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Utilization and characteristics of black carrot (*Daucus carrot* L.): Potential health benefits and effect of processing

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Abstract
The black carrot *Daucas carota* L. ssp. *Sativus* var. *atrorubens* Alef. is a root vegetable, widely grown across the world. It is an important root vegetable that is known for its excellent health benefits and nutraceutical effects. It has a valuable source of nutrients particularly anthocyanin and phenolic acids. Black carrot has been in recent years of great interest in the scientific field. It has been studied for its great nutritional, technological, and medicinal benefits. Black carrots have a significant amount of anthocyanin compound which is considered to be a functional food. This review aims to focus on the utilization products of black carrot which includes different types of products and beverages like shalgham, fortified cookies, etc. and the characteristics of black carrot anthocyanin. The potential health benefits are also discussed along with the significant role in several major metabolic syndromes, namely diabetes mellitus, cardiovascular diseases CVD, cancer, obesity, and oxidative stress-induced. Furthermore, the effects of processing are also highlighted in terms of anthocyanin and on different products of black carrot.

Keywords: *Polyphenols, Anthocyanin, Cardiovascular* disease, obesity, and cancer, new product development, utilization

1. Introduction

Daucus carota ssp. sativus var. atrorubens is a root vegetable that is found across Asia and the eastern Mediterranean. It is still grown and consumed in Eastern countries like India, Afghanistan, Pakistan, and the far east. The use of black carrots is recorded from the Neolithic period (Akhtar *et al*. 2017) [2]. According to Rodriguez-Concepcion and Stange (2013) [41], black carrot has been used to breed accordingly to decrease bitterness, maximize sweetness, and reduce the woody core. Indians adopted carrots as a food source and the British took carrots to Australia in 1788.

During World War II, carrots became more popular among warriors due to their consumption as an animal feed. In 1941, the UK Ministry of Food declared that the carrot can be used as a substitute vegetables. The British government also encouraged people to consume carrots to improve night blindness and also recover the food shortage during World War II (Stolarczyk and Janick, 2011).

Tanveer Ahmed *et al*. (2019) have reported black carrot is a multi-nutritional food. It is a good source of phytochemicals like phenolic compounds, carotenoids, polyacetylenes, and ascorbic acid. In most cases, the color of the carrot defines the type of compounds it may contain.

Similarly, anthocyanins are mainly present in purple roots (Baranski *et al*., 2012) [5]. Black carrot contains a relatively higher content of flavonoids as compared to orange or red carrots. These flavonoids are important in terms of their biochemical and pharmacological role as an antioxidant, anti-inflammatory, anti-atherosclerosis, antiplatelet aggregation, antitumor, antimicrobial, and anti-allergic agents (Akhtar *et al*. 2017) [2].

Accordingly, the current review aims at highlighting the health-promoting bioactive present in black carrots. The study further discusses the preventive role of bioactive compounds present in black carrots against various diseases, especially cancer, cardiovascular, obesity, and diabetes. Utilization of black carrot as a food of choice to combat certain physiological threats including long-term and acute hypo-glycemic and hypo-lipidemic effects in humans could be a sagacious and nutritionally viable approach.

2. Physiology of Carrot Plant

The edible carrot, Daucus carota, is the most important root vegetable plant grown worldwide and it is part of the *Apiaceae* family (Nguyen, 2015) [32]. The carrot body mainly has two parts, the stem, and the root. Most of the root consists of the peel (periderm), a pulpy outer cortex (phloem), and an inner core (xylem), which shows the carrot root's anatomy. Reddish, purple, black, or yellow roots are generally found in cultivated carrots. Generally, the root part of a carrot is consumed through the stems and leaves as well as per the choice of the consumer. (Ahmad *et al*. 2019) [1].

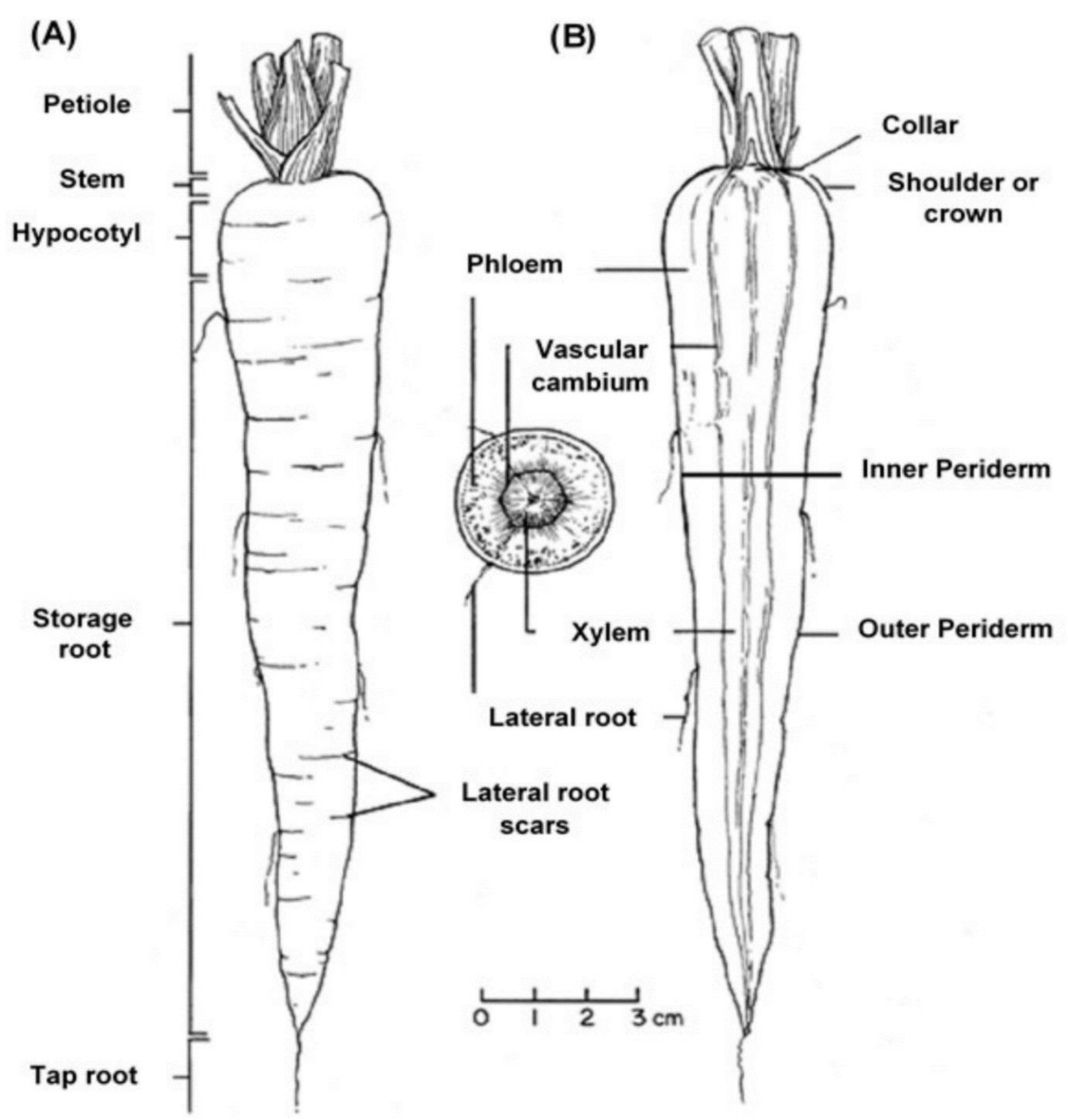

Fig 1: Structure of Black Carrot

3. Chemical and nutritional composition of black carrot

Carrots contain approximately 88% water, 1% protein, 7% carbohydrate, 0.2% fat, and 3% fiber (USDA, 2015) [15] and they are highly nutritious and rich in a diversity of phytochemicals including carotenoids (some of them with provitamin A activity), phenolic compounds, ascorbic acid, α-tocopherol, vitamins D, K, B_1, B_6, biotin, and polyacetylenes, which have antioxidant activity and health benefits. The contents of macronutrients in black carrots are presented in Table 1. The content of carotenoids and minerals in carrots is dependent on the cultivar, season, management production, environmental conditions, and postharvest handling and storage conditions. Similarly, the cooking process can affect the nutritional contents as well as the bioavailability of carotenoids and minerals (Char *et al*. 2017) [9].

3.1 Macronutrients

Geetha *et al*. 2020, reported that 7% of carbohydrates are exclusively simple sugars sucrose, glucose, and fructose. There is a small amount of protein, approximately 1%. Carrot also contains 0.2% fat and 0.3% fiber. Carbohydrate and dietary fibers can vary depending upon the cultivar. The greatest portion of total dietary fibers (50% to 92%) is composed of cellulose and hemicellulose. Around 4% of lignin is present. The soluble fibers in carrots consist of fermentable hemicellulose and pectin and represent 8% to 50% of the total fiber count.

Table 1: Nutritional composition of Macronutrients

Proximate	Percentage	References
Water	84% to 95%	Haqraees *et al* 2015. Cielo D. Char *et al*. 2017 [9]. Food data central USDA 2015 [15].
Energy	41 Kcal	Food data central USDA 2015 [15]
Protein	0.6% to 2.0%	Cielo D. Char *et al*. 2017 [9] Haq Raees *et al*. 2015. Food data central USDA 2015. [15]
Total lipid	4.75%	HaqRaees *et al* 2015.
Ash	15.32%	HaqRaees *et al* 2015.
Carbohydrate	9.58 g per 100g	Food Data Central, USDA
Fiber, total dietary	2.8 g per 100g	Food Data Central, USDA

Table 2: Nutritional Composition Micronutrients (Source: Food Data Central, USDA)

Vitamins and other components	Amount
Vitamin C, total ascorbic acid	5.9 mg
Thiamin	0.066 mg
Riboflavin	0.058 mg
Niacin	0.983 mg
Pantothenic acid	0.273 mg
Vitamin B6	0.138 mg
Folate, total	19 µg
Choline, total	8.8 mg
Betaine	0.4 mg
Vitamin A, RAE	835 µg
Anthocyanins	1.5-126 mg
Vitamin A, IU	16706 IU
Lycopene	1 µg
Vitamin E (alpha-tocopherol)	0.66 mg
Vitamin K (phylloquinone)	13.2 µg
Lutein and zeaxanthin	256 µg
Tocopherol, beta	0.01 mg
Tocotrienol, alpha	0.01 mg

4. Significance of nutritional and chemical composition

The black carrot is a good source of major micronutrients along with phytochemicals. According to Akhter *et al*. (2017) [2] anthocyanins are the major biological fractions to offer 24 disease prevention and to some extent curative properties. This establishes the pharmacokinetic perspective of black carrots. Park *et al*. (2015) [38] found that cyanidin and malvidin present in aqueous extracts of black carrots fermented with *Aspergillus oryzae* prevent menopausal symptoms, including impaired energy, and glucose and lipid metabolism in estrogen-deficient animals with diet-induced obesity. Olejnik *et al*. (2016) [34] established that purple carrots can regulate the reactive oxygen species (ROS) level in the gastrointestinal tract. Doge of carrot extract (1 mg/mL) exhibited intracellular ROS-inhibitory capacity and reduce oxidative DNA damage.

Claudio *et al*. (2016) [11] established that administration of 400 mg/L or 800 mg/L of black carrot extract can inhibit tissue degradation induced by calcium intoxication and can also reduce the 8-hydroxy-2'-491 deoxyguanosine (8OHdG) levels in liver cells. Xia *et al*. (2016) other researches have shown that anthocyanin can prevent the occurrence of oxidative stress induced by d-galactose in rats. They also cause a significant decrease in malondialdehyde (MDA) and carbonyl protein (PCO) levels compared with the d-galactose-treated group in the heart, liver, kidneys, and blood.

Anthocyanin from black carrots is also a natural food and beverage colorant. According to Massimo Iorizzo *et al*. (2020) [17] due to awareness among people and strict food manufacturing policies, there is a huge surge in demand for natural colorants, so to satisfy customer demand and apply policies food and beverages industries are using natural colorants. Black carrot provides organic colorant along with anthocyanin which itself has many health benefits. This surge in demand for black carrots makes it an economic crop.

5. Phytochemical composition

5.1 Carotenoids

Carotenoids have a significant number of micronutrient which provides specific health-related properties. The carrot root is one of the richer sources of these pigments, and the orange-rooted variety is the most familiar nowadays; these contain predominantly β-carotene (Gonzalez *et al*., 2014). According to Char (2017) [9], total root carotenoid content can vary significantly between cultivars. Orange cultivars contain about 8.3 mg/100 g fresh weight (fw) β-carotene but many breeding efforts have increased that value through the phenotypic recurrent selection of roots with a darker orange color.

5.2 Phenolic compounds

Different variety of carrots was analyzed to know the variations in total phenolic (phenolic acid and flavonoids) by Koley *et al*. (2014) [22]. They found that black colored genotype had the highest amount of free phenolics (31.9 to 290.0 mg gallic acid equivalents (GAE) per 100 g fw), followed by red (10.8 to 14.2 mg GAE/100 g fw) and orange (6.4 to 10.6 mg GAE/100 g fw) cultivars. Total phenolic content in carrots is often measured using the Folin-Ciocalteu method, which also reacts with flavonoids such as the anthocyanins in purple carrots. They found that the black carrot variety have the maximum concentration of total phenolic. Montilla *et al*. (2011) [29], li *et al* (2012) [18], Algarra *et al* (2014) [3] reported that anthocyanins present in black carrot range from 1.5-126 mg/100g.

Additionally, determined that approximately 25–33% of the total phenolics of red and orange carrots were present in the form of bound phenolics (Koley *et al*. 2014) [22]. However, in the black carrot genotype, the majority of phenols were present in soluble or free form. Bound phenolics are found mostly in ester form associated with cell-wall components conferring structural stability, and are determined by additional base digestion of the extract residues.

These bound phenolics have special health significance because they are resistant to upper gastrointestinal digestion and subsequently be released in the colon. Colonic digestion of such materials by microflora may release the bulk of the bound phenolics at this level, where they may exert positive health effects.

The main phenolic compounds found in carrots are chlorogenic acids, which are hydroxycinnamic acid derivatives formed by the esterification of cinnamic acids, such as caffeic, and ferulic. The anthocyanins found in black carrots are derivatives of cyanidin; however, pelargonidin and peonidin glycosides have also been identified.

The total monomeric anthocyanins in the black carrot cultivar varied from 7.4 to 83.4 mg cyanidin-3-glucoside (C3G) per 100 g fw; however, authors have published a range from 1.50 to 243.00 mg C3G/100 g fw. The anthocyanins in black carrots include mainly acylated and non-acylated cyanidin-based derivatives. In addition to the health benefits, the black carrot cultivar could be a potential natural source of stable food pigment; the majority of the anthocyanin it contains is reported to be acylated, which is more stable under heat, light, and other environmental conditions compared with the non-acylated fraction (Char *et al*. 2017) [9].

5.3 Vitamin C

Black carrots are also contain significant amount of vitamin C, containing 5.9 mg of total ascorbic acid per 100 g fw (USDA, 2015) [15]. Carrots contain more vitamin C than grapes, nectarines, pears, and plums, among others.

The stability of vitamin C in carrots can be influenced by factors from preharvest (including cultivars and environmental conditions) to harvest and postharvest handling. The total vitamin C content in plant tissues increases under high intensity of sunlight.

It has been found that the concentration of vitamin C decreases with the delaying of harvesting. (Leong and Oey, 2012) [27].

5.4 Polyacetylenes

Falcarinol, falcarindiol, and falcarindiol-3-acetate are the main compounds found in carrot root, it ranges between 20 to 100 mg/kg fw. Polyacetylenes gives the bitter off-flavor of carrots. Polyacetylenes can act as external sanitizers, and at high concentration can cause toxicity. And in many regions considered as toxicants. In recent studies, polyacetylenes have been considered bioactive compounds with potential effects on human physiology and disease.

In vitro studies suggest that carrot polyacetylenes can act as anti-inflammatory agent in macrophages, biphasic stimulatory and cytotoxic effects on primary mammalians' epithelial cells, and cytotoxic activity against number of cell activity acting as defense line for the body. More research is needed to be conducted to know more about this molecule and its health benefits. (Char *et al*. 2017) [9].

6. Characteristics of Black Carrot

6.1 Anthocyanin

Black carrot is a vegetable that has an attractive purple color (Turkyilmaz *et al*. 2012). A natural pigment known as anthocyanin is responsible for the purple or black color and due to this property, anthocyanin from Black carrot is widely used as a source of natural food color as well as for synthetic colors.

Black carrots have a unique profile of anthocyanin pigment which attracts the scientific community (Olejnik *et al*. 2016) [34]. Anthocyanin has free radical scavenging capacity, therefore it is recognized as a part of di*et al*ong with validated nutraceutical properties.

Anthocyanin does not undergo any metabolic changes and can be absorbed in the intestine directly and further causing it to convert into glucuronide, methyl, or sulfate compounds in the small intestine and liver where phase II enzymes exist, which may show a protective effect on the endothelial cells (Kuntz *et al*. 2015).

Black carrot has a high amount of acylated anthocyanin (Pandey *et al*. 2020) [36]. In Black carrots, more than half of the total anthocyanins are compounds with an acylated structure (John *et al*. 2017) [9].

The major types of anthocyanins found in black carrots were cyanidin-based; 3-xylosyl glucosylgalactoside, cyandinin 3-xylosylgalactoside, and the sinapic, ferulic, and coumaric acids (Garcia-Herrera *et al*. 2016).

According to Algarra *et al*. 2014 [3] in the Antonina variety the level of anthocyanin correlated with half of the total phenolic content of black carrot.

Apart from anthocyanins, black carrot also contains a good amount of phenolic acids. Hydroxycinnamic acid in black carrot is recognized as the main derivative of phenolic acids (Pandey *et al*. 2020) [36]. In the roots of the black carrot, an ester of caffeic, chlorogenicc acid (5-0-caffeoylquinic acid), and quinic acid was found to be 657mg/kg (S Kamiloglu *et al*. 2017) [19]. In some studies, black carrot roots show a great number of phenolic compounds than other colored root vegetables (Koley *et al*. 2014) [22].

In Black carrots, the anthocyanin content is approximately 350 mg per 100 g of edible carrots (Kiran *et al*. 2020) [37]. Anthocyanin decreases in the presence of air, light, temperature acids, and enzymes. (Fernades *et al*. 2014).

In acidic pH, the anthocyanin is more stable, therefore any change in pH higher than 4 led to the degradation of the pigment into phenolic acids (Fang *et al*. 2014).

Cyanidin glycoside, a major type of compound of anthocyanin via black carrot shows an attractive red shade close to FD & C red 40 (Allura Red) Kiran *et al*. 2020) [37]. Colors from black carrots can be found in liquid as well as dry forms (Pandey *et al*. 2020) [36]. It is reported that anthocyanin can be optimized for maximum extraction at a large scale production by subjecting it to a low pH and high temperature.

7. Effects of processing on Black Carrots

The impact of food processing on the polyphenol content of fruits and vegetables has been studied notably (Rothwell *et al*. 2015). Heat treatments prompt the degradation of black carrot anthocyanins, (Murali *et al*. 2015). However, the increase in the pH results in a small overall increase in the degradation of the anthocyanin compared to values at low pH (Ilipoulou *et al*. 2015).

Suzme *et al*. (2014), reported that when black carrots were processed into concentrate, there was a reduction of total phenols by 70%, total flavonoids by 73%, and anthocyanins by 44%.

Murali *et al*. (2015), reported that drying the black carrot by subjecting it to heat treatment decreased the anthocyanins.

Toktas *et al*. (2016), 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%.

According to Pragya *et al*. 2020, anthocyanin degradation is fast in higher temperatures than in lower temperatures for storage degradation.

Murali *et al*. 2015 outlined the two different types of methods to increase the stability of black carrot anthocyanins, which are, microencapsulation and co-pigmentation. It is reported that a material carrier, maltodextrin 20DE has the tendency to retain the maximum anthocyanins and the entrapment of anthocyanin from black carrot was better in whey protein hydrogels than other phenolic compounds (Ersus Bilek *et al*. 2017). Until the concentrations of co-pigments exceeded their natural source, the stability for anthocyanin was barely improved for the combined black carrot extract with chlorogenic acids which acted as co-pigment (Gras *et al*. 2016). 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) [19]. Furthermore, in some studies, depectinization resulted in increased total phenolics and hydroxycinnamic acids (Dereli *et al*. 2015), and gelatin-kieselsol treatment resulted in decreased polyphenols.
There was a reduction as well as enhancement in polyphenols content of black carrot juice due to bentonite treatment and pasteurization (Dereli *et al*. 2015).
Processing the black carrots into concentrate caused the decline in phenolics, flavonoids, and anthocyanins (Ersus Bilek *et al*. 2017). Under the solid and aqueous states, the differences in the degradation mechanism of anthocyanins were noticed, specifically at solid conditions in high pH, the anthocyanins were more stable than in the aqueous state. Furthermore, the acylated anthocyanin was more stable in solid form compared to the liquid form (Iliopoulou *et al*. 2015).
Senem *et al*. (2017) 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.
The production of alcoholic beverages by fermenting the black carrot with Saccharomyces cerevisiae caused an increase in total phenolic content however the changes in anthocyanin were not much (Kocher *et al*. 2016).

Table 3: Effects of processing on different products of black carrot

Product Name	Processing Condition	Conclusion	Reference
Black Carrot Juice, Shalgham	Fermenting the extract for 21 days using Lactic acid bacteria using four different batches.	LAB plays an important role in fermenting all the samples, where the level of fermentation at the end was between 4.84 and 6.51 log CFU/ml, with an average of 5.53 log CFU/ml.	Halil Ibrahim Kahvea, Mehmet Akbulutb, HacerCoklarb (2022)
Anthocyanin-infused Potato Chips	The potato slices to be infused with anthocyanin-rich ALEBC were performed at two levels i.e., 1:1 ratio and 1:2 ratio	The infusion of potato chips with ALEBC resulted in a positive outcome in terms of the total anthocyanin content and antioxidant activity as well as the cooking time	Sunil Kumar, PrernaNath, Ajinath Dukare, Sakharam Kale, PankajKannaujia (2021)
Yogurt	Black carrot concentrate was used as an ingredient. Yogurt was prepared by the method purposed by De (2006) using Yogurt culture NCDC 144 (L. delbrueckii subsp bulgaricus and S. thermophiles, 1:1)	The yogurt was developed and analysed for sensory attributes, physicochemical characteristics, polyphenols, and antioxidant capacity and storage stability.	Pragya Pandey, Kiran Grover, Tarsem Singh Dhillon, Amarjeet Kaur, Mohammed Javed (2021) [37]
Black Carrot Pomace	Black Carrot pomace was dehydrated by subjecting them to five different types of drying. Freeze drying, Microwave drying, Convective drying, Vacuum/convective drying, and Conductive hydro drying.	The conductive hydro drying method resulted in the shortest drying time and color quality with fresh samples.	Suleyman Polat, Gamze Guclu, Hasim Kelebek, Muharrem Keskin, Serkan Selli (2022)
Rice Cake	The rice cake was incorporated with black carrot flour in 6 different quantities (0% BC flour), BC0.5 (0.5% BC flour), BC1 (1% BC flour), BC2 (2% BC flour), BC3 (3% BC flour), and BC4 (4% BC flour) and subjected to steam for 20mins. The samples were analyzed after cooling for 30mins at room temperature.	Black carrots are suitable for the production of rice cakes. It also reduces the retrogradation effects and improves the quality properties. The 4% black carrot flour is considered suitable for improving quality properties whereas 0.5% - 1% of black carrot flour was suitable for delaying retrogradation.	Ka-Young Song, Hyeonbin O, Yangyang Zhang, Ki Youeng Joung, Dal Woong Choi, Young-Soon Kim (2018) [46]

7.1 Black Carrot Juice, Shalgham

The extract was fermented for 21days using lactic acid bacteria using four different batches. Lab dominated the fermentation process in all four batches. By the end of the fermentation, the LAB levels were between 4.84 and 6.51 log CFU/ml, with an average of 5.53 CFU/ml. A similar result of LAB dominance was also reported by Arici (2004) and Tanguler & Erten (2012) [49].
Different yeast species were also reported during the fermentation which include, *P. kudriavzevii*, *P. fermentans*, *S. cerevisiae*, *Candida oleophila*, *Kazachstaniabulderi*, and *Geotrichumcandidum. P.* kudriavzevii, was reported to have dominated the fermentation process on contrary.
Due to the technological characteristics which resulted in the importance of *P. kudriavzevii*, yeasts were recommended to be used as a starter culture combination for the improvement of the flavor and aroma of the shalgham.

7.2 Anthocyanin-infused Potato Chips

The potato slices to be infused with anthocyanin-rich ALEBC were performed at two levels, that is, 1:1 and 1:2 (potato slices: ALEBC) at ambient temperature (25° C). The potato slices were infused with ALBEC for 0, 15, 30, 45, 60, 90, and 120 mins. The samples were dried and stored in a cool place for further analysis which includes total soluble solids, total phenolic content, total antioxidant activity, total monomeric anthocyanin content, ascorbic acid, and color attributes. Cooking quality and organoleptic evaluations were also performed.
The results were, that the anthocyanin content and antioxidant activity of potato slices corresponded positively to the amount of ALBEC-infused. Cooking the potato slices in the microwave didn't affect the biochemical composition of the potato slices compared to the cooking oil method which adversely affected the biochemical constituents and color. The

60 min infusion time was accepted by the panelist and the color of the slices after cooking was darker which was unacceptable.

7.3 Yogurt
Yogurt was developed using De (2006) method. Yogurt culture NCDC 144 (*L. delbrukii sub spbulgaricus* and *S. thermophiles*, 1:1) was used which was obtained from NDRI, Karnal. The black carrot concentrate added with the yogurt samples were processed as control but a selected percentage (0%, 5.0%, 7.5, and 10%) was added prior to the addition of culture to the samples. The yogurt was developed and analyzed for sensory attributes, physicochemical characteristics, polyphenols, antioxidant capacity, and storage stability.

7.4 Black Carrot Pomace
The black carrot pomace was obtained from a carrot juice concentrate production company located in the Eregli city of the Konya province, Turkey.
The pomace samples were dehydrated using five drying methods, freeze-drying, microwave drying, convective drying, vacuum/convective drying, and conductive hydro drying. The dried samples were vacuum-packed and kept at -20°C until further analyses.
Conductive hydro drying resulted in the shortest drying time and the highest anthocyanin content. In addition, the conductive hydro drying provided color quality with fresh samples and colorless phenolic concentrations.

7.5 Rice Cake
The rice cake was prepared as described by Lee YN *et al*., and Kim YS (2012, 2013). The rice cake was incorporated with black carrot flour in 6 different quantities (0% BC flour), BC 0.5 (0.5% BC flour), BC1 (1% BC flour), BC2 (2% BC flour), BC3 (3% BC flour), and BC4 (4% BC flour) and subjected to steam for 20 mins. The samples were analyzed after cooling for 30 mins at room temperature.
The evaluation of quality properties and ability to reduce retrogradation was done with Korean rice cake incorporated with black carrot flour in different portions. It resulted that the black carrot is a good source for producing Korean rice cakes as it improves the quality properties and reduces retrogradation effects. The 4% black carrot flour is considered suitable for improving quality properties whereas 0.5% - 1% of black carrot flour was suitable for delaying retrogradation.
The moisture content and water holding capacity of black carrot rice cakes were directly proportional to the black carrot, as the moisture content and water holding capacity of black carrot rice cakes increased with increased black carrot, whereas the pH notably decreased with an increase in black carrot ($P< 0.05$).

8. Health Benefits of Black Carrot
8.1 Prevention of Oxidative damage
Black carrots have been discovered by various researchers to have significant anti-oxidant properties. These antioxidants, as the name entails, fight the oxidation chain reaction in the body which could lead to damage of the body cells. Olejnik *et al*. (2016) [34] conducted a study on antioxidant effects of digested black carrot extracts on the human cells of colonic mucosa, it was discovered that the compounds known as anthocyanins, in black carrot extract fought against oxidative stress.
Kamiloglu, & Pasli (2015) [20] found out that the phenolic compounds in black carrot had anti-oxidant effects. Blando, & Marchello. (2021) [7] research ranked black carrot first, in anti-oxidant activity, followed by purple carrot and lastly orange Carrot. Ekinci & Baser, (2016) [13] according to their findings stated that black carrot had anti-oxidant activity. Smeriglio, & Denaro, (2018) [45] in their research mentioned that black carrot crude extract had anti-oxidant activity.
Cho & Chung, (2019) [10] conducted a study on the antioxidant activity of cookies made with black carrot powder, these cookies “as mentioned in this study” exhibited anti-oxidant activity, as per quantity of black carrot powder added. Yildiz & Guldas (2020) [53] found kombucha black carrot which was added in kombucha tea to have antioxidant activity.
Suzme, & Boyacioglu, (2014) found out in their study that processing resulted in reduction in anti-oxidant activity, this is an indication that black carrot exhibits anti-oxidant activity. Algarra &Fernandes (2014) [3] found out and stated in their study that black carrot had higher antioxidant activity compared to orange carrot. Saleem, & Akhtar (2018) [42] reported that black carrot extract exhibited anti-oxidant activity at much more degrees than acetone extract.

8.2 Prevention inflammatory diseases
Kamiloglu, & Grootaert (2017) [19] mentioned in their study that polyphenols downgraded the secretion of pro-inflammatory markers, which included IL-8, monocyte chemoattractant protein 1, vascular endothelial growth factor, and intercellular adhesion molecule 1, in normal and tumor necrosis factor α induced inflammatory conditions. Pandey, & Grover (2020) [36] in their study stated that Phenolic compounds from black carrot extract have a significant effect in reducing inflammation by blocking inflammatory pathways. Blando & Calabriso, (2018) [6] in their study mentioned that TNF-induced VCAM-1 expression was effectively decreased by PAS from black carrot.
Singh, & Koley, (2018) [23] mentioned that among many activities, black carrot was found to have anti-inflammatory activity. Iahtisham-ul-haq *et al*., (2019) in their research concluded that anthocyanins, found in black carrot, are dietary antioxidants with anti-inflammatory effects.

8.3 Preventing metabolic disorders
Esatbeyoglu *et al*., (2016) [14] conducted a study on the polyphenol composition of black carrot, they went further to do a study on the anti-diabetic activity of these compounds, they discovered that these compounds inhibited alpha~amylase and alpha~glucosidase activity and also on the cellular uptake of glucose, meaning they had antidiabetic activities. Park *et al*. (2015) [38] conducted a study on black carrots fermented with *aspergillus oryzae*, in this study, the research scholars concluded with saying that increasing cyanidin and 484 malvidin levels in rats can protect lipid and glucose metabolism from deteriorating via boosting hepatic 485 insulin signalling and AMPK activation. Akhtar, & Rauf, (2017) [2] mentioned that the phytochemicals found in black carrot have multiple defensive mechanisms on metabolic syndromes such as cardiovascular diseases, diabetes mellitus and oxidative stress.
Jiang & Li (2019) [18] in their study mentioned that anthocyanins in black carrot have various bio-mechanisms which help prevent metabolic syndromes. Park, & Kang

(2016) [22] reported that fermented black carrot helps in diabetes prevention. Karkute *et al*., (2018) [23] reported that anthocyanins were found to be effective in the control of diabetes, and proposed that cyanidin 3-xylosyl galactoside was best potential molecule for inhibiting enzymes involved in glucose metabolism.

8.4 Preventing degenerative diseases

Saleem & Akhtar (2018) [42] reported that black carrot extract has anti-cancer effects, a result which was in favour with others researchers. (Pala *et al*., 2016) [35] in his study examined the cytotoxicity of black carrot extracts on various cancers, the results clearly showed that black carrot extract had anti-cancer activities on the cancer cell lines.

Song, & Hyeonbin, (2016) [46] reported anti-cancer effects in the cake which was prepared with black carrot extract. Yesil-Celiktas, & Pala, (2017) [35] conducted a study on the synthesis of silica-PAMAM dendrimer nanoparticles as promising carriers in neuroblastoma cells, it was reported in this study that the anthocyanins activity was remarkable against neuroblastoma. Smeriglio & Denaro. (2018) [45] in their study mentioned that due to the presence of a powerful anti-oxidant, the chemicals included in Black Carrot Crude Extract (BCCE) have a moderate dose-response activity, reducing cell death and oxidative damage.

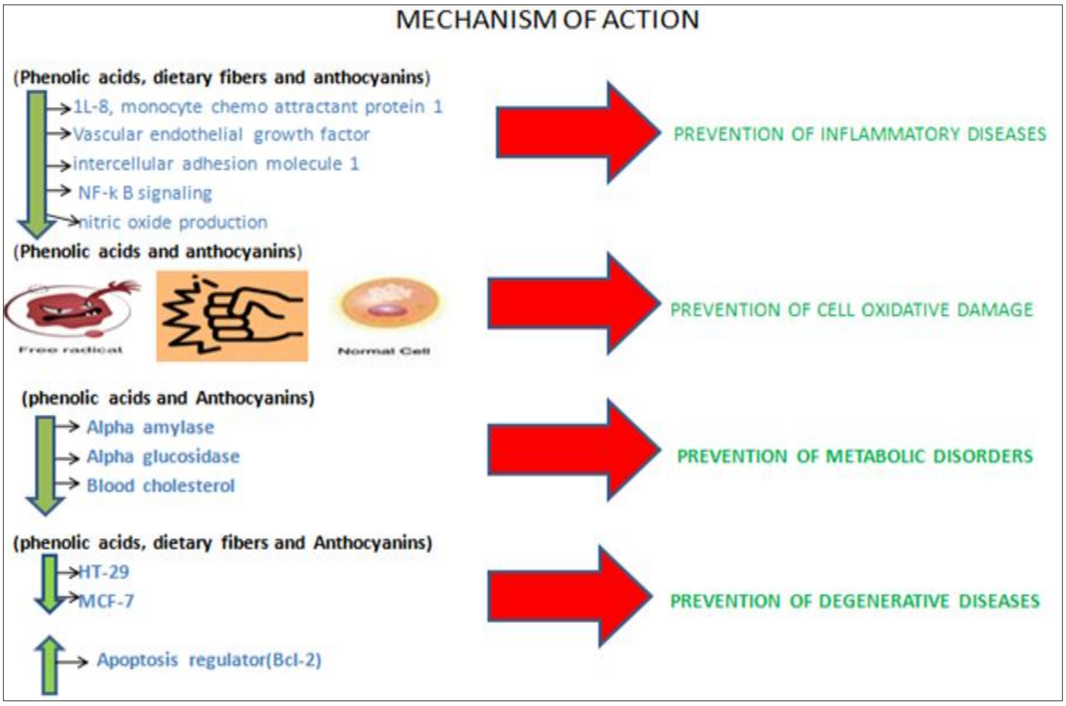

Fig 2: Mechanism of action

Table 4: Health Benefits of Black Carrot

Health benefits	Compounds responsible	Reference
It helps in the prevention of oxidative damage	Anthocyanins Phenolic acids Phenolic compounds	Kamiloglu & Pasli, (2015) [20] Blando & Marchello (2021) [7] Ekinci & Baser (2016) [13] Smeriglio & Denaro (2018) [45] Cho & Chung (2019) [10] Yildiz & Guldas (2020) [53] Olejnik & Rychlik (2016) [34] Saleem & Akhtar (2018) [42]
It has anti-inflammatory effects	Anthocyanins Phenolic compounds	Kamiloglu & Grootaert (2017) [19] Pandey & Grover (2020) [36] Blando & Calabriso, (2018) [6] Singh & Koley (2018) [23]
It helps in preventing metabolic syndromes	Anthocyanins Fibres Polyphenols	Esatbeyoglu *et al*. (2016) [14] Park *et al*. (2015) [38] Akhtar & Rauf (2017) [2] Jiang & Li (2019) [18] Park & Kang (2016) [22] Karkute & Koley (2018) [23]
It has anticancer properties	Phenolics Anthocyanins	Saleem & Akhtar (2018) [42] Pala *et al*. (2016) [35] Song & Hyeonbin (2016) [46] Yesil-Celiktas & Pala (2017) [35]

(iL-8= Interleukin 8, NFκB= Nuclear factor kappa B, HT-29= Human colon adenocarcinoma cell line, MCF-7= Michigan Cancer Foundation, Bcl-2= B-Cell lymphoma 2.)

9. Utilization of Black Carrot
9.1 Bakery Products
9.1.1 Black Carrot Powder Cookies: Cho *et al*., (2019) [10], prepared a black carrot cookie for an experiment to find out the quality characteristics and antioxidant activity of cookies made with black carrot. In the formulation, the black carrot powder was added in different concentrations, 0%, 5% 10%, 15%, flour, baking powder and black carrot powder were collected, then sieved, then the mixture was placed in a bowl and eggs were put in then mixed.in a different bowl, heavy butter and sugar were creamed it for 2 minutes. This cream was then added to the first mixture and mixed. Then the mass was cookie shaped and baked to cookies. The results of this experiment tell us that Consumer symbols did not lead to significant differences in the odor, texture, taste and just the overall acceptance. Phenolic content increased with the increase in concentration of black carrot powder, the increase was at 24.0 ~ 103.5mg GAE / 100g. Adding purple sugar root powder to 9.11~88.79% increased the DPPH radial purge ability. With consideration of both the symbol side and the antioxidant active aspect. It was decided that in the manufacture of cookies, the purple sugar root powder should be added 15% to the cookies to get a stable and favorable product.

9.1.2 Black Carrot Fiber Fortified Bread

Pekmez, & Yılmaz, (2018) [39] formulated black carrot fiber fortified bread to conduct an experiment on the Quality and Antioxidant Properties of Black Carrot. Black carrot pomace from blended carrot was collected, then dried to 12% moisture and then pounded and kept at 4 °c.

Then wheat flour was mixed with carrot fiber and dough was created, then later feremented and baked at 250°c for 5 minutes. The bread was prepared with different black carrot fiber quantities, 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 results of this experiment tells us that Up to a 2.5 percent BCF level is suitable to formulate BCFF bread, with consideration of its physical qualities.

9.2 Beverages
9.2.1 Shalgam juice

Tanguler *et al*., (2014) [49] formulated shalgam juice, with different quantities of black carrot, to see the variety of effects of the black carrot (*Daucus carota*) in different quantities. In this experiment, bulgur flour, sourdough, rock salt, and water were mixed. Further kneading was done and the dough was fermented. Then the dough was divided into five masses, for the various Black carrot concentrations. To each of the masses, black carrot was added and mixed. Then water and water rock salt was added to each of these masses and the second fermentation was done. Shalgam juice was now ready. The Black carrot concentrations included (10%, 12.5%, 15%, 17.5%, 20%). The most preferred sample was 17.5%. The Samples with 20% and 10% black carrot were totally unacceptable. The amount of black carrots increased Overall acceptance of shalgam by all panelists. They concluded in this study that at least 15% of black carrot was to be used for the Manufacture of shalgam beverages, as this amount reduces the manufacturer and production costs.

9.2.2 Fermented Vegetable Juice

Değirmencioğlu, N., Gurbuz, O., & Şahan, Y. (2016) [53] in their experiment formulated fermented vegetable juices, one with black carrot. Watermelon radishes, red beets and black carrots were used in this.

Two fermentations were done. In the first one, bulgur flour, activated yeast strains, salt and water were mixed. Two dough masses were created and fermented separately, one with *S. cerevisiae* and the other with *S. boulardii* for 5 days. In second fermentation, 30 kg of sliced R, RB, and RC were placed separately into 50 kg plastic bags, then brines containing 1.0 percent (w/v) salt and dough were added, sealed, and anaerobic fermentation was carried out for 16 days.

The experiments in this study were twice replicated for each of the different vegetable juices. In this study, only black carrot had high amounts of cyanidin-3-O-glycoside chloride (1549.86–1774.86 mg/L), in spite of the fact that vanillic corrosive was found in other aged vegetable juices. The solid antioxidant movement of RC juices matured by *S. boulardii* was connected to higher add up to phenolic component concentrations, though matured RB juices had the next bioaccessibility of antioxidant action.

Table 5: Utilization of Black Carrot

Baked Product	Product Formulation	Concentration	Result	Reference
Black carrot powder cookies	Flour, baking powder, and black carrot powder were collected, then sieved, then the mixture was placed in a bowl and eggs were put in then mixed in a different bowl, heavy butter and sugar were creamed it for 2 minutes. This cream was then added to the first mixture and mixed. Then the mass was cookie shaped and baked to cookies	5% 10% 15%	It was concluded that the cookies containing 15% black carrot powder were preferable in terms of acceptability and antioxidant activity.	Cho & Chung (2019) [10]
Black Carrot Fiber Fortified Flat Bread	Black carrot pomace from blended carrot was collected, then dried to 12% moisture and then Pounded and kept at 4 °c. Then wheat flour was mixed with carrot fiber and dough was created, then later fermented and baked at 250°c for 5 minutes.	1% 2.5% 5% 7.5%	It was concluded that Up to a 2.5 percent BCF level, suitable products can be made by using BCF into flat bread manufacture without compromising their physical qualities.	Pekmez, & Yılmaz, (2018) [39].

Product Beverages	Product Formulation	Concentration	Result	Reference
Shalgam juice	Bulgur flour, sourdough, rock salt, and water were mixed. Then kneading was done, and then the dough was fermented. Then the dough was divided into 5masses, for the various Black carrot concentrations. -To each of the masses, the black carrot was added	10.5% 12.5 15% 17.5% 20%	It was discovered that at best, black carrot must be used at least at the rate of 15% for the production of shalgam beverage	Tanguler & Gunes (2014) [49].

	and mixed. Then water and water-rock salt was added to each of these masses and the second fermentation was done. Shalgam juice was now ready			
Fermented Vegetable Juice	Watermelon radishes, red beets, and black carrots were used in this. Two fermentations were done. In the first one, bulgur flour, activated yeast strains, saltand water were mixed. Two dough masses were created and fermented separately, one with S. cerevisiae and the other with S. boulardii for 5 days. In second fermentation, 30 kg of sliced R, RB, and RC were placed separately into 50 kg plastic bags, then brines containing 1.0 percent (w/v) salt and doughs were added, sealed, and anaerobic fermentation was carried out for 16 days at 20 6 2C.		Only black carrot juice had a high quantity of cyanidin-3-O-glycoside chloride (1549.86–1774.86 mg/L), although vanillic acid was found in other fermented vegetable juices. The strong antioxidant activity of RC juices fermented by S. boulardii was linked to higher total phenolic component concentrations, whereas fermented RB juices had a higher bioaccesibility of antioxidant activity	Değirmencioğlu & Şahan (2016) [12].

10. Recommendation and Toxicology

Black carrots contain a high amount of flavonoids as compared to red and orange carrots (Akhtar *et al*. 2017) [2]. Black carrot is rich in its nutritional and antioxidant profile it can so prevent metabolic syndrome (Hina Rasheed *et al*. 2022) and due to this fact, it has attracted the scientific community. The black carrot does not protect from H_2O_2-induced DNA damage but it increases the H_2O_2-inducedgenotoxicity. Excess consumption of black carrots can also lead to diarrhea.

There has been consecutive studies on the black carrot in the recent years, and it has been proven by various researchers that it has multiple health benefits, ranging from constipation relief to cancers. On the antioxidant activity of black carrot Kamiloglu & Pasli, 2015; Ekinci & Baser 2016; Cho & Chung 2019) [20, 13, 10] On the anti-inflammatory effects, Kamiloglu and Grootaert 2017; Blando and Calabriso 2018; Singh and Koley 2018) [23, 6, 19]. On the prevention of metabolic disorders, Park & Kang 2016; Kaekute & Koley 2016; Jiang & Li 2016) [22, 18]. On the prevention of metabolic disorders, Saleem and Akhtar 2018; Pala *et al*. 2016; Smeriglio & Denaro 2018) [22 42, 45, 35].

A lot more studies have been conducted on the health benefits of black carrot and it has been proven how beneficial this Vegetable could be. But with this, it still has not gotten popularity in the production of pharmaceutical products. We recommend that there be exploration of this product in the medical field.

Black carrots existed way before the 15th century, but till now are not as popular. So far it has been seen how valuable this vegetable is. Therefore we recommend that the black carrot must be popularized so that it can be extensively used by people for health and preparation of various dishes.

11. Future Perspective of black carrot

The Black Carrots (*Daucus carota* L.) is a root vegetable widely grown across the globe and consumed because of its rich nutritional content along with phytochemicals and dietary fibers. In the recent era with the advancement of scientific tools, more about vegetables at a microscopic level and their related health benefits and other uses are being discovered. Some of its benefits include anticancer activity, antioxidant activity, and food/textile coloring properties.

There is still a lot that can be and needs to be explored in this vegetable, its rich fiber content gives it a broad spectrum of use in the poultry, medicine, and nutritional use besides what has already been discovered.

The black carrot is rich in anthocyanin, a polyphenols compound that falls under flavonoids, giving it a scope of use in the medical industry. Due to awareness among people and strict food manufacturing policies, there is a huge surge in demand for natural colorants, so to satisfy customer demand and apply policies food and beverages industries are using natural colorants. Black carrot provides organic colorant along with anthocyanin which itself has many health benefits. This surge in demand for black carrots makes it an economic crop (Massimo Iorizzo*et al*. (2020) [17].

According to Simon *et al*. (2019) [44] classical plant breeding has been successful in improving the quality and productivity of black carrots but research is being done on a genomic level by editing and insertion genes to develop carrot cultivars that maximize anthocyanin yield in product performance and stability.

Black carrot also has a positive effect on Type 2 diabetes and phenolic components of black carrot have this medicinal property. Along with this research, various research has been also conducted to establish the ground for medicinal benefits in different cases like cancer, inflammation, etc. (Suhas *et al*. 2018). Phenolic compounds, such as anthocyanin, present in purple carrot roots may be especially productive in avoiding or delaying the onset of cardiovascular disease (CVDs), obesity, diabetes, and cancer. Anthocyanins and other phenolics are successful in reducing metabolic changes and inflammation by inhibiting inflammatory effects.

Research is being conducted in all fields. In agriculture, researchers are working at the genomic level to develop the best and most advanced and stable cultivator, while food industries are working to find out the best possible ways of incorporating black carrot and its components as per need. On the other side medicine researchers trying to find out its health benefits in most diseases. In India, Black carrot is a underutilized despite having an excellent nutraceutical properties. It is affordable rates are high still its consumption is very low. Therefore it is necessary to highlight this vegetable to utilize its full potential.

12. Conclusion

This review highlights the black carrot consumption as it is considered as an underutilized vegetable especially in India. Anthocyanin, the compound of interest in black carrot has attracted the scientific community due to its excellent health benefits and nutraceutical effects. It is therefore also considered as a functional food. In addition to its anthocyanin contain, black carrots are reported to have a high amount of polyphenols.

The polyphenols, flavonoids, and carotenoids present in black carrots have been considered a preventive agent against certain ailments including many types of cancer, diabetes mellitus, and cardiovascular and oxidative stress. It also discusses the various types of products and beverages incorporated with black carrots which have been made from black carrots. Anthocyanin is reported to be stable in various processing conditions which is why they have been widely used in the food industry as a food coloring agent.

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