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Bioavailability and health effects of some carotenoids by different cooking methods

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Abstract

Humans lack the inherent capability to synthesize carotenoids, necessitating their acquisition through dietary sources or supplementation. Among the carotenoids prevalent in our daily nutritional intake are beta-carotene, lycopene, lutein, beta-cryptoxanthin, alpha-carotene, and zeaxanthin. They have antioxidant features thanks to their ability to capture ROS (reactive oxygen species) and free radicals. Particularly beta-carotene, lycopene and lutein are carotenoids with high antioxidant capacity. However, with the effects of factors, such as oxygen, high temperature, light exposure, and pH, they are oxidatively degraded and their bioavailability in the body changes. Among food processing methods, reducing food size and dietary fiber inhibits the absorption of carotenoids by micellization and inactivating pancreatic lipase, while monounsaturated fatty acids have been shown to increase bioavailability and absorption. In vitro studies on various vegetables and fruits with the effect of exogenous factors showed that the addition of oil, increase in lycopene processing, decrease in food particle size, increase in micellization with the breakdown of dietary fibers, and increase in bioavailability as a result of the destruction of cell walls with heat treatment. The addition of olive oil with heat treatment and the factors of decreasing food particle size have positive effects on health by transforming carotenoids into forms with high bioavailability in the body. This review endeavors to investigate the bioavailability of select carotenoids, namely lycopene, beta-carotene, and lutein, in light of various cooking methods and processes, as well as to elucidate their implications for health resulting from heat treatments.

Keywords: Cooking methods, Carotenoids, Health, Bioavailability.

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1. Introduction

Carotenoids were first obtained by Weckenroder in 1831 by isolating them from carrots, but studies on carotenoids began in 1837 when yellow compounds in autumn leaves were named xanthophylls (Erge & Karadeniz, 2010). Carotenoids are the second most common natural pigments worldwide, which are synthesized by some plants, algae, fungi and bacteria and give yellow-red colors to fruits and vegetables and are fat-soluble with more than 750 members. In general, carotenes are isoprenoids formed by the combination of eight isoprene units (Gökbulut & Şarer, 2008). In the structure of carotenoids, conjugated double bonds provide color formation. For color formation, at least seven conjugated double bonds must come together. While phytoene compound with five conjugated double bonds is colorless, lycopene compound with eleven conjugated double bonds is red. Thus, as the number of conjugated double bonds increases, the color concentration also increases. Carotenoids are categorized into four main groups according to their structures: Carotenes, Xanthophylls, Carotenoid ketones and Carotenoid acids. Carotenoids that contain oxygen in their structure are called 'xanthophylls,' and those that contain carbon in their structure are called 'carotenes' (Türkcan & Ökmen, 2012). Xanthophylls can be classified as lutein, zeaxanthin, astaxanthin and canthaxanthin and carotenes as alpha carotene, beta-carotene and lycopene (Gökbulut & Şarer, 2008).

Carotenoids are synthesized in the plastids of photosynthetic organisms, such as fruits, vegetables and flowers. They are composed of carotenoids and isoprenoids and IPP (isopentyl pyphosphate). Sources of IPP in plants are the MVA (cytosolic mevalonic acid pathway) and the MEP (methylerythritol 4-phosphate)

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pathway. In the cytosolic pathway, IPP is first isomerized to DMAPP (dimethylallyl diphosphate). From DMAPP, GGPP is formed by the enzyme GGPPsynthase. Phytoene is produced by phytoene synthase enzyme, and lycopene is formed in the last step (Erge & Karadeniz, 2010; Rosas-Saavedra & Stange, 2016).

Carotenoids cannot be synthesized by humans. They should be taken from foods or supplements (Eggersdorfer & Wyss, 2018). Carotenoids most commonly found in our daily food consumption are beta-carotene, lycopene, lutein, beta cryptoxanthin, alpha carotene and zeaxanthin (Desmarchelier & Borel, 2017). Although carotenoids cannot be synthesized by animals, they are also present in some animal-derived foods, such as eggs, fish, dairy products and chicken, in our daily consumption (Martini et al., 2022). Other than these foods, carotenoids are also found in vegetables, such as tomatoes, carrots, red peppers, zucchini, eggplants, broccoli, beans, and spinach and fruits and vegetables with yellow-red colors, such as raspberries, strawberries, blackberries and blueberries according to their different levels of carotenoid content (Erge & Karadeniz, 2010). Dark green plants are rich in lutein, tomatoes and their derivatives in lycopene, red fruits and vegetables in alpha and beta-carotene, and egg yolk in zeaxanthin and lutein. Although 40 natural carotenoids in the daily diet have been identified, 20 carotenoid species are measured in tissues and blood plasma. Approximately 90% of the 20% species are composed of alpha, beta-carotene, lycopene and lutein in in vivo studies (Rivera-Madrid et al., 2020; Yılmaz, İ. 2020). In one study, 62 prospective cohort studies and case controls were analyzed. Based on the study, plasma carotenoid levels and health outcomes were analyzed. Therefore, a carotenoid health index was obtained. In accordance with this index, a plasma carotenoid concentration of <1000 nmol/L poses a risk for metabolic diseases, such as cardiovascular disease and cancer, while ≥ 2500 mmol/L is protective (Böhm et al., 2021; Donaldson, 2011).

Thanks to their ability to capture ROS (reactive oxygen species) and free radicals, carotenoids have antioxidant properties. In particular, beta-carotene, lycopene and lutein are carotenoids with high antioxidant capacity. In addition, some carotenoid species show provitamin A activity. Especially beta-carotene is the carotenoid with the highest conversion activity to vitamin A (Desmarchelier & Borel 2017; Gökbulut & Şarer 2008; Yılmaz, 2020). By blocking the transylation of nuclear factor, carotenoids provide inhibition of inflammatory cytokines, such as IL-8 and prostaglandin E2. At the same time, they interact with the nuclear factor-associated factor 2 pathway and increase its translocation to the nucleus. Consequently, it activates phase enzymes, such as glutathione S transferase and suppresses oxidative stress by showing antioxidant activity (Kaulmann & Bohn, 2014). Because of these properties, they have positive effects on many diseases, such as degenerative skin diseases, cancer, Alzheimer's, cardiovascular disease, osteoporosis, age-related macular degeneration and cataract (Rivera-Madrid et al., 2020). There are certain factors affecting the antioxidant capacity of carotenoids, including concentrations of carotenoids, molecular structure, oxygen pressure, carotenoid sites of action, and interaction with other carotenoids and antioxidants (Gao et al., 2020)

Contents of carotenoids in foods change according to some factors. Among these factors are the type of food, seasonality, variety, maturity level, processing, storage conditions and climatic conditions (Martini et al., 2022). Also, carotenoids are stable and independent of cooking and storage. However, they are oxidatively degraded with the effects of factors, such as oxygen, high temperature, light exposure, and pH (Martini et al., 2022; Türkcan & Ökmen, 2012). However, the bioavailability of carotenoids in the body is also significant and is affected by some factors. These factors are classified as intrinsic and extrinsic. Intrinsic factors are dietary factors (plasma vitamin A concentration), presence of fat and fat-soluble micronutrients and food processing methods that may impair the bioaccessibility of foods. Especially among food processing methods, reducing food size and dietary fiber inhibits the absorption of carotenoids by micellization and inactivating pancreatic lipase while increasing the bioavailability and absorption of monounsaturated fatty acids. On the other hand, extrinsic factors include gender, age, presence of disease (hormonal status), lifestyle (drug use, smoking, alcohol intake), pregnancy and breastfeeding, and genetic variations. These factors may affect carotenoid bioavailability and metabolism positively or negatively (Moran et al., 2018). Thus, to increase the bioavailability of carotenoids, nutrition rich in unsaturated fatty acids, and terminal and mechanical treatments that will ensure cell wall degradation are effective (Yao et al., 2021).

This review aims to examine the bioavailability of some carotenoids (lycopene, beta-carotene and lutein) as a result of cooking methods and processes and their effects on health due to heat treatments.

2. Cooking Methods

Cooking is the process of applying controlled heat to foods for specific purposes. By doing so, it increases the value of the food, changes its taste, improves its digestibility and destroys harmful microorganisms. Different cooking methods are available. Traditional methods known as cooking methods are divided into two dry heat and wet heat. Dry heat cooking methods are cooking in a pan with little oil, frying in a pan with oil, frying in plenty of oil, cooking by applying heat from the top, grilling and baking in the oven. On the other hand, cooking methods in aqueous heat are cooking in hot water, cooking below boiling temperature, boiling, steaming and cooking in a small amount of liquid. There are also contemporary cooking methods and techniques. Some of them are sous vide, microwave and bleaching methods (Mutlu & Sandıkçı, 2018). Among the various cooking methods used in studies on carotenoids, boiling method, steaming method, frying, microwave, sous vide, cook vide methods are preferred.

The boiling method is based on the method of cooking foods in cold or hot water. With this method, foods can be placed in cold water and then boiled or cooked directly in boiling water (Mutlu & Sandıkçı, 2018). Steaming is one of the healthiest cooking methods. In this method, foods are cooked with the vapor of boiling water without contact with water (Kasar et al., 2021). The microwave cooking method plays a vital role in heating, cooking, drying and sterilization of foods. Due to the water molecules in the food, the food is cooked as a result of molecular friction by vibrating with the effect of microwaves (Ağagündüz & Bilici, 2016).

The frying method can be divided into pan-frying and deep-frying. Pan frying is done by evenly distributing the heat in a widespread, shallow, thick-bottomed pan. In the process of frying in plenty of oil, it is the method of cooking the foods thrown in oil at 160-180°C by immersing them in oil. Foods are cooked in a short time due to high heat contact (Mutlu & Sandıkçı, 2018).

Sous vide cooking method is a cooking method originated in France. In this method, foods are placed in vacuum bags with evacuated air and cooked in a controlled manner in a low temperature (<100°C) and water environment (Baltalı, 2019). Cook vide cooking method is cooking in <100°C boiling water on a low-pressure cooker without changing the atmospheric conditions (García-Segovia et al., 2007).

3. Cooking Effects on Carotenoid Bioavailability and Health

Consuming high amounts of fruits and vegetables rich in carotenoids (especially β-carotene and lycopene) has been associated with a reduced risk of developing cancer and cardiovascular problems, especially for lung and stomach cancer types. It is also suggested that lutein and zeaxanthin, among the carotenoids, have a protective role against the development of some eye diseases (Toydemir et al., 2022).

Previous studies show that cooking processes, such as microwave heating, canning, and baking, lead to an increase in (Z)-isomers at the expense of (all-E)-carotenoids. Literature data indicate that the consequences of E/Z isomerization are changes in bioavailability and physiological activity. Furthermore, literature data also show that each carotenoid exhibits a distinct pattern of absorption, plasma transport and metabolism. Overcooking may cause a decrease in carotenoid concentrations, which may result from thermal degradation or E/Z isomerization. The concentration of (9Z)/(9′Z)-carotenoid isomers increased with the increase in boiling time throughout the entire cooking process, probably due to E/Z isomerization. It is extremely important to be aware of the significant increase in (9Z)-β-carotene because it has the potential to inhibit tumor progression in humans (Kao et al., 2012). Lycopene bioavailability is lowest in raw sources, slightly increased in lightly processed foods, and highest in heat-processed food sources and purified fatty preparations (Caseiro et al., 2020). It was noted that serum lycopene levels were higher in humans after consuming heat-treated tomato juice but not after unprocessed juice. This enhanced bioavailability of lycopene in processed food has again been attributed to its release as a result of plant cell disruption during mechanical and thermal processing, as well as heat-induced trans-cis-isomerization (Gärtner et al., 1997).

Liu et al. (2004) compared the bioavailability of carotenoids in raw and cooked whole foods using an in vitro simulated gastrointestinal digestion model combined with an in vitro Caco-2 cell culture model. They determined that cooking (15 minutes at 100°C in a water bath) led to significant increases in the bioavailability of carotenoids (Liu et al., 2004). Mild heat treatment has also been suggested to increase carotenoid bioavailability from plant foods by weakening carotenoid-protein complexes and solubilizing cell wall pectin, subsequently softening the tissue. Thus, the absorption of the compounds becomes easier (Toydemir et al., 2022). Orlando et al.

investigated the human plasma bioavailability of β-carotene, lutein, and isothiocyanate after consumption of broccoli subjected to various cooking procedures, including steaming (100% relative humidity, 99°C, 13 min) and boiling (10 min). Lutein and β-carotene levels in serum did not change significantly with consumption of broccoli prepared with different cooking procedures (Orlando et al., 2022).

To predict the in-vivo bioavailability of lycopene and beta-carotene in different processed soups, a study on in-vitro models included 14 participants for study 1 and 72 participants for study 2. Blood samples were also taken from the participants. In study 1, broccoli and carrots were boiled at >85°C and, tomato paste was added and a soup containing 5% olive oil was made at 80°C. Fourteen participants consumed 300 ml/day of soup containing 3.9 mg carotene, 4 mg lycopene and 5% olive oil for four weeks. In study 2, 5% soup was prepared by boiling broccoli, tomato and carrot in a 1:1:1 ratio. Participants consumed reference soup containing 2.5% olive oil and prepared soup containing 5% olive oil for four weeks. The beta-carotene content for the prepared/reference soups was 4.10/2.90 mg and lycopene content was 3.90/2.71 mg, respectively. Carotenoids were determined from the soups by HPLC analysis. An in vitro digestion module was established to determine the bioavailability of carotenoids in soups. Caco-2 (human colon epithelial cells) cell experiments were performed. Micellization fractions of reference and prepared soups digested in vitro were examined. At the end of the model, the carotenoid content in the cells was analyzed within two weeks. The bioavailability ratio was calculated as the ratio between the increase in blood plasma carotenoid levels after consumption of the prepared soups and the rise after consumption of the reference soup. Bioaccessibility was calculated by comparing the number of carotenoids released from the food matrix or incorporated into the micelle phase after in vitro digestion of the prepared soup or uptake in Caco-2 cells with the amounts measured after in vitro digestion. The results of the study showed that both the release from the food matrix and the amount of beta-carotene were higher in the soup prepared after in vitro digestion than in the reference soup. In study 1, lycopene bioavailability was higher than in study 2. This is believed to be because the tomatoes were heat-treated and processed. When the Caco-2 cell uptake level was examined, beta-carotene micellization was higher in the prepared soup compared to the reference soup. Also, serum beta-carotene and lycopene levels increased by 141% and 132%, respectively, in the study 1 group at the end of four weeks. In the study, two groups, serum beta-carotene concentrations increased 139% and lycopene concentrations increased 54% compared to baseline. Consequently, it was concluded that while beta-carotene bioavailability and accessibility increased with easier micellization, more in vitro studies are needed to examine lycopene bioavailability and bioaccessibility (Alminger et al., 2012).

In a study in which corn carotenoids were analyzed by HPLC analysis, three different cooking methods were compared. In the first method, corn kernels boiled at 95C for 15 minutes were cooled and dried with filter paper. In the second method, the corn kernels were mixed into porridge after heating and carotenoids were determined in the cooled form. In the third method, after boiling at 95°C for five minutes, the grains were dried in an oven at 50°C for 48 hours, and tortillas were made. In the study, an in vitro digestion model was created, and the bioavailability of corn kernels was examined by examining micellization and bioaccessibility. According to the results of the study;

- Boiled corn has the highest total carotenoid content.
- Lutein and zeaxanthin content also increased after boiling.
- The carotenoid content of maize increased after heat treatment.
- The carotenoid content of oat porridge decreased by 76% compared to the crude form, and it was thought that this may be due to the exposure of the ground corn kernels to oxidation by air.
- The tortilla retained 78.4% of its raw state, but the beta-carotene content decreased by 0.45. The reason for this is beta-oxidation due to contact with oxygen during the drying process.
- Oxidation may be the main factor affecting carotenoid losses induced by light and heat.
- β-carotene was more sensitive and vulnerable to heat treatment.
- The micellization efficiency (6.66 ± 0.13%) and bioaccessibility (2.36 ± 0.10%) of total carotenoids in boiled kernels were the lowest among the three cooked products.
- The carotenoid in the boiling method is stable until the chewing stage.
- Cooking by grinding increases the bioaccessibility of carotenoids due to dietary fiber breakdown.
- During digestion, the carotenoid content in porridge is lowest in the cone.
- The β-carotene contents in porridge and tortilla were higher than the contents before digestion, indicating that the digestive stability of porridge

and tortilla β-carotene reached 104 ± 11% and 309 ± 63%, respectively.

- β -carotene digestive stability in tortillas increased 309-fold compared to porridge - the washing process removed pericarp and fibers and increased beta-carotene digestive stability
- In boiled kernels and tortillas, micellization efficiency of carotenoids, lutein>beta-carotene (Zhang et al., 2020).

Another study of freeze-dried vegetable snacks examined the bioavailability and bioaccessibility of onions, carrots, parsley and broccoli for carotenoids in in vitro models. A human bioavailability study was also conducted and included 19 healthy participants. The participants were divided into two groups. One group was offered a 75-gram snack while the other group was offered a comparator cooked vegetable meal. After consuming the test meals, blood and urine were analyzed to measure the bioavailability of the nutrients. In the study, the target dose for measurable levels of beta-carotene in plasma 15 mg. To reach the target, the vegetable contents of the products were 10.5% broccoli, 27.6% onion, 56.9% carrot and 5% parsley. While creating the snacks, three different processes were followed.

i. Combining freeze-dried broccoli, carrots and onions with flash-frozen parsley and cook in a hot air oven
ii. Cooking all flash-frozen vegetables in a hot air oven
iii. Combining frozen and microwaved broccoli, onions and carrots with frozen and baked parsley, cooked in the microwave and dried in the oven

Snacks that passed through the three processes were combined in different concentrations. Beta-carotene contents were 10.3 mg/100 grams in freeze-dried products, 2 mg/100 grams in frozen products and 5.7 mg/100 grams in freeze-microwave products. An in vitro human digestion model was established to determine bioavailability and bioaccessibility. According to the study results, the beta-carotene content in the dough content before cooking decreased after cooking. In the in vitro digestion model, there was no detectable beta-carotene content released from the food matrix in the snacks and vegetable dishes, while the lutein content was 0.4 mg. Based on fasting blood samples, plasma beta-carotene levels fluctuated between 13.6-447.9 nmol/L and 24.7-516.1 nmol/L in both groups after consumption of the test meal. The reason for this was thought to be transport from endogenous fat stores reflecting habitual carotenoid intake (Perez-Moral et al., 2018).

In a study on lutein and beta-carotene liberation and in vitro bioavailability of spinach after different treatments; the results of pureeing, steaming and oil addition were examined to improve carotenoid release. 75 grams of spinach leaves were steamed at 100°C for three minutes with the addition of 2.5 grams of oil (olive oil, butter, or peanut oil). The comparison of fresh spinach and cooked spinach leaves was made. Oral phase, gastric phase and intestinal phase were established with an in vitro digestion model. In the study, a decrease in both carotenoid types was observed due to steaming, with or without the addition of oil. It is thought that this is due to the oxidation and degradation of carotenoids as a result of steaming. However, in pureed spinach, no change was observed in both carotenoid types as a result of steaming. Nevertheless, lutein and beta-carotene in pureed and cooked spinach leaves were found to have higher release from the food matrix (minimum and maximum values of beta-carotene and lutein in raw state; 2.7-4.3, 6.3-8.1, 9-13.7, 21.7-25 in cooked state) and in vitro bioavailability (2-3.5, 5.3-6.4, 5.6-6.2, 16.8-21.7 in cooked state) compared to raw spinach leaves in both states with/without the addition of oil. This suggests that the chewing factor is one of the main factors affecting bioavailability through a decrease in tissue particle size. Following oil addition, lutein release and in vitro bioavailability decreased, while the opposite effect was observed for beta-carotene. In particular, as a result of the steaming process with the addition of oil, it was observed that there was a 35% increase in release compared to the raw state (Eriksen et al., 2017).

In a study in which the carotenoid bioavailability was evaluated in in vitro models as a result of different thermal processes applied on tomatoes, two different blanching processes were performed. The first blanching process lasted four minutes at 90°C and the second blanching process lasted 40 minutes at 60°C. Pre-bleaching process was applied. In addition, an in vitro digestion model was established to examine bioavailability. According to the results of the study, a significant decrease in beta-carotene was observed as a result of heat treatment, while lycopene remained relatively stable. According to the results of the in vitro digestion model, lycopene bioavailability rates increased from 5.1 mg/kg to 9.2 mg/kg at low temperature, while this rate was 9.7 mg/kg at high temperature (Svelander et al., 2010).

In a study on the effect of different heat treatments on the in vitro bioavailability of lycopene in tomato, microwave heat treatment and high-pressure homogenization were applied at 70, 90 and 120°C for

20 minutes. Three different 5% oils (coconut oil, fish oil, olive oil) were also added. An in vitro digestion model was established. No significant difference was found regarding bioavailability in the in vitro model in high pressure/no pressure and with/without oil addition. Among the three different microwave heat treatments applied, the total bioavailability rate increased only at 120°C. This was explained by the increase in micellization with the disruption of the cellular structure. In addition, lycopene bioavailability increased by increasing micellization in the function of heating at 70 and 90°C with 5% oil addition (Colle et al., 2013).

In a study on the bioavailability of lutein and zeaxanthin in vitro after boiling seven different types of yellow-fleshed potatoes, potatoes were boiled for 20-25 minutes and then frozen at -70°C. An in vitro digestion model was established to examine bioavailability. The lutein and zeaxanthin concentrations of undigested samples varied between 65.4-395 mcg/100 g and 51.1-1196 mcg/100 g, respectively. In the in vitro digestion model, lutein and zeaxanthin concentrations decreased during the digestion stages and showed the least stability in the gastric environment. The digestive stability of both carotenoids in the duodenum was high, ranging between 70-95% (Burgos et al., 2013)

In a study investigating the relationship between different cooking methods of broccoli and the health of human subjects, three male and four female participants aged 25-35 years with a BMI of 18.5-25 kg/m2 participated. In the study, broccoli was frozen at -20°C for 15 days before cooking. The effects of boiling for 10 minutes and steaming at 99°C for 13 minutes on carotenoid contents were compared. Simultaneously, the participants followed a cleansing diet for at least two weeks and then took 400 grams of broccoli or three capsules of BroccoMax supplement in the morning on an empty stomach. Blood samples were then analyzed. According to the results of the study, lutein and beta-carotene were 0.37mg /100 g in raw broccoli. Beta-carotene content increased 3.3 times as a result of boiling method and 0.9 times as a result of steaming method compared to its raw state. Lutein increased 2.4 times after boiling method and 1.3 times after steaming method. The reason for this effect was observed to be the tissue softening event triggering the release of matrix components with boiling. However, no difference was observed between blood plasma carotenoid levels in both cooking methods (Orlando et al., 2022).

In a study with three men and nine women aged 25-48 years, the effect of bioavailability of different tomato purees on blood values in humans was examined. The participants were divided into two groups. The first group received Rustic tomato puree (32 kcal, 6 grams CHO, 1.1 dietary fiber) and the second group received strained tomato puree (26 kcal, 4.6 grams CHO and 0 grams fiber). The tomato purees were boiled for 30 minutes and frozen at -20°C before consumption. Participants were given 500 ml of water and 150 grams of tomato puree accompanied by five slices of white bread. At the same time, fasting blood was taken from the participants and blood samples were taken again at two, four, six and 24 hours after the test meal. Following the procedures, it was observed that strained tomatoes had higher concentrations of trans- and 5-cis-lycopene isoforms than rustic tomatoes. At the same time, lycopene and beta-carotene concentrations increased as a result of 10, 20, 30 and 40 minutes of boiling, cooking time and olive oil addition. When lycopene plasma concentrations were analyzed in the participants, trans lycopene concentration in the group consuming strained tomato puree exceeded basal levels two hours after food consumption compared to the other group. In the group consuming rustic tomatoes, an increase in lycopene levels was observed two and four hours after meal consumption. In conclusion, an increase in the bioavailability of lycopene was observed with the addition of olive oil and an increase in the cooking process (Vitucci et al., 2021).

Daniella tomatoes (Licopersicon esculentum Mill. cv) were treated with olive oil at 95-96°C at two different concentrations, 5% and 10%. The tomato was cooked for 15, 30, 45 or 60 minutes. The amounts of 13-, 5- and 9-(Z) lycopene increased by 31%, 18% and 15% in the tomato sauce obtained after cooking. In addition, 85.5 mg/kg in the form of all-E lycopene and 85.5 mg/kg in the form of all-E lycopene as a result of the addition of 5% olive oil in the cooking process for 15-30 minutes. As a result of the addition of 10% olive oil, it increased by 140.09 mg/kg. The findings obtained in the study suggest that as a result of this increase in carotenoid levels, lipid peroxidation may decrease, HDL may increase, and as a result of these effects, the incidence of chronic neurodegenerative diseases, such as cancer and cardiovascular diseases, may decrease (Vallverdú-Queralt et al., 2015).

In a study that investigated the changes in carotenoid concentrations of fresh leaves of Spinacia oleracea (oriental spinach) as a result of frying and non-frying process; the leaves were fried in 500 grams of sunflower oil at 250°C for 15, 30, 45 and 60 minutes. As a result of frying, the amount of beta-carotene increased from 1.44 mg/100 g to 6.64 mg/100 g. All-e-lutein content increased from 19.1 mg/100 g to 37.5, 44.2, 47.8 and 50 mg/100 g at 15, 30, 45 and 60 minutes, respectively (Zeb & Nisar, 2017).

A study examined the changes in blood lycopene concentrations of cooking and fresh forms of tomatoes in nine men and nine women aged 25-75 years; crushed tomatoes, crusted tomatoes with olive oil added and cooked tomatoes with olive oil added were compared. Blood samples were taken from the participants. The results of the study showed that blood lycopene levels increased less in crushed tomatoes (0.17 mmol/L) than in tomatoes with added olive oil (0.21 mmol/L). Cooked and olive-oil added tomatoes showed an increase in blood lycopene levels. Age and gender did not play a role in the effect on plasma lycopene levels (Perdomo et al., 2012).

4. Conclusions

Common cooking techniques include boiling, microwaving, frying, and steaming. It can enhance flavor, neutralize anti-nutritional compounds and toxic substances by softening the food matrix after foods are cooked. However, cooking may or may not affect the bioavailability of carotenoids. While some studies suggest that carotenoid contents increase after cooking, others have shown a detrimental effect on these compounds. These variable results may depend on the cooking method applied, the duration of heat exposure, and the type of food used in cooking. Carotenoid contents differ according to various factors, such as food type, seasonality, variety, maturity level, processing, storage conditions and climatic conditions. However, some factors increase or decrease the bioavailability of crude amounts of carotenoid concentrations in foods. One of them is heat treatment, which may decrease or increase according to the type of carotenoid. It was observed that there were changes in the bioavailability of lycopene, lutein and beta-carotene carotenoids in the body as a result of heat treatments, such as boiling, microwave, frying, steaming, sous vide and cook vide. According to the results of in vitro studies investigated various vegetables and fruits with the effect of exogenous factors as a result of the literature review, it was observed that the bioavailability increased as a result of the addition of oil, increase in lycopene processing, decrease in food particle size, increase in micellization with the breakdown of dietary fibers, and destruction of cell walls with heat treatment. Besides, the addition of olive oil with heat treatment and the decrease in food particle size had positive effects on health by transforming carotenoids into forms with high bioavailability in the body.

Declaration of Competing Interest

The authors declare that they have no financial or non-financial competing interests.

Author's Contributions

M. A. Çakır (0000-0001-5066-1956): *Study design, Methodology, Draft preparation, Critical review, Final approval.*

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