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Chemistry, encapsulation, and health benefits of β-carotene - A review

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Abstract: *β*-carotene is a principle carotenoid in carrots, and of the most common and widely studied carotenoids. Carotenoids are the phytonutrients that impart a distinctive yellow, orange, and red color to various fruits and vegetables. *β*-carotene is important not only for the color that it imparts to the food stuffs, but also because of the myriad of associated health benefits. It is the most potent precursor of vitamin A and is present naturally as a mixture of various isomers (*cis* and *trans*) of *β*-carotene molecule. It has a potent antioxidant capacity and offers an array of health benefits such as lowering the risk of heart diseases and certain types of cancers, enhancing the immune system, and protection from age-related macular degeneration—the leading cause of irreversible blindness among adults. Consumer attitude towards bioactive compounds, including *β*-carotene, as natural colorants and for health benefits is promising. Incorporation of *β*-carotene in various food systems is limited by its poor water solubility and instability in presence of light, heat, and oxygen. Encapsulation can be a way forward to improve the stability and help in effective delivery of *β*-carotene.

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PUBLIC INTEREST STATEMENT

β-carotene is one of the important bioactive components with potent antioxidant activity. The review focuses on various aspects concerning the chemistry and health benefits of this important carotenoid. The present work collects information that may be of interest both to industry and to researchers as regards the opportunity of healthier diets and their role in disease prevention.

Subjects: Engineering & Technology; Food Science & Technology; Health and Social Care

Keywords: *β*-carotene; natural colorant; antioxidant; encapsulation; health benefits

1. Introduction

Carotenoids are organic pigments found in chloroplast of plants and other photosynthetic organisms like algae, some bacteria, and fungi. Carotenoids are defined by their chemical structures having 40 carbon chains and are classified as: (i) Carotenes comprised entirely of carbon and hydrogen, e.g. *α*-carotene, *β*-carotene, and lycopene; and (ii) Oxygenated derivatives of these hydrocarbons known as xanthophylls, e.g. lutein and zeaxanthin (Britton, 1995; Qian, Decker, Xiao, & McClements, 2012).

Beta carotene (Greek *beta* and Latin *carota* (carrot)) is an important member of the carotenoid family and is a strongly red orange-colored pigment abundant in plants and fruits. *β*-carotene is regarded as the major carotenoid present in human diet (Johnson, 2002) and is in turn the main source of vitamin A in humans. It is a precursor of vitamin A having potential to yield two retinol molecules in presence of oxygen by the action of *β-carotene* 15, 15′-monooxygenase (Van-Arnum, 2000). The main sources of β-carotene are apricots, asparagus, carrots, broccoli, Chinese cabbage, grapefruits, chilli powder, and paprika (Table 1). *β*-carotene is most widely studied of the major carotenoids in the human diet, blood, and tissue as it has the highest provitamin A activity and its deficiency can result in xerophthalmia, blindness, and premature death (Mayne, 1996).

Table 1. *β*-carotene content in various foods

Source	*β*-carotene content/range	Reference
Carrot	5,340 (μg/100 g)	Patricia, Nizu, and Rodriguez (2004)
	11,210 (μg/100 g)	Ahamad, Saleemullah, Shah, Khalil, and Saljoqi (2007), Ullah et al. (2011)
	47.5 (μg/g)	EL-Qudah (2009)
	1,030 (μg/g)	Ben-Amotz and Fishier (1998)
	61 (μg/g)	Niizu and Rodriguez-Amaya 2005
Tomato	1,610 (μg/100 g)	Ahamad et al. (2007), Ullah et al. (2011)
	3,500 (μg/100 g)	Patricia et al. (2004)
	0.79 (μg/g)	EL-Qudah (2009)
	14.5 (μg/g)	Ben-Amotz and Fishier (1998)
	61 (μg/g)	Niizu and Rodriguez-Amaya 2005
	0.23–2.83 mg/100 g	Baranska, Schütze, and Schulz (2006)
Spinach	9,940 (μg/100 g)	Ahamad et al. (2007)
Lady finger	520 (μg/100 g)	Williams, Boileau, and Erdman (1998)
	3,320 (μg/100 g)	Ahamad et al. (2007)
	3,220 (μg/100 g)	Ullah et al. (2011)
Brinjal	2,100 (μg/100 g)	Ahamad et al. (2007), Ullah et al. (2011)
Green chilli	1,750 (μg/100 g)	Ahamad et al. (2007), Ullah et al. (2011)
Strawberry	8.5 (μg/100 g)	Charoensiri, Kongkachuichai, Suknicom, and Sungpuag (2009)
Green beans	0.23 (μg/g)	EL-Qudah (2009)
Grapes	6.6 (μg/100 g)	Charoensiri et al. (2009)
	24.5 (μg/100 g)	Kim, Giraud, and Driskell (2007)

Research studies and epidemiological data have shown that antioxidants such as vitamin E and carotenoids such as *β*-carotene, lycopene, lutein, and zeaxanthin contribute to preventing degenerative diseases, such as cardiovascular diseases, diabetes, and several types of cancers (Maughan, 2005; Singh & Goyal, 2008). *β*-carotene, a phytochemical, is believed to have many health benefits as it has potential anticancerous and antioxidant properties (Silalahi, 2002). Recent years have witnessed rapid expansion of world markets and the demand for foods (fruits and vegetables) rich in carotenoids and other bioactives is promising (Wani, Singh, Gul, Wani, & Langowski, 2014).

β-carotene, used in food industry as a precursor of vitamin A or as a natural colorant, is a labile compound and easily degraded by heat, light, and oxygen. Attempts are being made to increase the shelf stability of *β*-carotene towards various processing conditions. Among several strategies to protect *β*-carotene, encapsulation is one of the prominent means and has improved its stability for use in food and allied industries. This review aims to explore various functionalities of *β*-carotene including its chemistry, isolation, encapsulation, and the associated health benefits.

2. Chemistry and isolation of *β*-carotene

β-carotene is an isoprenoid compound and one of the approximately 600 fat-soluble carotenes found in plants (Khachik, Beecher, & Smith, 1995) and micro-organisms (EFSA, 2012) with chemical formula $C_{40}H_{56}$ and molecular weight 536.88. It is biosynthesized by tail-to-tail linkage of two C_{20} geranyl-geranyl diphosphate molecules, producing parent C_{40} carbon skeleton from which all individual variations are derived (Dutta, Raychaudhuri, & Chakarborty, 2005a). *β*-carotene is recognized as an antioxidant capable of preventing cellular damage and is a promising potent antioxidant with capability of quenching up to 1,000 free radicals per molecule. *β*- carotene occurs in the form of red to brownish-red to violet crystals or crystalline powder, and contains predominantly all *trans* (Z) isomer of *β*-carotene with varying amounts of the *cis*-isomer depending on different formulations. Most *β*-carotene is naturally present in the all-*trans* form; however, some amounts of *cis*-form are also present in foods (Ma, Xu, Zhang, Shangguan, & Li, 2008); with relative abundances in following order: all-*trans*>9-*cis*->13-*cis*>15-*cis* (Guo, Tu, & Hu, 2008). All *trans*-*β*-carotene is highly unstable and is easily isomerized into *cis*-isomers. *Trans*-*β*-carotene immediately undergoes thermal and chemical oxidation, isomerization, and photosensitization when exposed to oxygen, light, and high temperature during processing and storage. Some of the important characteristic features of *β*-carotene are presented in Table 2.

More than 600 different carotenoids have been isolated and characterized from natural sources. *β*-carotene, a principle carotenoid in foods, can reliably be determined either by using an open column chromatography (OCC) or high-performance liquid chromatography (HPLC) and the purity of *β*-carotene standard obtained and quantified by HPLC is between 92.21 and 97.95% (Noorshazila, Irwandi, Othman, & Yumi-Zuhanis, 2012). Isolation of *β*-carotene from fruits abundant in carotenoids is commonly done using column chromatography (Jing, Qun, & Rohre, 2012). The separation of *β*-carotene is based on the polarity of a compound. As *β*-Carotene is non-polar in nature; it is separated with a non-polar solvent such as hexane (Mercadante, Steck, & Pfander, 1999). Filtration method is required after the extraction before analyzing the extract further. Sample and the solvent are placed in a round-bottom flask equipped with a condenser. The mixture is heated to reflux for a predetermined time and the sample is possibly taken during the time of the session to analyze the reaction progress and eventually all the solute is extracted from the matrix without too much solvent consumption. Most researchers use hexane for extraction and measure OD at 450–460 nm (Kim & Gerber, 1988; Zhou, Gugger, & Erdman, 1994). In case of algae, extraction can be carried out by using large amounts of edible oil where the mass transfer is promoted by homogenization at high pressure. Other methods of extraction have also been used such as supercritical carbon dioxide extraction (Maćias-Sánchez et al., 2005), extraction using pressurized liquids (Herrero, Jaime, Martin-Alvarez, Cifuentes, & Ibanez, 2006), and solvent extraction with solvents like hexane, acetone, and ethanol. Marchal, Mojaat-Guemir, Foucualt, and Pruvost (2013) employed centrifugal partition chromatography (CPC) to extract *β*-carotene from *Dunaliella salina* and optimized the process for efficient and biocompatible recovery of metabolites.

Table 2. Some of the characteristic features of β-carotene

S. No	Characteristics	Description
1	*Structure/chemistry*	
	Molecular formula	$C_{4}0H_{56}$
	Molecular mass	536
	Double bonds	11
	Beta-ionone ring	Present
	Solubility	Highly lipophilic
2	*Activity*	
	In vitro antioxidant	Modest
	In vitro prooxidant	Yes, at high concentrations and partial pressures
	In vivo antioxidant	Circumstantial evidence for lipids
	Smoking oxidation products	Yes
	Conversion to retinoids	Substantial, by multiple routes
	Immune function	Enhanced
	Cell-to-cell communication	Enhanced
	Cell cycle progression	Circumstantially inhibits
	Carcinogen metabolism	Can modulate
	Animal cancer studies	Antitumor
3	*Exposure sources*	
	Diet	Dark green, yellow, and orange fruits and vegetables, red palm oil, food colorant
	Dominant source	Carrots, cantaloupe, broccoli, spinach, and mixed greens
	Supplements	Multivitamins, single-source supplements, and food/beverage fortification
4	*Metabolism*	
	Bioavailability	Poorly available from greens and carrots
		Cooking enhances
		Dietary fat enhances
		Highly available from supplements
	Isomerization	All *trans*-in circulation
	Tissue accumulation	Found in all human tissues
		Supra-accumulation in testes and adrenal glands
	Major storage pool	Adipose tissue and liver
	Circulation half-life	< 12 days
	Plasma concentrations	Multifactor dependency: Diet, Lipoprotein concentrations, Adiposity, and Smoking

Source: Adapted and modified from Arab, Steck-Scott, and Bowen (2001).

Extraction of carotenoids with water and separation is the general method used and same stands true for β-carotene as well. However, the hydrogen-carbon skeleton of the molecule endows it a lipophilic property and even marginally soluble in oil at room temperature (Mattea, Martin, Matias-Gago, & Cocero, 2009; Ribeiro & Cruz, 2005). The extraction yield of β-carotene is strongly influenced by the time, temperature, and treatment (storage) given to particular food. Heat treatments such as blanching, cooking, and steaming can help release carotenoids bound by proteins and render them easily extractable (Dutta, Raychaudhuri, & Chakarborty, 2005b). The influence of various conditions (time, temperature, and storage) on extraction yield of β-carotene (Table 3) has been reported by Fikselova, Silhar, Marecek, and Francakova (2008).

Table 3. Influence of time, temperature, and storage conditions on extraction yield (mg/100 g) of β-carotene from carrot

Time of extraction (min)	Treatment of samples at 40°C			Extraction time (min)	Treatment of samples at 60°C		
	After harvest	Cold storage	Freezing		After harvest	Cold storage	Freezing
60	2.11	2.35	2.52	10	2.59	2.9	3.63
120	2.14	2.56	2.56	60	4.12	5.22	5.68
180	2.19	2.59	2.59	120	4.22	5.29	6.22
240	2.3	2.61	2.61	180	4.05	5.14	6.33
300	2.47	2.69	2.69	240	3.98	5.11	6.45

Source: Adapted and modified from Fikselova et al. (2008).

The successful incorporation of this carotenoid in various food systems is limited by low water solubility accompanied with crystalline nature at ambient temperature.

3. Bioavailability of β-carotene

The bioavailability is the proportion of a particular nutrient that is digested, absorbed, and metabolized through normal pathways. There are diverse factors which limit the bioavailability of β-carotene (Sy et al., 2012). In general, bioavailability of β-carotene has often been found to be limited depending on the accompanying components present in the food (Ribeiro, Chu, Ichikawa, & Nakajima, 2008). Various studies have been carried out to understand the bioavailability of β-carotene in different model systems (Garrett, Failla, & Sarama, 1999; Gireesh, Nair, & Sidhakaran, 2004; Granado-Lorencio et al., 2007; Haskell, 2012; Rodriguez-Amaya, 2010). Fruits and vegetables and their co-products are the major dietary sources of β-carotene. In plant tissues, it is localized in cellular plastids where carotenoids are associated with light harvesting complexes or crystalline structures. Intestinal absorption of β-carotene in humans depends largely on a number of factors, but not limited to amount of β-carotene consumed in a meal, conversion of provitamin A carotenoids to vitamin A, rate of absorption, transport, chemical nature, nutrient status of the host, genetic factors, host-related factors, interactions of these factors, fat content of the diet, and the complexity of its release in GI tract during digestion (Castenmiller & West, 1998; Parada & Aguilera, 2007; Parker, 1997; Qian et al., 2012).

The type of food matrix in which carotenoids are located is a major factor influencing the bioavailability of β-carotene (Haskell, 2012). The bioavailability of β-carotene from vegetables in particular has been reported to be low (14% from mixed vegetables) compared with that of purified β-carotene added to a simple matrix (Gireesh et al., 2004). The relatively low bioavailability of carotenoids from natural sources has been attributed to the fact that they exist either as crystals or are located within protein complexes that are not fully released during digestion within GI tract (Williams et al., 1998).

Carotenoid (β-carotene) is extracted from the food matrix, solubilized in bile acid micelles, and absorbed by the enterocytes, also called as intestinal absorptive cells. Dietary fat and endogenous emulsifiers (bile acids) are necessary to incorporate carotenoids released from the food matrix into mixed micelles. It appears that 3–5 g of fat is sufficient for the absorption of carotenoids (van Het Hof, West, Westrate, & Hautcast, 2000). Factors such as food, food treatment and composition, secretion of digestive enzymes and bile acids into the small intestine make it difficult to predict the relative bioavailability of β-carotene for any subject on the basis of his fruit and vegetable consumption.

In vitro models can help investigate the uptake of particular carotenoid, simultaneously avoiding the effects of certain factors like efficacy of food matrix disruption, solubilization of carotenoid, and incorporation into mixed micelles, which are difficult to control (Briviba, Schnabele, Schwertle, Blockhaus, & Rechkemmer, 2001).

4. Encapsulation of β-carotene

The utilization of β-carotene as a nutraceutical ingredient or natural colorant within foods is currently limited by a number of factors such as poor water solubility, high melting point, chemical instability, lipophilic character, and low bioavailability (Gutiérrez et al., 2013; Liang, Huang, Ma, Shoemaker, & Zhong, 2013; Qian et al., 2012). β-carotene is also highly unstable and susceptible to physical and photochemical degradation during food processing and storage due to the effects of chemical, mechanical, and thermal stresses (Desobry, Netto, & Labuza, 1998; Nguyen & Schwartz, 1998; Mao et al., 2009). The nature of being prone to degradation results in loss of its properties. Low water solubility and crystalline nature at ambient temperature means that β-carotene has to be dissolved in oils or dispersed in suitable matrices before it can be utilized in various food systems (Donhowe, Flores, Kerr, Wicker, & Kong, 2014).

Encapsulation techniques have been found to offer possible solutions to enhance bioavailability, water solubility, and stability of hydrophobic carotenoids (Rascon, Beristain, Garcia, & Salgado, 2011; Sutter, Buera, & Elizalde, 2007). Therefore, to address the concerns of stability, handling, and bioavailability, encapsulation of β-carotene is carried out which has created an opportunity for the development of β-carotene forms for supplementation and food fortification. Microencapsulation has been often applied and was found to enhance the stability of carotenoids (Rascon et al., 2011; Sutter et al., 2007). It is the technique by which sensitive ingredients are packed within a coating or wall material (Loksuwan, 2007). Different methods for encapsulation of β-carotene in appropriate delivery system, such as nanoemulsion (Liang et al., 2013; Qian et al., 2012), microemulsion (Donhowe et al., 2014), liposome (Lee et al., 2002), solid lipid nanoparticles (Cornacchia & Roos, 2011), and complex assemblies with macromolecules (Pan, Yao, & Jiang, 2007) are reported. Effectiveness of microencapsulation depends on the method employed (Donhowe et al., 2014). The method used significantly affects moisture content, water activity, particle size, morphology of microcapsules, and encapsulation efficiency. Oil-in-water nanoemulsions are considered to be efficient, low-cost, and convenient way to increase the dispersibility, stability, and bioavailability of nutraceuticals (Huang, Yu, & Ru, 2010). In spite of having improved thermal stability, nanoemulsions are sensitive to the environment stresses such as heat, freezing, and thawing, and alterations in pH can further destabilize the encapsulated compound (McClements, 1999).

To overcome this limitation, a drying process, spray drying is one of the most popular, attractive, and widely studied encapsulation technologies owing to high-production capacity and minimal operation costs. The key steps for spray drying are the choice of a suitable wall material with good emulsifying properties and good film forming properties during dehydration (Madene, Jacquot, Scher, & Desobry, 2006). But the use of this method must be justified by verifying bioavailability in addition to preserving functionality (Desobry et al., 1998). Different wall materials for coating can be used and polysaccharides such as maltodextrin, inulin, gum Arabic, tapioca starch, and citrus fiber are often used. Other matrix materials like glucose syrup and soy protein isolate are also used. Starches being widely available can be used for containment of bioactives by spray drying in a manner that will provide an oxidative protection and for a controlled release over defined period of time (Wani et al. 2012). The use of natural polymers as coating material can enhance the stability of β-carotene and help in controlled release of this functional ingredient in the human body for more efficient nutraceutical usage. Maltodextrins have been demonstrated to be a good compromise between price and preservation as they are bland in flavor, have low viscosity at a high solid ratio, and afford good protection against oxidation (Desobry et al., 1998). Spray drying of carotene with maltodextrins improved shelf by 100–200 times when compared to a carrot juice that was spray dried with no excipients (Wagner & Warthesen, 1995). Preservation and enhancement of the storage stability of β-carotene by spray drying has been successfully reported by Desobry, Netto, and Labuza (1997) and Loksuwan (2007). However, β-carotene bioavailability and release during *in vitro* digestion was not carried. Bioavailability of β-carotene in spray-dried chitosans–alginate microcapusles has been reported by Roman, Burri, and Singh (2012). Donhowe et al. (2014) recently reported physical characterizations of spray-dried β-carotene, water-dispersible β-carotene, and β-carotene chitosans alginate microcapsules, and studied release and bioavailability during *in vitro* digestion as affected by different food matrices. Microencapsulation method significantly influences release and incorporation into micells, regardless of the food matrix (Donhowe et al., 2014).

In addition to spray-dried powders and microcapsules, the development of water-dispersible β-carotene holds promise because it has significantly higher bioavailability *in vivo* than in carrot juice (Thurmann et al., 2002). Other encapsulation processes have been tested (Desobry et al., 1997) and, surprisingly, drum has provided a better retention of β-carotene than spray drying and freeze drying. Although this may serve as low-cost alternative, however, these results need to be validated with release properties as well which have not been carried out. From all research studies on encapsulation, one can conclude that spray drying β-carotene has proved to be one of the acceptable methods to preserve β-carotene while maintaining bioavailability.

5. Physiological/Health benefits of β-carotene

Various carotenoids, found in different foods, such as β-carotene, lycopene, lutein, and zeaxanthin are believed to have a role in maintaining bodily functions and preventing diseases. β-carotene, along with many other carotenoids, is a source of provitamin A. Vitamin A, a fat soluble vitamin, is an important nutrient not only for the vision and, preventing nyctolapia (night blindness) and xeropthalmia (lack of tears/abnormal dryness), but it also helps to strengthen the ability of immune system to resist infections, proper growth, development, gastrointestinal function, and functioning of reproductive systems (Handelman, 2001; Haskell, 2012; Grune et al., 2010; Semba & Bloem, 2001). Humans lack the ability to synthesize vitamin A *de novo* (Haskell, 2012; Semba & Bloem, 2001) and, therefore, must get proper amounts of it from the dietary sources, rich in β-carotene, like dark green leafy vegetables (e.g. spinach), fruits, and vegetables (e.g. carrot, orange, and mango) (Gul, Singh, & Jabeen, 2015). The rising awareness of the potential health benefits of β-carotene has lead to the development of functional foods enriched with β-carotene (Sy, Dangles, Borel, & Caris-Veyrat, 2013).

Besides, being attractive natural colorant, β-carotene provides additional advantages due to its provitamin and antioxidant properties. As β-carotene has highest vitamin A activity among other provitamin A carotenoids (α-carotenes and cryptoxanthins) (Donhowe et al., 2014) and most efficient conversion to vitamin A (Yeum & Russell, 2002), it stands as one of the most widely studied of all carotenoids present in nature. Apart from the primary role that β-carotene plays in being as the nutrient source of vitamin A, β-carotene has a myriad of health benefits associated to it when consumed at appropriate levels. It is a potent antioxidant and can function as a lipid scavenger and a singlet oxygen quencher due to the unique structure of conjugated double bonds and inone rings (Grune et al., 2010). Epidemiological studies and clinical trials have established a number of potential health benefits of β-carotene, e.g. decreased risk of some cancers, cardiovascular disease, age-related macular degeneration, and cataracts, and increased immune response (Boon, McClements, Weiss, & Decker, 2010; Gerester, 1993; Walter, 1995). The physiological benefits that have been proposed to account for the health benefits include preventing oxidative damage, quenching singlet oxygen, altering transcriptional activity, and serving as a precursor of vitamin A (Abdel-Aal & Akhtar, 2006; Qian et al., 2012; Singh & Goyal, 2008).

Various studies have demonstrated possible relationships between consumption of β-carotene and prevention of cancers (Backer & Meydany, 1994; Goralczyk 2009; Grewal, 1995; Naves & Moreno, 1998; van Poppel & Goldbohom, 1995), and there has been a general consensus that individuals who consume large quantity of carotenoid-rich fruits and vegetables have a decreased risk of cancer at the tumor site (Block, Patterson, & Subar, 1992). Le-Marchand et al. (1993) found that the dietary intake of β-carotene was associated with reduced lung cancer and high dietary intake of β-carotene has been associated with reduced risk of cancers at several specific organs especially lung cancer (van Poppel & Goldbohom, 1995; Ziegler, 1989). Infante et al. (1991) reported their laboratory findings in patients receiving high dose of vitamin A as an adjunct for the treatment of stage 1 lung cancer. However, no effects or even protective effects have been demonstrated in smokers and intervention studies have unexpectedly reported increased lung tumor rates after high, long-term

β-carotene supplementation; however, in non-smokers, there is no evidence for adverse events and even suggestion for protective effects (Goralczyk, 2009). Recently it has been reported that β-carotene inhibits neuroblastoma—most prevalent extracranial solid tumor in childhood (Kim et al., 2014). The authors also claimed that their study provides the first evidence which shows that β-carotene may act as an effective chemotherapeutic agent by regulating invasion and metastasis of neuroblastoma. Although carotenes does not have hormone-like properties of retinol, they do have potent antioxidant effect and could thus reduce cancer risk by preventing oxidative tissue damage (Mukherjee, Ghosh, & Hossain, 2011). Britton (1995) defined carotenoids as effective antioxidant, it would have to remove the free radicals from the system either by reacting with them to yield harmless products or by disrupting free radical chain reactions. The chemo preventive actions of β-carotene have been mainly demonstrated in the initiation or early promotion stages, inhibiting the formation of preneoplastic lesions in both *in vitro* and *in vivo* experimental models (Bertram et al., 1991; He, Root, Parker, & Campbell, 1997; Moreno et al., 1991).

β-carotene has been considered nearly non-toxic because humans can tolerate high dietary intake of β-carotene without possible harm (Bendich, 1988; Hathcock et al. 1990). The free radical scavenging nature of β-carotene and its immediate involvement in trapping singlet oxygen providing an overall increased reducing environment in the hepatic tissues involves the anticancer potential of long-term exposure to β-carotene (Mukherjee et al., 2011). β-carotene has shown to inhibit ultraviolet-induced skin cancer or oral carcinomas caused by dimethyl benzanthracene and colon tumors caused by dimethyl hydrazine treatment given to animals in laboratory (Krinsky, 1989). β-carotene goes through metabolism to retinol (vitamin A), which is required for normal cell differentiation of stem cells in epithelial tissue (Bender & Mayes, 2003).

Although controversies regarding the effectiveness of β-carotene against various forms of cancers exist, the findings are suggestive of its potential role against chemical induced carcinogenesis. Further research needs to be conducted to elucidate the exact mechanisms and provide a deep insight of its protective effects.

6. Conclusion

β-carotene is one of the important bioactive components with potent antioxidant activity. Apart from its nutritive value and health benefits, β-carotene can serve as a substitute to synthetic dyes as the poor stability and solubility issues can be addressed by encapsulation. A number of potential health benefits have been associated with the consumption of this bioactive at appropriate levels; however, despite large number of publications the exact characteristics that make this carotenoid effective are still at large unknown. More research is needed to fully understand the antioxidant mechanisms involved in β-carotene physiology in addition to knowing the exact possibility of this carotenoid acting as an anticarcinogen at appropriate dosage.

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