkin (*Cucurbita pepo* L.) seeds: evaluation of its functional properties on wound healing in rats. Lipids in Health and Disease, **15:**1-12.

Baccarin, T., Mitjans, M., Ramos, D., Lemos-Senna, E., & Vinardell, M. P. (2015). Photoprotection by Punica granatum seed oil nanoemulsion entrapping polyphenol-rich ethyl acetate fraction against UVB-induced DNA damage in human keratinocyte (HaCaT) cell line. Journal of Photochemistry and Photobiology B: Biology, **153:**127–136.

Busson-Breysse, J., Farines, M., & Soulier, J. (1994). Jojoba wax: Its esters and some of its minor components. Journal of the American Oil Chemists' Society, **71:**999-1002.

Cheng, W. Y., Haque Akanda, J. M., & Nyam, K. L. (2016). Kenaf seed oil: A potential new source of edible oil. Trends in Food Science and Technology, **52:**57-65.

Chew, S. C., Tan, C. P., Long, K., & Nyam, K. L. (2016). Effect of chemical refining on the quality of kenaf (*Hibiscus cannabinus*) seed oil. Industrial Crops and Products, **89:**59-65.

Cheong, A. M., Tan, C. P., & Nyam, K. L. (2018). Stability of bioactive compounds and antioxidant activities of kenaf seed oil-in-water nanoemulsions under different storage temperatures. Journal of Food Science, **0:**1-9.

Chu, C. C., Tan, C. P., & Nyam, K. L. (2019). Development of nanostructured lipid carriers (NLCs) using pumpkin and kenaf seed oils with potential photoprotective and antioxidative properties. European Journal of Lipid Science and Technology, **121:**1900082.

Calka, M., & Pawlica, P.J. (2019). Substances of natural origin used in the sun protection of the skin. European Journal of Medical Technologies, **3:**29-37.

Chu, C. C., Azizul Hasan, Z. A., Chua, S. K., & Nyam, K. L. (2020). Formulation and characterization of novel nanostructured lipid carriers with photoprotective properties made from carnauba wax, beeswax, pumpkin seed oil, and UV filters. Journal of the American Oil Chemists' Society, **97:**531-542.

Chu, C.C., & Nyam, K.L., (2020). Kenaf (*Hibiscus cannabinus* L.) seed oil: Application as cosmetic product ingredients. Industrial Crops and Products, **95:**742-750.

Chu, C. C., Azizul Hasan, Z. A., Tan, C.P., & Nyam, K. L. (2021). Application of kenaf seed oil-nanostructured lipid carrier into palm-based α-tocopherol cream for photoprotection. Journal of the American Oil Chemists' Society, (in press).

Chew, S.C., Tan, C.P., Lai, O.M., & Nyam, K.L., 2018. Changes in 3-MCPD esters, glycidyl esters, bioactive compounds and oxidation indexes during kenaf seed oil refining. Food Science and Biotechnology, **27:**905-914.

Chew, S.C., Tan, C.P., Nyam, K.L., (2017). Application of response surface methodology for optimizing the deodorization parameters in chemical refining of kenaf seed oil. Separation and Purification Technology, **184:**144-151.

Çavdar, H. K., Yanık, D. K., Gök, U., & Göğüş, F. (2017). Optimisation of microwave-assisted extraction of pomegranate (*Punica granatum* L.) seed oil and evaluation of its physicochemical and bioactive properties. Food Technology and Biotechnology, **55:**86–94.

Darvin, M. E., Sterry, W., Lademann, J., & Vergou, T. (2011). The role of carotenoids in human skin. Molecules, **16:**10491-10506.

Dar, A. H., Sofi, S. A., & Rafiq, S. (2017). Pumpkin the functional and therapeutic ingredient: A review. International Journal of Food Sciences and Nutrition, **2:**165-170.

Drinić, Z., Mudrić, J., Zdunić, G., Bigović, D., Menković, N., & Šavikin, K. (2020). Effect of pomegranate peel extract on the oxidative stability of pomegranate seed oil. Food Chemistry, **333:**127501.

El-Mallah, M. H., & El-Shami, S. M. (2009). Investigation of liquid wax components of Egyptian jojoba seeds. Journal of Oleo Science, **58:**543-548.

Freitas-Rodríguez, S., Folgueras, A. R., & López-Otín, C. (2017). The role of matrix metalloproteinases in aging: Tissue remodeling and beyond. BBA Molecular Cell Research, **1864:**2015-2025.

Fiedor, J., & Burda, K. (2014). Potential role of carotenoids as antioxidants in human health and disease. Nutrients, **6:**466-488.

Federal Register (2019). Sunscreen drug products for over-the-counter human use. Retrived from: https://www.federalregister.gov/documents/2019/02/26/2019-03019/sunscreen-drug-products-for-over-the-counter-human-use.

Floratech (2019). Introducing L22®. Retrieved from: http://www.lipids22.com.

Floratech (2018). Formulas for L22®. Retrieved from: https://www.floratech.com/Formulas/L22%C2%AE.

Gorjanovic, S. Z. Rabrenovic, B. B., Novakovic, M. M., Dimic, E. B., Basic, Z. N., & Suznjevic, D. Z. (2011). Cold-pressed pumpkin seed oil antioxidant activity as determined by a DC polarographic assay based on hydrogen peroxide scavenge. Journal of the American Oil Chemists' Society, **88:**1875-1882.

Glampedaki, P., & Dutschk, V. (2014). Stability studies of cosmetic emulsions prepared from natural products such as wine, grape seed oil and mastic resin. Colloids and Surfaces A: Physicochemical and Engineering Aspects, **460:**306-311.

Garavaglia, J., Markoski, M. M., Oliveira, A., & Marcadenti, A. (2016). Grape seed oil compounds: Biological and chemical actions for health. Nutrition and Metabolic Insights, **9:**59-64.

Grajzer, M., Prescha, A., Korzonek, K., Wojakowska, A., Dziadas, M., Kulma, A., & Grajeta, H. (2015). Characteristics of rose hip (*Rosa canina* L.) cold-pressed oil and its oxidative stability studied by the differential scanning calorimetry method. Food Chemistry, **188:**459-466.

Górnaś, P., Soliven, A., & Segliņa, D. (2015). Seed oils recovered from industrial fruit by-products are a rich source of tocopherols and tocotrienols: Rapid separation of α/β/γ/δ homologues by RP-HPLC/FLD. European Journal of Lipid Science and Technology, **117:**773-777.

Heinrich, U., Neukam, K., Tronnier, H., Sies, H., & Stahl, W. (2006). Long-term ingestion of high flavanol cocoa provides photoprotection against UV-induced erythema and improves skin condition in women. The Journal of Nutrition, **136:**1565-1569.

Habashy, R. R., Abdel-Naim, A. B., Khalifa, A. E. & Al-Azizi, M. M. (2005). Anti-inflammatory effects of jojoba liquid wax in experimental models. **51:**95-105.

Huang, Z. R., Lin, Y. K., & Fang, J. Y. (2009). Biological and pharmacological activities of squalene and related compounds: Potential uses in cosmetic dermatology. Molecules, **14:**540-554.

Hruza, L. L., & Pentland, A. P. (1993). Mechanisms of UV-induced inflammation. Journal of Investigative Dermatology, 100:35S-41S.

Ilyasoglu, H. (2014). Characterization of rosehip (*Rosa canina* L.) seed and seed oil. International Journal of Food Properties, **17:**1591-1598.

Johnson, W. Jr. (2017). Final report on the safety assessment of *Ricinus communis* (castor) seed oil, hydrogenated castor oil, glyceryl ricinoleate, glyceryl ricinoleate SE, ricinoleic acid, potassium ricinoleate, sodium ricinoleate, zinc ricinoleate, cetyl ricinoleate, ethyl ricinoleate, glycol ricinoleate, isopropyl ricinoleate, methyl ricinoleate, and octyldodecyl ricinoleate. International Journal of Toxicology, **26:**31-77.

Kaur, C. D., & Saraf, S. (2010). In vitro sun protection factor determination of herbal oils used in cosmetics. Pharmacognosy Research, **2:**22-25.

Kim, M. Y., Kim, E. U., Kim, Y. N., Choi, C. S., & Lee, B. H. (2012). Comparison of the chemical compositions and nutritive values of various pumpkin (*Cucurbitaceae*) species and parts. Nutrition Research and Practice, **6:**21-27.

Krol, E. S., Kramer-Stickland, K. A., & Liebler, D. C. (2000). Photoprotective actions of topically applied vitamin E. Drug Metabolism Reviews, **32:**413-420.

Khoddami, A., Che Man, Y., & Roberts, T. H. (2014). Physico−chemical properties and fatty acid profile of seed oils from pomegranate (*Punica granatum* L.) extracted by cold pressing. European Journal of Lipid Science and Technology, **116:**553-562.

Kwon, K. R., Alam, M. B., Park, J. H., Kim, T. H., & Lee, S. H. (2019). Attenuation of UVB-induced photo-aging by polyphenolic-rich Spatholobus Suberectus stem extract via modulation of MAPK/AP-1/MMPs signaling in human keratinocytes. Nutrients, **11:**1-20.

Kulaitienė, J., Medveckienė, B., Levickienė, D., Vaitkevičienė, N., Makarevičienė, V., & Jarienė, E. (2020). Changes in fatty acids content in organic rosehip (*Rosa spp*.) seeds during ripening. Plants, **9:**1793.

Lin, T. K., Zhong, L., & Santiago, J. L. (2017). Anti-inflammatory and skin barrier repair effects of topical application of some plant oils. International Journal of Molecular Sciences, **19:**1-21.

Leccia, M. T., Lebbe, C., Claudel, J. P., Narda, M., & Basset-Seguin, N. (2019). New vision in photoprotection and photorepair. Dermatologic Therapy, **9:**103-115.

Lacatusu, I., Niculae, G., Badea, N., Stan, R., Popa, O., Oprea, O., & Meghea, A. (2014). Design soft lipid nanocarriers based on bioactive vegetable oils with multiple health benefits. Chemical Engineering Journal, **246:**311-321.

Lorencini, M., Brohem, C. A., Dieamant, G. C., Zanchin, N. I. T., & Maibach, H. I. (2014). Active ingredients against human epidermal aging. Ageing Research Reviews, **15:**100-115.

Lee, X. Y., Chu, C. C., Azizul Hasan, Z. A., Chua, S. K., & Nyam, K. L. (2019). Novel nanostructured lipid carriers with photoprotective properties made from carnauba wax, beeswax, and kenaf seed oil. Journal of the American Oil Chemists' Society, **96:**201-211.

Lutterodt, H., Slavin, M., Whent, M., Turner, E., & Yu, L. (2011). Fatty acid composition, oxidative stability, antioxidant and antiproliferative properties of selected cold-pressed grape seed oils and flours. Food Chemistry, **128:**391–399.

Melo, I. L. P., Carvalho, E. B. T., Silva, A. M. O., Yoshime, L. T., Sattler, J. A. G., Pavan, R. T., & Manchi-Filho, J. (2016). Characterization of constituents, quality and stability of pomegranate seed oil (*Punica granatum* L.). Food Science and Technology, **36:**132-139.

Mirmiran, P., Fazeli, M. R., Asghari, G., Shafiee, A., & Azizi, F. (2010). Effect of pomegranate seed oil on hyperlipidaemic subjects: a double-blind placebo-controlled clinical trial. British Journal of Nutrition, **104:**402-406.

Michalak, M., & Kiełtyka-Dadasiewicz, A. (2018). Oils from fruit seeds and their dietetic and cosmetic significance. Herba Polonica, **64:**63-70.

Montenegro, L. & Santagati, L. M. (2019). Use of vegetable oils to improve the sun protection factor of sunscreen formulations. Cosmetics, **6:**1-10.

Matsumoto, Y., Ma, S., Tominaga, T., Yokoyama, K., Kitatani, K., Horikawa, K., & Suzuki, K. (2019). Acute effects of transdermal administration of jojoba oil on lipid metabolism in mice. Medicina, **55:**1-11.

Marmol, I., Sanchez-de-Diego, C., Jimenez-Moreno, N., Ancín-Azpilicueta, C., Rodriguez-Yoldi, & Maria, J. (2017). Therapeutic applications of rose hips from different rosa species. International Journal of Molecular Sciences, **18:**11-37.

Mezzomo, N., & Ferreira, S. R. S. (2016). Carotenoids functionality, sources, and processing by supercritical technology: A review. Journal of Chemistry, **2016:**1-16.

Melendez-Martinez, A. J., Britton, G., Vicario, I. M., & Heredia, F. J. (2007). Relationship between the colour and the chemical structure of carotenoid pigments. Food Chemistry, **101:**1145-1150.

Melendez-Martinez, A. J., Stinco, C. M., & Mapelli-Brahm, P. (2019). Skin carotenoids in public health and nutricosmetics: The emerging roles and applications of the UV radiation-absorbing colourless carotenoids phytoene and phytofluene. Nutrients, **11:**1-39.

Maalouf, S., El-Sabban, M., Darwiche, N., & Gali-Muhtasib, H. (2002). Protective effect of vitamin E on ultraviolet B light–induced damage in keratinocytes. Molecular Carcinogenesis, **34:**121-130.

Muthukumarasamy, R., & Ideris, N. (2016). Formulation and evaluation of antioxidant cream containing methanolic extract of Piper betel leaves. International Journal of Pharmacy and Biological Sciences, **7:**323-328.

Muller, R. H., Petersen, R. D., Hommoss, A., & Pardeike, J. (2007). Nanostructured lipid carriers (NLC) in cosmetic dermal products. Advanced Drug Delivery Reviews, **59:**522-530.

Melo, C. W. B. de, Bandeira, M. de J., Maciel, L. F., Bispo, E. da S., Souza, C. O. de, & Soares, S. E. (2020). Chemical composition and fatty acids profile of chocolates produced with different cocoa (*Theobroma cacao* L.) cultivars. Food Science and Technology, **40:**326-333

Melo, I. L. P., Carvalho, E. B. T., & Mancini-Filho, J, 2014. Pomegranate seed oil (*Punica Granatum* L.): A source of punicic acid (conjugated α-linolenic acid). Journal of Human Nutrition and Food Science, **2:** 1024-1035.

Muntz, A., Sandford, E., Claassen, M., Curd, L., Jackson, A. K., Watters, G., Wang, M.T.M., & Craig, J. P. (2020). Randomized trial of topical periocular castor oil treatment for blepharitis. The Ocular Surface, (in press).

Mohamad, R., Agus, B., & Hussain, N. (2019). Changes of Phytosterols, Rheology, Antioxidant Activity and Emulsion Stability of Salad Dressing with Cocoa Butter During Storage. Food Technology and Biotechnology, **57:**59–67.

Meier, L., Stange, R., Michalsen, A., & Uehleke, B. (2012). Clay jojoba oil facial mask for lesioned skin and mild acne-Results of a prospective, observational pilot study. Forschende Komplementärmedizin / Research in Complementary Medicine, **19:**75–79.

Mattson, M. P. (2008). Hormesis defined. Ageing Research Reviews, **7:**1-7.

Nyam, K. L., Tan, C. P., Lai, O. M., Long, K., & Che Man, Y. B. (2009). Physicochemical properties and bioactive compounds of selected seed oils. LWT - Food Science and Technology, **42:**1396-1403.

Nichols, J. A., & Katiyar, S. K. (2010). Skin photoprotection by natural polyphenols: anti-inflammatory, antioxidant and DNA repair mechanisms. Archives of Dermatological Research, **302:**71-83.

Niculae, G., Lacatusu, I., Badae, N., Meghea, A., & Stan, R. (2014). Influence of vegetable oil on the synthesis of bioactive nanocarriers with broad spectrum photoprotection^{+}. Central European Journal of Chemistry, **12:**837-850.

Nyam, K. L., Sin, L. N., & Kamariah, L., 2015. Phytochemical analysis and anti-inflammatory effect of kenaf and roselle seeds. Malaysian Journal of Nutrition, **22:**245-254.

Ndiaye, P. M., Franceschi, E., Oliveira, D., Dariva, C., Tavares, F. W., & Oliveira, J. V. (2006). Phase behavior of soybean oil, castor oil and their fatty acid ethyl esters in carbon dioxide at high pressures. The Journal of Supercritical Fluids, **37:**29–37.

Omenna, E. C., Uzuegbu, D. C., & Okeleye, D. D. (2017). Functional and nutritional properties of kenaf seed. EC Nutrition, **11.4:**166-172.

Oracz, J., Nebesny, E., & Żyżelewicz, D. (2014). Effect of roasting conditions on the fat, tocopherol, and phytosterol content and antioxidant capacity of the lipid fraction from cocoa beans of different *Theobroma cacao* L. cultivars. European Journal of Lipid Science and Technology, **116:**1002-1014.

Pinto, F., de Barros, D. P. C., & Fonseca, L. P. (2018). Design of multifunctional nanostructured lipid carriers enriched with α-tocopherol using vegetable oils. Industrial Crops and Products, **118:**149-159.

Puiggros, F., Llópiz, N., Ardévol, A., Bladé, C., Arola, L. & Salvadó, M. J. (2005). Grape seed procyanidins prevent oxidative injury by modulating the expression of antioxidant enzyme systems. Journal of Agricultural and Food Chemistry, **53:**6080-6086.

Patel, V. R., Dumancas, G. G., Kasi Viswanath, L. C., Maples, R., & Subong, B. J. J. (2016). Castor oil: Properties, uses, and optimization of processing parameters in commercial production. Lipid Insights, **9:**1-12.

Prasad, R. B. N. & Rao, B. V. S. K., (2017). Chapter 8-Chemical derivatization of castor oil and their industrial utilization, fatty acids chemistry, synthesis, and applications. India, CSIR-Indian Institute of Chemical Technology.

Perez, C., Ruiz del Castillo, M. L., Gil, C., Blanch, G. P., & Flores, G. (2015). Supercritical fluid extraction of grape seeds: extract chemical composition, antioxidant activity and inhibition of nitrite production in LPS-stimulated Raw 264.7 cells. Food and Function, **6:**2607-2613.

Ryu, J. H., Kwon, S. J., Ahn, J. W., Jo, Y. D., Kim, S. H., Jeong, S. W., Lee, M. K., Kim, J. B., & Kang, S. Y. (2017). Phytochemicals and antioxidant activity in the kenaf plant (*Hibiscus cannabinus* L.). Journal of Plant Biotechnology, **44:**191-202.

Ramak, P., & Mahboubi, M. (2018). The beneficial effects of Pumpkin (*Cucurbita pepo* L.) seed oil for health condition of men. Food Reviews International, **35:**166-176.

Rabrenovic, B. B., Dimic, E. B., Novakovic, M. M., Tesevic, V. V., & Basic, Z. N. (2014). The most important bioactive components of cold pressed oil from different pumpkin (*Cucurbita pepo* L.) seeds., LWT - Food Science and Technology, **55:**521-527.

Radice, M., Manfredini, S., Ziosi, P., Dissette, V., Buso, P., Fallacara, A., & Vertuani, S. (2016). Herbal extracts, lichens and biomolecules as natural photo-protection alternatives to synthetic UV filters. A systematic review. Fitoterapia, **114:**144-162.

Ribeiro, A. S., Estanqueiro, M., Oliveira, M. B., & Lobo, J. M. S. (2015). Main benefits and applicability of plant extracts in skin care products. Cosmetics, **2:**48-65.

Rezig, L., Chouaibi, M., Msaada, K., & Hamdi, S. (2012). Chemical composition and profile characterisation of pumpkin (*Cucurbita maxima*) seed oil. Industrial Crops and Products, **37:**82-87.

Rekik, D. M., Khedir, S. B., Moalla, K. K., Kammoun, N. G., Rebai, T., & Sahnoun, Z. (2016). Evaluation of wound healing properties of grape seed, sesame, and fenugreek oils. Evidence-Based Complementary and Alternative Medicine, **2016:**1-29.

Ranzato, E., Martinotti, S., & Burlando, B. (2011). Wound healing properties of jojoba liquid wax: An in vitro study. Journal of Ethnopharmacology, **134:**443-449.

Rattan, S. I. S. (2004). The future of aging interventions: Aging intervention, prevention, and therapy through hormesis. The Journals of Gerontology: Series A, **57:**B705-B709.

Rattan, S. I. S., Kryzch, V., Schnebert, S., Perrier, E., & Nizard, C. (2012). Hormesis-based anti-aging products: A case study of a novel cosmetic. Dose-Response, **11:**99-108.

Rattan, S. I. S., (2015). Hormetins as novel components of cosmeceuticals and aging interventions. Cosmetics, **2:** 11-20.

Soto, M.L., Falque, E., & Domínguez, H. (2015). Relevance of natural phenolics from grape and derivative products in the formulation of cosmetics. Cosmetics, **2:**259-276.

Szentmihalyi, K., Vinkler, P., Lakatos, B. Illes, V., & Then, M. (2002). Rose hip (*Rosa canina* L.) oil obtained from waste hip seeds by different extraction methods. Bioresource Technology, **82:**195-201.

Scapagnini, G., Davinelli, S., Di Renzo, L., De Lorenzo, A., Olarte, H. H., Micali, G., Cicero, A. F. & Gonzalez, S. (2014). Cocoa bioactive compounds: significance and potential for the maintenance of skin health. Nutrients, **6:**3202-3213.

Sarkar, R., Podder, I., Gokhale, N., Jagadeesan, S., & Garg, V. K. (2017). Use of vegetable oils in dermatology: an overview. International Journal of Dermatology, **56:**1080-1086.

Shahin, M., Hady, S. A., Hammad, M., & Mortada, N. (2010). Optimized formulation for topical administration of clotrimazole using Pemulen polymeric emulsifier. Drug Development and Industrial Pharmacy, **37:**559-568.

Stahl, W., & Sies, H. (2012). β-carotene and other carotenoids in protection from sunlight. American Journal of Clinical Nutrition, 96:1179S-84S.

Shobha, N., Nanda, N., Giresha, A. S., Manjappa, P., Dharmappa, K. K., & Nagabhushana, B. M. (2018). Synthesis and characterization of Zinc oxide nanoparticles utilizing seed source of Ricinus communis and study of its antioxidant, antifungal and anticancer activity. Materials Science and Engineering: C, **97:** 842-850.

Sbihi, H. M., Nehdi, I. A., Mokbli, S., Romdhani-Younes, M., & Al-Resayes, S. I. (2018). Hexane and ethanol extracted seed oils and leaf essential compositions from two castor plant (*Ricinus communis* L.) varieties. Industrial Crops and Products, **122:**174-181.

Servent, A., Boulanger, R., Davrieux, F., Pinot, M. N., Tardan, E., Forestier-Chiron, N., & Hue, C. (2018). Assessment of cocoa (*Theobroma cacao* L.) butter content and composition throughout fermentations. Food Research International, **107:** 675-682.

Shabbir, M. A., Khan, M. R., Saeed, M., Pasha, I., Khalil, A. A., & Siraj, N. (2017). Punicic acid: A striking health substance to combat metabolic syndromes in humans. Lipids in Health and Disease, **16:**140-150.

Thiele, J. J., Hsieh, S. N., & Ekanayake-Mudiyanselage, S., Vitamin E: Critical review of its current use in cosmetic and clinical dermatology. *Dermatol. Surg*. 2006, 31, 805-813.

Thring, T. S. A, Hili, P., & Naughton, D. P. (2009). Anti-collagenase, anti-elastase and anti-oxidant activities of extracts from 21 plants. BMC Complementary and Alternative Medicine, **9:**1-11.

U.S. Food and Drug Administration (FDA) (2019). FDA advances new proposed regulation to make sure that sunscreens are safe and effective. Retrieved from: https://www.fda.gov/news-events/press-announcements/fda-advances-new-proposed-regulation-make-sure-sunscreens-are-safe-and-effective.

Winther, K., Hansen, A. S. V., & Campbell-Tofte, J. (2016). Bioactive ingredients of rose hips (*Rosa canina* L) with special reference to antioxidative and anti-inflammatory properties: in vitro studies. Botanics: Targets and Therapy, **6:**11-23.

Yusri, N. M., Chan, K. W., Iqbal, S., & Ismail, M. (2012). Phenolic content and antioxidant activity of *Hibiscus cannabinus* L. seed extracts after sequential solvent extraction. Molecules, **17:**12612-12621.

Yara-Varon, E., Li, Y., Balcells, M., Canela-Garayoa, R., Fabiano-Tixier, A. S. & Chemat, F. (2017). Vegetable oils as alternative solvents for green oleo-extraction, purification and formulation of food and natural products. Molecules, **22:**1-24.

Zarfeshany, A., Asgary, S., & Javanmard, S. H. (2014). Potent health effects of pomegranate. Advanced Biomedical Research, **3:**1-26.

Zaid, M. A., Afaq, F., Syed, D. N., Dreher, M., & Mukhtar, H. (2007). Inhibition of UVB-mediated Oxidative Stress and Markers of Photoaging in Immortalized HaCaT Keratinocytes by Pomegranate Polyphenol Extract POMx. Photochemistry and Photobiology, **83:**882–888.

Table 1 Fatty acid composition of seed oils reported from the previous studies.

Fatty acid (%)	**Pomegranate seed oil**	**Castor oil**	**Cocoa butter**	**Jojoba oil**	**Rosehip oil**	**Grapeseed oil**	**Kenaf seed oil**	**Pumpkin seed oil**
C12:0	-	-	-	-	0.01-0.03	-	-	-
C14:0	-	-	0.08-3.9	0.30-3.50	0.04-0.05	-	0.14-0.25	0.2
C16:0	2.4-4.6	0.3-5.0	22.5-26.6	3.10-9.00	2.73-3.65	7.1-7.8	19.3-23.3	14.8-19.1
C16:1	-	-	0.2-0.3	0.6-2.2	0.1-0.2	-	0.5-0.6	0.02-0.15
C17:1	-	-	0.2-0.2	-	0.04-0.06	-	0.2-0.3	0.08
C18:0	2.3-2.6	0.9-5.4	35.0-37.9	28.2-46.3	.1-2.8	2.5-4.7	3.8-4.6	6.7-7.4
C18:1	6.2-8.0	2.1-7.4	31.9-35.8	0.2-3.1	13.5-18.2	13.9-21.9	33.0-37.6	25.8-42.8
C18:2	5.5-8.7	1.8-10.4	2.7-3.3	0.2-3.1	47.4-54.3	66.0-75.3	31.7-36.5	30.4-50.9
C18:3	75.2-82.3	0.7-0.9	0.1-0.2	-	19.3-30.6	0.3-1.1	1.1-1.2	0.18
C18:1-OH	-	75.8-94.6	-	-	-	-	-	-
C20:0	0.2-0.5	-	1.0-1.1	0.4-3.8	0.7-1.0	0.1-0.2	0.6-0.7	0.4
C20:1	0.6-0.7	-	0.03-0.04	20.8-47.0	0.3-0.7	0.1-0.6	-	0.09
C20:5	-	-	-	-	0.01-0.1	-	-	-
C21:0	-	-	-	8.2-19.7	0.03-0.05	-	-	-
C22:0	-		0.1-0.2	-	0.2-0.4	-	0.3-0.4	0.06
C22:1	-	-	-	-	0.1-0.3	-	-	0.06
C24:0	-	-	0.05-0.1	1.4-4.4	0.1-0.2	-	0.2-0.4	-
C24:1	-	-	-	-	0.03-0.3	-	0.2-3.6	-
SFA	5.4-7.5	5.5-10.9	58.8-69.8	41.6-67.0	5.2-7.6	9.7-12.6	24.9-29.4	22.1-27.2

MUFA	6.8-8.7	78.3-84.8	32.4-36.3	21.6-52.3	14.7-18.9	14.5-22.2	37.1-41.9	26.1-43.2
PUFA	83.9-87.9	9.5-11.4	2.8-3.5	0.2-3.1	73.9-79.5	66.3-75.8	32.8-37.7	30.6-51.1
Oil yield (%)	17.5-35.1	34.6-56.6	34.8-41.8	48.7-54.6	4.9-16.1	8.0-12.0	2.1-24.8	49.1
References	Khoddami et al. (2014); Çavdar et al. (2017); Drinić et al. (2020)	Ndiaye et al. (2006); Sbihi et al. (2018)	Servent et al. (2018); Melo et al. (2020)	Agarwal et al. (2018)	Kulaitienė et al. (2020)	Lutterodt et al. (2011); Garavaglia et al. (2016)	Chew et al. (2016; 2018); Cheng et al. (2016)	Nyam *et al*. (2009); Bardaa et al. (2016)

SFA, Saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids.

Table 2 Tocopherol and tocotrienol content of seed oils reported from the previous studies.

Tocopherol (mg/100 g oil)	Pomegranate seed oil	Castor oil	Cocoa butter	Jojoba oil	Rosehip oil	Grapeseed oil	Kenaf seed oil	Pumpkin seed oil
α	3.8-6.5	0.6-1.3	0.9-1.6	8.5	11.7-14.7	9.6	12.2-21.9	15.2-35.3
β	1.0	0.3-0.7	-	0.2	-	0.08	6.4-6.8	-
γ	153.2-382.7	30.9-46.5	17.9-25.8	33.0	63.0-77.7	3.4	17.8-27.2	61.3-77.5
δ	8.8-17.0	53.0-96.6	0.7-0.8	0.02	23.0-26.0	0.09	1.3-2.5	4.14
Tocotrienol (mg/100 g oil)								
α	0.07	0.2-0.4	-	-	-	34.5	2.2-3.7	-
β	-	-	-	-	-	0.3	-	-
γ	0.7	-	-	-	-	49.5	2.0-2.4	-
δ	-	0.5-0.6	-	-	-		3.0-6.0	-
Total (mg/100 g oil)	175.1-398.7	92.5-129.7	19.5-28.2	41.7	103.8-112.5	97.5	51.3-64.1	80.65-116.9
References	Górnaś et al. (2015); Melo et al. (2016)	Sbihi et al. (2018)	Oracz et al. (2014)	El-Mallah, M. H., & El-Shami (2009)	Grajzer et al. (2015)	Górnaś et al. (2015)	Chew et al. (2017)	Nyam et al. (2009); Naziri et al. (2015)

Table 3 Phytosterols of seed oils reported from the previous studies.

Phytosterol (mg/100 g oil)	Pomegranate seed oil	Castor oil	Cocoa butter	Jojoba oil	Rosehip oil	Grapeseed oil	Kenaf seed oil	Pumpkin seed oil
Campesterol	49.0	249.2-273.2	140.4-172.1	67.2	23.3	2.6-95.7	58.1-52.9	22.6
Stigmasterol	12.0	520.1-554.1	164.5-279.5	26.6	18.9	102.0-108.0	23.3-28.5	18.0
β-Sitosterol	374.0	1070.0-1192.0	191.1-203.0	278.0	544	666.0-674.0	289.9-468.0	211.0
Others	104.0	530.7-583.7	-	259.0	46.8	107.8-127.8	-	590.7 (squalene)
Total	539.0	2370.0-2603.0	496.0-644.1	397.7	663	878.4-1005.5	371.3-549.3	864.7
References	Melo et al. (2016)	Sbihi et al. (2018)	Mohamad et al. (2019)	Busson-Breysse et al. (1994)	Ilyasoglu (2014)	Garavaglia et al. (2016)	Nyam et al. (2009); Chew et al. (2018)	Nyam et al. (2009)

Table 4 List of seed oils with major contributed compounds and molecular pathways that benefit in photoprotection.

Seed oil	Effects in photoprotection	Major contributed compounds	Molecular pathways	References
Pomegranate seed oil	• Inhibit UVB-induced protein oxidation and markers of DNA damage • Prevent from photoaging • UV filter booster	• Phytosterols • Phenolic compounds	AP-1 signalling pathway which regulates MMPs expression in human skin	Montenegro & Santegoti (2019); Afaq et al. (2009)
Castor oil	• Protect from UV-induced damage • Antioxidants	Fatty acid composition	• UV absorption	Kaur & Saraf (2010)
Cocoa butter	• Protect from ROS-induced damage • Anti-inflammation • Antioxidants	• Polyphenols	• Extracellular matrix (ECM) remodelling • Downregulate pro-inflammatory cytokines	Scapagnini et al. (2014); Heinrich et al. (2006)
Jojoba oil	• Prevent from photoaging • Antioxidants • Anti-inflammation	• Phytosterols • Vitamin E • Vitamin A	• UV absorption • Reduced nitric oxide level and tumor necrosis factor-alpha (TNF-α) pathway	Habashy et al. (2005); Calka & Pawlica (2019)
Rosehip oil	• Inhibit ROS-induced damage • Anti-inflammation	• β-carotene and lycopene • Vitamin E	• MMPs gene expression pathway • NF-κB activation pathway	Marmol et al. (2017)
Grapeseed oil	• Inhibit lipid oxidation • Inhibit ROS-induced damage • Anti-inflammation	• Phenolic compounds • Vitamin E	• Glutathione related enzymes expression • Inhibit the activity of arachidonic acid	Garavaglia et al. (2016); Puiggros et al. (2005)

Kenaf seed oil	• UV filter booster • Antioxidants	• Vitamin E • Carotenoids • Flavonoids	No report	Lee et al. (2019); Chu et al., (2019; 2021); Yusri et al. (2012)
Pumpkin seed oil	• UV filter booster • Antioxidants • Anti-inflammation	• Vitamin E • Squalene • β-carotene	• Extracellular matrix (ECM) remodelling • Inhibit the activity of arachidonic acid	Chu et al. (2020); Badae et al. (2016); Al-Okbi et al. (2017)

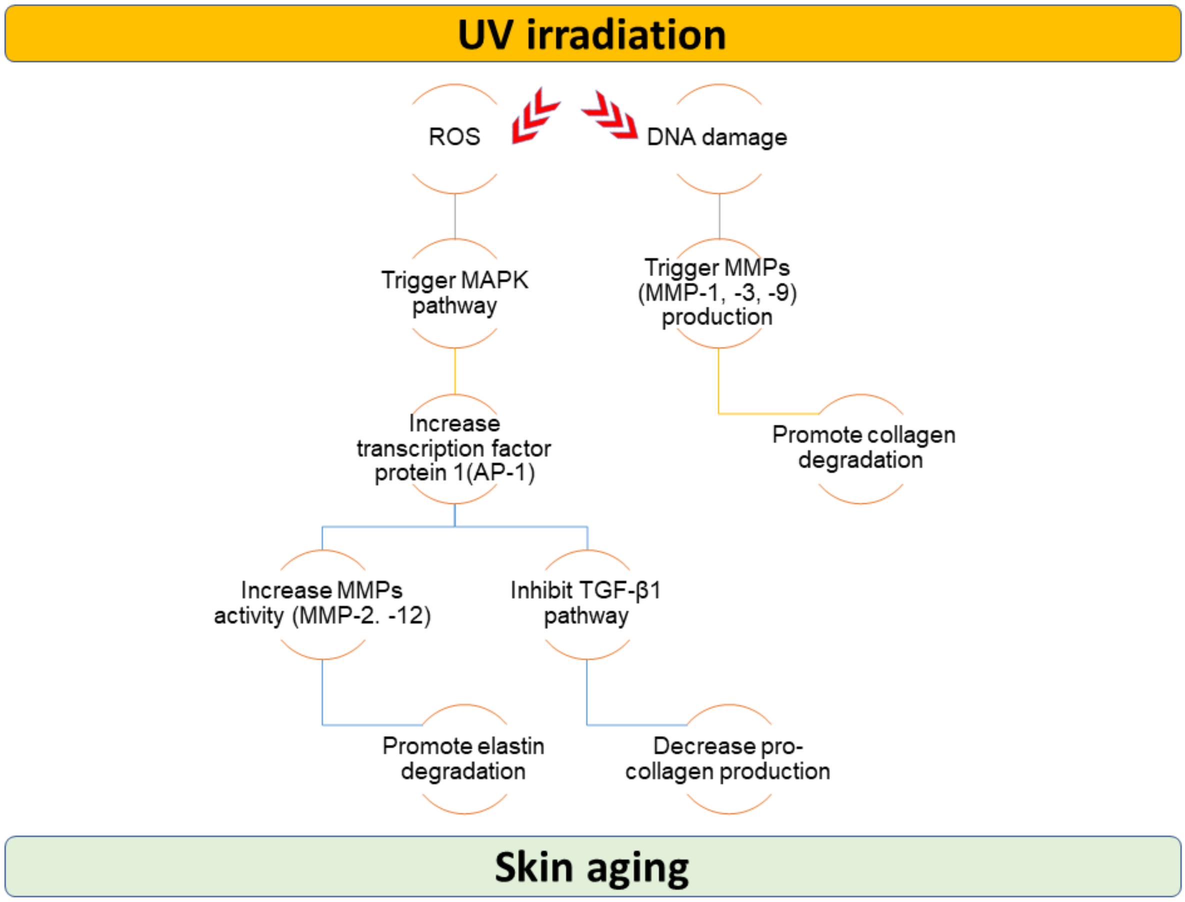

Figure 1 UV-induced pathways that result in skin aging (Kwon et al., 2019; Freitas-Rodríguez et al., 2017).