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Chapter 3

BETA-CAROTENE: FUNCTIONS, HEALTH BENEFITS, ADVERSE EFFECTS AND APPLICATIONS

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ABSTRACT

The purpose of this chapter is to review the main functions, benefits and possible adverse effects of beta-carotene on human health and its applications in food. More than 600 carotenoids have been identified from vegetable and animal sources, which possess varying levels of pro-vitamin A activity. Carotenoids from vegetables provide approximately 68% of the vitamin A ingested in the diet. According to FAO (2003), approximately 500 million people suffer from the effects of vitamin A deficiency, such as xerophthalmia, and each year three million malnourished people go blind due to insufficient vitamin A. The antioxidant capacity of carotenoids, i.e., ability to prevent peroxidation, is most likely responsible for their ability to protect against the detrimental health effects of vitamin A deficiency. Subclinical vitamin A deficiency, in which visible signs of xerophthalmia are absent, intensifies the severity of certain illnesses, such as diarrhea and other infectious diseases, eventually resulting in immunodeficiency of exclusively nutritional origin. Other roles have also been described for carotenoids in humans, the best known of which is their capacity to be converted into retinols (provitamin A activity). In addition to their function as the macular pigment of the eye, these substances are involved in a series of cellular processes, including the modulation of the inflammatory response, protection against cancer, prevention of cardiovascular diseases and cataracts, and antioxidant activity. The main carotenoids involved in human health are beta-carotene, alpha-carotene, lycopene, lutein, beta-cryptoxanthin and zeaxanthin, which can be found in blood plasma. Except for zeaxanthin, these compounds are easily obtained from foods; beta-carotene is the most abundant in the human diet. However, the absorption and utilization of carotenoids are influenced by several factors, such as the type and physical form of dietary carotenoids, the ingestion of fat, vitamin E and fibers, and the presence of certain diseases and parasite infection. The provitamin A carotenoid *cis*-isomer (*Z*) is converted less readily into vitamin A than is the *trans*-isomer (*E)*. Recently, (*all*-*E*)-beta-carotene was reported to be absorbed preferentially over (9-*Z*)-beta-carotene in humans. Few adverse effects related to the ingestion of supraphysiological doses of beta-carotene have been described. In rats, excess beta-carotene consumption had a positive effect on the control of arterial hypertension that did not affect biological parameters and had no detectable toxic effects. Due to the controlled conversion of beta-carotene into vitamin A, overconsumption does not cause hypervitaminosis A. In fact, the excessive ingestion of beta-carotene usually leads to carotenodermia, a reversible condition that results in an orange color in the skin due to beta-carotene deposition in the outermost layer of the epidermis. Carotenodermia is often observed in patients with hyperlipidemia, diabetes mellitus or hyperthyroidism. Moreover, it was reported that the combination of beta carotene and vitamin A may have had an adverse effect on the incidence of lung cancer and the risk of death from lung cancer, cardiovascular disease, or any other cause in smokers and workers exposed to asbestos.

INTRODUCTION

1. General Aspects

Carotenoids are natural pigments that are present in fruits and vegetables (Di Mascio et al., 2001) and can also be found in algae, fungi, bacteria and animals. More than 600 carotenoids have been isolated from vegetable and animal sources, with varying levels of pro-vitamin A activity (Palace et al., 1999). These substances have been suggested to play a protective role against diseases such as cancer and atherosclerosis (Di Mascio et al., 2001).

Carotenoids can only be biosynthesized by plants and microorganisms. Their presence in animals and accumulation in certain tissues like flamingo feathers, egg yolks and invertebrate exoskeletons is attributed to ingestion via food. In plants, carotenoids are located in subcellular organelles, namely chloroplasts and chromoplasts. In the chloroplasts, they are associated with specific proteins and act as photoprotective pigments and membrane stabilizers during photosynthesis (Schieber, 2005).

Carotenoids from vegetables provide approximately 68% of the vitamin A ingested in the diet. According to FAO (2003), approximately 500 million people suffer from the effects of insufficient vitamin A, such as xerophthalmia, and each year three million malnourished people go blind due to vitamin A deficiency.

2. CAROTENOIDS AND BETA-CAROTENE

These substances can be divided into two classes: carotenoids containing only carbon and hydrogen atoms, and the oxicarotenoids (xanthophylls), containing at least one oxygen atom. Based on the number of double bonds, multiple cis / trans configurations are possible for the same molecule, these isomerizations may occur due to chemical reactions, light radiation and thermal energy (Tapiero et al., 2003).

Structurally, vitamin A (retinol) is essentially half of a β-carotene molecule linked to a water molecule at the end of a polyene chain (Rodrigues-Amaya (2001) (Figure 1).

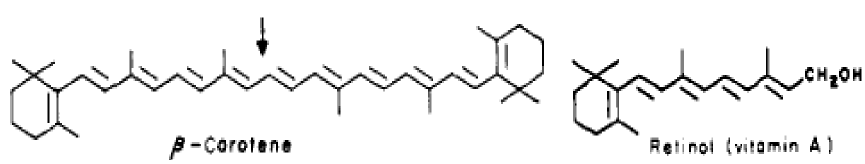

Figure 1. β-carotene and Vitamin A (Retinol).

Compared to vitamin A, carotenoids are more stable with respect to light and oxidation, possibly due to its location in the plant tissues. However, exposure to oxygen and heat treatments may result in destruction of the provitamin A carotenoids (Gayathri et al., 2004).

Seo et al. (2005) found lutein, lycopene, cryptoxanthin, α-carotene, β-carotene and *cis* β-carotene isomers in raw pumpkins (*Cucurbita moschata*). Among these compounds, β-carotene was the most abundant, followed by α-carotene.

High concentrations of O_2 can reduce the antioxidant activity of β-carotene, and studies conducted in pulmonary tissues and peripheral tissues revealed that the carotenoid effectiveness may be greater in peripheral tissues because the oxygen pressure is lower (Cerqueira, Medeiros & Augusto, 2007).

β-carotene is able to capture free radicals at the oxygen pressures commonly found in most tissues under physiological conditions. Each molecule of β-carotene can react with a number of free radical molecules, leading to the formation of stable products for periods up to one hour, even after exposure to air, under *in vitro* conditions (Cardoso, 1997).

Among the carotenoids, β-carotene exhibits the highest pro-vitamin A activity (100%) in biological tests with rats (Zemplei, Bowman & Russell, 2001).

Carotenoids with vitamin A activity, such as β-carotene, are considered pro-vitaminic until they are enzymatically cleaved at the central C15 - C15 ' oxidative bond in the intestinal mucosa to release two active molecules of retinol. The natural configuration of most carotenoid types in plants is the *trans* isomer. Because these are highly unsaturated compounds, they are susceptible to isomerization and oxidation during food processing and storage. The isomerization of the *trans-cis*-carotenoids into cis carotenoids is promoted by exposure to acidity, heat and light, which decreases both the color and vitamin A activity of the food (Ambrósio, Fields & Faro, 2006).

The occurrence of vitamin A deficiency in the northeastern regions of Brazil, where cassava is grown and is part of the normal diet, puts this culture in a privileged position with a viable alternative to combat hidden hunger (Ortiz & Nassar, 2006).

In animals and humans, carotenoids, particularly β-carotene and lycopene, protect against photo-oxidation by peroxyl radicals and can interact synergistically with other antioxidants. The vitamins in this group are important metabolic carotenoids. The structure of vitamin A (retinol) is derived from the di-terpene oxidative metabolism of tetraterpenoids, especially β-carotene obtained in the diet, which occurs in mammals. The cleavage or rupture of β-carotene occurs in the intestinal mucosal cells and is catalyzed by the O_2-dependent dioxygenase enzyme, most likely via a peroxide intermediate. Over 600 carotenoids are known, but only 20 are found in plasma and tissues. Lycopene is the most abundant carotenoid in human plasma and has a half-life of 2-3 days, according Tapiero et al. (2004), but lycopene shows no pro-vitamin A activity (Setiawan, et al., 2001; Micronutrient, 2002).

Table 1 shows the effects of β-carotene dose in studies of cancer carried out *in vivo*.

3. Dietary Recommendations

It is estimated that carotenoids from vegetables contribute to approximately 68% of the dietary vitamin A worldwide and 82% in developed countries. One benefit of pro vitamin substances is that they are only converted to vitamin A when the body needs more of this vitamin, thus preventing its overaccumulation. Several factors influence the absorption and utilization of provitamins, such as the type and physical form of the carotenoids in the diet, fat intake, vitamin E, fiber and the presence of certain diseases and parasitic infections (Souza & Boas, 2002).

Campos et al. (2003) studied the amount of carotenoids in vegetables and concluded that 100 g of raw carrot can provide an average of 627 g RAE (Retinol Activity Equivalent), representing approximately 70% of the daily recommendation of vitamin A for an adult male between 19 and 50 years of age (900 µg RAE). Comparatively, fortified milk has 240 µg of RAE/100 g; thus, it would be necessary to consume 375 mL of fortified milk to reach the recommended intake of vitamin A. Considering that milk is an inaccessible resource for the poorest of the population due to its market value and lack of distribution in areas with little access to industrial products, plant sources are the most affordable way to meet the nutritional deficiencies of these populations.

RAE (Retinol Activity Equivalent). 1 RAE = 1 µg retinol; 12 µg β-carotene, 24 µg α-carotene or 24 µg β-cryptoxanthin. The dietary RAE for provitamin A carotenoids is two times larger than the retinol equivalent (RE). However, the RAE of preformed vitamin A is the same as the RE.

4. BETA-CAROTENE EXTRACTION, QUANTIFICATION AND IDENTIFICATION

The analysis of carotenoids involves extraction, saponification (when necessary), and mobile phase chromatography. The methodology currently used for carotenoid analysis is high performance liquid chromatography (HPLC), although these findings are often confirmed by open column chromatography and mass spectrometry (Rodriguez-Amaya, Kimura & Amaya-Farfan, 2008).

In the extraction, several water miscible solvents (for fresh products) and immiscible solvents (for dry products) are used, typically acetone and petroleum ether. Different solvents are used for the mobile phase; however, complete separations have been observed with a combination of methanol and methyl tert-butyl ether. The C30 column is typically used because of its high selectivity and resolution. Difficulties related to the cost and quality of analytical standards have contributed to the use of extracts isolated from natural sources as standards by many researchers (Mercadante, 1999; Sander et al., 2000; Nunes & Mercadante, 2006).

Bushway (1986) demonstrated that high performance liquid chromatography (HPLC-HPLC) analysis is a fast, simple and reproducible method for the identification of carotenoids, and some isomers may also be separated from fruits and vegetables.

According to Cortes et al. (2004), several methods have been described for determination of carotenoids. HPLC has been chosen as the best method of separation, identification and quantification of carotenoids found in biological tissues.

According to Lessin et al. (1997), the analysis of carotenoids in fresh and processed samples by reverse phase HPLC enabled the observation of chemical changes in some thermally processed vegetable and fruits, namely the transformation of the cross-β-carotene to the cis-geometrical isomer, β-carotene.

Lessin et al. (1997) found that a reverse phase C30 column could be used for the separation of cis and trans isomers of β-carotene under isocratic analysis conditions, but in some extracts (carrot, orange juice and tomato), it was necessary to separate carotenoids like xanthophylls that coelute with α-carotene and β-carotene prior to the analysis.

Table 1. The effects of β-carotene *in vivo* at different sites and steps of experimental carcinogenesis

Site	Animal	Carci-nogen	β-carotene dose	Effect	References
Skin	Rat (without skin)	UV-B radiation	1 g/kg of the diet	reduced cancer incidence (when administered afterUV-B)	Mathews-Roth & Krinsky (1987)
	Rat (Sencar)	DMBA + TPA	0.6 g/kg of the diet (after DMBA)	inhibited the conversion of papilloma to carcinoma	Chen et al. (1993)
	Rat	DMBA + TPA	2 × 200 ηmol / weeks (topical application, with TPA)	reduced tumor incidence	Nishino (1995)
Oral cavity (lining of the bag facial)	*Hamster* (Syrian)	DMBA + BP	DMBA + 3 × 190 ηg/mL BP /weeks (topical application)	reduced tumor incidence (when applied with or after DMBA)	Suda et al. (1986)
	Hamster	DMBA	2 × 250 mg/week (topical application after DMBA)	inhibited the appearance of tumors in 100% of animals	Gijare et al. (1990)
Liver	rat (Wistar)	DEN + 2-AAF (RH model)	70 mg/kg body weight body (airway gastric days alternate	inhibited the incidence of precancerous lesions (if given before DEN or continuously)	Moreno et al. (1991 e 1995*a*)
	rat (Sprague - Dawley)	2 – AAF (0.05% in the diet	0.1 g/kg of the diet	inhibited the incidence of precancerous lesions (if provided before the AAF or continuously)	Sarkar et al. (1994)
	rat (Wistar, SPF)	DEN + 2-AAF+ PHB	0.3.g / kg diet i.p. - 9 × 1 mg/kg body weight	no effect (administered before and after DEN)	Astorg et al. (1996)
Colon	Rat (F-344)	AOM	0, 1, 10 or 20 mg/kg diet (↑fat ↓ or ↑ in fiber)	inhibited the incidence of pre-neoplastic and neoplastic (administered continuously)	Alabaster et al. (1995)
Pancreas	rat (Wistar)	AZA	0.1 and 1 g/kg or + Se (1 or 2 mg/kg diet)	inhibited the incidence of precancerous lesions (when administered concomitant with and after AZA)	Appel & Woutersen (1996)

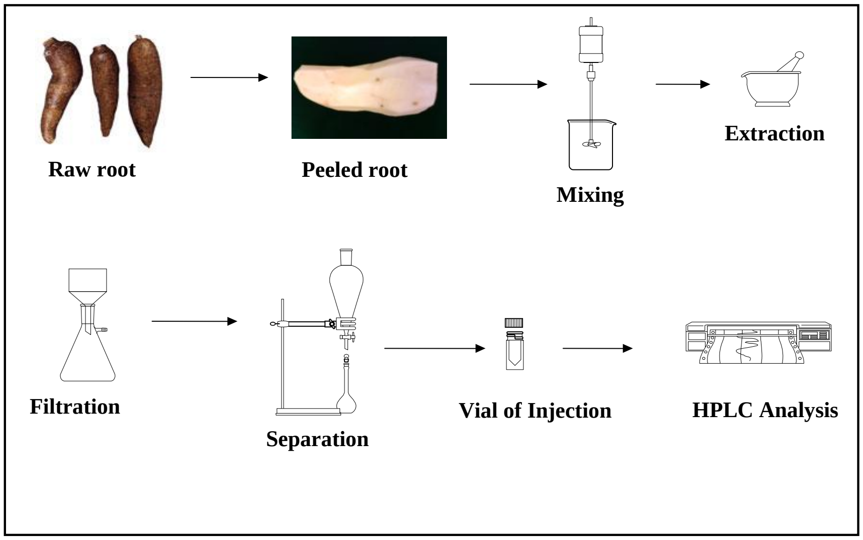

Figure 2. Scheme of carotenoid extraction from cassava for HPLC analysis (Oliveira, 2006).

According to Britton (1995), the carrot (*Daucus carota* L.) is one of the best sources of α-carotene and β-carotene. Nevertheless, purity of the standards must be at least 90% (Rodriguez-Amaya & Kimura, 2004). Figure 2 shows the beta-carotene standard extraction. Oliveira (2006) found that β-carotene prepared from carrots (Figures 3 and 4) was 93.99% pure.

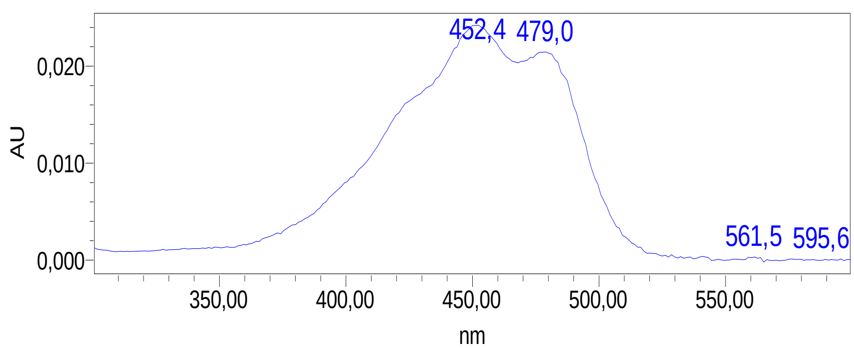

Figure 3. β-carotene UV Absorption Spectrum. Source: Oliveira (2007).

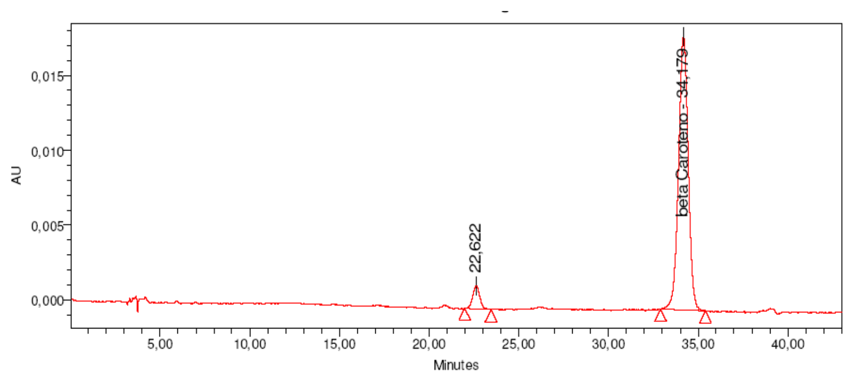

Figure 4. HPLC chromatogram of the β-carotene standard.

Several factors can affect the qualitative and quantitative composition of carotenoids in foods, such as variety/cultivar, season, the tissue (plant part) sampled, growth conditions, and post-harvest handling, processing and storage conditions. Because carotenoids are highly unstable and oxidizable, several factors may cause the loss of its biological activity or total loss of the molecule (Penteado, 2003, Rodriguez-Amaya, Kimura & Amaya-Farfan, 2008).

5. Benefits to Human Health

The main carotenoids involved in human health are beta-carotene, alpha-carotene, lycopene, lutein, beta-cryptoxanthin and zeaxanthin, which can be found in blood plasma. Except for zeaxanthin, these compounds are easily obtained from food, and beta-carotene is the most abundant in the diet (Silva & Mercadante, 2002; Penteado, 2003; Rodriguez-Amaya & Kimura, 2004).

Fifty carotenoids have provitamin A activity, and the most important precursor is β-carotene (Olson, 1987). The other important precursors are α-carotene and β-cryptoxanthin, which each has at least one ionone ring at the end of the isoprenoid structure (Meléndez-Martínez, Vicario & Heredia, 2004).

In addition to their roles as vitamin A precursors, other health benefits have been suggested for carotenoids, such as the prevention of certain cancers, protection of gastric mucosa against ulcers, capacity to prevent photosensitization in certain skin diseases, increase of immune response to infection and anti-aging properties (Bako, Delhi & Tóth, 2002). Carotenoids can also be converted into retinols (provitamin A activity). Furthermore, in addition to their role as the macular pigments of the eye, these substances have antioxidant activity and are involved in a series of cellular processes, such as modulating inflammatory response, protecting against cancer, preventing cardiovascular diseases and cataract.

The antioxidant capacity of carotenoids is most likely responsible for their ability to protect against the detrimental health effects of vitamin A deficiency. Subclinical vitamin A deficiency, in which visible signs of xerophthalmia are absent, intensifies the severity of certain illnesses, such as diarrhea and other infectious diseases, eventually resulting in immunodeficiency of exclusively nutritional origin (Ramalho et al., 2008).

6. Adverse Effects on Human Health

Few adverse effects related to the ingestion of supraphysiological doses of beta-carotene have been described. In rats, the consumption of excess beta-carotene has a positive effect on the control of arterial hypertension that did not affect biological parameters and had no detectable toxic effects (Oliveira et al., 2007).

However, due to the controlled conversion of beta-carotene into vitamin A, overconsumption does not cause hypervitaminosis A. The excessive ingestion of beta-carotene usually leads to carotenodermia, a reversible condition which produces an orange color in the skin, resulting from beta-carotene deposition in the outermost layer of the epidermis. Carotenodermia is often observed in patients with hyperlipidemia, diabetes mellitus and hyperthyroidism. However, high doses of beta-carotene have been associated with an increased incidence of lung cancer in smokers (News Medical, 2012).

7. Bioavailability of Carotenoids and their Applications

The absorption and utilization of carotenoids are influenced by several factors, such as the type and physical form of dietary carotenoids, the ingestion of fat, vitamin E and fibers, and by certain diseases and parasite infections (Souza & Boas, 2002).

It is estimated that carotenoids from vegetables and fruits provide more than 70% of vitamin A in the human diet in more than thirty countries of the world. Carotenoid bioavailability and metabolism are affected by many factors, including the properties of the food matrix, food preparation, coingestion with fat and fiber, gastrointestinal diseases and malnutrition status. They can also influence the translation or transduction of certain genes and may act as inhibitors of regulatory enzymes. In this context, they have been discussed as active in cancer prevention (Stahl & Sies, 2005).

The interest in plant materials that contain provitamin A carotenoid activity has increased significantly in recent years, considering that these micronutrients can help counteract the nutritional deficiencies observed in low-income populations and the populations of developing countries (Ambrósio, Fields & Faro, 2006).

The provitamin A carotenoid cis-isomer (Z) is less readily converted into vitamin A than is the trans-isomer (E). Recently, (all-E)-beta-carotene was reported to be absorbed preferentially over (9-Z)-beta-carotene in humans (Stahl et al., 1995; Ben-Amotz, Levy, 1996; Stahl & Sies, 2003).

Ortega-Flores et al. (2003) evaluated the bioavailability of beta-carotene in cassava leaves using a model of hepatic depletion of vitamin A reserved in rats. The results showed that the bioavailability of β-carotene in the cassava leaves was lower compared to synthetic β-carotene. Similar results were found in studies conducted by Bulux *et al.* (1996) and Tanumihardjo (2002).

Carotenoid absorption and transport are similar to those of lipids. After ingestion, carotenoids are incorporated into mixed micelles composed of bile acids, fatty acids, monoglycerides and phospholipids. Absorption occurs without cleavage, but carotenoids such as β-carotene and cryptoxanthin are partially converted to retinal by hydrolysis within the intestinal cells. Subsequently, the retinal is converted to retinol and transported in the lymph vessels to the liver by chylomicrons in the form of esters of retinol. The retinol is then stored in the liver, which stores 90% of the vitamin A into the body (Ambrósio, Campos & Faro, 2006).

In vivo structural alterations of the all-trans, 9-cis and 13-cis β-carotene isomers were studied in a biological assay to verify the possible structural interconversion of the 9-cis, 13-cis and all-trans-beta-carotene isomers. Different pure β-carotene isomers (either all-trans-β-carotene, all 9-cis or all 13-cis-β-carotene) were administered for 15 days to rats that had been previously depleted of liver carotenoids. The *in vivo* re-isomerization of the isomers was verified. The 9-cis isomer can be converted into all-trans-β-carotene, all-trans-β-carotene re-isomerized into 9-cis, and 13-cis was re-isomerized into 9-cis and all-trans-β-carotene. The authors concluded that the 13-cis-β-carotene was more susceptible to isomerization than the 9-cis because

9-cis could be isomerized into all-trans but not into 13-cis, while the 13-cis could be modified to either 9-cis or all-trans-β-carotene (Costa, Ortega-Flores & Penteado, 2002).

Thakkar et al. (2007) studied the β-carotene accessibility in 10 cassava cultivars (processed by boiling for 30 minutes) with varying concentrations of β-carotene using a coupled *in vitro* digestion/Caco-2 cell uptake model. All-trans, 9-cis, and 13-cis β-carotene were the most abundant carotenoids in raw cassava, and recoveries after digestion exceeded 70%. The efficiency of micellization of total β-carotene was 30% for various cultivars, with no significant difference in isomers and linearly proportional to the concentration in cooked cassava. The accumulation of all-trans β-carotene by Caco-2 cells incubated with the diluted micelle fraction for 4 h was proportional to the quantity present in micelles. These results suggest that all-trans β-carotene content appears to provide the key selection marker for breeding cassava to improve Vitamin A status and that a more complicated screening procedure using *in vitro* digestion coupled to cell uptake does not provide additional information about potential bioavailability.

8. Beta-Carotene in Raw Materials and in Processed and Home Cooked Food

β-carotene is the most abundant of the various carotenoids existing in vegetables, especially in yellow leaves and fruits and vegetables such as papaya, pear, kale, spinach and pumpkin. The maintenance of the natural carotenoid color after processing and during storage is the major concern of the food industry (Dutta et al., 2005; Clydesdale et al. 1970; Ihl et al., 1998).

Beta-carotene, among other carotenoids, has been shown to have an important and positive effect on human health. This compound is commonly found in many vegetables, and cooking can modify its activity. Twenty-five fresh vegetables were submitted to three common Chinese domestic cooking methods - boiling, stir-frying and deep-frying. Boiling preserved the majority of carotenoids, whereas stir-frying and deep-frying did not. Cilantro (fresh) showed the highest total and *trans*-β-carotene contents (3.19 and 1.92 μmol × 10^2 g fresh vegetable, respectively) followed by fern, sweet potato leaves, vegetable fern and Thai basil leaf. An overall increase of 9-Z isomers was observed in all boiled vegetables, most likely because of E/Z isomerization, which could result in the formation of more bioactive compounds, such as (9-

Z)-β-carotene. Boiling may be the preferred domestic cooking method to preserve carotenoids in vegetables (Chiu *et al.*, 2012).

Wada et al. (2005) determined the most common carotenoids and trans- and cis-isomers in raw vegetables and the impact of bioactive compounds after Chinese cooking practices (boiling, stir-frying, and deep-frying). The cilantro, Thai basil leaf, sweet potato leaf, and choy sum exhibited the highest total carotenoid contents (TCC). Boiling preserved the majority of the carotenoids, whereas stir-frying and deep-frying significantly decreased TCC and (all-E)-forms of carotenoids.

These results show that it is important to consider the effects of home cooking, industrial processing and storage methods to reduce micronutrient loss.

Normally, the real retention percentage (% RR) is calculated according to Murphy, Criner, Gray (1975) by the formula:

$$\%RR = \frac{\text{carotenoids content per gram of cooked sample x weight (g) cooked sample}}{\text{carotenoids content per gram of raw sample x weight (g) of raw sample}} \times 100$$

Depending on the time and temperature applied, different levels of degradation and isomerization of carotenoids occur. Blanching, pasteurization and sterilization processes cause *trans-cis* isomerization, while more aggressive thermal processing destroys the carotenoids (Pérez-Gálvez et al., 2005).

Gayathri *et al.* (2004) found that the β-carotene loss in carrots (27%) was greater when cooked under pressure for 10 min than when cooked in boiling water (16%).

A similar study was conducted by Pinheiro - Sant'ana et al. (1998) in carrots using different cooking processes (steam cooking, cooking in water with and without pressure, moist/dry cooking and conventional dehydration). The total carotenoid retention ranged from 60.13 to 85.64%. Water cooking promoted a higher retention of α-carotene (63% to 70) and β-carotene (65% to 77%) than other methods. Despite the significant carotenoid losses, carrots prepared at home remain a rich source of provitamin A under different processing conditions. Blanching for three and five minutes in boiling water increased the β-carotene content compared with fresh carrots, possibly due to the higher extractability caused by boiling or to moisture and soluble solids losses that concentrate the sample (Dutta et al, 2005).

However, it should be noted that thermal processing promotes the isomerization of carotenoids in food from *trans (E)* to *cis* (Z) and that the degree of isomerization is directly related to the intensity and duration of heat treatment (Rock et al., 1998). Rodrigues & Penteado (1989) concluded that, nutritionally, the differentiation between the *cis* and *trans* isomers of provitamins is important because the *cis* form (Z) has lower activity.

Figure 5 shows the colors of yellow sweet cassava roots before (raw) and after cooking.

a)

b)

Figure 5. Yellow Sweet Cassava Root Samples: a) red color and intense color after cooking in water; b) yellow color and intense yellow color after cooking in water (Oliveira, 2006).

Melo et al. (2009) concluded that vegetables subjected to steaming exhibited differential antioxidant properties, with broccoli and pumpkin (squash) displaying antioxidant activity greater than 70%. The highest DPPH radical sequestration activities were observed in cauliflower, carrots and spinach and did not differ from the action of the synthetic antioxidant BHT. Therefore, the application of heat did not drastically affect the antioxidant properties of vegetables in these systems and models.

Oliveira (2006) evaluated yellow bitter cassava roots before and after flour processing and storage for 26 days. The total carotenoid losses after 19 days of storage ranged from 86 to 99%, and the average degradation found in all the roots just after processing (time zero) was 50%. The exposure of the carotenoids to heat during the flour process was the main degradation factor (oxidation) (Bauernfeind, 1972).

Losses of α and β-carotene and its 9 and 13-*cis*-β-carotene isomers were observed in pumpkins (*C. moschata*) after steaming or cooking in boiling water. The steamed pumpkins presented the highest α and β-carotene contents. The α-carotene contents were lower than the *trans (E)*-β-carotene contents in both pumpkin samples (raw and cooked). An increase in the 13-cis-β-carotene isomer was observed after both cooking methods (Neves, 2011).

Similarly, Oliveira (2006) found that *trans (E)*-β-carotene was the most abundant carotenoid in yellow sweet cassava after cooking.

Rodriguez-Amaya et al. (2011) evaluated the carotenoid compositions of sweet potato roots, cassava roots and corn kernels, observing that β-carotene predominates in sweet potato and cassava, while lutein and zeaxanthin prevail in corn. The major carotenoid of orange-fleshed sweet potatoes (OFSP) is all-*trans*-β-carotene, and the consumption of this vegetable has been shown to improve the vitamin A status of children. These authors suggested that OFSP flour can be used as a substitute for wheat flour in bakery products other than breads.

APPROACHES

As observed throughout this chapter, beta-carotene, although possessing high provitamin A and antioxidant activities, may lose these activities during the cooking process and even during preparation. Another important factor is its bioaccessbility, which should be studied further. The results of studies regarding the improvement of vegetable matrices may improve access to foods with high beta-carotene content, appropriate for addressing the nutritional needs of low-income populations.

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