

Mini review

Carotenoids - Effective Radical Scavengers for Healthy and Beautiful Skin

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Abstract

Free radicals are involved in various diseases and skin aging. To reduce and prevent this risk, our body produces antioxidants that can neutralize free radicals. However, some antioxidants need to be taken up with food, so a balanced and varied diet is essential for human health and beauty, along with sufficient exercise. Vegetables, especially curly kale, show very good antioxidative capacity due to the presence of carotenoids. As the recommended daily intake of vegetables is usually not consumed, dietary supplements are a good possibility to ingest carotenoids in a controlled and natural way. The positive effect of carotenoid-based dietary supplements on the skin has already been shown in several studies on healthy volunteers. Innovative non-invasive measuring methods have shown that oil extracts from vegetables significantly reduce not only free radicals in the skin but also the age-related breakdown of collagen and have a positive effect on skin parameters such as wrinkle volume. Thus, a balanced mixture of different natural carotenoids contributes to maintaining health and beauty.

Keywords: free radicals, antioxidative capacity, collagen, wrinkle volume, elasticity

Introduction

Health and beauty contribute significantly to improve their personal attitude to life and general well-being. Especially with increasing age, the desire for a healthy, fresh and youthful appearance increases. Everyone will sooner or later be affected by skin aging, which is associated with wrinkling, loss of elasticity and increase of roughness. One of the most common causes of skin aging and a variety of diseases are free radicals [1]. These are molecules with an unpaired electron which are continuously produced in our body, but are also induced by external factors such as solar radiation and smoking. To ward off any oxidative attacks, our body has a defence system, the antioxidative system. Antioxidants neutralize the radicals and are able to regenerate without damage. On the one hand, they are produced by the body itself (endogenously) and on the other hand they need to be taken up with food (exogenously). However, an excessive production of free radicals leads to an imbalance between

radicals and antioxidants, the state of which is called oxidative stress. Free radicals attack the biomolecules in the body, such as proteins, lipids or DNA, inducing damage and reduction or even loss of function. This can contribute to the development of various diseases, such as neurodegenerative [2], cardiovascular [3] as well as skin diseases including skin cancer [4]. Oxidative stress also leads to the activation of certain signaling pathways, whereby the elastic collagen fibers in the deeper layers of the skin are degraded and only produced in small amounts, which leads to the typical characteristics of skin aging [5]. To what extent can our diet help to prevent oxidative stress and thus diseases and skin aging in a natural and controlled way? To answer this question, this mini review address in more detail the potential of antioxidant-based dietary supplements, especially carotenoids, to maintain health and youthful appearance.

Carotenoids - the “Healthy” Component of Vegetables

In addition to physical exercise, a balanced diet plays a key role in the prevention of diseases and skin aging. Every year, people die of chronic diseases such as cancer or cardiovascular diseases, which are promoted by insufficient consumption of fruit and vegetables [6]. For this reason, the World Health Organization (WHO) recommends a daily fruit and vegetable intake of at least 400 g, corresponding to five portions of 80 g each, to prevent chronic diseases [7]. The German Society for Nutrition even recommends a daily fruit and vegetable intake of 650 g, with a daily fruit intake of 250 g and a daily vegetable intake of 400 g, respectively. The reason for this is that vegetables in particular contain not only vitamins but also carotenoids, which are responsible for the “healthy” and beneficial properties. In a National Consumption Study II (NVS II) carried out in 2005 and 2006, it was found that 87.4 % of respondents between the age of 14 and 80 did not achieve the recommended vegetable consumption. On average, women consume 129 g of vegetables daily and men 112 g of vegetables (including mushrooms and legumes), which corresponds to approximately 1.5 portions. The amount of vegetables consumed also depends strongly on age and socio-economic environment [8]. These data clearly show that the consumption of vegetables and their carotenoids must increase for a better prevention of chronic diseases in the future.

Carotenoids are natural fat-soluble pigments produced by plants and microorganisms. Carotenoids belong to the phytochemicals and are responsible, among other things, for the colors of the various vegetable varieties. The carotenoid lycopene gives tomatoes their red color and α - and β -carotene are responsible for the yellow-orange color of carrots. Dark green leafy vegetables like kale, broccoli and spinach are rich in lutein. The different colors are the result of minor structural differences. As an example, Figure 1 shows the structure of the carotenoids lycopene, β -carotene and lutein. The carotenoids differ in their end groups, which are altered by cyclization or by the introduction of oxygen atoms and which cause different colors [9].

To date, 20 different carotenoids have been identified in human blood and tissue [9]. However, carotenoids cannot be produced by the body itself and must therefore be taken up by other means [9]. Since carotenoids are large molecules ($M > 500$ g/mol), their uptake through the use of creams on the skin and their distribution into deeper layers, where the wrinkles occur, is difficult [10]. Therefore, carotenoids should be taken up orally with food and can work from the inside. Carotenoids are important for the body as they have a strong antioxidant effect which has been shown in numerous *in vitro* (cell culture) and *in vivo* (human) studies [9,11,12]. Furthermore, carotenoids protect against damage induced by UV radiation (photo-protective properties) [13], promote cell communication [9,11] and modulate the immune system, thereby improving the immune response [14].

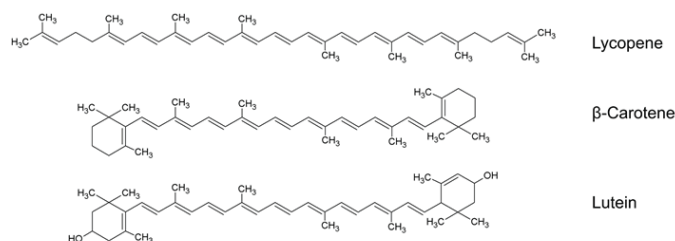


Figure 1. Structure of the carotenoids lycopene, β -carotene and lutein

To ensure a good absorption of carotenoids by the body, both the food matrix and the processing of vegetables are important. In a study it could be shown that by the intake of carrots, carrot juice or dietary supplements, β -carotene concentration increased, however, the highest amounts of β -carotene were taken up with the dietary supplements [15]. According to this, it was also found that the consumption of vegetables results in much less β -carotene being absorbed by the body compared to, e.g. β -carotene in salad dressing [16]. The use of fat-free, low-fat and fat-rich salad dressing also showed that the carotenoid amounts in the blood were highest for fat-rich salad dressing and that only negligible amounts could be detected for fat-free salad dressing [17]. Thus the food matrix plays a crucial role and the use of oil can considerably enhance the uptake of the carotenoids [18]. The processing of vegetables also influences the bioavailability of carotenoids. Olsen et al. [19] showed that the processing of kale including blanching, freezing and heat treatment significantly reduces its antioxidant capacity by 40 %. Extreme heat and freezing, for which the vegetables are blanched, leads to the destruction of carotenoids in the vegetables, significantly reducing the antioxidant capacity. However, the preparation of vegetables by common household cooking methods such as microwave, steaming or boiling does not significantly alter the carotenoid amount of food. On the contrary, mechanical breakdown and cooking of vegetables releases carotenoids and supports their uptake [9]. However, the bioavailability of carotenoids for the body varies from person to person and represents a challenge in human food studies. In addition to the preparation of the products, it also depends on the intensity of chewing [21]. In order to improve the quality of human studies, standardized oil extracts from vegetables can be used, which significantly increase the bioavailability of lipophilic antioxidants and significantly reduce individual differences.

Carotenoids should be consumed in a varied manner and in physiological amounts, since the intake of excessive amounts of carotenoids can entail side effects. The probably best-known effect with the consumption of high amounts of β -carotene, e.g. in form of carrots, is the yellow coloring of the skin, especially on the palms and soles, also known as carotenaemia [22] which, however, is not harmful. Furthermore, it is known that the consumption of high amounts of β -carotene in form of

dietary supplements can lead to more serious consequences. It has been shown in vitro that a low concentration of β -carotene (0.02 $\mu\text{g}/\text{mL}$) has an antioxidative effect when exposed to visible and near infrared light (420 nm - 2000 nm), whereas a fivefold higher concentration (0.1 $\mu\text{g}/\text{mL}$) induces oxidative stress [23]. This effect was also shown in an in vivo long-term study with smokers, where the risk of lung cancer increased by taking β -carotene (20 mg per day) over a period of five to eight years [24]. An increase in lung cancer risk was also observed in another in vivo study with smokers, former smokers and workers exposed to asbestos after ingesting β -carotene (30 mg per day) and vitamin A (25,000 IU) [25].

For a good nutrient supply it is important to know which vegetables offer the best nutritional benefits. In this context, kale vegetables are a very good source of nutrients and belong to the vegetables richest in carotenoids [26]. Among these, curly kale ranks first, as it is the best supplier of lutein [27] and has the highest antioxidant capacity, whilst also containing high amounts of vitamins (vitamin C, vitamin K1, vitamin E) as well as minerals and trace elements. Curly kale is a green or red/violet colored vegetable and very robust because it tolerates agricultural and climatic fluctuations very well. Light frost even results in a sweeter taste compared to the pungent, bitter taste before [9]. Since curly kale is cultivated mainly in the north, it is also known as "palm of the north" or "ginseng of the north".

Use of Dietary Supplements

Dietary supplements represent a suitable way of taking sufficient carotenoids in a natural and controlled way and thus counteracting the above-mentioned problems. There are many dietary supplements that are rich in carotenoids. One example is the dietary supplement Lutex Skin® (BioActive Food GmbH, Bad Segeberg, Germany), which consists of an oil extract of curly kale and sea buckthorn, contains no artificial antioxidants and is gently extracted without chemical additives. The preventive effect of Lutex Skin® on the skin has already been investigated in two in vivo studies with healthy volunteers. The first double-blind placebo-controlled in vivo study investigated the antioxidant effect of Lutex Skin® because oxidative stress contributes to skin aging and various diseases. Innovative non-invasive measuring methods were used to determine the amount of carotenoids, total antioxidative capacity and radical production by visible and near infrared light in the control group (12 volunteers) and Lutex Skin® group (10 volunteers).

In this study a physiologically concentrated dose of natural carotenoids (Lutex Skin®) was given daily to the volunteers: 2.2 mg lutein, 1 mg β -carotene, 50 μg α -carotene, 400 μg lycopene, 700 μg zeaxanthin, 100 μg cryptoxanthin. After 8 weeks of oral administration of Lutex Skin® the amount of carotenoids in the skin of the 10 volunteers increased by 50 % and thus showed a significantly higher amount of carotenoids compared to the

control group who took a preparation of olive oil without antioxidants (Figure 2). This result also shows that the body takes up the carotenoids very well via Lutex Skin®. Furthermore, the total antioxidant capacity in the Lutex Skin® group increased by 48 %, which was also significantly higher compared to the control group. Due to the improved antioxidant system, the Lutex Skin® group showed significantly lower radical production after 10 minutes of irradiation compared to the control group [28]. These results clearly show that the product Lutex Skin® has an antioxidant effect and therefore can be used to prevent oxidative stress.

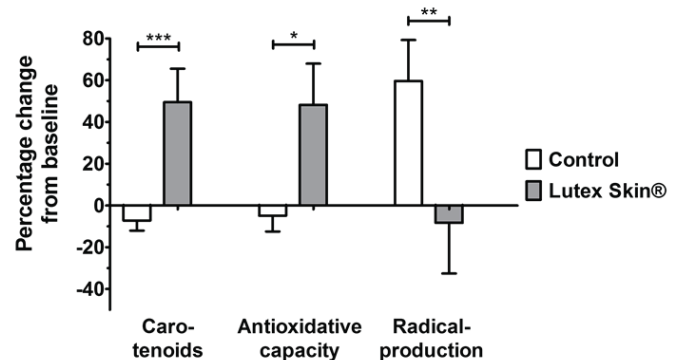


Figure 2. Effect of Lutex Skin® after 8 weeks of use on carotenoid amount, antioxidative capacity and stress-induced radical production in the skin; visualization of the percentage change of control and Lutex Skin® group to the respective initial value at the beginning of the study; n=12 (control); n=10 (Lutex Skin®); mean±SEM; *p<0.05; **p<0.01; ***p<0.001.

In a further double-blind placebo-controlled in vivo study, the preventive effect of Lutex Skin® on age-related skin characteristics was investigated. The amount of collagen in the dermis, wrinkle volume, skin elasticity and skin hydration were measured in 29 female volunteers. The daily dose of Lutex Skin® contained 1.3 mg lutein, 210 μg β -carotene, 90 μg lycopene and 60 μg zeaxanthin. After 5 months of taking Lutex Skin® more collagen was found in the dermis of the face compared to the control group. This difference in collagen content increased after 10 months of use with statistical significance (Figure 3) [29].

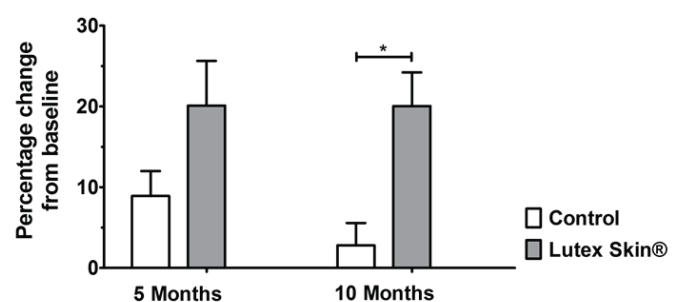


Figure 3. Effect of Lutex Skin® after 5 and 10 months of use on facial collagen amount; visualization of the percentage change of control and Lutex Skin® group to the respective initial value at the beginning of the study; n=12 (control); n=12 (Lutex Skin®); mean±SEM; *p<0.05.

In addition, the collagen amount in the forearm was also higher than in the control group after 5 months of Lutex Skin® intake (Figure 4) [29]. Furthermore, wrinkle volume and skin elasticity remained stable in the Lutex Skin® group after 5 months of use, whereas the control group showed a trend towards higher wrinkle volume and lower elasticity, respectively (Figure 4). The skin hydration increased to the same extent in both groups [30]. Thus, the product can potentially decelerate the progression of age-related skin characteristics to a certain extent.

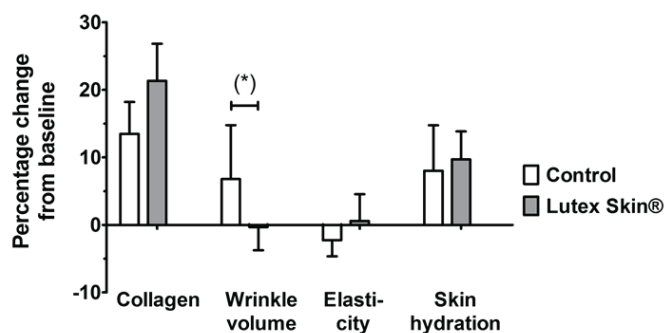


Figure 4. Effect of Lutex Skin® after 5 months of use on age-related characteristics in the skin (collagen on forearm, wrinkle volume, skin elasticity, skin hydration); visualization of the percentage change of control and Lutex Skin® group to the respective initial value at the beginning of the study; n=14 (control); n=15 (Lutex Skin®); mean±SEM; (*) p<0.1.

Another dietary supplement called Lutemax® 2020 (OmniActive Health Technologies, United States), which contains 10 mg lutein and 2 mg zeaxanthin isomers, also showed an improvement in skin conditions in a 12-week randomized double-blind placebo-controlled study in 2016, which was demonstrated by improved skin elasticity, skin lightening and increased tolerance to UVA/UVB radiation (minimal erythema dose) compared to baseline [31]. In a further in vivo study in 2017, the 8-week intake of "Anti-Aging Formula" (Bend Skincare, Canada), which included 5 mg lutein, 2.5 mg zeaxanthin and 1000 IU vitamin D3, led to a significantly higher tolerance to UV radiation compared to the start of the study, reflecting the photo-protective effect of carotenoids [32]. The results of these in vivo studies show that carotenoids, especially lutein, have a positive effect on our skin, maintain our beauty and health from the inside and prevent skin aging. In addition to this, carotenoid uptake is also associated with a reduced risk of chronic diseases such as osteoporosis [33], the eye disease macular degeneration [34], neurodegenerative [35] and cardiovascular diseases, and various cancers [36] emphasizing the potential of vegetables and carotenoids.

Conclusion

Dietary supplements based on a balanced mixture of natural carotenoids provide a controlled and sustainable way to prevent disease and skin aging, promoting health and beauty from within. They do not replace a balanced and varied diet or a healthy lifestyle, but can contribute to

a better protection against oxidative stress. The intake of dietary supplements to restore or maintain a physiological dose of carotenoids is therefore highly advisable.

Conflicts of Interest

The authors declare no conflict of interest.

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