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Review

Delving into the Nutraceutical Benefits of Purple Carrot against Metabolic Syndrome and Cancer: A Review

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Abstract: Metabolic syndrome (MetS) constitutes a group of risk factors that may increase the risk of cancer and other health problems. Nowadays, researchers are focusing on food compounds that could prevent many chronic diseases. Thus, people are shifting from dietary supplements towards healthy nutritional approaches. As a nutritious and natural food source, purple carrot (*Daucus carota* spp. *Sativus* var. *atrorubens* Alef.) roots could have an important role in the prevention of MetS as well as cancer. This review provides deep insight into the role of purple carrot's main bioactive compounds and their effectiveness against MetS and cancer. 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. Many researchers have made efforts to employ this vegetable in the prevention and treatment of MetS and cancer. However, more advanced studies are required for the identification of its detailed role, effectiveness, suitable intake, and the effect of its bioactive compounds against these diseases.

Keywords: metabolic syndrome; cancers; purple carrot; anthocyanins; bioactive component; nutraceutical

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1. Introduction

Nowadays, we know more and more about the genesis and causes of many chronic diseases. Certain interconnected factors could predispose to type 2 diabetes and cardiovascular disease and currently are defined as metabolic syndrome (MetS). The main considered factors are dyslipidemia (high levels of low-density lipoprotein (LDL), triglycerides (TG), and low levels of high-density lipoprotein (HDL)), high blood pressure, obesity, impaired glucose metabolism, and/or insulin resistance [1,2]. Although it is diagnosed based on at least any three metabolic changes, the most common features of the pathophysiology of MetS are insulin resistance and visceral adiposity [3]. The pathogenic processes of MetS are complex and still debated. The geographic diversity in MetS distribution highlights the importance of environmental and lifestyle factors as major causes. Most of the mechanisms are triggered by visceral adiposity. However, major contributors to the onset, progression, and transition of MetS to cardiovascular diseases (CVD) are neurohormonal activation, insulin resistance, and inflammation [4]. It is considered that MetS could considerably

increase personal healthcare costs and be an important risk factor for mortality in most developed countries [5].

Another serious public health issues across the world is cancer [6]. The link between MetS and cancer mortality is of particular concern. MetS could be associated with cancer because it increases cancer risk and cancer-related mortality; also, cancer survivors are more likely to develop MetS [7]. MetS and cancer are chronic and biologically complex diseases with numerous modifiable and non-modifiable risk factors in common [8]. However, a study indicated that in MetS patients adipose tissue is characterized by dysregulation of cytokine production, which may result in chronic inflammation. This inflammation, as well as its mediators, could have a role in tumor formation [9]. As, the term "cancer" covers a large group of diseases, but common features of cancers are uncontrolled growth and division of cells. The most common cancers are breast, lung, colon and rectal and prostate cancers. Deaths caused by cancer are estimated at nearly 10 million per year and it is the leading cause of death worldwide [10].

Lifestyle, as well as environmental and genetic factors, could increase the risk of developing cancer and MetS [11]. Alcohol consumption has remained a prominent cause behind the prevalence of MetS but the link however is still controversial [12]. Similarly smoking has remained a major risk factor for overweight and abdominal obesity in older people [13]. Overweight and obesity is one of the significant risk factors for MetS and a worldwide challenge for nutrition [14], affecting both children and adults [15]. MetS is a valuable clinical tool for predicting diabetes and cardiovascular disease, particularly in high-risk individuals with MetS [16]. In addition, MetS has shown associations with diverticulosis (bowel disease), in a univariate analysis for age, increased waist circumference, hypertension, and hyperlipidemia [17].

Numerous studies have found significant gene–environment interactions in the etiology of obesity as well in the pathogenesis of type 2 diabetes and coronary heart disease [18]. Individual genetic predispositions and environmental circumstances work together to support or hinder cellular processes. Complications emerge as a result of accumulated genetic and environmental risk factors, impacting health and reducing lifespan [19]. The single-nucleotide polymorphism (SNP) rs662799 in the *APOA5* (apolipoprotein A5) gene is associated with an increased risk of MetS and its components [20]. Moreover, data have revealed that the adiponectin rs266729 gene polymorphism is reduced in colorectal cancer patients, implying that lower levels may be a significant risk factor for colorectal cancer in MetS patients [21].

Figure 1 demonstrates the factors affecting MetS and cancer. Although the burden of cancer rises at all human development index (HDI) levels, the epidemiological transition of cancer in developing HDI countries is anticipated to be the most affected. Many nations with low and medium HDI levels are seeing a significant increase in the incidence of known cancer risk factors that are also prevalent in high-income western countries (e.g., smoking, excess body weight, bad eating habits and physical inactivity). However, substantial work should be done to incorporate current effective interventions into existing health strategies as well as to cultivate novel interventions that either address global exposure or cancers with few preventative options [22].

Unfortunately, the prevalence of MetS is escalating worldwide [23]. It can also be noticed in developing countries due to sudden shifts in dietary habits and lifestyle patterns [24]. Globally, MetS ranges from 10–85%. Epidemiological studies highlighted that MetS probability increases with age [25]. It was reported to have a prevalence of 24.3% in Europe, with the chances of occurrence gradually increasing from 3.7% in <30-year-old to <30% in ≥70-year-old subjects [3]. Prevalence rates differ due to the presence of multiple criteria in its diagnosis. Therefore, it is accepted that as body mass index (BMI) and age increase, the incidence of MetS usually grows [26]. Although the prevalence of MetS was reportedly high (65.5%), it was observed that the occurrence of MetS was associated with acute and severe coronary artery disease [27] and may also increase the chances of CVD and diabetes [28]. The combined prevalence of overweight (>85th percentile) and obesity

(>95th percentile) is 31%. Thus, sufficient and balanced nutrient consumption has been the main factor in prevention strategies. In the present era, the consumption of refined and processed foods could have contributed to the progression of MetS [24]. Research highlights that metabolic parameters (fasting blood glucose, abnormal lipid profile, and waist circumference) are greatly affected by diet and physical activity levels [29]. Increased consumer awareness has also altered consumption profiles. Foods and certain specific dietary components have recently gained a lot of attention in the treatment of MetS. In this regard, fruits and vegetables have been demonstrated to have health-promoting properties, making them promising sources of polyphenols [30]. Carrots are becoming more widely available plants in the midst of growing health concerns [31]. Due to higher production and utilization as a fresh and processed product, carrots are the most significant nutritive plants and are ranked among the top 10 plant crops in the world [32]. Among different colored carrot cultivars, the most well-known are orange. Purple (black) carrot varieties (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef.) are not so popular, but in some countries are still traditionally cultivated and consumed. Purple carrot roots are a rich source of nutrients, especially phenolic compounds, anthocyanins, and carotenoids. All of these may play a potent role in reducing the risk of chronic diseases. Based on a number of available studies, an evaluation of the effects of purple carrots on MetS and cancer was undertaken. The present review is based on in vitro, in vivo, and clinical studies and attempts to clarify the mechanisms of action and the importance of particular compounds in purple carrots.

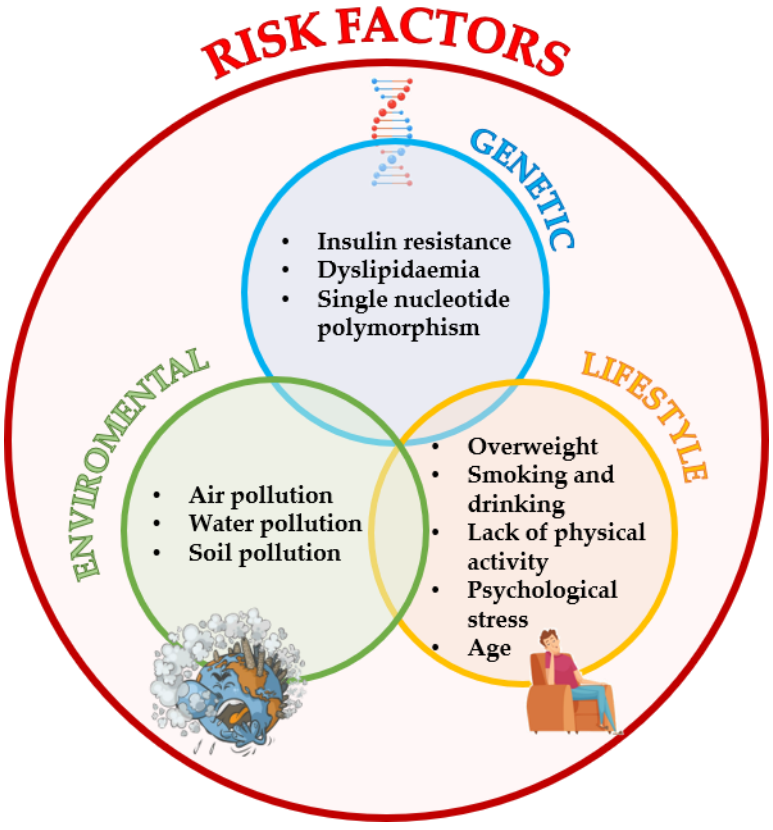

Figure 1. The factors affecting MetS and cancer.

2. Purple Carrot and Its Nutritional Value

Carrots (*Daucus carota* L.) belong to the family *Apiaceae* [33]. Orange varieties represent the majority of carrot production (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef.), though in some regions, such as Turkey, Afghanistan, Egypt, and India, purple carrot varieties are traditionally grown and consumed. Purple carrot roots have a bluish-purple color associated with the presence of a high number of anthocyanins. Due to the constraints on artificial additives and the growing demand for natural antioxidants, these pigments

have recently received more interest as a natural food colorant [34]. The utilization of natural food colorants from purple carrots has increased because of the high stability of the acylated anthocyanins they contain [35]. Similarly, many studies have demonstrated that purple carrot roots contain high numbers of phenolics as compared with other colored vegetables [36]. Table 1 presents the average nutritional values of purple carrot roots per 100 g FW. Purple carrots contain significant quantities of carbohydrates, vitamins, minerals, and anthocyanins. Therefore, they are considered to be a valuable vegetable with a rich nutritional profile [37].

Table 1. The average nutritional values of purple carrot per 100 g.

Components	Nutritional Concentration	Reference
Energy	42 kcal	[38]
Protein	0.87 g	
Fat	0.14 g	
Carbohydrates	8.01 g	
Total dietary fiber	2.48 g	
Iron	0.26 mg	
Zinc	0.15 mg	
Sodium	82 mg	
Potassium	256 mg	
Calcium	33 mg	
Magnesium	17 mg	
Phosphorus	29 mg	
Vitamin B1	0.029 mg	
Vitamin B2	0.029 mg	
Vitamin B3	1.211 mg	
Vitamin B6	0.072 mg	

Table 2 presents some bioactive compounds present in purple carrot roots. The dietary importance of carrots due to a range of phytochemicals, mainly phenolic compounds, carotenoids, polyacetylenes, and dietary fiber [39]. Purple carrot cultivars contain high amounts of phenolic compounds as compared to other colored varieties [40]. The total phenolic content of purple carrot roots could range from 43.31 to 76.64 [41] mg/100 g fresh weight (FW), of which 78% are anthocyanins, 18% phenolic acids and 4% other flavonoids [42]. Moreover, purple carrot roots are an interesting natural food source, due to the high levels of polyphenols, particularly anthocyanins and phenolic acids, all of which make a significant contribution to biological activities [42]. Furthermore, 5-*O*-caffeoylquinic acid is an important phenolic acid present in purple carrot roots. Additionally, these carrots contain some derivatives of hydroxybenzoic acid, quercetin, ferulic, and caffeic acid. Two non-acylated anthocyanins (cyanidin-3-xylosyl glucosyl galactoside and cyanidin-3-xylosylgalactoside) and three mono-acylated anthocyanins (cyanidin-3-xylosylgalactoside, feruloyl glucosyl galactoside, and coumaroyl-glucosyl galactoside) have been quantified and recognized in purple carrots in recent research [35]. Purple carrot is also a good source of carotenoids, mainly β- and α-carotenes and lutein. Its roots could contain 600–20,000 µg carotenoids per 100 g. These amounts could be higher than typical orange varieties [41,43,44].

Table 2. Bioactive components of the purple carrot.

Main Group	Type of Component	References
Anthocyanins	Cyanidin-3-xylosyl-glucosyl-galactoside, cyanidin-3-xylosyl (coumaroylglucosyl) galactoside, cyanidin-3xylosyl (feruloylglucosyl) galactoside, cyanidin-3xylosyl (sinapoylglucosyl) galactoside, malvidin-3,5diglycosides, peonidin-3xylosylgalactoside, cyanidin-3-rutinosides, delphinidin-3-glucoside	[45–47]
Carotenoids	Lutein, zeaxanthin, α-carotene, 13-cis-β-carotene, β-carotene	[47,48]

Table 2. *Cont.*

Main Group	Type of Component	References
Polyacetylenes	(Z)-heptadeca-1,9-diene-4,6-diyn-3-ol (falcarinol), (Z)-heptadeca-1,9-diene-4,6-diyne-3,8-diol (falcarindiol), (Z)-3-acetoxyheptadeca-1,9-diene-4,6-diyn-8-ol (falcarindiol 3-acetate)	[49,50]
Phenolic acids	Hydroxybenzoic, protocatecuic, gallic, syringic, chlorogenic, caffeic, cumaric, ferulic	[42,47,51]
Flavonoids	Flavanones: erodictiol-7-*O*-glucoside, eriodictiol and naringenin-7-*O*-glucoside Flavanols: Epicatechin and catechin Flavonols: Kaempferol-3-*O*-rutinoside and quercetin-3-*O*-galactoside	[42]

3. Purple Carrot and Prevention of MetS and Cancers

Purple carrot and its bioactive compounds show a protective effect against various diseases (cancer, CVD, obesity, diabetes) [31]. Especially due to their high nutritive values and good storage attributes, carrots play a major role in fiber and nutrition provision to the body [52]. The current study highlights the prospects of purple carrot polyphenols for health promotion.

Table 3 shows the potential contributions of purple carrot constituents in relation to MetS and cancer.

Table 3. The mechanism of purple carrot against MetS and cancer.

Main Group	Active Component	Mechanism	References
Purple carrot	Anthocyanins	Potential anti-diabetic properties, delay glucose absorption by inhibition of the enzymes α-amylase and α-glucosidase	[53]
Purple carrot extract	Vimentin	Cause poor prognosis in human breast cancer without any side effects by radical scavenging activity	[54]
Purple carrot	Dietary fiber	Reduction in the secretion of inflammatory biomarkers	[38]
Purple carrot and its parts	Anthocyanins	Regulate the markers of inflammation by reducing NF-$_K$B signaling via different pathways	[55]
Purple carrot	Cyanidin, Malvidin	Markedly reduces the accumulation of fat (3T3-L1 cell lines of adipocytes) by reducing SREBP, reducing FAS and enhancing CPT-1	[46]

Nuclear factor kappa light chain enhancer: NF$_K$B; sterol regulatory element-binding protein-1c: SREBP; fatty acid synthase: FAS; carnitine palmitoyltransferase-1: CPT-1.

It has been documented that in animals, anthocyanins and phenolic acids were successful in reducing metabolic changes and inflammation by inhibiting inflammatory markers [56]. Moreover, polyacetylenes derived from plant extracts are known for their health-promoting properties, and in vitro results indicate their anti-inflammatory [57] and anti-cancer potential. Similarly, they also exhibit anticoagulant, antifungal, and anti-inflammatory actions [58]. Meanwhile, bioavailable polyphenols are reported to potentially counteract the harmful effects of elevated blood triglyceride levels and are considered beneficial health compounds that can minimize the risk of cardiovascular disease [51]. In obese rats, it was hypothesized that substituting purple carrot and purple potato for carbohydrates would improve blood pressure and insulin resistance, the main components of MetS [59]. Another study supports the stated metabolic health benefits of purple carrots and potatoes, confirming that these vegetables are effective replacements for other simple carbohydrate sources for improved metabolic health [60].

Anthocyanins (cyanidin, petunidin, delphinidin) may have a preventive role against various diseases, are a proven source of cyanidin-based pigment and protect against certain forms of malignancies [61,62]. Furthermore, combined treatments with two or three antioxidants demonstrated higher antioxidant activity as compared to individual treatments,

implying that anthocyanins from purple carrots could have synergistic effects with other antioxidant compounds, for example, carotenoids. Synergistic effects of antioxidants were found in rats suffering from D-galactose-induced oxidative damage [63]. Due to the presence of anthocyanins, purple carrots can inhibit cancer cell proliferation [64]. As purple carrot anthocyanins reach the colon in an intact or modified form, they have shown an ability to protect colon cells against oxidative stress [62].

Park et al. [46] found that purple carrot anthocyanins could alleviate menopause symptoms by preventing the exacerbation of lipid and glucose metabolism via activation of hepatic insulin signaling and AMP kinase activation. Purple carrot extract, especially obtained after fermentation by *Lactobacillus plantarum* or *Aspergillus oryzae*, substantially reduced lipid adiposity in 3T3-L1 cell lines of adipocytes by enhancing the expression of carnitine palmitoyltransferase-1 (CPT-1) and reducing fatty acid synthase (FAS) and sterol regulatory element-binding protein-1c (SREBP) levels in rats. Figure 2 is a graphical representation of the nutraceutical benefit of purple carrot against MetS and cancer.

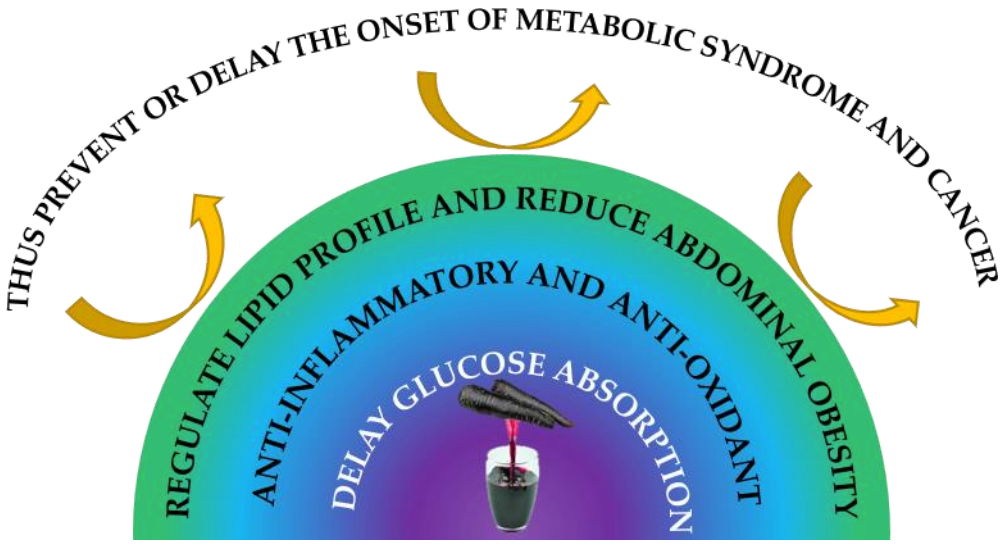

Figure 2. A graphical representation of the nutraceutical benefits of purple carrot against MetS and cancer.

3.1. Anti-Diabetic Potential of the Purple Carrot

It has recently been proposed that purple carrot compounds can influence the metabolism of glucose. Anthocyanins from purple carrot, especially cyanidin 3-xylosyl galactoside, were found to be good inhibitors of α-amylase, α-glucosidase, and dipeptidyl peptidase IV [65]. Kaeswurm et al. [66] also found that α-glucosidase inhibition is not significantly affected by the glycosidic side of cyanidin chains (monoglucoside has a similar effect compared to diglicoside). However, a markedly stronger action of the acylated structures compared to anthocyanin-3-glycosides was found. About 58% of purple carrot anthocyanins are present in an acylated form [66,67]. Not only anthocyanin but also other phenolic compounds could affect carbohydrate digestion enzymes. As proved by Esatbeyoglu et al. [45], phenolic acid from purple carrot fractions (containing mainly chlorogenic acid) was the strongest α-amylase inhibitor. Moreover, purple carrot extract caused a moderate inhibition of intestinal glucose uptake in Caco-2 cells. The authors did not observe impaired Caco-2 and enteroendocrine GLUTag cell viability due to purple carrot extract up to a concentration of 100 µg/mL or 50 µg/mL, respectively.

These properties could be associated with slowing down glucose absorption and metabolism. Inhibition of these enzymes involved in carbohydrate digestion could therefore partially reduce postprandial blood glucose levels and prevent hyperglycemia [45].

It was found that increased insulin resistance in body tissues could be associated with type 2 diabetes development. Fermented extracts of purple carrot with *Aspergillus oryzae*

and *Lactobacillus plantarum* exhibit strong anti-diabetic potential by preventing insulin resistance. They also improved first-phase insulin secretion and insulin sensitivity in the hyperglycemic state in type 2 diabetic rats with dementia [68,69].

Another study based on animal models explained and assessed purple carrot phenolic compound contributions in antioxidant defense, glucose metabolism, and renal and hepatic toxicity in rats. The positive effects of thirty days of consumption of purple carrot juice were a significant reduction in blood triglyceride concentration and superoxide dismutase activity in both dose-dependent and time-dependent manners. Therefore, no major impact on blood glucose concentration and no toxicity was observed concerning the functioning of the kidneys and liver [35]. Additionally, Dragano et al. [70] conducted a study that demonstrated the effectivity of anthocyanin-rich supplementation in the reduction of insulin resistance by improving signal transduction using the insulin receptor substrate-1/Akt pathway in adipose tissue. Similarly, anthocyanins also lower insulin resistance by decreasing insulin concentrations in blood [71].

3.2. Anti-Obesity and Cardioprotective Potential of Purple Carrot

Purple carrot's bioactive compounds, especially phenolic compounds and anthocyanins, could considerably reduce the risk of cardiovascular disease and cancer [72]. It was established by others that high serum triglycerides and elevated blood pressure could contribute to CVD [73]. It was proved in a human study that consumption of 200 g of purple carrot (containing 700 mg of cyjanidin-3-glicoside) per day for 12 weeks may decrease serum triglyceride levels and reduce systolic and diastolic blood pressure in individuals at risk for cardiovascular disease [73]. Another human trial confirmed that consumption of purple carrot containing 18.5 mg/day of anthocyanins and 259.2 mg/day of phenolic acids for 4 weeks lowered high-density lipoprotein cholesterol levels. Although the intake of purple carrots did not affect other body parameters, such as mass, body composition, appetite, dietary intake, low density lipoprotein, total cholesterol, blood pressure, or C-reactive protein, its consumption could be considered safe. Aspartate amino transferase and alanine amino transferase in humans did not change after consumption of dried purple carrot reconstituted in water equivalent to approximately 300 g fresh carrot per day for 4 weeks, allowing the conclusion that purple carrot consumption did not cause hepatoxic problems [74].

There is also an animal study of purple carrot anthocyanin and phenolic effectiveness in obesity and cardiovascular risk prevention. The study conducted by Poudyal et al. [56] demonstrated that treatment of diet-induced MetS in rats with purple carrot juice attenuated or reversed the changes in cardiovascular and liver structure and functions as well as in metabolic parameters, especially abdominal fat deposition and plasma lipid profiles. Obesity is a major public health concern around the world, which increases the risk of cardiovascular disease and disrupts blood glucose homeostasis. Purple carrot anthocyanins and phenolic acids help reduce inflammation and metabolic changes in animal models, possibly through inhibiting inflammatory pathways. A randomized controlled trial was conducted to investigate the effect of dried purple carrot on body composition, body mass, blood pressure, lipids profile, inflammatory markers, and hepatic function. There were no statistically significant changes. The levels of aspartate aminotransferase (AST) and alanine aminotransferase (ALT) remained unchanged, indicating that the treatment was safe [75]. Higher anthocyanin intake was linked to considerably reduced systolic blood pressure in a cross-sectional study of 1997 females conducted in the United Kingdom [71]. Likewise, in another cross-sectional study, higher serum HDL levels were observed due to intake of anthocyanidins, which reflect better lipid profiles [63]. The authors also assigned this effect to anthocyanins present in purple carrot juice, because in their study β-carotene did not reduce oxidative stress, cardiac stiffness, or hepatic fat deposition and the pressed carrot juice itself contained a low concentration of carotenoids.

3.3. Anti-Inflammatory and Anti-Cancer Potential of Purple Carrot

Compounds with antioxidant activity could play important roles in the prevention of many health problems, such as carcinogenesis, aging, metabolic events, immune disorders, and neurodegenerative diseases. Some studies have suggested that purple carrot bioactive compounds possess anti-inflammatory and anti-cancer potential.

Blando et al. [76] conducted a study to investigate the biological activity and antioxidant potential of purified anthocyanin from different anthocyanin-rich plants. The findings showed that biological and antioxidant activity was seen in all tested purified anthocyanin samples differing in anthocyanin content (from 4.9 to 38.5 mg/g DW). Different anthocyanins exerted radical scavenging activity of various magnitudes, and this was higher in samples containing non-acylated anthocyanins. Accordingly, purified anthocyanins decreased endothelial inflammatory antigen expression, indicating a possible beneficial impact in cardiovascular protection. That effect was also dependent on structural differences in anthocyanins; non-acylated forms were more effective than anthocyanins acylated with cinnamic acid derivatives.

Some nutrients present in purple carrots could be considered as anticancer agents, for instance, carotenoids, which could be easily provided by consumption of purple carrots. High concentrations of carotenoids are inversely proportional to oxidative stress in the human body. Butalla et al. [77] have highlighted in their work that intake of purple carrot juice is an easy and efficient way of enhancing the total carotenoid content in blood plasma. These authors conducted a randomized intervention study among breast cancer survivors with obesity (the BMI of participants ranged from 25 to 45). For 3 weeks, participants consumed about 240 mL of purple carrot juice (which corresponded to about 5 carrot roots). This intervention led to a statistically significant increase in carotenoid content in blood plasma. At the same time, the content of 8-iso-PGFα, which is an indicator of oxidative stress in the human body, was decreased. High carotenoid contents and low 8-iso-PGFα levels in blood plasma may lead to a reduced risk of cancer recurrence.

Anthocyanins from purple carrot could also possess anticancer, antioxidant and chemoprotective properties. Jing et al.'s [78] research showed that the aqueous extract of purple carrot anthocyanins effectively reduced human colorectal adenocarcinoma cell (HT-29) line growth. Non-acylated anthocyanins were more effective than acylated ones; the suppressive effects of purple carrot anthocyanins were stronger than those of radish or elderberry.

A study conducted by Sevimli-Gur [54] considered the cytotoxic activity of purple carrot calli extract against different cancer cells in humans. The lowest IC50 values against MCF-7, SK-BR-3, and neuro-2A cell lines were obtained. However, low cytotoxicity in the normal cell line VERO was achieved, suggesting that purple carrot phenolics are a superior option which do not cause negative effects in normal healthy cells.

Purple carrot polyphenols effectively downregulated the secretion of certain proinflammatory markers, namely, interleukin-8 (IL-8), monocyte chemoattractant protein-1 (MCP-1), vascular endothelial growth factor (VEGF), and intercellular adhesion molecule-1 (ICAM-1), under normal and TNF-α-induced inflammatory conditions. Better functionality was achieved after extract digestion compared to undigested extract. After digestion, the phenolic profile of purple carrot was similar to undigested carrot, but digestion increased the amounts of transported anthocyanins and phenolic acids through Caco-2 monolayers by about two times. The study suggested that anthocyanins are transported in intact glycone form and that increasing their concentration could not change absorption efficiency and lead to saturation of the absorption mechanism [79].

Purple carrot extracts also downregulated other proinflammatory factors, such as interleukins Il-1β (decrease by 91%) and Il-6 (decrease by 69%), as well as inflammatory mediators, such as cyclooxygenase-2 (Cox-2) and inducible nitric oxide synthase (iNos) [57], in lipopolysaccharide-activated RAW264.7 cells. The important point is that anthocyanins, even in an acylated form, were able to cross the intestinal barrier and may potentially contribute to health effects in other tissues in the human body [57].

Research suggests that purple carrot compounds could be useful for the treatment of liver injury caused by alcohol. Purple carrot extract recovered the cell viability of in vitro ethanol-treated hepatocytes. The butanol fraction of purple carrot extract was able to scavenge reactive oxygen species induced by ethanol. Moreover, this fraction also regulated the activities of three alcoholic metabolism-related enzymes: cytochrome P450 2E1 activity was suppressed and alcohol dehydrogenase and aldehyde dehydrogenase activities were increased. The butanol fraction of purple carrot extract could also increase cyclic adenosine 3′,5′-monophosphate concentration by suppressing the expression of phosphodiesterase 4b mRNA. The authors suggested that polyphenols and anthocyanin pigments extracted from purple carrots in considerable amounts were responsible for this effect [80].

Data also indicated that certain phytochemicals (carotenoids, polyacetylenes, phenolics, sesquiterpenes, iso-coumarins, and anthocyanins) exhibited potential against inflammation, reducing nitric oxide production by up to 65% without causing any cytotoxicity, and also played an important role in the reduction of pro-inflammatory cytokines TNF-α, IL-1β, IL-6, and iNOS (in macrophage cells) [81]. In another study, it was proposed that the bioactive components of carrots (polyacetylenes) were effective in the treatment of leukemia despite beta-carotenes or lutein [82]. The anticancer effect of purple carrot extracts was determined against breast cancer cell lines (MCF-7) by MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, a tetrazole) assay. The results showed that acetone and ethanol extracts of purple carrot (50 µg/mL) demonstrated 8.13% and 30.6% inhibition of breast cancer cell lines, respectively. These findings demonstrated that purple carrot extracts contain bioactive compounds that are effective against breast cancer [37].

Likewise, the effect of purple carrot extract anthocyanins on encapsulation with halloysite nanotubes (HNT) indicated that the percentage of anthocyanins loaded into the nanotubes was 4% by weight. Compared to pure anthocyanins, anthocyanin-containing HNTs displayed strong anti-proliferative potential against cancer cells, such as HT-29 and MCF-7 [83].

Another study was designed in which the cytotoxic potential of purple carrot anthocyanin extract was assessed against bone osteosarcoma, neuroblastoma, breast adenocarcinoma, and alveolar adenocarcinoma. In most cell lines, cytotoxic activity was remarkable, with IC_{50} values < 5.5 mg/mL [84]. Another recent in vivo study was conducted on male rats, proposing that carrot juice attenuates circulatory free fatty acids and inflammatory markers, while MCP1 and hsCRP levels induced by a high fructose diet did not have an effect on the adiposity of the abdomen or the cell size of organ fat deposits [61].

In a study of black carrot crude extract (BCCE), it was also found that phenolic contents positively correlated with antioxidant activity and anti-angiogenic cytoprotective properties. Purple carrots are recognized as a functional food owing to their high content of phenolic acid, flavonols, flavanol, and flavanones, all of which make a significant contribution to biological activities. Moreover, the employment of nutraceutical-like (BCCE) avoids the onset of diseases linked to oxidative stress [42]. In addition, a study investigated the chemopreventive potential of purple carrot extract after 4-nitroquinoline 1-oxide induced carcinogenesis in rat tongues. A total of 20 male rats were divided into four groups (n = 5 in each group). The research was carried out for 12 weeks. The antioxidant activity, anti-inflammatory potential and antiproliferative and antimutagenic properties of purple carrot extract protected rats from oral lesions [17].

Anthocyanins are flavonoids with strong biological activity against a variety of malignancies, including colorectal cancer. The specific molecular mechanism through which anthocyanins fight cancer is unknown. Anthocyanins inhibited cell proliferation while promoting apoptosis in HT29 cells as compared to the control group. Anthocyanins boosted the apoptosis regulator (Bcl-2) protein coding gene and caspase-dependent apoptotic pathways by targeting the phosphoinositide 3-kinase (PI3K) pathway, causing colorectal cancer growth to be inhibited [85].

Furthermore, self-reported raw carrot intake of up to 2 to 4 or more carrots per week, more than 32 g/day, was linked with a 17% reduction in colorectal cancer (CRC) occurrence as compared to subjects without raw carrot intake. An intake of less than two to four carrots per week, less than 32 g/day, was not linked with CRC reduction [86]. Table 4 shows the impact of purple carrot consumption with regard to MetS and cancer.

Table 4. The impact of purple carrot consumption with regard to MetS and cancer.

Main Group	Subject	Material and Method	Result	References
Purple carrot juice	Rats	5% of the whole diet	Reduced lipid profile, cardiac fibrosis, abdominal adiposity, blood pressure (systolic) hepatic steatosis, inflammatory markers and improved glucose tolerance	[56]
A fermented extract of purple carrot by *Aspergillus oryzae*	Estrogen-deficient rats	-	Reduces energy impairment, lipid level and improves glucose metabolism	[46]
Purple carrot extract (fermented with *Lactobacillus Plantarum*, *Aspergillus Oryzae*)	Type 2 Diabetes in rats with dementia	Diet containing dextrin (2%), (ovariectomized-control group), purple carrot extract 2% (unfermented), 2% extract of purple carrot fermented by *L. plantarum* and 2% extract of purple carrot fermented by *Aspergillus oryzae* for 12 weeks	Improved cognitive ability by improving hippocampal insulin resistance	[68]
Dried purple carrot	Overweight and obese adults	Anthocyanins (118.5 mg) and phenolic acids (259.2 mg) consumed each day for 4 weeks	Significant alterations in body composition, diet intake, total cholesterol, low-density lipoprotein levels, body composition, blood pressure, appetite, and C-reactive protein levels	[75]
Purple carrot /Orange carrot	Individuals at risk of cardiovascular disease	100 g of colored carrot, 2 times/day for 12 weeks	Purple carrots enriched with anthocyanins may improve blood pressure (systolic and diastolic) and triglyceride levels	[73]
Purple carrot and shalgam juice	-		Reduces the risk of cancer and CVD	[72]
Purple carrot juice	Animal model	Juice of purple carrot for thirty days	Reduced SOD activity and blood triglyceride concentration, with no significant changes in plasma glucose	[35]
Purple carrot	Human	-	Effective against diabetes; cyanidin 3-xylosyl galactoside is an ideal component for the inhibition of enzymes involved in glucose metabolism	[65]
Purple carrot juice	-	Carrot juice (0.5 mg/mL, 0.7 mg/mL, and 1 mg/mL)	The results showed increased glucose uptake and insulin activity	[69]
Deep purple carrot (DPC)	-	-	An inhibitory effect was observed on α-glucosidase α-amylase and glucose uptake of cells, thus showing anti-diabetic potential	[45]
Fresh carrot Juice	Breast cancer survivors	69, duration of 3 weeks	The result showed enhancement in plasma carotenoid levels and reductions in oxidative stress	[77]
Lyophilized powder of anthocyanins of purple carrot	Human colorectal cancer cell line	Dose: 0.0 to 2.0 mg/mL	2.0 mg per mL anthocyanin concentration reduced the 80% growth of cancer cells (HT-29 and HL-60)	[78]
Purple carrots	-	-	In a dose-dependent manner, reduced nitric oxide production by 65%, without causing any cytotoxicity, in addition to reducing inflammatory markers iNOS, TNF-α, IL-6, and IL-1β	[81]

Table 4. *Cont.*

Main Group	Subject	Material and Method	Result	References
Purple carrot extract	-	Acetone and ethanol extracts (50 μg/mL)	Exhibited 8.13% and 30.6% inhibition, respectively. This showed that *D. carota* extracts contain bioactive compounds that are effective against breast cancer proliferation.	[37]
Young purple carrot shoot extracts	-	All calli and natural extracts	Against neuro-2A cell line, an increased cytotoxic level was observed (capability of 38 to 46% at 6.25 μg/mL), and an increased IC_{50} value of 170.13 μg/mL was achieved in normal cells, suggesting that it is a principal component against brain cancer	[54]
Purple carrot and its parts (peel and pomace)	-	-	Regulates the inflammatory response of TNF-α	[38]
HNT of purple carrot	-	-	Anti-tumour activity was observed against breast cancer cell lines (HT-29 and MCF-7 cells) in contrast to pure anthocyanins	[83]
Anthocyanin extract from purple carrot	-	-	The cytotoxic activity against breast carcinoma, alveolar adenocarcinoma, brain cancer, and osteosarcoma was significantly high, with IC_{50} values < 5.5 μg/mL	[84]
Purple carrot extract	-	-	Reduces the onset of different oxidative stress-linked disorders	[42]

Cardiovascular diseases: CVD; superoxide dismutase: SOD; nitric oxide synthase: iNOS; tumor necrosis factor-alpha; TNF-α; Interleukin-6: IL-6; Interleukin -1beta: IL-1β; Michigan Cancer Foundation-7: MCF-7; halloysite nanotubes: HNT; *D. carota*: *Daucus carota*; half-maximal inhibitory concentration: IC50; human leukemia: HL-60; human colorectal adenocarcinoma cell line: HT-29.

4. Conclusions

Different research is directed towards food compounds to prevent and fight different diseases. Purple carrots (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef) are a rich source of health-enhancing nutrients. The most important for targeting MetS and cancer seem to be phenolic compounds. There is a great deal of in vitro evidence that anthocyanins and other phenolics could improve the biochemical parameters of human cells. In addition, some human trials support the positive influence of purple carrot consumption. Carrots rich in anthocyanin content can improve blood pressure and serum triglyceride levels in people at risk of CVDs. Furthermore, while querying various databases, it was found that there are limited studies related to CVDs and obesity, so further research is required to identify the effectiveness, suitable intake of purple carrot, dosage, and the effectivity of its bioactive components against different diseases.

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