A.20

Carotenoids and Their Health Benefits

Karina B. Lewerissa

Industrial Engineering Study Program, Ma Chung University, Malang 65151
email: karina.bianca@machung.ac.id

Abstract

High consumption of fruits and vegetables has been correlated with low occurrence of degenerative disease such as cancer and cardiovascular diseases [1-3]. This effect is associated with phytochemical compounds which are abundantly available in fruit and vegetable diets, such as carotenoids. In addition, recent studies also indicated that certain carotenoids, such as lutein and zeaxanthin, play an important role in preventing age-related macular degeneration (AMD) and cataract disease [2, 4, 5]. Carotenoids protective role in health and disease is believed to be related to their molecular structure, which can serve as antioxidant [4]. This review will discuss the beneficial health effects of carotenoids. In addition, factors that involve the potential bioavailability of carotenoids and accessibility will also be evaluated.

Keywords: carotenoids, degenerative diseases, bioavailability

Introduction

Diet food rich in fruits and vegetables has been associated with low incidence of degenerative diseases such as cancer, cardiovascular and cerebro-vascular diseases [2, 6]. According to Basu et al. (2001), plant-based diets rich in a variety of vegetables and minimally processed starchy staple food each day, can reduce the overall cancer rates as much as 20% [2]. Numerous studies have been conducted in order to know the relationship between diets rich in phytochemical and antioxidants with a protective role in health and disease. Some natural substances, such as carotenoids, phenolic compound, flavonoids in food are attributed with their good effects for human health in reducing the risk of above mentioned diseases [7, 8].

Carotenoids are present in commonly consumed vegetables and fruits, and in fact they are the second most widely distributed pigment in nature, after chlorophylls [9]. The most investigated carotenoids are α-carotene, β-carotene, lycopene, lutein, zeaxanthin and cryptoxanthin. Evidences have indicated that lycopene plays a role in the prevention of prostate cancer and lutein is good for the prevention of age-related macular degeneration [6]. In addition, some carotenoids are precursor to vitamin A (e.g. β-carotene, α-carotene, β-cryptoxanthin) and become the main source of dietary vitamin A [6]. In this review, the health effects of high ingestion of carotenoids will be discussed.

Carotenoids

Carotenoids are a family of fat-soluble pigments [10]. They are the basic source of yellow, orange and red plant pigments and can be found in plants, algae and several lower organisms [4]. Carotenoids can be classified into two groups: the carotenes that contain only carbon and hydrogen atoms, and xanthophylls, which are the oxygenated derivatives. The color of carotenoids (such as yellow, orange and red) is resulted from a system of conjugated carbon-carbon double bonds [9]. Carotenoids are present in most commonly consumed vegetables and fruits and their amount are generally correlated with the color of fruits or vegetables [9]. In addition, oxygenated carotenoids such as astaxanthin and canthaxanthin are commonly distributed in marine animals. Both pigments are known as sources of the pinkish-red colored pigmentation in salmonids and crustaceans.

Antioxidant properties of carotenoids

Antioxidants are compounds that are able to inhibit lipid oxidation [11]. Based on their origin, antioxidants are divided into 2 groups, natural and synthetic antioxidant. Nowadays, the use of synthetic antioxidant is declining because of their possible adverse effects on health. People are more aware of what they eat and prefer to have natural ingredients in food. Natural antioxidants are not only safer than the synthetic ones but might also be absorbed into human body which can eventually give beneficial effects [12]. It is believed that
antioxidants protect cell membranes, lipoproteins and nucleic acid from oxidation [8]. The main groups of natural substances that may contribute to the total antioxidant arc polyphenols, carotenoids, and vitamin C and E [11].

It has been reported that carotenoids have multiple antioxidant activities, such as the ability to scavenge single oxygen and peroxyl radicals [7, 9]. Singlet oxygen is the excited form of reduced oxygen which is very unstable. They are formed in biological systems by type II photosensitization reactions [4]. The molecules are very reactive and tend to interact with polyunsaturated fatty acids or guanine bases in DNA [4]. Compared to tocopherol, the rate constants for singlet oxygen scavenging by carotenoids are much higher [9]. Carotenoids scavenge singlet oxygen by physical or chemical quenching [4, 9]. In physical quenching there is energy transfer from singlet oxygen to the carotenoid, resulting in stable form of oxygen and excited triple–state carotenoids [4], with subsequent energy dissipation as heat to yield a nonreactive ground-state carotenoid [4, 9]. In this process, there is no concomitant loss of carotenoids. Chemical quenching contributes less than 0.05% to the overall quenching of singlet oxygen by carotenoids, however that process is responsible for the final decomposition of carotenoids [4].

The ability of carotenoids to scavenge peroxyl radicals has been elusive. It is suggested that carotenoids may combine with peroxyl radicals to form a large resonance stabilized radical. Numerous sites along the polyene chain or in the terminal carbon rings seem to be potential sites for the initiation of autoxidation or radical attack [9]. The peroxyl scavenging ability appears to depend on the length of the conjugated double bond structure. More conjugated bond resulted in better peroxyl scavenger. Studies show that at least 11 conjugated double bonds (β-carotene, cryptoxanthin, lutein, lycopene and zeaxanthin) are about 5 times more effective than retinoids (retinyl palmitate, retinoic acid and retinol) for conferring oxidative resistance [9]. However, in the oxygen rich environment the presence of carotenoids (beta carotene) can act conversely, becoming prooxidant [13].

### AMD (Age-related Macular Degeneration) prevention

The important role of carotenoids for eye health has been known for long time ago. This refers to the fact that some carotenoids have provitamin A properties. It would later be converted into vitamin A, which is essential for human visual function [10, 14]. However, just recently it has been known that certain carotenoids, such lutein and zeaxanthin, play an important role in preventing AMD and cataract disease [14].

Age-related macular degeneration (AMD) is a degenerative disorder of the central part of the retina [15]. The disease affects about 20% of the elderly people (older than 65%) in the industrialized countries and the disease causes an irreversible blindness among them [4]. Actually, there are many risk factors for AMD, such as advanced age, light skin, eye color, high exposure to sunlight, low dietary intake, and low serum levels of xanthophylls [4].

Lutein and zeaxanthin are carotenoids that do not have provitamin A property, therefore they are not metabolized to vitamin A. They are accumulated in the macular region of the human retina, whereas other important carotenoids, such as lycopene, a-carotene or β-carotene are present only in the blood and in most human tissues [6]. Lutein and zeaxanthin are thought to protect against the development of age-related macular degeneration [16]. It has been suggested that lutein and zeaxanthin are beneficial in preventing damage by absorbing blue light through their antioxidant properties [2]. Furthermore, there is evidence that oxidation products (such as nitric oxide and lipid peroxidation) are increased in AMD’s patient. The occurrence is also associated with decreased antioxidant enzyme activities [5]. Both pigments may reduce cumulative photochemical damage of the ageing retina because of their antioxidant properties [2]. According to Handelman et al. (1988), lutein is the major carotenoid in the peripheral retina, whereas zeaxanthin becomes more and more dominant approaching the foveal center [14]. Research has shown that zeaxanthin acts as an effective free radical quencher, whereas lutein is an effective filter of short wavelength radiation [16].

Studies by several scientists showed that there is a correlation between dietary intake of carotenoids with a lower risk of AMD [2, 6]. Two specific carotenoids, lutein and zeaxanthin, were more strongly associated with a reduced risk for AMD compared with vitamin A (retinol), vitamin E or total vitamin C consumption [2]. Since the existence of those pigments in human blood and tissues is entirely due to the ingestion of food sources, consumption of xanthophylls-rich food is inevitably important. Some sources of lutein and zeaxanthins are corn and egg products, fruits and vegetables (such as apple, asparagus, kiwi, peach, spinach) [16]. There is increasing evidence that lutein and zeaxanthin may protect against AMD, however final proof still requires appropriate intervention studies [4].

### Cataract prevention

Cataract is clouding of the lens of the eye and/or of its surrounding transparent membrane [2]. It usually occurred among older adults and can lead to blindness. The development and progression of cataractous lesion is thought to be related to the oxidation of lens protein [4, 17, 18]. Antioxidant properties of carotenoids may
prevent the oxidative modification of protein and lipid in our lens. At low partial pressures of oxygen (such as in the lens), carotenoids are very effective antioxidant [2]. It was observed that there was a relation between antioxidant nutrients and cataract risk [18, 19]. However, some studies also showed that there was insufficient scientific evidence to support the protective role of carotenoids in the prevention of cataract [20]. According to Venkatesh et al. (2001) the discrepancy may occur because of several factors, such as bioavailability of the nutrient, association of the carotenoids with other substances in the body, and the intensity of the exposure of oxidative stress [21]. Although there is still inconclusive opinion about the effectiveness of carotenoids in preventing cataract disease, the adequate antioxidant-rich food should be encouraged [20].

**Cancer protection**

Free radicals and other reactive oxygen species (ROS) have been implicated in the pathology of several human diseases, including cancer [22]. ROS and free radicals are naturally formed in human body, but when the endogenous antioxidant defenses are inadequate, their existence can lead to ongoing oxidative damage to DNA which is suggested to be a crucial step in carcinogenesis [22, 23]. Therefore, it is acceptable to assume that agents that decrease oxidative damage to DNA should also decrease risk of cancer development [22]. However, it is hard to conclude to what extent oxidative stress is directly involved in carcinogenesis since full development of the disease may take 20-40 years [23].

The effect of β-carotene and/or its analog in preventing human cancer has been confirmed by animal studies and epidemiological studies although the exact mechanism is still unknown [2]. At the moment, the modes of actions of dietary micronutrients are complex and are not being completely understood [21]. The effects of carotenoids on cancer are not very clear yet [2, 23]. However, it is believed that carotenoids may play an important role in the prevention and/or treatment of cancer in conjunction with other antioxidants such as vitamins E and C [2].

**Cardiovascular Disease (CVD) prevention**

According to the World Health Organization, heart disease has become a true pandemic. It is the principal cause of death worldwide [24]. In recent years antioxidant-rich diets have been emphasized for their inverse relationship between cardiovascular disease and vegetable- and fruit-rich diets [25]. There is a strong belief that atherosclerosis and arteriosclerosis are connected to oxidative stress [25].

Oxidative modification may occur to low density lipoprotein (LDL) since the lipids in LDL are fatty acids that are very sensitive to oxidation. LDL particles which suffer oxidation are no longer recognized by the normal LDL receptor. Further oxidation will lead to the accumulation of cytotoxic products. This situation induces platelet aggregation, which eventually will promote the formation of atherosclerotic plaque [3]. Since β-carotene is an antioxidant, it is generally believed to have a beneficial effect on CVD [2]. Epidemiologic study by Kohlmeier and Hastings (1995) has shown that the protective role of β-carotene against CVD is consistent [26]. However, findings from the first single intervention trial conducted in a large free-living population cast doubts on the utility of beta-carotene for all high-risk populations [26]. Moreover, clinical trial evidence shows that supplemental β-carotene does not prevent coronary heart disease [27]. Nevertheless, the epidemiologic evidence is generally supportive of the notion that a diet rich in high carotenoid foods is associated with a reduced risk of heart disease [27]. It is suggested that the risk reduction may be caused by the action of one or several carotenoids or other plant-based substances [27]; therefore research into other carotenoids is still needed [26].

**Carotenoids and their bioavailability**

In order to know the potential benefits of carotenoids, there is a need in gaining information about factors involving their bioavailability and factors determining their accessibility [6, 28]. The information is also important for an accurate assessment of carotenoid content in foods. According to Duchateau and Klaffke (2008) bioavailability is the dose fraction of a substance entering systemic circulation to elicit the intended physiological function upon reaching the target site [29].

The uptake of carotenoids is much more complex compared to hydrophilic substances. Since they do not dissolve in the aqueous intestinal environment, presence of fat, release of bile, enzymes and gut motility to induce lipolysis are required [29]. Carotenoids are absorbed into human body with the same path as dietary fat. The absorption of dietary carotenoids involves their transfer from the food matrix to micelles during digestion, delivery to apical surface of absorptive epithelial cells and packaging within chylomicron for secretion into lymph [30].

Health benefit from high intake of carotenoids from fruits and vegetables is dependent on the bioavailability of these molecules. Studies have shown that the extent of vegetable intake is positively correlated
with the plasma concentration of carotenoids [31, 32]. Their bioavailability is influenced by food type, mode of preparation, individual response, and presence of fiber [32]. In recent study by Livny et al. (2003) using plasma concentrations in determination of carotenoids availability, it is found that cooked, pureed vegetables was more absorbed into human body compared to meals containing raw vegetables [31]. According to Ryan et al. (2008) cooking methods enhanced beta-carotene transfer to micelles [28], although several researchers have reported substantial losses, others no change on the level of carotenoids in food during cooking [32]. It is suggested that cooking methods, carotenoid retention, micellarisation for each carotenoid and carotenoids content in food influence their bioavailability [28].

Intracellular location of carotenoids, the rate at which carotenoid-protein complexes are disrupted during cooking and solubility of these compounds in digesta and the efficiency of micellarisation resulted in differences in carotenoid bioavailability [28]. In case of lycopene, it is found that the extent of tissue softening and protein denaturation influence the level of extractability of that substance [28]. Lycopene retains to a greater extent than beta-carotene after cooking, however its micellarisation is much lower than beta-carotene [23, 28]. On the contrary, lutein has shown to be more bioavailable than beta-carotene, possibly because of its lower lipophilicity [28]. Since there are many health claims in food supplement or food products rich in carotenoids, knowledge about the bioavailability of carotenoids is important. Food manufacturer can be encouraged to maximize the potential bioavailability of carotenoids based on the gained information so that customer can obtain adequate amount of carotenoids [28].

Conclusions

Based on epidemiological data, carotenoids role in preventing against some degenerative diseases is generally accepted. However, research also showed that in some cases the findings are conflicting. The mode of actions of carotenoids for cancer and CVD prevention is still unclear. Nevertheless, adequate antioxidant-rich food should be encouraged. In addition, investigations on their bioavailability are still needed in order to maximize the potential benefits of carotenoids for human health.

References


