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Black carrot as functional food: A review

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Abstract
Black carrot (*Daucus carota* L.) is a root vegetable that has gained attention as a potential functional food due to its high content of bioactive compounds, such as anthocyanins, carotenoids, and polyphenols. These compounds have been linked to various health benefits, including antioxidant, anti-inflammatory, and antimicrobial properties, as well as potential anti-cancer and anti-obesity effects. This review aims to provide an overview of the current knowledge on the composition, bioavailability, and health benefits of black carrot. The paper discusses the phytochemical profile of black carrot and its potential health-promoting properties. The high levels of anthocyanins, carotenoids, and polyphenols in black carrot contribute to its antioxidant capacity, which may protect against oxidative stress and chronic diseases, such as cancer and cardiovascular disease. Moreover, black carrot may also exert anti-inflammatory effects due to the presence of various phytochemicals, such as falcarinol and falcarinol, which can suppress the production of inflammatory cytokines. This anti-inflammatory effect may help prevent or mitigate chronic inflammation, which is a common underlying factor in various diseases, including metabolic syndrome, diabetes, and obesity. In addition to its antioxidant and anti-inflammatory effects, black carrot may also possess antimicrobial properties. Studies have shown that black carrot extracts can inhibit the growth of various microorganisms, including bacteria and fungi, which may make it a potential natural food preservative or topical antimicrobial agent. Overall, the evidence suggests that black carrot has significant potential as a functional food with various health-promoting properties. However, further research is needed to fully understand its mechanisms of action and potential health benefits. Additionally, the review highlights the various ways black carrot can be incorporated into the diet, such as in the form of a food ingredient or supplement, to maximize its potential health benefits.

Keywords: phytochemicals, metabolic syndrome, diabetes, obesity

Introduction

As the global population becomes increasingly health-conscious and seeks out more nutritious food options, the food industry has responded by placing greater emphasis on the creation of functional foods. These foods contain bioactive compounds with nutraceutical and functional properties that can provide numerous health benefits beyond basic nutrition. As a result, manufacturers have had to focus on understanding the functional and phytochemical qualities of various processed food products. The concept of functional foods refers to foods that contain one or more functional ingredients or components that offer important or limited functions in the organism and promote overall health and welfare. The modern society is becoming more and more health-conscious, leading to an increased demand for functional foods. The food industry is also taking note and has started to explore the functional bioactive compounds in food products and their impact on health and wellness. Polyphenols, which are found in fruits and vegetables, have been shown to have numerous health-promoting properties and may help protect against various disorders and diseases caused by reactive oxygen species (ROS). One vegetable that has been widely cultivated for its nutritional value is the carrot. Carrots are a great source of carotenes, fiber, vitamins, and minerals and have been widely consumed by people of all ages. In addition to the commonly cultivated, orange-colored carrots, red, black, pink, purple, yellow, and white carrots are also grown. Among these, the black carrot (*Daucus carota* ssp. sativus var. atrorubens) is a type of carrot with a purple-black color that is due to the presence of anthocyanin pigments. It belongs to the Apiaceae family, which is also known as the Umbelliferae family. Within the Apiaceae family, the Daucus genus contains about 25 species, including wild carrot (*Daucus carota* ssp. carota), which is the ancestor of the cultivated carrot. The genetic makeup of the black carrot is similar to that of the orange carrot, with both containing the same set of genes that control carotenoid biosynthesis. However, the black carrot has an additional set of genes that control anthocyanin biosynthesis, which gives it its distinctive color.

Anthocyanin biosynthesis in black carrots is regulated by a set of genes called MYB transcription factors. These genes control the production of enzymes that are involved in anthocyanin synthesis. The expression of these genes is influenced by various factors, such as light and temperature, which can affect the color of the carrot. The black carrot is a member of the Eastern group of originally domesticated carrots and is known for its anthocyanins, which are responsible for its deep purple color. Black carrots include anthocyanins, which raise their nutritional worth in addition to the other elements which include dietary fibre, potassium-rich minerals, ascorbic acid, thiamine, riboflavin, and niacin (Arscott & Tanumihardjo, 2010) [6]. According to Mazza and Miniati's (1993) study, black carrots were found to have a high anthocyanin content of 1750 mg/kg fresh weight. The Kashmir-Afghanistan-Turkestan regions were the key domestication centers for the black or purple carrot (*Daucus carota* ssp. sativus var. atrorubens Alef.), which is a member of the Eastern group of originally domesticated carrots and has been confirmed by molecular data (Iorizzo *et al*., 2013) [20]. Due to its excellent stability to the processing conditions and storage (Purkiewicz *et al*., 2020) [38] The black carrot is one of the most popular anthocyanin sources used as a food colorant. Additionally, black carrot extract has powerful antioxidant and anti-radical properties (Blando *et al*., 2018a) [7]. The black carrot is popular as a food colorant due to its excellent stability to processing and storage conditions. Furthermore, black carrot extract has been found to have powerful antioxidant and anti-radical properties. In this research paper, we will delve into the functional and phytochemical qualities of the black carrot, with a focus on its anthocyanins, and their potential impact on human health.

Nutritional composition of black carrot and its significance

The USDA estimates that carrots are 88% water, 1% protein, 7% carbohydrates, 0.2% fat, and 3% fiber. They are also rich in a variety of nutrients. Phytochemicals having antioxidant activity and positive health effects include carotenoids (some of which have provitamin A activity), phenolic compounds, ascorbic acid, tocopherol, vitamins D, K, B1, B6, biotin, and polyacetylenes. The cultivar, season, management of production, environmental conditions, and postharvest handling and storage conditions all affect the number of carotenoids and minerals in carrots. Similar to this, cooking can change the nutritional value as well as the minerals' and carotenoids' bioavailability (Char, 2017a) [10]. According to Geetha *et al*. 2020 [5], sucrose, glucose, and fructose make up all 7% of carbohydrates. Only 1% or so of the food has protein. Additionally, carrots provide 0.3% fibre and 0.2% fat. Depending on the cultivar, dietary fibre and carbohydrates can differ. Cellulose and hemicellulose make up the majority (50 to 92%) of all dietary fibres. Black carrots also contain lignin, which is a complex polymer that is found in the cell walls of some plants. Lignin provides structural support to the plant and helps to prevent water loss. There is about 4% lignin present. Lignin is known to have potential health benefits, such as antioxidant and anti-inflammatory properties. Carrots' soluble fibres, which make up 8% to 50% of the total fibre content, are made up of fermentable hemicellulose and pectin. The black carrot is a good source of phytochemicals and important micronutrients. Anthocyanins are the principal biological components with 24 disease preventive and, to some extent, therapeutic characteristics, according to (Akhtar *et al*., 2017) [3] The pharmacokinetic viewpoint of black carrots is now established. According to (Park *et al*., 2015) [37], menopausal symptoms such as decreased energy and abnormalities in the metabolism of glucose and lipids in rats with diet-induced obesity are prevented by the cyanidin and malvidin contained in aqueous extracts of black carrots fermented with Aspergillus oryzae. According to (Olejnik *et al*., 2016) [29], purple carrots can limit the production of reactive oxygen species (ROS) in the gastrointestinal system. Carrot extract (1 mg/mL) showed the ability to prevent intracellular ROS production and lessen oxidative DNA damage. According to (Claudio *et al*., 2016) [12], administering black carrot extract in doses of 400 mg/L or 800 mg/L can prevent tissue breakdown brought on by calcium toxicity and can also lower the levels of 8-hydroxy-2'-491 deoxy guanosine (8OHdG) in liver cells. Black carrot anthocyanin is another naturally occurring food and beverage colourant. Massimo (Iorizzo *et al*., 2020a) [18] claim that there has been a significant increase in the demand for natural colorants as a result of public awareness campaigns and stringent food manufacturing regulations. As a result, the food and beverage industries are using natural colourants to meet consumer demand and adhere to regulations. Anthocyanin, which is an organic colorant found in black carrots and has numerous health advantages, is also present. Due to the increase in demand, black carrots are now a profitable crop.

Phytochemical composition of black carrot

Carotenoids: Carotenoids are a group of organic pigments that are widely distributed in nature and are responsible for the yellow, orange, and red colors of many fruits, vegetables, and flowers. They are synthesized by plants, algae, and some bacteria, and play an important role in photosynthesis, photoprotection, and the attraction of pollinators. Carotenoids can be classified into two main types: carotenes and xanthophylls. Carotenes are hydrocarbons and are typically red or orange in color, while xanthophylls are oxygen-containing carotenoids and are typically yellow in color. Some common examples of carotenoids include beta-carotene, lycopene, lutein, and zeaxanthin. Black carrots are a particularly rich source of anthocyanins and other flavonoids, but they also contain significant amounts of carotenoids, including beta-carotene and lutein (Khoo *et al*. 2011, Moreno *et al*. 2006) [52, 53]. Beta-carotene is a provitamin A carotenoid that is converted into vitamin A in the body, and plays an important role in vision, immune function, and skin health. Lutein, on the other hand, is a xanthophyll carotenoid that is known to accumulate in the macular region of the eye and is thought to protect against age-related macular degeneration (AMD) and other eye diseases.

Phenolic compounds: Phenolic compounds are a diverse group of secondary metabolites that are widely distributed in the plant kingdom. They play important roles in plant growth, development, and defense against biotic and abiotic stressors. Phenolic compounds are also known for their health-promoting properties, including antioxidant, anti-inflammatory, and anti-cancer activities. Phenolic compounds can be classified into several subgroups based on their chemical structure, including phenolic acids, flavonoids, stilbenes, lignans, and tannins. Black carrots are particularly rich in anthocyanins, which are water-soluble pigments that belong to the flavonoid subgroup of phenolic compounds. Anthocyanins are responsible for the purple-red color of black carrots, and have been shown to possess antioxidant, anti-inflammatory, and anti-cancer properties (Khoo *et al*. 2011) [52]. In addition to anthocyanins, black carrots also contain other phenolic compounds such as chlorogenic acid, caffeic acid, ferulic acid, and quercetin. Chlorogenic acid is a type of phenolic acid that is found in many fruits and vegetables, and has been shown to have antioxidant, anti-inflammatory, and anti-cancer activities. Caffeic acid and ferulic acid are also phenolic acids that are found in many plants and have been shown to have antioxidant and anti-inflammatory properties. Quercetin is a flavonoid that is found in many fruits and vegetables, and has been shown to possess antioxidant, anti-inflammatory, and anti-cancer activities. To determine the changes in total phenolic (phenolic acid and flavonoids) in various varieties of carrots a study is done by (Koley *et al*., 2014) [26]. They discovered that red (10.8 to 14.2 mg GAE/100 g fw), black (31.9 to 290.0 mg GAE/100 g fw), and orange (6.4 to 10.6 mg GAE/100 g fw) cultivars were the ones with the highest concentrations of free phenolics. They discovered that the black carrot cultivar contains the most total phenolic (Jiang *et al*., 2019) [21], (Montilla *et al*., 2011) [28]. According to (Algarra *et al*., 2014) [4], there is 1.5-126 mg/100g of anthocyanins in black carrots. Furthermore, it was found that between 25 and 33 percent of the total phenolics in red and orange carrots were present as bound phenolics (Koley *et al*., 2014) [26]. However, the bulk of phenols were found in soluble or free form in the black carrot genotype. The black carrot cultivar's total monomeric anthocyanin content ranged from 7.4 to 83.4 mg of cyanidin-3-glucoside (C3G) per 100 g of fresh weight, however writers have reported a range of 1.50 to 243 mg C3G/100 g fw. Black carrots contain mostly acylated and non-acylated cyanidin-based derivatives as anthocyanins. The bulk of the anthocyanin it contains is said to be acylated, suggesting that the black carrot cultivar could be a possible natural source of stable food colouring in addition to its health benefits.

Polyacetylenes: Polyacetylenes are a class of organic compounds that are characterized by the presence of two or more acetylene functional groups (-C≡C-) in their structure. Polyacetylenes are typically found in the Apiaceous family, which includes plants such as carrots, celery, parsley, and parsnips. Black carrots are known to contain several polyacetylenes, including falcarinol, falcarindiol, and falcarindiol-3-acetate. Falcarinol is the most abundant polyacetylene in black carrots and is responsible for the bitter taste and pungent odor of the vegetable. Studies have shown that falcarinol has a range of health benefits, including anti-inflammatory, anti-cancer, and anti-microbial activities (Sørensen *et al*. 2009) [54]. Falcarindiol and falcarindiol-3-acetate are other polyacetylenes found in black carrots. These compounds have been shown to possess anti-cancer, anti-inflammatory, and anti-microbial activities (Sun *et al*. 2012) [55]. Their concentrations range from 20 to 100 mg/kg fw. Carrots get their bitter off flavour from polyacetylenes. Recent research has suggested that polyacetylenes are bioactive substances with the potential to affect human physiology and disease. According to *in vitro* research, carrot polyacetylenes have anti-inflammatory effects on macrophages, biphasic stimulatory and cytotoxic effects on the primary epithelial cells of mammals, and cytotoxic action against a variety of cells that serve as the body's first line of defense. In order to learn more about this chemical and its health advantages, more research must be undertaken (Char, 2017b) [11].

Ascorbic acid: Black carrots are a rich source of ascorbic acid, also known as vitamin C. Ascorbic acid is an essential nutrient that plays a key role in a variety of physiological processes, including collagen synthesis, wound healing, and immune function. It also has antioxidant properties that can help protect against oxidative stress and prevent chronic diseases such as cardiovascular disease and cancer. Several studies have investigated the ascorbic acid content of black carrots. For example, a study published in the Journal of Food Composition and Analysis found that black carrots contained a higher amount of ascorbic acid than orange carrots, with a mean value of 13.86 mg/100 g fresh weight compared to 7.48 mg/100 g fresh weight for orange carrots (Kumar *et al*., 2011) [56]. Another study published in the International Journal of Food Sciences and Nutrition investigated the effect of different processing methods on the ascorbic acid content of black carrots. The study found that blanching and boiling had a significant effect on the ascorbic acid content of black carrots, with blanched carrots retaining more ascorbic acid than boiled carrots (Mangaraj *et al*., 2015) [57].

Effect of processing on black carrot

Carotenoids: Several studies have investigated the effect of processing on carotenoid content in black carrots. One study found that blanching and boiling reduced the total carotenoid content in black carrots by 26-33% (Jung *et al*., 2014) [58]. Another study found that oven-drying reduced the total carotenoid content by 70%, while microwave drying resulted in a smaller reduction of 35% (Rathore *et al*., 2019) [59]. However, a third study found that fermentation increased the total carotenoid content by up to 50% (Park *et al*., 2011) [37]. Overall, processing conditions such as heat and drying can significantly reduce carotenoid content in black carrots, while fermentation may have a positive effect.

Phenolic compounds: The effect of processing on phenolic compounds in black carrots is less clear, as different studies have reported conflicting results. One study found that blanching and boiling reduced the total phenolic content in black carrots by 27-44% (Jung *et al*., 2014) [58], while another study found that oven-drying had no significant effect on total phenolic content (Rathore *et al*., 2019) [59]. However, a third study found that steaming increased the total phenolic content in black carrots by 55% (Andersson *et al*., 2008). Processing methods such as blanching and boiling may reduce phenolic content in black carrots, while steaming may have a positive effect.

Anthocyanins: Anthocyanins are water-soluble pigments that give fruits and vegetables their red, purple, and blue colors, including the deep purple color of black carrots. Several studies have investigated the effect of processing on anthocyanin content in black carrots, with consistent findings that heat processing can significantly reduce anthocyanin content. For example, one study found that boiling reduced anthocyanin content in black carrots by up to 75%, while steaming and microwave heating resulted in smaller reductions of 34-45% (Jung *et al*., 2014) [58]. Another study found that oven-drying reduced anthocyanin content by 60%, while freeze-drying resulted in a smaller reduction of 28% (Rathore *et al*., 2019) [59]. Overall, processing methods that involve heat, such as boiling and oven-drying, can significantly reduce anthocyanin content in black carrots, while freeze-drying may have a less severe effect.

Ascorbic acid: Ascorbic acid, also known as vitamin C, is a water-soluble antioxidant that plays an important role in maintaining human health. It is a common compound found in fruits and vegetables, including black carrots. Ascorbic acid is known to be sensitive to heat, oxygen, and light, and can be easily degraded during processing and storage. The degradation of ascorbic acid in black carrot can be influenced by various processing factors, such as temperature, pH, and processing time. Studies have shown that blanching black carrots before drying can cause a significant loss of ascorbic acid due to the high temperatures used during blanching. However, some studies have also suggested that ascorbic acid retention can be improved by adding citric acid or other antioxidants during processing. Furthermore, the processing technique used can also affect the retention of ascorbic acid. For example, air-drying has been shown to cause less ascorbic acid loss than other drying methods such as sun-drying and oven-drying. Similarly, high-pressure processing has been found to preserve more ascorbic acid compared to other traditional processing methods such as canning.

The impression of food processing on the polyphenol content of fruits and vegetables has been studied notably (Rothwell *et al*. 2015). Enzyme-assisted processing enhanced TPC (27%) and TFC (46%), as well as ACNs (100 percent), (Khandare *et al*.2011) [62]. Clarification method by Turkyilmaz *et al*. (2012) resulted in increase in ACNs whereas pasteurization resulted in reduction in ACNs by 3-16%. Koley *et al*. (2014) [26] reported the total monomeric anthocyanins in black carrot cultivar varied from 7.38 to 83.40 mg C3G/100 g fw. Black colored genotype had highest amount of free phenolics followed by red and orange cultivar. Suzme at al (2014) [63], reported that processing black carrot into concentrate led to an overall reduction of 70%, 73% and 44% in TPC, TFC and ACNs respectively. Murali *et al*. (2015), reported that drying the black carrot by heat treatment leads to decrease the anthocyanins. Toktas *et al*. (2016) [60], reported the loss of anthocyanin by 94% on the initial day during the fermentation of black carrot juice for the production of shalgam, which later increased after 12th days by 8 to 10 folds, however, it was lower than the initial anthocyanin content of black carrot by 39% to 46%. A study showing different types of drying methods on anthocyanin content of black carrot showed that for the deep purple cultivator, microwave- convection drying was better than convection drying methods, due to maximum degradation (Esra Capanoglu *et al*. 2017). Senem *et al*. (2017) [61] observed in their study that, the use of sweetener instead of sugar in jams and marmalades did not cause drastic changes in polyphenol content, however, the processing of jam and marmalade led to the reduction of total phenolics, anthocyanins, and phenolic acids.

Table 1: Effect of processing on black carrot.

Sample	Processing	Observation	References
Black carrot juice.	Pre-press maceration treatment with pectinase.	Enzyme-assisted processing enhanced TPC (27%) and TFC (46%), as well as ACNs (100%)	Khandare *et al*. (2011) [62].
Black carrot juice.	Clarification and pasteurization.	Depectinization and bentonite treatments resulted in increases (7 and 20%, respectively) in ACNs. Gelatine–kieselsol treatment and pasteurization resulted in reduction (10 and 3–16%) in ACNs.	Turkyilmaz *et al*. (2012).
Black carrot juice concentrates.	Clarification and pasteurization.	ACNs were identified in BCJC, which comprised the cyanidin based two nonacylated ACNs and three mono-acylated ACNs with coumaric, ferulic and sinapic acids. ACNs of BCJC had higher stability than those of other sources (e.g. pomegranate, blueberry and elderberry).	Meltem Turkyılmaz *et al*. (2012).
Black carrot juice.	Juice processing.	Black carrot cultivar had varying amounts of total monomeric anthocyanins and free phenolics.	Koley *et al*. (2014) [26].
Black carrot.	Concentrate processing.	Processing black carrot into concentrate led to an overall reduction of 70, 73 and 44% in TPC, TFC and ACNs, respectively.	Suzme *et al*. (2014) [63].
Black carrot juice.	Encapsulation with spray drying and freeze drying	Maltodextrin 20DE as the carrier material has proven to be better in retaining ACNs compared to gum arabic and tapioca starch. The best spray dried product was obtained at 150°C, while freeze dried product was the most acceptable one with maximum ACNs.	Murali *et al*. (2015)
Black carrot juice.	Clarification and pasteurization.	TPC and HCAs increased with depectinization and pasteurization, decreased with Bentonite	Dereli *et al*. (2015) [64].
Black carrot powder.	Freeze drying at pH 3.5 and 6.8 and thermal treatment at 180 °C.	Powder was more stable than solution at pH 6.8, acylated ACNs were significantly higher.	Iliopoulou *et al*. (2015) [17].
Black carrot jam/marmalade	Processing with sugar or sweetener	TPC, ACNs, and PAs decreased after processing, no significant difference between sugar and sweetener	Kamiloglu *et al*. (2015a, b) [22, 23].
Black carrot juice.	Fermentative alcoholic beverage production.	TPC increased significantly, ACNs also increased but not statistically significant	Kocher *et al*. (2016).
Black carrot juice.	Thermal treatment at 90-degree C for 5 h.	ACN stability during heating was barely improved unless the concentrations of co-pigments exceeded those of their natural source.	Gras *et al*. (2016) [14].
Black carrot.	Concentrate processing and microencapsulation in whey protein Hydrogels.	The degradation rates of TPC, TFC, and ACNs of black carrots from raw material to concentrate were 25%, 20%, and 19%, respectively. ACNs were entrapped more than other phenolic compounds.	Ersus Bilek *et al*. (2017)

Health Benefits of Black Carrot.

Antioxidant properties

Researchers have shown that black carrots contain a substantial number of antioxidants. These antioxidants work to prevent the body's oxidation chain reaction, which has the potential to harm cells. In a study by (Olejnik *et al*., 2016) [29] on the antioxidant effects of digested black carrot extracts on human colonic mucosal cells, it was found that the anthocyanin-containing components in black carrot extract protected against oxidative stress. According to (Kamiloglu, Pasli, *et al*., 2015) [22, 23] black carrot phenolic compounds have antioxidant properties. According to a study by (Blando *et al*., 2021) [9] black carrots had the highest antioxidant activity, followed by purple carrots and orange carrots. According to (Ekinci *et al*., 2016) [13] black carrot has antioxidant activity. In their study, (Smeriglio *et al*., 2018) [45, 46, 47], noted that black carrot crude extract has antioxidant activity.

Anti-inflammatory properties

In both natural and tumour necrosis factor-induced inflammatory conditions, polyphenols decreased the secretion of proinflammatory markers like IL-8, monocyte chemoattractant protein 1, vascular endothelial growth factor, and intercellular adhesion molecule 1, according to (Kamiloglu, Capanoglu, *et al*., 2015) [22, 23]. According to (Pandey & Grover, 2020) [35] phenolic components from black carrot extract significantly reduce inflammation by inhibiting inflammatory pathways. In their investigation, (Blando *et al*., 2018b) [8] noted that PAS from black carrot efficiently reduced TNF-induced VCAM-1 expression. According to (Karkute *et al*., 2018) [25], black carrot was discovered to have anti-inflammatory activity.

Anticancer properties

Black carrot extract exhibits anti-cancer benefits, according to (Saleem, 2018), a finding that was supported by other researches. Black carrot extract displayed anti-cancer properties on the cancer cell lines, according to the findings of a study by (Pala *et al*., 2017d) [33] that studied the cytotoxicity of black carrot extracts on different malignancies. (Song, 2016) reported that a cake made with black carrot extract had anti-cancer properties. In a study by (Pala *et al*., 2017e) [34] on the creation of silica-PAMAM dendrimer nanoparticles as prospective carriers in neuroblastoma cells, it was shown that anthocyanins had an exceptional anti-neuroblastoma effect. (Smeriglio *et al*., 2018c) [47] noted in their study that the compounds included in Black Carrot Crude Extract (BCCE) have a medium dose- response action, lowering cell damage and oxidative damage due to the presence of a potent antioxidant.

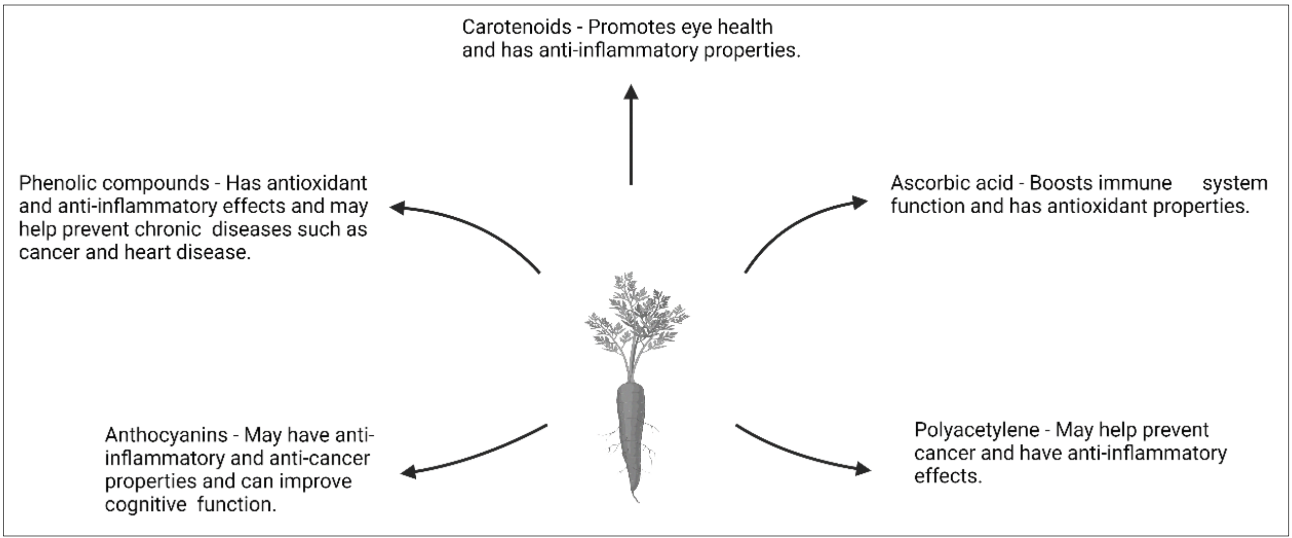

Fig 1: Benefits of bioactive compounds in black carrot

Application in different food-based products

Black Carrot Fortified Instant Noodles: Attempts had been made to develop noodles incorporated with black carrot powder. The antioxidant activity, total flavonoid content and anthocyanin content significantly increased (p<0.05) with increased incorporation of black carrot powder in the noodles. However, being heat labile, the anthocyanin content of the cooked black carrot noodles decreased significantly (p<0.05). The Water Absorption Capacity (WAC) increased from 190.6±4.93% (control sample) to 241.3±5.68% (20% incorporation). The Oil Absorption Capacity (OAC) rather remained constant. The results revealed that 10% black carrot powder incorporation was optimal for black carrot fortified noodles production based on functional, physical cooking and sensory properties. The anthocyanin, flavonoid and antioxidant activities of the optimum formulation in raw and cooked noodles were 14.94±0.021 and 7.94±0.074 mg/100g, 30.06±0.188 and 20.10±0.141 mg/100g and 35.47±0.15 and 16.55±0.18% inhibition, respectively.

Black Carrot Fortified Flat Bread: The bread making formula consisted of different levels of wheat flour/BCF blends 100/0, 99/1, 97.5/2.5, 95/5 and 92.5/7.5 (w/w) were designated as the control, 1%, 2.5%, 5% and 7.5%, respectively. The all ingredients wheat flour/BCF blends, instant dry yeast (4.0%), salt (1.5%) and water (the amount of water is required to reach 500 BU of consistency) were mixed by using professional mixer at speed 2 for 3 min. Later, dough was rested for 20 min and divided (150 g). Dough was kneaded and molded to obtain a desirable shape. The dough was put on the tray in a fermentation unit (at 35 °C and 85% relative humidity for 10 min). Fermented dough was baked at 250 °C for 5 min. The TPC which was 86.24 mg GAE/100 g for outer part and 92.74 mg GAE/100 g for inner part of the control sample considerably increased depending on the BCF addition ($p \leq 0.05$), and these values, respectively, increased to 793.12 mg GAE/100 g and 788.86 mg GAE/100 g in the sample with the addition of the BCF of 7.5%. Estimation of AA revealed that 7.5% BCF supplemented outer part had highest Antioxidant activity (75.26%) followed by 5%, 2.5%, 1% BCF added. It can be concluded that acceptable products can be prepared by incorporation of BCF for flat bread production without affecting their physical properties up to 2.5% BCF level. BCF also provides more attractive appearance for bread especially for children due to its brown-purple color. Therefore, BCF fortification could be an alternative way to produce functional flat bread for healthy daily diet.

Black carrot fibre enriched functional yogurt: It was found that the addition of pectin, gum arabic and black carrot fibre to probiotic yoghurt stimulated the growth of probiotic bacteria and gel development during storage. The viability of the probiotic bacteria was determined within the bio-therapeutic level (>7 log10 cfu/g) with potential prebiotic effects. It was determined that black carrot, pectin and gum arabic addition increased the total phenolic content and antioxidant activity of probiotic yoghurts, as well as improved the textural properties. Sensorial attributes increased throughout storage with yoghurts containing gum arabic and black carrot displayed higher scores for sensorial qualifications.

Apple chips by fortification with black carrot anthocyanin: The incorporation of black carrot anthocyanins in apple tissue by using ethanol (concentrations 0-300 mL L^{-1}) as a pre- treatment to ultrasound-assisted convective drying. Samples were pre-treated in acidified ethanol solutions, with and without anthocyanins, and then dried (50 °C, 1 m s^{-1}) by convective and ultrasound-assisted convective (21.77 kHz, 20.5 kW m^{-3}) drying. Both the drying process improvement and the obtained product properties were studied. The anthocyanins did not influence the drying kinetics. In contrast, time reduction was > 50% by using both ethanol pre-treatments and ultrasound. Ethanol pre-treatments decreased the external resistance to mass transfer, while ultrasound decreased both internal and external resistances. The impregnation increased the anthocyanins (above 947%), which were retained after drying. Colour modifications after pre-treatments and after drying (L*, b*, h° decrease, and a* increase), and antioxidant capacity retention were observed in samples with anthocyanin addition.

Black carrot ice cream, buttermilk and yogurt: Ice cream, buttermilk and yogurt were prepared by incorporating black carrot concentrate at 2.5, 5.0, 7.5 and 10% level and were subjected to sensory analysis. The most acceptable products with 7.5% black carrot concentrate were analyzed for minerals, polyphenols and antioxidant activity. Effects of storage on physicochemical, microbial and sensory attributes of black carrot concentrate incorporated dairy products were further analyzed. Black carrot concentrate could be used up to 7.5% as an ingredient into dairy product with high acceptability. Significant improvement in mineral content (Mg and Fe), polyphenols and antioxidant activity were reported in black carrot concentrate added dairy products. Developed dairy products exhibited an excellent amount of 24.52–113.27 mg/100g anthocyanins. Flavinoids increased by 14.52–34.62 times and Folin-Ciocalteu reducing capacity increased by 26.39–35.87 times in experimental dairy products. The storage study revealed that ice cream could be stored for more than 60 days, yogurt up to 5 days and buttermilk up to 10 days with excellent stability attributes.

Table 2: Application of black carrot in different food-based products

Product	Result	Reference
Black Carrot Fortified Instant Noodles.	Anthocyanin increased from 14.94 to 20.10 mg/kg after cooking	J. Singh *et al*., 2019 [43]
Black Carrot Fortified Flat Bread.	Total phenolics at 1% BCF level: 175.97 mg GAE/100 g in outer portion and 119.67 mg GAE/100 g in inner portion	Hatice Pekmez & Betül Bay Yılmaz, 2018 [16]
Black carrot fibre-enriched functional yoghurt.	Total anthocyanins: 63.66 mg/kg in experimental and not detected in control yoghurt	Karaman & Ozcan, 2021 [24]
Apple chips by fortification with black carrot anthocyanin.	Anthocyanin content increased by more than 947%	Rojas *et al*., 2021 [40]
Eggless gluten-free rice muffins by utilizing black carrot dietary fibre concentrate.	BCF incorporation increased total dietary fibre content and decreased lightness, yellowness, water activity, specific volume, and firmness of muffins.	J. P. Singh *et al*., 2016 [44]
Black carrot ice cream.	Total anthocyanins: 98.09 mg/kg in black carrot ice cream and not detected in control.	Pandey *et al*., 2021 [36]
Black carrot buttermilk.	Total anthocyanins: 24.52 mg/kg in black carrot buttermilk and not detected in control.	Pandey *et al*., 2021[36]
Black carrot yogurt.	Total anthocyanins: 98.09 mg/kg in black carrot yogurt and not detected in control.	Pandey *et al*., 2021[36]

Future Perspective of black carrot

The Black Carrot (*Daucus carota* L.), a root vegetable that is commonly cultivated and consumed due to its high nutritional value as well as phytochemicals and dietary fibre, is a member of the mustard family. More is being discovered about vegetables at a micro level and their associated health advantages and other uses in the modern day thanks to the development of scientific techniques. It has anticancer, antioxidant, and food/textile colouring characteristics, among other advantages. In addition to what has already been discovered, there is still a lot about this vegetable that has to be discovered. Its high fibre content allows it a wide range of uses in poultry, medicine, and nutrition. The black carrot has a variety of uses in the medical field since it is high in anthocyanin, a polyphenolic substance that belongs to the flavonoid family. There is a large increase in demand for natural colourants as a result of public awareness campaigns and stringent food manufacturing regulations. As a result, the food and beverage industries are utilising natural colourants to meet consumer demand and adhere to regulations. Anthocyanin, which is an organic colourant found in black carrots and has numerous health advantages, is also present. Due to the increase in demand, black carrots are now a viable crop (Iorizzo *et al*., 2020b) [19]. The quality and productivity of black carrots have been successfully improved by conventional plant breeding, according to (Simon, 2019) [42], but research is now being conducted at the genomic level by editing and insertion genes to create carrot cultivars that maximise anthocyanin yield in product stability and performance. Every field of study is being studied. While food manufacturers hunt for the best possible ways to use black carrot and its components as needed, agricultural teams are focusing at the genome level to create the best, most advanced, and reliable cultivator. On the other hand, medical experts are attempting to determine its health advantages in the majority of disorders. Black carrot is very useful in various health conditions due to its various properties. Its prices in market is very affordable but its consumption is not that much because people are still unaware about its health benefits.

Conclusion

In this review, we discuss the biologically active chemicals found in black carrot, including carotenoids, phenolic compounds and polyacetylenes. These compounds also have antioxidant and other health-promoting properties. Researchers are more focused on the anthocyanin content found in black carrot due to its good health advantages and potential as a nutraceutical. As a result, it is also regarded as a functional food. Black carrots are said to contain a lot of polyphenols in addition to their anthocyanin content. Black carrots' polyphenols, flavonoids, and carotenoids are thought to protect against a variety of diseases, including diabetes mellitus, heart disease, and oxidative stress. Therefore, we recommend that eating black carrots increases your intake of health-promoting phytochemicals and may even prevent some diseases or disorders linked to these phytochemicals. For the phytochemicals' efficacy and safety, more research is needed. Universities and research institutions should do more studies on black carrots to get find out more benefits of black carrots and promote it more for its health benefits.

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