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FACTORS AFFECTING CAROTENOID AMOUNT IN CARROTS (Daucus Carota)

ABSRACT

In this study investigated the factors affecting the changes in carotenoid levels in carrots which are rich in vitamins, minerals, pulp, antioxidants and carotoneids. Nowadays, increasing interest in healthy nutrition, determining the positive effects of vegetables on human health are increasing the importance of carrot plant which contains plenty of antioxidant substances like carotenoids, β-carotene and vitamin A. Carrot contains carotenoids such as α-, β-, γ-, ζ-carotene, lutein, β-zeacharotene and lycopene, and 60-80% of them are β-carotene. Carrot is the first carotene isolated vegetable and one of the most important sources of vitamin A.

Keywords: Daucus carota L, Carotenoids, Beta carotene, Vitamin A, β-zeacharotene and Lycopene

1. INTRODUCTION

In recent years, vegetables are not only nutrition, but also come to the fore with healthy living, protection from diseases and therapeutic properties. Vegetables and fruits are important sources of vitamins, minerals, trace elements, dietary fibre and a large variety of beneficial phytochemicals, which might decrease the risk of certain age-related and cardiovascular diseases. Therefore, the dietary guidelines recommend eating at least five portions of fruits and vegetables a day [1]. Carrot is a vegetable rich in bioactive compounds that contributes to human health. The nutrient content of fresh carrot, considered as 100g of vegetables, is given in Table 1.

Table 1. Carrot nutrient content

Nutrient Content Unit	100 g Consumable Quantity
Water(g)	88.29
Protein(g)	0.93
Total Fat(g)	0.24
Ash(g)	0.97
Carbohydrate(g)	9.58
Fiber(g)	2.8
Total Sugar(g)	4.54
Starch(g)	1.43
Vitamin C(mg)	5.9
Vitamin A(IU)	16811

USDA National Nutrient Database for Standard Reference, Release 18 (2005) [2]. Several factors are affecting the quality of carrots. The quality characteristics of the carrot are closely related to biotic and abiotic stress factors. Carrot is exposed to stress factors that affect quality in different aspects from seed to consumption. The

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genetic factor gives an idea about the level of important chemical compounds that determine the sensory and health-related properties of carrots. In addition, processing factors such as climate characteristics, growing system (traditional or organic), fertilization and post-harvest transport and heat treatment affect the sensory quality of carrots [3].

2. RESEARCH SIGNIFICANCE

To grow genetically high carotenoid-rich varieties in ideal conditions, to use appropriate processing technologies to minimize carotenoid losses, is very important for healthy nutrition. The aim of this study is to contribute to the preservation of the health and nutritional properties of carrot by determining the factors affecting the amount of carotenoid in carrots during the production and processing period.

3. CAROTENOIDS

Carotenoids were first isolated from the carrots by Weckenroder in 1831. It is one of the most important pigment groups in nature with its wide distribution, structural differences, and a wide variety of effects and functions [4]. Carotenoids are a class of natural pigments familiar to all through the orange-red colours of popular foods like oranges, tomatoes and carrots and the yellow colour of many flowers. They have been studied for a number of years because of their diverse roles in photobiology, photochemistry and photo medicine. Carotenoids are also added as colorants to many manufactured foods, drinks, and animal feeds, either in the forms of natural extracts (e.g annatto, paprika or marigold extracts) or as pure compounds manufactured by chemical synthesis. Carotenoids are often described as provitamins A, as this particular vitamin is a product of carotenoid metabolism. The distribution of carotenoids among the different plant groups shows no obvious pattern. b-Carotene is the most abundant in leafy vegetables, though the colour is masked by its co-existence with chlorophyll, and this carotenoid has the highest vitamin A activity. Zeaxanthin, a-carotene and antheraxanthin are also present in small amounts [5].

3.1. Chemical Structure and Properties of Carotenoids

More than 600 different carotenoids from natural sources have been isolated and characterized. Physical properties and natural functions and actions of carotenoids are determined by their chemical properties, and these properties are defined by their molecular structures. Carotenoids consist of 40 carbon atoms (tetraterpenes) with conjugated double bonds. They consist of eight isoprenoid units joined in such a manner that the arrangement of isoprenoid units is reversed at the center of the molecule so that the two central methyl groups are in a 1,6-position and the remaining nonterminal methyl groups are in a 1,5-position relationship. They can be acyclic or cyclic (mono- or bi-, alicyclic or aryl). Whereas green leaves contain unesterified hydroxy carotenoids, most carotenoids in ripe fruit are esterified with fatty acids. However, those of a few fruits, particularly those fruits that remain green when ripe, such as kiwi fruit, undergo limited or no esterification. Cyclization and other modifications, such as hydrogenation, dehydrogenation, double-bond migration, chain shortening or extension, rearrangement, isomerization, introduction of oxygen functions, or combinations of these processes, result in a myriad of structures. A distinctive characteristic is an extensive conjugated double-bond system, which serves as the light-absorbing chromophore responsible for the yellow, orange, or red color that these compounds impart to many types of foods [6].

Carotenoids have conjugated reactive double bonds, which give these pigments antioxidant properties that affect free radicals [7]. Carotenoids according to their chemical structure are classififed in two groups Carotenes which contains no oxygen atom, contains carbon and hydrogen atoms (α-carotene, β-carotene, lycopene, etc.) and Xanthophylls; carotenoids (lutein, zeaxanthin, canthaxanthin, astaxanthin etc.) which have at least one oxygen atom in the structure and may contain hydroxyl and ketone groups. When carotenoids are named, they are usually associated with the source from which they are isolated (β-carotene-Daucus carota) [8]. The most common carotenoids are β-carotene, the leading agent of lycopene and vitamin A. Boiling points are high and range from 130-220°C. They show maximum absorbance at wavelengths of about 430-480 nm. In addition, some carotenoids found in roots and leaves are the precursor of abscicic acid which is a chemical carrier and growth regulating compound [9]. During photosynthesis, they have biological functions such as absorbing light, transferring energy, and protecting cells from the harmful effects of light [10]. Carotenoids are lipophilic compounds which dissolve in oil and organic solvents such as chloroform, benzene, petroleum ether, carbon disulfide, and are not soluble in alcohol. Carotenoids, which have a polyunsaturated structure, are stable to heat but are isomerized during process and storage [11].

3.2. Carrot Carotenoids

Carrot is an important source of vitamin A and antioxidants with high carotenoid content. Carrot contains carotenoids such as α-, β-, γ-, ζ- carotene, lutein, β-zeacharotene and lycopene. The most dominant ones are α-carotene and β-carotene which theoretically meets 50-100% of vitamin A activity [12]. 94-97% of total carotenoids comprise α-, β-, γ- carotene. β- carotene have the largest share with 44-79%, followed by α- carotene with 13-40% [13]. Carotenoid amounts may vary in different parts of carrot, fruit crust and flesh is found in higher amounts than the inner core. Carotenoids and their amounts determined in carrots by different investigators are given in Table 2.

Table 2. Carotenoids in carrots

Resource	Carotenoids (mg/kg)			
	β-karoten	α-karoten	Lutein	γ-karoten
Alasalvar et al. (2001) [12]	69.4	39.9	-	-
Bureau and Bushway (1986) [14]	76	37.9	-	-
Bushway and Wilson (1982) [15]	46.0-125.0	20.0-59.0	-	-
Bushway (1986) [16]	68.3-111.2	37.7-40.2	-	-
Hart and Scott (1995) [17]	85.2-108.0	26.6-36.1	1.7-2.8	-
Heinonen et al. (1989) [18]	76.0	53.0	3.0	-
Heinonen (1990) [19]	46.0-103.0	22.0-49.0	1.1-56	6.3-270
Konings and Romans (1997) [20]	130.0	48.7	2.9	-
Niizu and Rodriguez-Amaya(2005)[21]	61.5	35.0	51	-
Olives Barba et al. (2006) [22]	63.0-96.0	-	-	-
Simon and Wolff (1987) [23]	52.0-117.0	32.0-66.0	-	-
Skrede et al. (1987) [24]	55.5-66.0	23.0-25.0	-	-
Sulaeman et al. (2001) [25]	86.26	31.6	3.9	-

4. FACTORS EFFECTING THE CAROTENOID AMOUNT IN CARROTS

4.1. Effect of Genotype

In scientific studies conducted with a large number of carrot varieties with different characteristics; different line, fruit flesh color, hue, chroma values are reported to be different. Therefore, it is possible to say that carotenoid content is a genetically controlled property. Carotenoid substances in fruits and vegetables vary in different varieties of the same species, usually orange and red carrot varieties are found to contain higher carotenoids than white and yellow colored [26]. Carotenoid amounts in different parts of the carrot may vary. Usually the amount of carotenoid is higher in the shell part than the woody core part. In their study, Surles et al 2004 found that white, yellow, orange and red carrots had different carotenoid composition and the carotenoid content changed according to the color characteristics of carrot roots [27]. Although hereditary factors are effective on carotenoid components in carrot, the variations obtained as a result of cultivation of the same variety in different ecologies indicate that environmental factors are effective on accumulation. Total carotenoid matter distribution and antioxidant content of different carrot varieties were determined in different regions and total carotenoid amounts between orange carrot varieties (Bolero, Presto-F1, Nanco, Maestro-F1) ranged from 65.14 to 93.17mg/kg. and the carrots obtained from Beypazarı were found to have higher carotenoid values than the Burdur and Konya regions [28]. In the work studied in control and water-restricted conditions with five carrot genotypes contrasting by their root color, carotenoid content and the relative expression of 13 genes along the carotenoid biosynthesis pathway were measured in the respective tissues. This work shows that the structural aspect of carrot root is more important for carotenoid accumulation in relation with gene expression levels than the consequences of expression changes upon water restriction [29].

4.2. Effect of Climatic Factors

Scientific studies shows that weather conditions affect the carotenoid content of carrot, the carotene content increases with the length of the growing season and is affected by changes in climatic conditions[30; 31]. Considerable variation can also be seen for total sugars (82%), β-carotene (40%), phenolics (28%), sweet taste (35%), bitter taste (30%) and DM (29%) when comparing carrots grown in different climates, locations or years. Thus the quality that is laid down by a particular variety or cultivation practice can to large extent be changed in unexpected directions by climate factors [3].

4.2.1. Temperature

It is reported that the most important climate factor affecting carrot cultivation is temperature [32]. Temperature is effective on the shape and color of the root as well as the plant growth and the optimum temperature limits are 15-18°C. Light color carrots are obtained in cold and wet production seasons. In harvest period at temperatures of 10°C colour is not satisfactory. Temperature is directly effective in root formation and carrot length remains short at high temperatures. At low temperatures, carrots show the characteristics of carrots, but this time the color and the diameter of the carrot grow poorly, and longer and light colored carrots occur. The best growth is at temperatures around 20°C. In the spring production in hot regions, a significant portion of the plants are flowered by passing the generative phase without producing carrots of sufficient size. During the first root growth period of the carrot, the plant shows only the longitudinal growth, during the second root development root begins to develop as a storage organ and grows transversely. Low temperatures, inadequate sunshine and nutrient deficiencies in this period cause the root to remain thin, carotenoids are poor and the color shifts to yellow [33]. Besides genetic factors, environmental factors significantly affect the amount of carotenoid in carrot. Carotenoid content is generally higher in warmer conditions [34 and 35]. Karabacak, E.Ç., in the study on mini carrots in 2010 identified that total carotenoid content is related to root color and the amount of dry matter. The amount of carotenoid increases as the root color of the carrot becomes darker and dry matter accumulation increases [36]. Temperature was found to have a significant influence on root firmness, total soluble solids, carotene, β-pinene and caryophyllene. The internal quality parameters such as root firmness, total soluble solids and carotene were the best at the lower temperature treatments [37].

4.2.2. Light

It is known that carotenoids in chloroplasts in high plants play a role in photosynthesis and protect the plant from light. Carotenoids are secondary plant pigments that store light energy in all plant tissues containing chlorophyll. In addition, it is stated that some carotenoids are present in the roots and leaves and are the precursor of abscic acid which is a growth regulating compound. It is reported that light promotes carotenoid synthesis and that light exposure level of the plant is one of the important factors affecting carotenoid concentration. [38]. It was determined that increased amount of photosynthetic light increases the carrot yield per plant and the yellow and white cover increases the β-carotene concentration. Reflection of colored light from the soil surface affected the developing leaves, increased the edible root yield of the carrot and affected the chemical composition [39]. Work with Arabidopsis revealed molecular factors coordinating carotenoid biosynthesis and storage with photosynthetic development during deetiolation, when underground seedlings emerge to the light. Some of these factors also adjust carotenoid biosynthesis in response to plant proximity (i.e., shade), a mechanism that was readapted in tomato to monitor fruit ripening progression. While light positively impacts carotenoid production and accumulation in most cases, total carotenoid levels decrease in roots of colored carrot cultivars when illuminated [40]. It was determined that the frequency of planting affects the α-carotene content in carrots and increased the amount of carotene as the number of plants in the unit area decreases and the UV radiation reaching the plants increases. Cultivation of carrot in the intense UV rays may increase the carotene content [3].

4.3. Impact of Cultural Transactions

4.3.1. Soil Type

Soil pH is important for carrot growing. Carrot is sensitive to high acidity. Deep textured sandy-clayey soils with a pH value of 6-6.5 are ideal soils for carrot cultivation [33]. Pietola, in his study in 1995, was carried out carrot production in untreated fine sand, clay and humusous soils where sprinkler irrigation was used and compacted by cylinder. It was determined that the internal quality characteristics of the carrots were affected very little by the changes in the physical properties of the soil and the external quality of the carrot (thick, short, deformed and conical root) was adversely affected. The lowest carotene content (4mg/100g carrots) was obtained from carrots grown in loosely grown soils, sown in March and harvested after a cool summer [41].

4.3.2 Environmental stress

Studies show that feeding the plants with ideal N, P, K provides more resistance to diseases and pests, and that root growth and health values are higher. Information on the impact of environmental and other stress factors on carotenoid accumulation is limited. Florent, et al 2017 investigated the effect of environmental stress on carotenoid accumulation in carrot roots and leaves in two different seasons. Consequently, combined stress significantly reduced carotenoid content in leaf and root, carotene accumulation was more than the leaves on the roots, *A. dauci* infection in the roots reduced the carotenoid content, carotenoid and sugar contents had high correlation and stresses changed the carotenoid content depending on genotype and year [42].

4.3.3. Fertilization

Studies have shown that the use of Nitrogen fertilizer has a positive effect on the total amount of carotenoid, phenolic and vitamin C in carrot roots [43]. Kiracı, et. al, in his study in 2014; investigated the effects of different microbial fertilizers and their different doses on carrot quality characteristics. As a result, it was determined that the applications had a positive effect on the β-carotene content of carrot [44]. N, P, K and organic fertilizers applications increased the carotene content in carrots and the most suitable feeding program for maximum carotene accumulation was established [45]. Analysing the influence of soil fertilization with iodine and selenium compounds on the carotenoid content of carrot, a significant decrease of carotenoid content in plant roots fertilized simultaneously with iodine and selenium was clearly distinguished [46]. Foliar application of selenite increased the content of Se in the shoots and the content of carotenoids in the roots. Both sources of Se (selenate and selenite) and application forms (soil or foliar application) increased their content in the roots [47].

4.3.4. Irrigation

The studies revealed a significant increase in the contents of dry matter, free amino acids and carotenoids in carrot roots cultivated in the year with the lowest amount of rainfall in the summer months [6]. In their study, Fikseloua et al 2010 found that irrigation and excessive rainfall reduced the content of dry matter and β-carotene and that β-carotene content was significantly different between varieties and that hot and dry air increased the content of β-carotene [48].

4.4. Harvest Time and Effect of Growing Period

Heinonen was determined that the carrot longer growing season increased the accumulation of dry matter and increased the amount of carotenoid and β-carotene content (26-55mg/kg), which was low in summer (June-August), reached the highest level in winter (46-77mg/kg) in his research in 1990 [19 and 49]. Similar results were found in the study of mini carrots. Total carotenoid amounts in mini carrots are low due to short production period in spring and summer months, in autumn and winter, due to the length of time until harvest, total carotenoid amounts were found to be high [36].

4.5. Color and Degree of Ripening

The degree of ripening affects the amount of carotenoid material in plants and carotenoid amounts increase during carrot development. Approximately 4 weeks after seed sowing, small, colorless roots are formed in all white, yellow, orange and red carrots. Carotenoid levels are very low at this stage. It was determined that carotenoid amount increased between the 4th and 8th weeks of development. After 8 weeks, a rapid increase in carotenoid accumulation was detected and at the 14th week all carrot varieties had different carotenoid contents and the highest pre-harvest accumulation was found [50]. Wu, et al, in their study in 2000, the relationship between β-carotene content and dry matter content of 4 different carrot varieties was investigated. As a result, increased amount of dry matter increased the amount of β-carotene, β-carotene content was different among varieties and in all varieties in the mature period β-carotene amount reached the maximum level [51]. The total amount of carotenoid matter was associated with the root color and as the carrots mature, the color became more pronounced and dry matter accumulation increased.

4.6. The Effect of Post-Harvesting and Storage

In carrot after harvesting, some quality defects such as carotenoid loss, loss of taste and bitterness may occur. In order to reduce quality loss, it is recommended to store carrots at the most ideal 0°C and %93-98 relative humidity. Bagdatlioglu, et al., in 1999 determined that the most effective inhibitor protecting carotenoids against oxidation was sulfur dioxide and sülfite, food should be stored under inert gas and in packages with low light transmittance in order to store the carotenoid ratio unchanged. It was determined that carotenoids are more resistant to heat treatment applications in oxygen-free environments and the humidity of the environment is effective in maintaining the carotenoid stability. Carotenoid degradation slowed down at high humidity (%10-14), and carotenoid fragmentation was accelerated at low humidity (<%8). It is stated that moisture protects the carotenoids from oxidation by directly affecting the free radicals [52]. The deterioration rate of carotenoid pigments was determined to be dependent on storage time, oxygen and light presence, while the oxygen effect is the lowest, the storage time is the most effective factor [53]. It was observed that the loss of β-carotene content in carrots was higher in the cellar than in the cold storage and that Florida F1 was the most suitable for storage [54]. After 5-months of storage, the organic carrots had significantly higher total soluble solids (TSS) and β-carotene content compared to the conventional ones indicating that organically grown carrots were less susceptible to storage conditions [1].

4.7. Effect of Processing Technology

Differences in carotenoid losses due to factors such as heat, light and oxidation were determined. β-carotene in dried carrots stored at different temperatures was found to be lost according to the first order reaction kinetics [55]. The double bonds in the carotenoid molecule make the molecule susceptible to oxidative degradation. The susceptibility of carotenoids to oxidation is influenced by environmental conditions and increases by processes such as physical damage or extraction [9]. When the carotenoids stable within the structural composition of the food are exposed to enzymes such as heat, light, oxygen, peroxides, transition metals, lipoxygenase, they rapidly cause color and biological function losses as gradients. Oxidative changes in carotenoids occur in basic procedures such as desiccation, freezing and drying [56]. As the surface area increases in the drying of carrot slices, contact with air increases and carotenoids become more sensitive to oxidation [9 and 11]. Carotenoid losses occur during processes such as disintegration, grinding [57] boiling, cooking [58], drying, freezing, irradiation [59] storage [60]. It has been reported that oxidation is prevented due to the removal of air during the processing of canned food, but the carotene content is reduced due to the heat treatment and isomerization applied. In the case of pickled products, in addition to thermal processing, salt and acetic acid in salami are effective on carotenoids and the salt concentration has a negative effect on the stability of carotenoids [61]. Boiling affects nutritional and health aspects by degrading phenolics (−150%), ascorbic acid (−100%), terpenes (−85%), total carotenes (−20%) and sucrose (−38%) [3].

5. RESULT

Soil properties, plant density, irrigation and fertilization, sowing time, disease and pest control, post-harvest storage and processing technologies should be taken into consideration in order to provide the expected benefits of carrot in the health and nutritional characteristics. Genetic sources with high carotenoid content should be preserved, and healthy and quality products should be obtained by carrying out breeding studies to develop new varieties. If the ideal growing conditions can be provided in the varieties with high carotenoid content and the carotenoid amounts can be maintained while the basic procedures are applied, the health benefit will be maximized.

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