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Review Article

The Potency of Natural Carotenoids as a UV-Skin Protection and Sunburn Prevention: Review

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ABSTRACT

UV rays not only create unpleasant skin disorders including redness, rough skin, wrinkles, and pigmentation, but they are also responsible for the development of skin malignancies, therefore we need to protect our skin against exposure to UV rays. Carotenoids are metabolites commonly found in plants, often acting as pigments that give yellow to red colors. Carotenoids are predicted to have activity against UV radiation, which can pose risks to the skin, such as sunburn. This systematic literature review was carried out to explore the effects of carotenoids and plants containing carotenoids in protecting skin against UV rays exposures, and to investigate other plants containing carotenoids that were expected to have a potential as a natural UV filter and sunburn prevention. Carotenoids and some plants containing carotenoids are proven as anti-UV and sunburn prevention agents, but further re-examination needs to be done to produce anti-UV preparations with natural active ingredients that are guaranteed for their safety and effective use.

Keywords: Carotenoids, function, natural pigment, skin damage, sunburn, ultraviolet.

INTRODUCTION

The sun emits energy including UVA and UVB radiation, cosmic, gamma rays, x-rays, visible radiation and infrared radiation. These forms of energy are absorbed by the surrounding atmosphere of our planet[1]. Ultraviolet B (UVB) radiation induces the synthesis of melanin pigment and stimulates the skin cells to thicken the outer layer, known as the epidermis. On the other hand, Ultraviolet A (UVA) activates existing melanin on the epidermis and penetrates deeper into the skin. The effects of UVA exposure are more delayed compared to the immediate effects of UVB[2].

Hazards and Benefits of Sun Exposure

Sun exposure has both hazards and benefits. The proven advantages of sun exposure are the photosynthesis of vitamin D which is essential for maintaining healthy muscles and bones, treatment and prevention of skin diseases and seasonal affective disorder. However, it can also pose risks as it has the potential to harm the skin. One of the many skin damages that often happens is sunburn. Sunburns are dermal erythema arising that happens when the skin becomes red due to the widening of superficial blood vessels, resulting from exposure to UV rays. When exposed excessively, the skin can become swollen and painful, potentially in blisters or not[2,3,4].

To prevent disadvantages happening, protection is needed for the body and skin from ultraviolet exposure. One of the many ways is to apply topical anti-UV daily to filter, block, reflect, scatter, or absorb UV light[5]. Photoprotection, whether achieved through mechanical or pharmacological means, is considered the primary approach to preventing skin damage due to UV exposure. Photoprotection through pharmacological means can be applied topically or systemically. The fundamental principle of photoprotection involves the utilization of specific compounds that directly absorb UV light, thereby providing a shield against its harmful effects[6].

These days, there's an increase of interest in natural plant-based substances that provide defense against the harmful impact of UV rays. These natural alternatives have the potential to yield fewer adverse effects when compared to chemical sunscreens, making them appealing to individuals seeking more natural product options. In addition to their UV radiation absorption capabilities, many natural compounds have been discovered to possess antioxidant, anti-inflammatory, and immunomodulatory agents[7,8].

Harmful Effect of Ultraviolet Radiation

The majority of harmful effects caused by ultraviolet radiation (UVR) are primarily associated with oxidative stress, which disrupts various signal transduction pathways in the body. The oxidative stress caused by UVR leads to damage in biomolecules and compromises the integrity of skin cells, resulting in skin damage. Additionally, ultraviolet radiation triggers the activation of pro-inflammatory genes and weakens the immune system by reducing both the quantity and function of epidermal Langerhans cells. There is an increasing enthusiasm for utilizing endogenous protection with antioxidant (AO) properties for safeguarding the skin against the damaging effects of both UV and visible light, specifically carotenoids[6].

Carotenoids

One of the organic compounds that has the potential to protect against UV light and treatment of sunburn is carotenoids[9]. Carotenoids are a class of plant-specific metabolites categorized as terpenoids, which present in red, orange, yellow, and purple colors. Carotenoids can be divided into two main classifications, carotenes and xanthophylls. The carotene group are α-carotene, β-carotene, β, γ-carotene, and lycopene and the xanthophylls group are astaxanthin, fucoxanthin, lutein, β-cryptoxanthin, zeaxanthin, and peridinin[9]. β-carotene is the most commonly found, while α-carotene and γ-carotene are found in smaller amounts in different fruits such as apricots, cherries, carrots, mangos, and grapes. Lycopene, the primary pigment in red-colored fruits like watermelon and tomato, stands out as the most abundant among the non-cyclic carotenes[10]. Carotenoids possess certain structural and physicochemical characteristics that enable them to protect the skin from the damaging effects of UV rays. They achieve this through various mechanisms, including enhancing optical density, quenching singlet oxygen ($^{1}O_2$), and generating retinoic acid. In this review, we examine data from the literature on the effect of carotenoids in plants that have potential as a natural UV filter and its mechanism against sunburn[11].

The carotene group consists of hydrocarbon compounds. On the other hand, xanthophylls groups are carotenoids containing oxygen atoms as aldehyde, carboxylic, carbonyl, hydroxy, furanoxide, and epoxide groups in these molecules[12]. Figure 1 shows the plant's carotenoid derivatives structure.

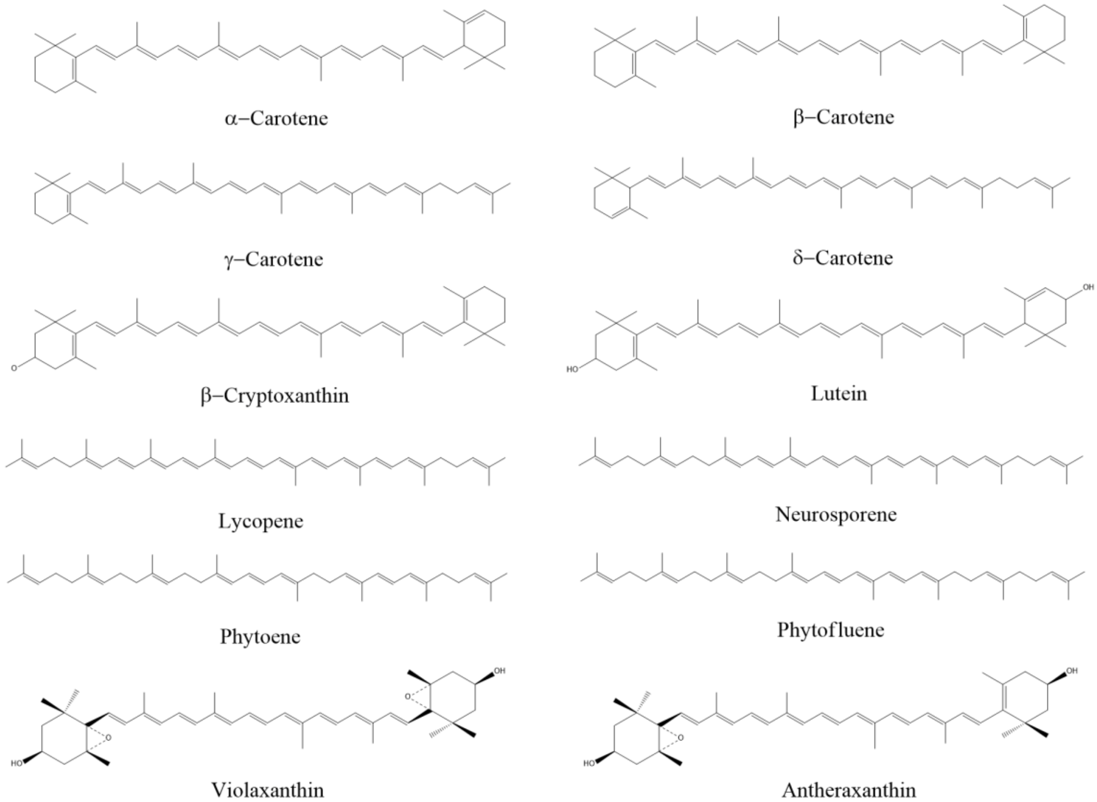

Figure 1: Carotenoid Derivatives Structure[13,14]

Carotenoid as UV Protection

Carotenoids have anti-inflammatory activity that shows protective effects against UV radiation. Due to their molecular structure, carotenoids usually exhibit their highest absorbance levels within the visible light spectrum. However, phytoene and phytofluene, with fewer conjugated double bonds (3 and 5, respectively), are capable of absorbing light in the UV-B and UV-A ranges. The role of carotenoids in filtering blue light is crucial for safeguarding the eyes and encompasses specific carotenoids like lutein and zeaxanthin, which are concentrated in the macula[15,16]. Lutein has the potential to prevent UV radiation-mediated skin irritation through its ability to decrease the generation of inflammatory mediators in keratinocyte (HaCaT) cells[17,18].

Carotenoids possess the ability to absorb direct light and also offer endogenous photoprotection within the human body. They play a part in the prevention of UV damage primarily through their well-established antioxidant effects. By scavenging reactive oxygen species (ROS), including excited singlet oxygen and triplet state molecules, carotenoids help prevent the photoinactivation of antioxidant enzymes, lipid peroxidation, and DNA damage. Moreover, carotenoids can interfere with UV-induced gene expression through various mechanisms, modulate stress-related signaling, and inhibit inflammatory reactions both within cells and tissue levels. The concept of endogenous photoprotection emphasizes the availability of active carotenoid compounds in sufficient quantities at the target site. Therefore, the structural characteristics of carotenoids play a crucial role. These features have impacts on pharmacokinetic parameters such as absorption, distribution, and metabolism, which, in turn, influence the concentration of active carotenoids in the skin[6].

Similarly, astaxanthin can suppress the secretion of inflammatory cytokine from epidermal keratinocytes as a reaction to UV-B radiation. Upon UV irradiation, lycopene has been identified as the antioxidant that is depleted quickest in the skin, suggesting its protective role. Furthermore, carotenoids like α-carotene, β-carotene and β-cryptoxanthin are provitamin A that provide benefit to the skin through promoting the generation of retinoic acid. It plays a role in various skin processes, encompassing keratinocyte proliferation, keratinization and epidermal differentiation, reduces inflammation and oxidative stress, improves the absorption of topical substances, treatment of acne and various skin conditions like sunburn[19,20,21].

In view of the disadvantages such as sunburn, photoaging, ocular damage, DNA harm, weakened immune response, and the risk of skin cancer, it is important to consider protective strategies[22]. Sunburn happens when the skin is exposed to an overabundance of ultraviolet (UV) rays from the sun or artificial sources like tanning beds, resulting in a radiation burn. Both UVA and UVB rays contribute to sunburn, but UVB rays are particularly in charge of directly harming the DNA by causing the formation of cyclobutane thymine dimers[23]. Upon the formation of these dimers, the body initiates a response for repairing DNA, which includes triggering programmed cell death and releasing inflammatory markers such as prostaglandins, ROS, and bradykinin[24]. As a consequence, there is vasodilation, swelling, and pain, which give rise to the characteristic redness and discomfort associated with sunburn. Furthermore, when the skin is exposed to UVB radiation, it triggers an elevation in chemokines like CXCL5 and stimulates peripheral nociceptors which leads to an excessive activation of the pain receptors in the skin[25,26].

Plants with Carotenoids

Carotenoids are naturally occurring pigments that play a significant role in the wide range of yellow to red colors observed in flora, fungi, algae, avian species, flesh or fish and the cuticles of crustaceans or insects. Take the example of carrots, whose yellow-to-orange hue is a result of β-carotene. One of the most well-known carotenoids as well as a precursor of vitamin A, from which the entire class of these natural pigments derives its name. In addition to their contribution to the captivating array of yellowish-red colors in leaves and flowers, carotenoids fulfill various essential functions for standard growth and development in plants. Furthermore, they contribute to the production of several aromas in plants[27]. Several plants are provided to prove that it contains carotenoid according to its color.

Table 1: Plants containing carotenoid derivatives

Family	Species	Common Name	Plant Parts	Carotenoid	Ref.
Fabaceae	*Dalbergia ecastaphyllum*	Coinvine	Leaves	β-carotene and lycopene	[28]
	Vigna unguiculata L. Walp	Cowpea	Seeds	Lutein, zeaxanthin, and β-carotene	[29]
Scrophulariaceae	*Linaria scariosa* Desf.	Linaria	Whole plant	Carotenoid but unknown derivative	[30]
Solanaceae	*Solanum lycopersicum* L.	Tomato	Fruits	α-carotene, γ-carotene, δ-carotene, β-carotene, phytofluene, phytoene, lutein, lycopene, and neurosporene	[31]
	Solanum paniculatum L.	Jurubeba	Fruit	β-carotene, β-cryptoxanthin, lutein, and zeaxanthin	[32]
	Capsicum annuum L.	Chili pepper	Fruit	β-carotene, α-carotene, zeaxanthin, lutein, and β-cryptoxanthin	[33]
	Lycium barbarum L.	Goji berries	Fruit	Lutein and zeaxanthin	[34]
Ebenaceae	*Diospyros kaki* Thunb.	Persimmon	Pulp, skin, and seeds	β-carotene, β- lycopene, cryptoxanthin, α-carotene, and lutein	[35]
Arecaceae	*Borassus flabellifer*	Lontar	Fruit	β-carotene	[36]
	Astrocaryum vulgare Mart.	Tucuma	Almonds and fruit	all-trans-α-carotene, β-carotene, 13-cis- β-carotene, all- trans- β-carotene, and all-trans-β-cryptoxanthin	[37]
Apiaceae	*Daucus carota* L.	Carrot	Root	β-carotene, α-carotene, lycopene, and lutein	38-40
	Apium graveolens L.	Celery	Leaves	β-carotene and lutein	[33]
Cucurbitaceae	*Citrullus lanatus*	Watermelon	Fruits	Neoxanthin, trans-lycopene, cis-lycopene, lutein and β-carotene, violaxanthin, zeaxanthin, and prolycopene	41,42

	Momordica cochinchinensis	Gac	Fruit	Lycopene	[43]
	Cucurbita maxima	Pumpkin	Flesh	β-carotene, lycopene, antheraxanthin, lutein, zeaxanthin, violaxanthin, and astaxanthin	[44]
	Cucumis melo L.	Melon	Fruit	Lutein, α-carotene, β-carotene, 13-*cis* β-carotene, 9-*cis* β-carotene, β-cryptoxanthin, and zeaxanthin	[45]
Myrtaceae	*Psidium guajava*	Guajava, guajava 'Honora red'	Fruit	β-carotene, β-cryptoxanthin, trans-lycopene, cis-lycopene, and lutein	[41] [46]
Anacardiaceae	*Mangifera Indica* L.	Mango	Fruits	β-carotene, 9-cis-β-carotene, 13-cis-β-carotene, β-cryptoxanthin, epoxycarotenoids, luteoxanthin, violaxanthin and neoxanthin	[47]
Rutaceae	*Citrus sinensis* (L.) Osbeck	Orange or sweet orange	Fruit	Lutein, isolutein, β-carotene, β-cryptoxanthin, cis-ζ-carotene, zeaxanthin, neoxanthin, all-trans-violaxanthin, and phytofluene	[48]
Onagraceae	*Chamerion angustifolium* (L.) Holub	Willow herb	Leaves	Zeaxanthin, lutein, and β-carotene	[49]
Lamiaceae	*Salvia hispanica* L.	Chia	Seeds	β-carotene and zeaxanthin	[50]
	Salvia rosmarinus	Rosemary	Leaves	β-carotene, lutein, zeaxanthin, and β-cryptoxanthin	[51]
Asteraceae	*Lactuca sativa var capitata* L.	Lettuce	Leaves	β-carotene, lutein, phytoene, violaxanthin, and neoxanthin, lactucaxanthin, and antheraxanthin	[52]
	Bidens ferulifolia	Apache beggarticks	Flower	Lutein, β-carotene, luteoxanthin, antheraxanthin, violaxanthin, lutein 5,6-epoxide, and zeaxanthin	[53]
Rosaceae	*Prunus armeniaca* L.	Apricot	Fruit	α-carotene, β-carotene, γ-carotene, ε-carotene, (E/Z)-phytoene, lutein, lycopene, neoxanthin, zeaxanthin, violaxanthin, apocarotenal, α-cryptoxanthin, and β-cryptoxanthin.	[54]
Amaranthaceae	*Amaranthus gangeticus* L.	Elephant-head Amaranth	Leaves	β-carotene, lutein, zeaxanthin, violaxanthin, neoxanthin, and total xanthophyll.	[55]
	Amaranthus tricolor L.	Chinese spinach	Leaves	β-carotene, lutein, zeaxanthin, violaxanthin, neoxanthin, total xanthophylls, and total carotenoids	[56]
Caricaceae	*Carica papaya* L.	Papaya	Fruit	Lycopene, β-carotene, and β-cryptoxanthin laurate	[57]
Umbelliferae	*Angelica keiskei*	Ashibata	Leaves	lutein, α-, trans β-, and 9-cis β-carotene	[58]
Ericaceae	*Arbutus unedo* L.	Strawberry tree	Fruit	β-carotene, β-cryptoxanthin, lutein, violaxanthin, neoxanthin, antheraxanthin, and zeaxanthin	[59]

Based on Table 1, it is evident that there are numerous plants containing carotenoids and their secondary metabolites. The family Cucurbitaceae and Solanaceae have the highest number of plants containing carotenoids compared to other families. The color of this part of the plant family corresponds to the color characteristics of the carotenoids, which are responsible for their yellow-to-red color[27]. Plants in the Solanaceae family have a characteristic red color. This is due to the carotene content in it, where carotene is a red-orange pigment contained in plants and fruits. Besides that, lutein and zeaxanthin provide the yellowish color in those fruits. Meanwhile, in the Cucurbitaceae family, the lycopene compound is a natural red pigment that is responsible for the pink to red color[60] and zeaxanthin provides the yellowish color to those fruits in the family[61].

Potential of Plants as UV Protection

The UV protection activity of most of the plants listed in Table 1 has not been tested, so further research is needed to determine the potential of these plants to be used as a natural anti-UV activity and sunburn prevention, as shown in Table 2.

Table 2: Ultraviolet protection activity from plants containing carotenoids.

Plant Name	Plant Parts used	Sample	Methodology	Result	Ref.
Dalbergia ecastaphyllum	Leaves	Dried hydro-ethanol extracts	In vitro method: with determination of the Sun Protection Factor (SPF) by using the equation of Mansur.	Sun protection factor values ranged from 13.08 to 47.80 µg/mL.	[28]
Linaria scariosa Desf.	Whole plant	Crude plant methanol extract (contains carotenoid)	In vitro method with determination of Sun Protection Factor (SPF) by using the equation of Mansur.	Based on these measurements, the estimated sun protection factor (SPF) was determined to be 38.46 ± 0.22.	[30]
Solanum lycopersicum L. and *Salvia rosmarinus*	Fruit	Carotenoid-rich TNC soft gel capsules contained tomato and rosemary extract with lycopene, phytoene and phytofluene, and β-carotene	Double-blind, Randomized, Placebo-Controlled Study of 149 healthy volunteers with determination of minimal erythema dose (MED), UVB irradiation, chromametry measurements, biopsies, and assessment of blood samples.	Carotenoid-rich TNC is effective as protection against UVB-induced erythema formation and upregulation of IL6 and TNFα.	[62]
Diospyros kaki Thunb.	Pulp, skin, and seeds	Persimmon extract rich in carotenoids	In vitro method using HaCaT cells and MTT assay.	The HaCaT keratinocyte cells internalized PEC carotenoids which resulted in reduction of the ROS production in UV-induced treated cells.	[63]
Borassus flabellifer	Fruit	Skin lotion formulation of mesocarp fruit extract lontar	In situ method: Observed the effect of erythema on the skin of 30 male Wistar rats stains irradiated with UV light.	The erythema score that occurred the least was in the positive control and the treatment group that was given lontar fruit peel skin lotion was Formula III with an average score of 1.7	[64]
Daucus carota L.	Root	Carrot extract	Randomized Post-test Only Control Group Design using fibroblast cell and statistical tests.	There's a significant difference observed in apoptotic cells between the control group and treatment group with the carrot extract.	[65]

Table 2 has shown the favorable outcomes of plant extracts rich in carotenoids in mitigating and averting skin harm caused by UV exposure. This is supported by conducting tests on plants containing carotenoids, which have shown that carotenoid compounds and their secondary metabolites have an impact on UV radiation.

Morais et al. (2018) observed dried extracts of *Dalbergia ecastaphyllum* protective effect. The hydro-ethanol extract of *Dalbergia ecastaphyllum* was diluted in ethanol with various concentrations and the absorbance was examined within the UV range of 290 and 320 nm. Then, calculating the sun protection factor (SPF) based on the formula proposed by Mansur et al. (1986) as follows[66].

$$SPF\ spectrophotometric = CF\ x \sum_{290}^{320} x\ EE(\lambda)\ x\ I(\lambda)\ x\ Abs(\lambda)$$

Where CF represents the correlation factor, EE represents the erythemal efficiency spectrum, I represents the solar simulator intensity spectrum, and Abs represents the sunscreen product's absorbance. Sun Protection Factor (SPF) refers to how well the sunscreen prevents the occurrence of erythema due to UV radiation exposure. The SPF only measures the defense against UVB rays. The grades for SPF values are categorized as follows: Low: SPF 2-15, Medium: SPF 15-30, High: SPF 30-50, and Highest: SPF > 50[67]. The SPF values of the samples varied between 13.08 and 47.80 µg/mL. These values indicate that the samples derived from *Dalbergia ecastaphyllum* extracts possess a protective effect against ultraviolet radiation, as their Sun Protection Factor (SPF) exceeded 6.

In the study by Mouffouk et al. (2020), phytochemical screening was conducted on the methanol extract of *Linaria scariosa* Desf., and it was found that the methanol extract contained carotenoids. The UV-VIS spectrophotometer was employed to assess the absorbance of the methanol extract within the wavelength range of 290 to 320 nm. Subsequently, its photoprotective activity was evaluated in vitro by calculating the sun protection factor (SPF) based on the formula proposed by Mansur et al. (1986). The SPF was approximately 38.46 ± 0.22. Therefore, the SPF value of the methanol extract from *Linaria scariosa* Desf. falls into the high category.

In the study by Groten et al. (2019), a double-blind, randomized, placebo-controlled multicenter study was used. First of all, a group of 149 individuals in good health were divided into two groups and subjected to a 5-week without any intervention, followed by a 12-week phase of treatment. During the treatment phase, one group received a daily dosage of β-carotene, phytoene and phytofluene, lycopene, carnosic acid from rosemary extract and tocopherols from tomato extract, while the other group received a placebo made from medium-chain triglycerides. Following the completion of each stage, activities such as determining the MED, exposing to UVB radiation, conducting chromameter assessments, obtaining biopsies, and collecting blood samples were carried out. Supplements containing carotenoids exhibit notable protection against the development of UVB-induced skin redness (erythema) and the increase of IL6 and TNFα triggered by UVB exposure.

Gea-Botella et al. (2021) stated that Persimmon (*Diospyros kaki* Thunb.) contains a significant number of carotenoids that can protect the skin from UV radiation. The benefits of these carotenoids were tested in vitro using the UV Photoprotective Assay method. Before the assay, HaCaT cells were exposed to UV irradiation and then treated with various concentrations of PEC, which is a persimmon extract that is rich in carotenoids. Subsequently, the photoprotective effect on HaCaT cell viability was determined using the MTT assay. The experiment demonstrated that HaCaT keratinocyte cells absorbed PEC carotenoids and reduced UV-induced reactive oxygen species (ROS) production in the treated cells.

The study by Amatullah et al. (2017), focused on the antioxidant effectivity of the fruit extract *Borassus flabellifer.* involved the formulation of a skin lotion to assess its stability and evaluate its antioxidant effects. A sample of 30 male Wistar rats was used for testing purposes. The antioxidant test was divided into 5 groups randomly, with 3 groups consisting of different concentrations of palm fruit mesocarp extract. According to the in-situ method, the skin lotion containing 0.8% extract of palm fruit mesocarp shows the lowest erythema score, with an average value of 1.7. It was comparable to positive control containing sunscreen brands, and both demonstrated a similar erythema score. It is potentially developed to be a sunscreen formulation.

In another study conducted by Satriyasa et al. (2022), the activity of carrot extract which contains β-carotene in skin protection and prevention of apoptosis was tested. The study utilized a Randomized Posttest Only Control Group Design, where the samples used were fibroblast cell cultures obtained from the back skin of 2 white mice. The samples were separated into a control group, treatment group 1, and treatment group 2. Treatment group 1 was added to parasol with SPF 15, and treatment group 2 was additionally treated with carrot extract. Then, all of these three groups were exposed to UVB irradiation. Subsequently, the fibroblast cells were observed using propidium iodide staining and the data were then analyzed using the One-Way ANOVA, Levene's test, Shapiro-Wilk test, and followed by the LSD test. According to the test outcomes, a notable contrast was identified in apoptotic cells between the control group and treatment group 2 utilizing the carrot extract. However, there wasn't a significant distinction between treatment group 1 (SPF15) and treatment group 2 based on the observed results.

While natural extracts cannot fully substitute conventional UV filters, they have notably reduced the reliance on chemical or physical UV filters. In contrast to synthetic sunscreens, natural sunscreens that possess potent abilities to absorb UV radiations are primarily restricted by their low specific extinction value and their incapacity to be evenly distributed in widespread cosmetic applications of sunscreen[68]. A perfect natural UV filter should have the ability to absorb UV rays, transform electrons to an excited state, and efficiently return them to their initial state via ultra-fast photoisomerization. As a result, it is essential to assess whether natural extracts demonstrate photoprotective qualities after exposure to UV radiation. This assessment is critical in gauging their appropriateness as UV filters in sunscreen formulations, given that natural ingredients hold promising potential for shaping the future of cosmetic products[69,70].

The consecutive studies have consistently shown that carotenoids have photoprotective activity, which can protect our skin from the dangers of UV radiation. However, research and testing on plants containing carotenoids are still limited and infrequent. Despite that, carotenoids themselves have promising potential as natural ingredients in photoprotective products and as a means of sunburn prevention. Therefore, further research and testing on plants containing carotenoids are necessary to utilize and develop the functions of these compounds.

CONCLUSION

Based on the conducted research, it is known that carotenoids are naturally occurring pigments that have potential as a natural UV filter and sunburn prevention. The family Cucurbitaceae and Solanaceae has the highest number of plants containing carotenoids compared to other families, it is possible to carry out further research related to its potential as UV protection. Some plants could be used as a photo protector against UV light and can also be utilized as a treatment for sunburn, such as tomato fruit (*Solanum lycopersicum* L.), carrot (*Daucus carota* L.), persimmon pulp, skin, and seeds (Diospyros kaki Thunb.), mesocarp fruit (*Borassus flabellifer*), coinvine creeper leave (*Dalbergia ecastaphyllum*), and crude plant (*Linaria scariosa* Desf.), but further examination needs to be done to produce anti-UV preparations with natural active ingredients that are guaranteed for their safety and effectiveness.

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