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Characterization of black carrot (*Daucus carota* L.) polyphenols; role in health promotion and disease prevention: An overview

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Abstract

This era is witnessing a drastic shift towards increasing the consumption of functional foods for promoting healthy lifestyle. Functional foods are recognized because of their high nutraceutical properties, which helps in prevention of various degenerative disorders. Black carrot is considered as functional food because of the presence of significant amount of bioactive compounds. The present review primarily aims at spotlighting the presence of potential phytochemicals in black carrots (*Daucus Carota* L.) and their significant role in oxidative stress induced major metabolic disorder. Effect of processing on polyphenols and anthocyanins of black carrot are also discussed. Black carrot anthocyanins are considered the major bioactive compound, which is associated with its health promotion and disease prevention properties. Functional properties of these bioactive compounds call for further studies to exploit its role in prevention of diseases.

Keywords: Functional food, Black carrot, anthocyanin, antioxidant, Polyphenol

1. Introduction

The tenet "Let food be thy medicine and medicine be thy food" quoted by Hippocrates nearly 2,500 years ago, is lately appealing to scientific community and is receiving a renewed interest. There has been an increase interest in the study of bioactive compounds and functional foods (Hasler 1998) [26]. Bioactive compounds are physiologically active components present in foods naturally or added to them as functional components with enhanced nutraceutical properties. It comprises a broad spectrum of functional compounds including dietary fiber, carotenoids, flavonoids, phenolic acids, fatty acids, isothiocyanates, plant stanols and sterols, polyols, prebiotics and probiotics, phytoestrogens, vitamins and minerals. Scientists have recognized that these bioactive components have a significant role in promoting health benefits.

In recent years, the role of antioxidants have been widely studied for its potential to quench free radicals. Free radicals are produced during various metabolic oxidative reactions (Jacob, 1995). Oxidative damage to biological molecules like DNA, protein and lipids induced by free radicals is considered to be linked with many degenerative diseases, CVD, ocular and neurological (Ames *et al.*, 1993; Harman, 1995; Hertog *et al.*, 1995 and Rice-Evans *et al.*, 1996) [4]. Recently, Polyphenols are getting a lot of attention because of their tremendous antioxidant properties. It has been now established that polyphenols could have a great role in the prevention of cancers, cardiovascular diseases and neurodegenerative disorders. Phenolic compounds has been demonstrated to possess great antioxidant property.

Carrots (*Daucus carota* L.) contains high amount of antioxidants. These antioxidants might be hydrophilic (phenolic compounds) and lipophilic (carotenoids). Carrots are available in various colours throughout the world. These colours are due the presence of responsible pigments in the carrots. The red carrots contain lycopene, anthocyanins are responsible for the colour of black carrot and the yellow carrots consist of a pigment called lutein. All these pigments have been reported to possess great free radical scavenging capacity.

Black carrots (*Daucus carota* L. ssp. *sativus* var. *atrorubens* Alef.) are attractive purple coloured vegetable (Turkyilmaz *et al.* 2012) [84]. Carrot cultivars can be classified into two groups; Western carrots, contain carotene (*Daucus carota* ssp. *sativus* var. *sativus*) and Eastern carrots, which contain anthocyanin (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef) (Pistrick and Hanelt 2001) [68].

Anthocyanins are a group of polyphenolic compounds, which are water-soluble pigments. They occur frequently in fruits and vegetables and impart characteristic red to purple colour to them (Kammerer *et al.* 2004a) [39, 40].

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As anthocyanins are natural pigments, so black carrots are widely treated as potential source of natural food colour and a promising alternative to synthetic colours now a days (Ekici *et al.* 2015) [13].

Besides their colouring properties, anthocyanins are polyphenols that also exhibit various beneficial health effects, e.g.; decrease in stroke risk, reduction in the risk of coronary heart disease, antitumor characteristic, anti-inflammatory effects etc. (Netzel *et al.* 2007) [61]. Black carrots were stated to contain 1750 mg/kg fresh weight of anthocyanins (Mazza and Miniati 1993) [55]. It contains high amount of acylated anthocyanins. Four main anthocyanins were identified in black carrot. Forty-one percent of anthocyanins were found to be acylated, namely cyanidin 3-feruloyl-xylosyl-glucosyl-galactoside (13.5%) and cyanidin 3-sinapoyl-xylosyl-glucosyl-galactoside (27.5%) (Stintzing *et al.* 2002) [79]. These acylated anthocyanins possess great stability due to its intramolecular co-pigmentation properties. Anthocyanins from black carrots extract have been exhibited to exert strong antioxidant activity in various in vitro tests (Narayan and Vankataraman 2000, Karakaya *et al.* 2001, Kaur and Kapoor 2002, Glej *et al.* 2003, Ravindra and Narayan 2003, Uyan *et al.* 2004) [59, 41, 43, 20, 71, 85]. The scientific community is attracted towards black carrots due to the unique profile of anthocyanin pigments (Olejnik *et al.* 2016, Padayachee *et al.* 2013 and Kamiloglu *et al.* 2015) [62, 64, 36, 37]. Anthocyanins has been recognized as the component of diet with established nutraceutical properties, associated particularly to their free radical scavenging capacity (Kamiloglu *et al.* 2015) [36, 37], anticancer activity (Sevimli-Gur *et al.* 2013) [77] and anti-inflammatory properties (Metzger *et al.* 2008) [56]. Anthocyanins can be directly absorbed in the intestine without any metabolic changes. They can further be converted into glucuronide, methyl, or sulfate compounds in the small intestine and liver in presence of phase II enzymes. These formulated compounds may exhibit a protective effect for endothelial cells (Kuntz *et al.* 2015) [49]. Apart from anthocyanins as the main polyphenol, black carrots also comprise a good amount of phenolic acids, such as caffeic and hydroxycinnamates acid (Kammerer *et al.* 2004) [39, 40]. It is believed to be the cheapest source of anthocyanin pigment

in India, which can be extracted and stored for utilization in food industry.

The current review aims at highlighting the characteristics of black carrot polyphenols, in terms of its structure, stability, its response to various processing conditions its preventive properties and its efficiency against oxidative stress induced health disorders. Utilization of black carrot as a food of choice to combat certain physiological threats including long-term and acute hypoglycemic and hypolipidemic effects in human could be a sagacious and nutritionally (Akhtar *et al.* 2017) [93].

2. Biochemical composition of black carrots

According to Turkish food composition, black carrot contains approximately 88 percent moisture, 1 percent protein, 0.14 percent fat, 2.5 percent fiber and 8 percent protein. Carrots are also good source of minerals like calcium, phosphorus, sodium, potassium, magnesium, iron and zinc. Gopalan *et al.* (2010) [21] have reported 80 mg calcium, 53 mg phosphorus and 2.2 mg/100g of iron. Whereas, Holland *et al.* (1991) [29] reported 34 mg of calcium, 25 mg of phosphorus, 40 mg of sodium, 240 mg of potassium, 9 mg of magnesium, 0.02 mg of copper, 0.4 mg of iron and 0.2 mg of zinc. Carrots are also good source of multivitamins. It contains very good amount of carotenes (5.33 mg/100 g), however thiamine (0.04 mg/100 g), riboflavin (0.02 mg/100 g), niacin (0.2 mg/100 g) and ascorbic acid are also present in appreciable quantities (Holland *et al.* 1991) [29].

Secondary metabolites of plants that exhibit functional properties are called phytonutrients. Carrots are reported to be a good source of carotenoids (Block 1994), phenolics (Babic *et al.* 2014) [5] and polyacetylenes (Hansen *et al.* 2003) [24]. Mostly carrots are known to contain carotenoids, a lipophilic compound, as major bioactive component however; in black carrots, carotenoids are present in negligible amounts. On the contrary, black carrots are excellent source of polyphenols, a lyophilic compound, which is responsible for its high free radical scavenging capacity.

3. Polyphenols in black carrot

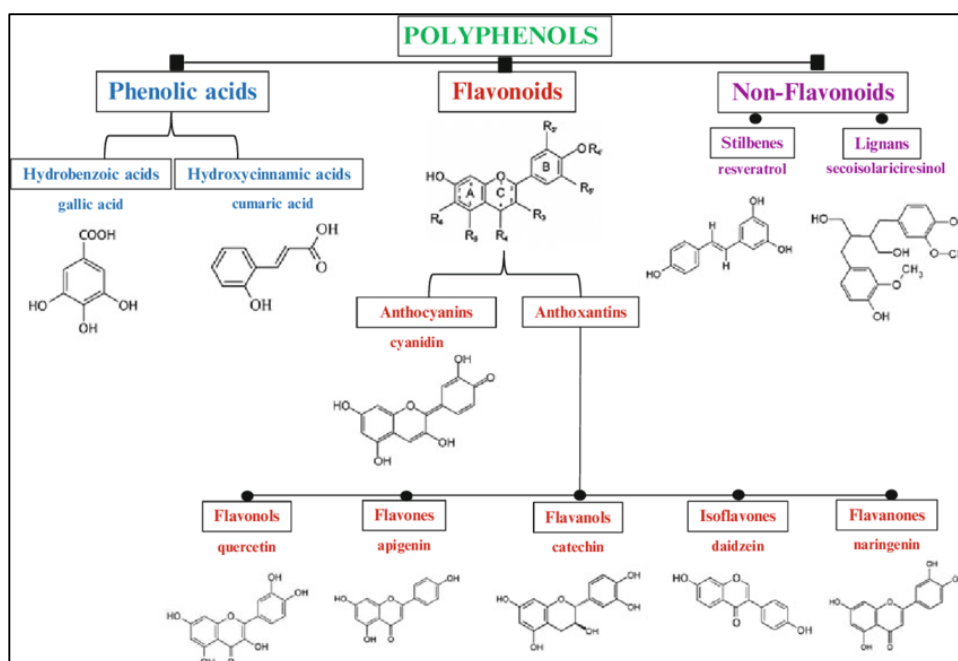


Illustration 1: Categorization of polyphenols (Vassallo, N. (Ed.). (2015) [86].

The following illustration (Illustration 1) represents the categorization of polyphenols. Polyphenols can be categorized into four categories namely flavonoids, phenolic acids, non-flavonoids (stilbenes and lignans), based on their molecular structure and phenolic ring (Vassallo, N, 2015) [86].

3.1 Phenolic acids

Phenolic acids are non-flavonoids having one functional group of carboxylic acid. It can be categorized into two subgroups, on the basis of its chemical structure namely hydroxycinnamic and hydroxybenzoic acids. In both the phenolic acids basic structure is not changed however, the difference is due to the number and position of hydroxyl groups on the aromatic ring of phenols. Hydroxybenzoic acids are polyphenolic compounds having C6-C1 structure, major example is Gallic acid whereas, hydroxycinnamic acids are aromatic compounds having three-carbon side chain (C6-C3). Caffeic, ferulic, *p*-coumaric and sinapic acids are the most common example of hydroxycinnamic acids (Balasundram *et al.* 2006, Robbins 2003) [6, 7]. Hydroxybenzoic acids are present in high amounts in raspberry, blackberry, and tea however; blueberry and coffee are excellent sources of hydroxycinnamic acids (D'Archivio *et al.* 2007) [9, 10].

Black carrots are also rich source of phenolic acids apart from anthocyanins. In black carrots, mainly derivatives of hydroxycinnamic acid are identified. Kammerer *et al.* (2004) [39, 40] have reported that chlorogenic acid (5-Ocaffeoylquinic acid), an ester of caffeic and quinic acid (Illustration 3), was major phenolic acid in black carrots. Several studies have been reported that black carrot roots exhibited the significantly higher amount of phenolic content as compared to other coloured root vegetables (Leja *et al.* 2013 and Koley *et al.* 2014).

Stilbenes contain two phenyl moieties connected by a two-carbon methylene bridge (Pandey and Rizvi, 2009) [65]. Resveratrol is the main example of stilbenes, which are abundantly present in plant species, majorly in berries, grapes and peanuts (Ignat *et al.* 2011) [30].

Lignans are produced by oxidative dimerization of two phenyl propane units. Linseed, containing secoisolariciresinol and low quantities of matairesinol, represents the main dietary source (Manach *et al.* 2004, D'Archivio *et al.* 2007) [54, 9, 10].

3.2 Flavonoids

Flavonoids are low molecular weight compounds, consisting 15 carbon atoms arranged in C6-C3-C6 configuration. The structure of flavonoids contains two aromatic rings, which is inter-connected by a 3- carbon bridge thus forming a heterocyclic ring. Further, flavonoids can be subdivided into 6 sub categories on the basis of position of this heterocyclic ring namely flavonols, flavones, flavonones, isoflavones and

anthocyanidins (Balasundram *et al.* 2006) [6, 7]. Differences in the groups are attributed to the number and arrangement of the hydroxyl groups and their extent of alkylation and/or glycosylation (Spencer *et al.* 2008, Pandey and Rizvi 2009) [78, 65]. Flavonols includes majorly quercetin, myricetin and kaempferol, which are abundantly found in broccoli, onions, and blueberries. Main example of flavones are glycosides of apigenin and luteolin. Major flavanone are naringenin, hesperetin and eriodictyol, which are abundantly present in grapefruit, oranges and lemons. Flavanols can be further categorized into two subclasses, monomers (catechins) and polymers (proanthocyanidins) forms. Good example of flavonols are catechin and epicatechin, which are majorly present in fruits, tea, red wine and chocolates. Isoflavones are primarily found in soy, which consists three main bioactive compounds namely genistein, daidzein and glycitein.

The major anthocyanidins are cyanidin, delphinidin, malvidin, pelargonidin, and peonidin, which are abundantly present in purple and red shades fruits such as blueberry, blackberry, cherry and strawberry and vegetable like brinjal and black carrots (Manach *et al.* 2004) [54].

3.2 Anthocyanins

The term anthocyanin is derived from the Greek word *anthos*- flower and *kyanos*- blue (He and Giusti 2010) [27]. Anthocyanins are water-soluble pigments which exert red, purple and blue colour and are widely distributed in plant kingdom (Prior and Wu 2009) [70]. Anthocyanins, because of its natural colouring properties have become very important pigment to food industry, as they have the ability to replace the synthetic colourants (Wallace and Giusti 2008) [87]. Anthocyanin pigments are considered under natural colourant by codex alimentarius and Food and Drug administration USA.

Anthocyanins are glycosides of flavylium (2-phenylbenzopyrylium) compound. They differ structurally due to following reasons (Faria *et al.* 2013) [16];

1. Number of hydroxyl groups
2. Degree of methylation of hydroxyl groups
3. The nature and number of sugar moieties attached to the molecule
4. Position of the attachment
5. The nature and number of aliphatic or aromatic acids attached to the sugars.

According to Forbes-Hernandez *et al.* (2014) [18], anthocyanins are glycosides of aglycones, known as anthocyanidins. Chemically the structure of anthocyanidins comprise of an aromatic ring A which is bound to oxygen containing heterocyclic ring C, that is attached by carbon-carbon bond to a third aromatic ring B (Ignat *et al.* 2011) [30].

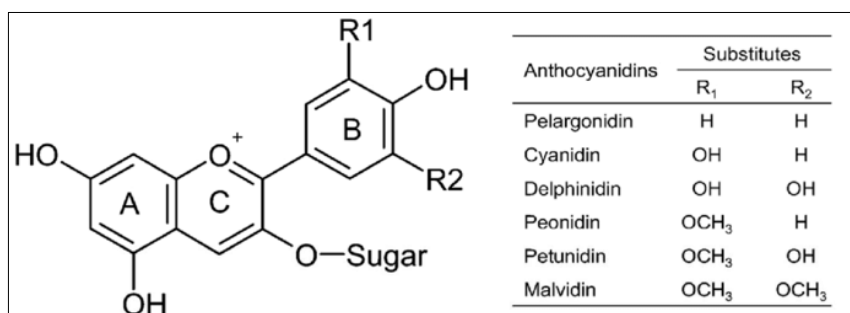


Illustration II: Chemical structure of the flavylium cation (left).

The main anthocyanidins are formed according to the specific substitutes at R1 and R2 positions (right). Anthocyanins, in turn, mostly present di-, tri or monosaccharide unit incorporated into the anthocyanidin structure. (De Sousa Moraes *et al.*, 2019) [12]

4. Black carrot Anthocyanins; Characteristic and Properties

There are almost 17 anthocyanidins that have been identified by scientists, but only six are widely distributed in plant kingdom, which are cyanidin, delphinidin, malvidin, pelargonidin, peonidin and petunidin (Illustration II). Although only there are only six available anthocyanidins, however more than 600 types of anthocyanins are distributed in nature (Wu *et al.* 2006). Sugar moieties that are attached to anthocyanidins are mainly Glucose, galactose, arabinose, rutinose, rhamnose, and xylose. These sugar moieties are

attached to anthocyanidins as mono-, di-, or trisaccharides (Fang 2014) [15]. Cyanidin-3- glucoside is the most widespread anthocyanin in plant species (Castaneda-Ovando *et al.* 2009) [8]. In many cases, the sugar moiety attached to anthocyanidins are acylated with *p*coumaric, caffeic, ferulic, sinapic, *p*-hydroxybenzoic, malonic, oxalic, malic, succinic or acetic acid (De Pascual-Teresa *et al.* 2013) [11]. Anthocyanins alone represents around 50 percent of total phenols in black carrot (Wallace and Giusti 2008) [87]. Algarra *et al.* (2014) [3] have also reported five main cyanidin based anthocyanins in black carrots, viz. cyanidin 3-xylosylglucosylgalactoside, cyanidin 3- xylosylgalactoside and the sinapic, ferulic and coumaric acids derivative of cyanidin 3-xylosylglucosylgalactoside. Black carrot anthocyanins were highly acylated and was accounted for 25-50 percent of total phenols (Illustration III).

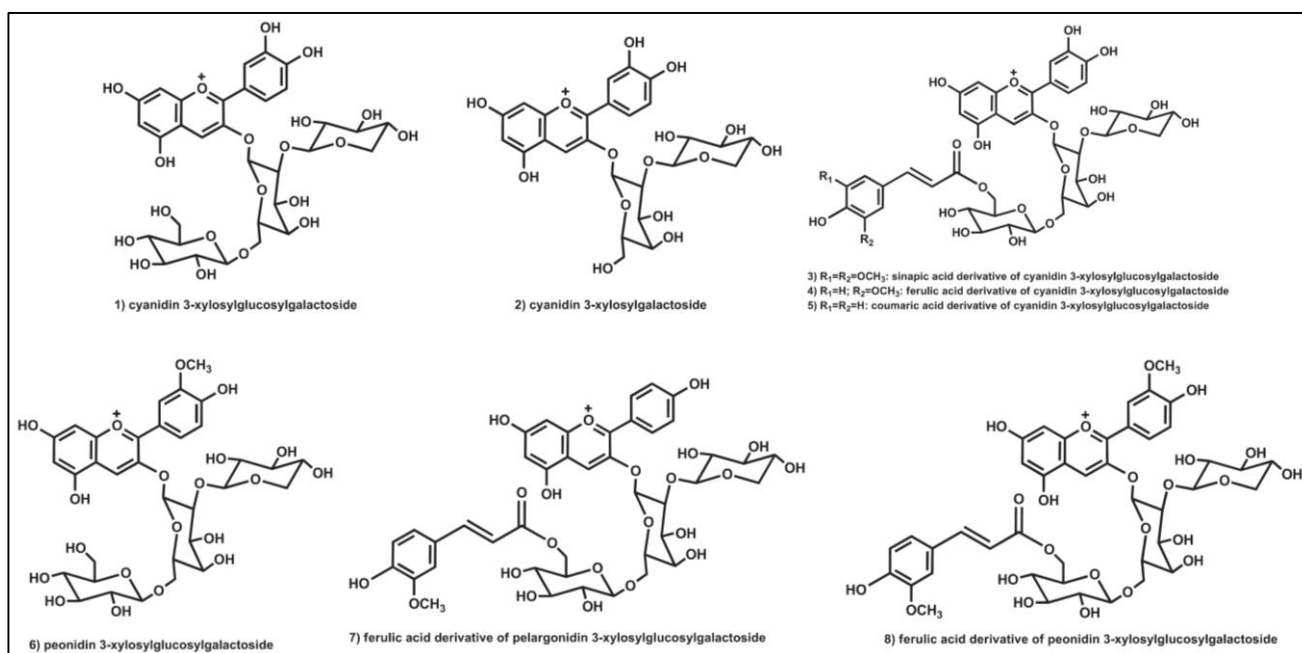


Illustration III: (Algarra *et al.* (2014) [3] retrieved from Kamoligulo, 2016)

5. Stability of Black Carrot Anthocyanin

The total anthocyanin content in black carrots has been estimated as up to 350 mg per 100 g of edible carrot. Anthocyanin content in the black carrots can vary widely between different cultivars and even within carrot cultivar on the basis of intensity of colour in the roots of black carrots (Kammerer *et al.* 2004a) [39, 40].

Anthocyanins compounds are degraded readily in the present of air, light, temperature, acids and enzymes (Fernandes *et al.* 2014). The intensity of anthocyanins pigment depends on the groups attached to B ring (Illustration III). This intensity of colour is directly proportional to number of hydroxyl groups and inversely proportional to the number of methoxyl groups (Tsuda 2012). Anthocyanins are stable in acidic pH. At higher pH (> 4) anthocyanin pigment gets degraded into phenolic acids (Fang 2014) [15]. The anthocyanin compounds (majorly cyanidin glycosides) from black carrot exhibit attractive red shades close to FD&C Red 40 (Allura Red). It imparts brilliant peach red shade at acidic pH (Giusti and Wrolstad 2003) [19].

The anthocyanin compounds (majorly cyanidin glycosides) from black carrot exhibit attractive red shades close to FD&C Red 40 (Allura Red). It is acylated with ferulic, *p*-hydroxybenzoic, *p*coumaric and sinapic acids. Therefore, it is

more stable to light, pH (3.0 to 5.0) and hydration (Malien-Aubert *et al.* 2001, Stintzing *et al.* 2002) [79]. The structural properties of anthocyanins from black carrot contributes to their better stability than extract from other sources, e.g. grapes, demonstrating a lower degree of acylation. The acylated anthocyanins have intramolecular co-pigmentation effect that prevents the nucleophilic damage by hydrolytic reaction in the presence of water. The hydrolytic cleavage of the aromatic system in pigments leads to the development of chalcones which results in the loss of pigment (Kammerer *et al.* 2004a) [39, 40]. Therefore, this resisting property black carrot anthocyanins make it ideal as a colour pigment for water-based, low pH systems. Colour extracted from black carrot is available in both liquid and dry form. Black carrot extract colours are widely used to provide red and purple colour to many acidic foods, soft drinks, confectionary and preserves (Kirca *et al.* 2006, Wrolstad and Culver 2012) [46, 90]. Juice of black carrot used in to food products as colour, is considered as ingredient therefore, it does not need declaration with an E-number on food labels.

In black carrot, majority of anthocyanins are cyanidin based namely cyanidin-3-xylosyl-galactoside, cyanidin-3-xylosyl-galactoside. Other anthocyanin are sinapic, ferulic and coumaric acids derivatives of cyanidin 3-xylosyl-

glucosylgalactoside (Wallace and Giusti 2008, Montilla *et al.* 2011) [87, 57].

Several scientists have optimized extraction of anthocyanin pigment from black carrot and reported that low pH and high temperature is the best technique for maximum extraction of anthocyanin at large scale production (Turker and Erdogdu 2006, Guldiken *et al.* 2016) [83]. Kammerer *et al.* (2004a) [39, 40] studied the anthocyanins content in black carrot and evaluated their colouring properties. The anthocyanins contents varied greatly between and within carrot cultivars. The black carrot responded positively under different pH which suggested that black carrot anthocyanins can be used as natural food colorants even for low acid foods.

6. Health-promoting effect of black carrots

6.1 Antioxidant properties:

Black carrots are proved to possess high free radical scavenging properties as reported by several authors (Kaur and Kapoor 2002, Kammerer *et al.* 2004a, Khandare 2008 and Kamiloglu 2016) [43, 39, 40, 35]. Day *et al.* (2009) [92] have compared the antioxidant capacity of black carrot concentrate with freshly produced fruits viz, cherry, strawberry, raspberry and blueberry and sweet potato. The results revealed that black carrot concentrate had equivalent scavenging capacity, which was at par with blue berries that depicted highest antioxidant activity among all the compared fruits and vegetable. Black carrot extracts have been exhibited to have protecting role against the oxidative stress (Olejnik *et al.* 2016) [62]. Algarra *et al.* (2014) [3] reported that black carrots exhibited significantly higher antioxidant capacity as compared to orange carrots.

6.2 Anti-inflammatory Effect

Phenolic compounds of black carrot extract were found to have significant effect on reducing inflammation by inhibiting the inflammatory pathways. There have been many clinical studies, which proved the anti-inflammatory effect of black carrot extract in in-vitro and in-vivo systems.

6.3 Preventive role in Metabolic Disorders

Park *et al.* (2015) [66] have reported positive effect of black carrot extract in the prevention of diseases characterized by metabolic disorders of carbohydrate, fats and energy. However, Wright *et al.* (2013) [89] reported that supplementation of black carrot powder (118.5 mg/day of anthocyanins and 259.2 mg/day of phenolic acids) for 4 weeks in 16 human subjects had no significant effect on body mass, body composition, LDL, total cholesterol and blood pressure. On the other hand, in a rat trial, Poudyal *et al.* 2010 [69] reported incorporation of black carrot juice at the 5 percent level in diet of rats (fed with high carbohydrate and fat diet), significantly improved glucose tolerance, and reduced the risk of reduced abdominal obesity, plasma lipids, systolic blood pressure, cardiac fibrosis, hepatic steatosis and inflammation. Anthocyanins from black carrots are reported to be responsible for these improved metabolic effects. Black carrots also contain polyacetylene compounds, which were reported to inhibit the production of NO₂ in macrophage cells by sixty-five percent. Therefore, it can be suggested that anti-inflammatory properties of black might also be attributed to its polyacetylenes content (Metzger *et al.* 2008) [56].

The bioactive compounds of black carrot were also found to reduce cardiovascular diseases by decreasing the blood cholesterol and glucose levels; additionally, cholesterol production in liver is reduced by the inhibition of 3-hydroxy-

3-methylglutaryl-coenzyme A reductase activity. Lymphocyte activation, the inhibition of cell proliferation, anti-inflammatory effects, a reduction of the body mass index, a reduction in triglyceride level and blood pressure, and a reduction in the binding activity of bile acid are other distinguishable properties of bioactive compounds of black carrot that help in the prevention of cardiovascular diseases (Akhtar *et al.* 2017) [93]. Phenolic compounds of black carrots are also helpful in reducing the risk of diabetes (Karkute *et al.* 2018) [42].

6.4 Preventive role in Cancer

The black carrot anthocyanins have been found to possess anti-cancerous properties. Lin *et al.* (2017) [52] demonstrated that ethanolic extracts of black carrot anthocyanins had anti-proliferative properties against various cancer cell lines, which could be used for the treatment of breast cancer, prostate cancers and colon cancer. Lyophilized powder of black carrot extract were reported to inhibit the growth of HT-29 and HL-60 cancer cells (Jing *et al.*, 2008; Netzel *et al.*, 2007) [33, 61].

Cancer types resistant to chemotherapy can be treated using black carrot extract alone or together with anticancer drugs.

6.5 Effect of processing on the functional properties of black carrots

As fruits and vegetable are available in particular season and are highly perishable in nature (70- 90 percent water content), they are subjected to different processing conditions for better storage and utilization. However, these processing conditions greatly affect the phytochemical composition, which have been widely studied (Kalt 2005, Patras *et al.* 2010, Khandare *et al.* 2011, Nayak *et al.* 2015, Rothwell *et al.* 2015, and Kamiloglu *et al.* 2015) [34, 67, 45, 60, 74, 36, 37]. Drying, by subjecting the black carrot to heat treatment have reported to degrade the anthocyanins (Ersus and Yurdagel 2007, Kirca *et al.* 2007, Khandare 2008, Murali *et al.* 2015) [14, 47, 44, 58]. Witrowa-Rajchert *et al.* (2009) [88] compared the drying methods and observed that microwave convection drying and freeze-drying resulted in minimal loss of anthocyanins as compared to convection drying in deep purple and purple haze carrot cultivars respectively. Treatment with pectinase enzyme in black carrot juice processing, had significant improvement in extraction of total phenols, flavonoids and anthocyanins (Khandare *et al.* 2011) [45]. Suzme *et al.* (2014) [80] have reported that when black carrot was processed into concentrate it led to reduction of 70 percent total phenols, 73 percent total flavonoids and 44 percent anthocyanins. Fermentation of black carrot juice for the production of *shalgam* have resulted in loss of 94 percent anthocyanins on the initial day, which increased after 12th day by 8 to 10 folds, however it was still 39 to 46 percent lower than the initial anthocyanin content of black carrots (Toktas 2016) [81]. Although processing leads to degradation of anthocyanins and phenolic compounds, however in black carrots, the stability of anthocyanins and other phenols to temperature and pH were reported to be significantly higher than anthocyanins present in purple-flesh potatoes and grapes (Reyes and Cisneros-Zevallos 2007) [72]. The stability of black carrot juice anthocyanins were significantly higher than strawberry juices. The higher stability of black carrot anthocyanins might be attributed to the higher proportion of acylated anthocyanins in black carrots (Sadilova *et al.* 2007) [75]. Storage stability of anthocyanins at higher temperatures resulted in faster

anthocyanin degradation as compared to storage at lower temperatures.

Lee *et al.* (2011) ^[50] stored the sliced black carrot at 2- 4°C for 4 weeks and observed no significant difference in total anthocyanins content. Alasalvar *et al.* (2005) ^[2] studied the storage stability of ready to eat black carrot shreds at chilled temperature (5 ± 2°C) in air and in modified atmosphere packaging. They reported that anthocyanin content did not decrease significantly during storage period at chilled temperature however in modified atmosphere packaging treatment (95% O₂ +5% CO₂) it decreased after 13 days of storage. Storage study of black carrot concentrate at 4, 20 and 37 °C revealed that cold storage had better recovery of anthocyanins as compared to storage at 20-37 °C (Kirca *et al.* 2007) ^[47]. Several other authors also reported higher degradation of black carrot concentrate anthocyanins at higher temperature of storage (Ozen *et al.* 2011 and Turkyilmaz *et al.* 2012) ^[84].

Kirca *et al.* (2007) ^[47] reported that black carrot anthocyanins were more stable pH below 5 and at a lower temperature. Pectinase enzyme-assisted processing significantly enhanced the antioxidant properties of black carrot juice, juice yield, total phenols and flavonoids content. Anthocyanin content in black carrot juice increased by nearly 2 folds (Khandare *et al.* (2011) ^[45]). Depectinisation and bentonite treatment had reported to have positive effect on the colour of black carrot juice, whereas pasteurization and gelatin kieselsol treatment had negative effect. Unclarified black carrot juice contained cyanidin-3 galactoside- xyloside-glucoside-ferulic acid as the major anthocyanins, followed by cyanidin-3 galactoside-xylosideglucoside- coumaric acid, and cyanidin-3-galactoside-xyloside-glucoside. After depectinisation, two more anthocyanins viz. cyanidin-3- galactoside xyloside and cyanidin-3 galactoside-xyloside-glucoside-sinapic acid were recognized (Turkyilmaz *et al.* (2012) ^[84]).

8. Conclusion

This review summarized that the black carrot incorporation in food products may prove beneficial owing to the presence of various nutrients and other bioactive compounds and enzymes. Anthocyanins of black carrot polyphenols are highly stable at various processing conditions. Therefore, it could be widely used in food industry as natural colourant and as a source of natural antioxidant. The anthocyanin of black carrot could possess major nutraceutical properties in disease prevention and health promotion. In addition to its remarkable anthocyanin profile, black carrots are reported to be highly rich of other polyphenols, which helps to avert a myriad of degenerative diseases. In India, Black carrot is highly underutilized despite its tremendous nutraceutical properties. It is available at highly affordable rates yet its consumption is very low. There is a need to popularize this vegetable to utilize its full potential. There is a great need to explore the therapeutic characteristics of black carrot to explore its complete role in human health.

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