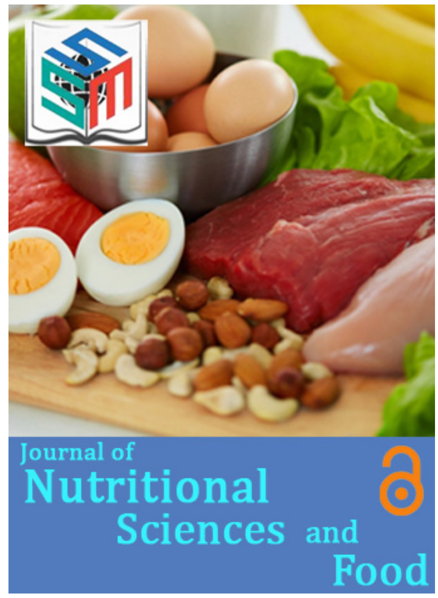

Review Article

Cooking, Carotenoids, and Cognitive Performance

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Citation: Crosby G (2022) Cooking, Carotenoids, and Cognitive Performance. J Nutri Sci Food 2: 006.

Received: June 10, 2022

Accepted: July 13, 2022

Published: July 20, 2022

Decreased cognitive performance with increasing age is well established, especially in adults beyond the ages of 65-75. As the average age of the population increases concern about cognitive decline mounts. Evidence is accumulating that diet affects cognitive performance both positively and negatively. Diets rich in carotenoids, vitamin E, folate, n-3 fatty acids, and polyphenols show evidence of slowing the onset of cognitive decline while diets high in saturated and trans-fat, together with copper and iron, appear to increase the rate of cognitive decline [1]. The PREDIMED study in Spain also showed that a diet high in extra virgin olive oil as well as nuts increased scores on cognitive performance. In this and other studies green leafy vegetables and seafood that are rich sources of the beneficial nutrients listed above appear to correlate with improved cognitive performance.

One common feature of the beneficial nutrients is their function as antioxidants in trapping destructive free radicles in the body, such as reactive oxygen species, which result in the oxidation of DNA, proteins, and lipids, and is thought to be a risk factor for age-related cognitive decline. However, a careful review of the research literature failed to find a clear correlation between antioxidant intake and cognitive performance [2].

The carotenoids are a large family of naturally occurring compounds in plants that are proven to function as potent antioxidants. Approximately 650 carotenoids have been identified in plants with about 60 being consumed in the human diet [3]. Of this large number of dietary carotenoids only six constitute about 95% of the carotenoids found in human blood and brain: lutein, zeaxanthin, lycopene, α-carotene, β-carotene, and β-cryptoxanthin [4]. The carotenoids are divided into two different groups of structures, the carotenes, which are highly unsaturated hydrocarbons, and the xanthophylls, which are carotenes containing one or more oxygen atoms. Lycopene, α-carotene, and β-carotene are examples of carotenes, while lutein, zeaxanthin and β-cryptoxanthin belong to the group of xanthophylls. In plants carotenoids are associated with the cell wall membrane proteins of chloroplasts that are part of the photosynthetic apparatus, as well as the chromoplasts responsible for the synthesis of colored pigments [5].

All carotenoids are soluble in fats and oils and insoluble in water. In foods such as fruits and vegetables the content of carotenoids varies widely depending on the variety, growing conditions, ripening stage, and post-harvest treatment. For example, the flesh of apricots can contain from 200-2000 or more micrograms (μg) of β-carotene per 100 grams of fresh fruit, while the total β-carotene content of raw carrots has been reported to vary as much as 2.4 fold. The highest levels of lycopene are found in tomatoes, yet the content of lycopene in fresh tomatoes ranges as much as 23 fold largely dependent on the ripeness of the tomatoes [6]. The carotenoids are quite stable when bound to the membrane proteins in fresh foods but very susceptible to isomerization and oxidation of the double bonds when foods are cooked or they are extracted into fats, oils, or organic solvents. The process of isomerization converts some of the naturally occurring more stable trans-double bonds to the less stable cis-double bonds. In the case of lycopene, the cis-isomers are more active antioxidants than the trans-isomers, while the provitamin A activities of several of the cis-isomers of β-carotene are only about half that of the all-trans-isomer [5]. Thus, the beneficial effects of carotenoids may show wide variation depending on their content and stereochemical structures in specific fruits and vegetables.

As antioxidants the carotenoids are especially effective at quenching oxygen free radicals such as singlet oxygen. For example, the all-trans form of lycopene is ten times more effective at quenching singlet oxygen free radicals than α-tocopherol (vitamin E). Studies have shown that diets rich in carotenoids significantly reduce the risk of prostate, colorectal, and pancreatic cancers, as well as coronary heart disease. Given their functionality at quenching oxygen free radicals it is tempting to consider that the dietary carotenoids may slow the onset of age-related cognitive decline. Unfortunately, only a very limited number of studies have attempted to examine the relationship between carotenoids and cognitive outcomes, and of these only diets with higher intakes of β-carotene showed any improvement in cognitive function [2]. The explanation for this lack of a clear correlation has been ascribed to large differences in study design and the difficulties in assessing the intake levels of the different carotenoid isomers in the diet [2].

The bioavailability of carotenoids from dietary sources is a major factor when considering their potential impact on human health. Studies of the effect of lycopene on reducing the risk of prostate cancer highlight its bioavailability from different forms of tomatoes and tomato products [7]. Tomatoes account for more than 80% of the lycopene in American diets explaining why the majority of studies on the bioavailability of lycopene have been carried out with tomatoes and tomato products. The absorption of lycopene into the body is relatively low (10-30%) compared with the lycopene consumed in the diet, presumably because the lycopene is bound to cell wall proteins making it more difficult to absorb the lycopene unless released by exposure to heat or fat [8]. Thus, the amount of lycopene absorbed into the blood from sun-dried tomatoes is more than three times greater than from fresh tomatoes, and almost four times greater from tomato paste. Lycopene absorbed into the blood from tomatoes cooked in extra virgin olive oil is 82% higher than from tomatoes cooked without oil [9]. Although the lycopene in fresh tomatoes occurs largely (90%) in the all- trans conformation, the lycopene found in human tissues is composed mainly of a mixture of cis-isomers [10]. The formation of cis-isomers by heat is relatively small (<10%-20%) suggesting that the cis-isomers are preferentially absorbed in the form of bile acid micelles or formed by isomerization following absorption. Lycopene in the blood was composed of 50% cis-isomers after consuming tomato juice containing just 20% of a mixture of cis-isomers (heat processing tomato juice increases the level of cis-lycopene from that in fresh tomatoes). It is clear that both the amount and form of the lycopene absorbed into the blood and tissues of humans is very different from that in fresh tomatoes [11].

Could the lack of a clear correlation between the dietary intake of carotenoids and cognitive performance be linked to their bioavailability and the influence of the post-harvest processing of foods, including the methods of cooking? This question is relevant when considering the bioavailability and biological properties of β-carotene, the most abundant carotenoid in carrots that occurs only in the all-trans form in raw carrots and possesses the highest provitamin A activity of any carotenoid [12]. Contrary to what has been found with lycopene, the all-trans form of β-carotene is more readily absorbed and exhibits higher vitamin A and antioxidant activities than the various cis-isomers (three isomers at C-9, 13, and 15 may be formed). In a study that fed equal amounts of the all-trans form and the 9-cis isomer of β-carotene the accumulation of the trans-isomer into blood plasma chylomicrons and very low-density lipoproteins was 10-50 fold higher than the cis-9 isomer [13], suggesting a selective mechanism for the uptake of the trans-isomer. Thus, the cis and trans-isomers of lycopene and β-carotene behave very differently in terms of bioavailability and biological activity.

Both storage conditions and cooking affect the stability of the *cis* and *trans-isomers of α-* and *β-carotene.* Storage at 4°C for up to 56 days showed an initial increase of all-trans α- and β- carotene of 35% and 25% respectively during the first 3 days of storage followed by a gradual decline of both isomers back to their initial levels by 56 days. Point of sale carrots are typically stored at 18-22°C. A study at 20°C for up to 21 days showed a similar pattern of a gradual increase in the content of all-trans α- and β-carotenes of 42% and 34%, respectively, over the first ten days followed by a decline back to the initial levels after 21 days [12]. These results are consistent with earlier studies, which have been attributed to an initial increase of carotene synthesis, or more efficient extraction due to cell wall softening. Boiling carrots for 15 minutes that had been stored at 20°C for 21 days resulted in a 15% increase of the all-trans β-carotene while carrots stored at 4°C for 56 days showed little change in the content of all-trans β-carotene after boiling. The authors of this study concluded that fresh carrots can be stored for up to 21days at 20°C, or 4°C for 56 days without a significant reduction in the all-trans β-carotene content due to storage or boiling for 15 minutes.

Table 1 below summarizes the results of a carefully controlled study of the increase or decrease of total carotenoids present in three vegetables after cooking for the specific times under three different conditions [14].

Food	Raw	Boiled	Cooking Time	Steamed	Cooking Time	Fried	Cooking Time
Broccoli	28.2*	37.1* (+32%)	8 min	33.6* (+19%)	13 min	9.3* (-67%)	3 min
Carrots	117.9	134.1 (+14%)	25 min	110.6 (-6%)	30 min	102.9 (-13%)	8 min
Zucchini	` 50.1	48.5 (-4%)	15 min	39.2 (-22%)	24 min	32.6 (-35%)	4 min

Table 1: Loss or Gain of Total Carotenoids in Cooked Vegetables.

*Carotenoid content of food expressed in milligrams per 100 grams of dry weight.

In this study all vegetables were cooked until tender, as determined by a trained sensory panel and confirmed by a Stable Micro Systems TA.XT2 texture analyzer, rather than being cooked for a specific length of time, thus being representative of how consumers would cook the vegetables in the home. Measurements of tenderness were made at 50°C, a typical temperature of consumption. Of the three vegetables, broccoli represents the greatest variation of total carotenoid contents ranging from an increase of 32% in boiled broccoli to a loss of 67% in fried broccoli relative to the raw vegetable. Exposure to high heat during boiling releases more of the water-insoluble carotenoids from the protein matrix, while frying in oil leaches out more of the oil-soluble carotenoids. In this example the number of available carotenoids varied by four-fold depending on the method of cooking the broccoli. Thus, the specific vegetable, the method of cooking and the bioavailability of different isomers of carotenoids have a significant impact on the number of total carotenoids obtained from food confirming the difficulties in assessing the intake levels of carotenoids in the diet.

Table 2 below shows the loss or gain of β-carotene in the same study as shown in table 1 (the cooking times are the same as shown in table 1) [14]. The results are similar but less dramatic than those shown in table 1. Boiling and steaming tend to release the most β-carotene during cooking while frying clearly reduces the available β-carotene for the reasons stated above.

Food	Raw*	Boiled*	Steamed*	Fried*
Broccoli	5.7	6.6 (+16%)	6.7 (+18%)	2.0 (-65%)
Carrots	53.8	54.6 (+1.5%)	48.5 (-10%)	41.0 (-24%)
Zucchini	4.8	5.7 (+19%)	5.8 (+21%)	4.3 (-10.4%)

Table 2: Loss or gain of β-Carotene in Cooked Vegetables.

*β-Carotene content of food expressed in milligrams per 100 grams of dry weight.

In light of the limited number of studies examining the influence of dietary carotenoids on cognitive performance, it is not surprising that a clear correlation has not been observed in view of the number of factors that affect the bioavailability of dietary carotenoids. To overcome these limitations feeding studies must be designed that clearly quantify the specific carotenoids delivered into the blood plasma by the diet.

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