Chapter

Root Vegetables: Biology, Nutritional Value and Health Implications

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Abstract

Plants served as main staple for humanity since time immemorial. Plant roots science is a fascinating domain that offers a window to the complex world of plants-microorganisms relationship. Plant roots were used throughout human history both as a food source particularly in times of food scarcity as well as for medicinal purposes aid in the treatment of various human disorders. Root vegetables are excellent sources of fiber and antioxidants and are low in calories and lipids—being indispensable in human diet. There is an increasing interest in the biochemical processes occurring in the rhizosphere between root tissues and the bacterial/fungal colonizers especially in soils where there is a deficiency in minerals such as iron, phosphorus and selenium or there is higher load of toxic metals such as aluminum, cadmium, nickel and lead. That interest stems from the need to improve crop yields in hostile environmental conditions such as drought and low nutrient availability in soils. In this chapter, we will focus on the typical edible plant roots as well as bulbs (are not proper roots) looking at their nutrient content as well as their use as health enhancers.

Keywords: edible roots vegetables, health enhances

1. Introduction

As roots grow and search for nutrients they evolve in a very complex environment called rhizosphere. This is defined as the area around plant root that is populated by a variety of different microorganism species, which “cooperate” with the plant for the benefit of both. However, not all bacteria in rhizosphere are beneficial and plants have developed mechanisms to protect themselves against harmful bacteria. It has been estimated that there are over 10,000 bacterial species in the rhizosphere, not all with “good intentions” toward the plant.

The rhizosphere comprises two main compartments: ecto-rhizosphere and endo-rhizosphere. The former is the outermost zone that extends from the rhizoplane out into the bulk soil. The latter includes parts of the cortex and endodermis between which bacteria find a “home.” As McNear wrote in 2013: “the rhizosphere is not a region of definable size and shape but instead, consists of a gradient in chemical, biological and physical properties, which change both radially and longitudinally along the root" [1].

Roots are in constant "touch" with their surroundings seeking water and nutrients and also shedding root cap and border cells, mucilage and exudates. The latter comprises part of the carbon fixed via photosynthesis, namely inorganic carbon, i.e. HCO_3^- and organic carbon, such as organic acids and polyphenols. The exchange of material is influenced by the plant species, climate, presence of insects that feed on plants, nutrient availability, soil moisture and its physicochemical properties. Out of all organic compounds released from roots the low molecular weight compounds are the most studied because they serve as nutrients for the bacteria in the rhizosphere. The organic compounds also serve as chemo-attractants for the soil microbial population. For example, the exudates of leguminous plant roots attract rhizobium bacteria such as *Rhizobium leguminosarum*. This bacterium colonizes the root and helps the plant by converting atmospheric nitrogen into NH_4^+ that is further used in amino acid synthesis [2]. The enzyme complex involved is called nitrogenase and it catalyzes the reaction:

$$N_2 + 8\,e^- + 8\,H^+ + 16\,ATP\,2\,NH_3 + H_2 + 16\,ADP + 16\,P_i$$

The nitrogenase complex consists of two enzymes: dinitrogenase reductase (a dimeric Fe-protein) and dinitrogenase (a tetrameric FeMo-protein). The nitrogenase is rapidly inactivated by atmospheric oxygen. That is why the root nodules provide for a low oxygen environment, so that the enzyme is kept active.

Leguminous plants, which provide the largest simple source of vegetable protein in human diet and livestock feed have evolved signaling systems when under nitrogen deprivation. Legumes possess specific flavonoids that under nitrogen scarcity are released near the root tips, close to the emerging root hair zone that is the site of infection by rhizobium bacteria.

Plant flavonoids are secondary metabolites derived from the phenylpropanoid pathway and include chalcones, flavonols, flavones, anthocianins among others [3]. Flavonoids accumulate in the dividing cells of roots and some of them act as chemo-attractants for the rhizobium bacteria. The rhizobial signaling molecules are called nodulation factors and include lipo-chitooligosaccharides having a N-acetylglucosamine backbone, N-acetylated on the terminal non-reducing sugar. The substitutions on the oligosaccharide moiety determine the specificity of the symbiosis. Some plant flavonoids such as luteolin-7-O-glucoside and quercetin-3-O-galactoside can act as growth regulators of rhizobium bacteria.

One of the bacterial phylum present in the rhizosphere of legumes is *Firmicutes*. These are beneficial bacterial that colonize human gastrointestinal (GI) tract and as such they produce butyric acid that lowers gut pH and limits the growth of harmful bacteria. Many microbes in the rhizosphere, including *Firmicutes* have developed mechanisms for physically interacting with plant roots and through complex processes can reach other parts of the plant, e.g. stem and leaves. The ingested part plants housing colonizing bacteria help these microbes settle in the colon and in so doing help keep in check pathogens.

The symbiosis between nitrogen-fixing bacteria and leguminous plants is one way by which plants cope with limited availability of nitrogen in the soil. Besides this root exudates promote nutrient acquisition by changing the pH within the rhizosphere or chelating ions in soil solution. The root exudates contain organic acids such as malic and citric acids that acidify the soil and solubilize phosphate bound in soil minerals. Moreover, in case of chemical fertilizers plants respond differently depending on the chemical form of nitrogen in the soil. An excess of ammonium ion (NH_4^+) leads to a more alkaline environment whereas an excess of nitrate results in a lower pH in the rhizosphere. The pH fluctuations influences the availability of minerals such as zinc, calcium and magnesium. In addition, plant-bacteria cooperation can broaden immune functions of the plant host [4]. Accumulating evidence suggests that the chemical composition of root exudates is of paramount importance in selecting beneficial bacteria, which in turn leads to healthier and more productive plants [5].

Iron (Fe) is an essential mineral for plant growth and development. It is well known that in alkaline soils (representing some 30% of the world's arable land) plants do not grow well because at higher pH, Fe is trapped in Fe oxides (Fe_2O_3). So plants have developed strategies for getting hold of iron. Thus, the root exudates contain a mixture of organic acids and phenols that reduce the pH in the rhizosphere, hence allowing for the reduction of Fe(III) to Fe(II), which is then taken up by the root epidermal cells (strategy I). Another strategy for Fe uptake is based on the solubilization of Fe_2O_3 by strong Fe(III)-chelating agents called phytosiderophores. They belong to the mugineic acid family and are released into rhizosphere by efflux transporters. The mechanisms of Fe uptake by plant roots have been extensively studied in the weed *Arabidopsis thaliana*. Its habitat includes side roads, railway tracks and disturbed habitats. It has been shown that secretion of phenolic compounds by this plant is critical for Fe acquisition from soils with low Fe availability. In an elegant study on the mechanism of Fe mobilization by *A. thaliana*, Schmidt and colleagues demonstrated that polyphenols such as coumarins are essential for Fe uptake by the plant [6]. Coumarins act both as reductants of Fe(III) and as ligands of Fe(II).

Two other minerals are in the attention of plant scientists, namely inorganic phosphorus (P_i) and aluminum (Al). In acidic soils (that occupy a sizable portion of arable lands worldwide) low P_i availability and high Al toxicity limit plant growth and productivity. Work on *A. thaliana* revealed that organic acid, phytohormones and Fe homeostasis are critical factors in plant's response to nutritional stressors such as low P_i and Al toxicity [7]. In acidic soils with high concentrations of Fe, Al, Mn, P_i is easily fixed in the form of insoluble salts. Moreover, when pH is below 5.5, Al becomes soluble and toxic to plant roots, impairing the absorption of water and nutrients. Recent studies suggested that Al-tolerant phosphobacteria isolated from ryegrass could assist plants to deal with P_i shortage and Al toxicity [8]. An active area of research deals with ways to activate genes involved in changing root system architecture (RSA) in conditions dictated by limited nutrient availability and metal toxicity. Changing RSA involves the inhibition of primary root growth and promoting the growth of lateral roots and hair.

2. Nutritional value and health benefits of edible root vegetables

Wild plant roots have been eaten by humans since ancient times, especially during periods of food scarcity or famine. With the advent of agriculture in settled communities the roots of cultivated plants became permanent fixtures on the panoply of human diet. In this chapter we will focus on cultivated edible plants, whose roots are routinely used as foods and consumed either raw or cooked. Besides being nutritious due to their macro- and micronutrients content, they also contain numerous phytochemicals that are increasingly sought after by the food and pharma-/nutraceuticals industries both as food quality enhancers and promoters of health and disease prevention, respectively.

Roots can be broadly classified in:

- edible taproots – consist of a main thick root from which other thin secondary roots grow laterally (ex.: carrots, radishes);

- edible tuberous roots – consist of lateral thick roots that serve main as nutrient stores (ex.: sweet and regular potatoes).

2.1 Beetroot

Nutritionally, beetroot is a food source rich in proteins, carbohydrates, amino acids, phytosterols, vitamins and minerals, fibers, as well as nitrates. It also contains many phytochemicals such as polyphenols, flavonoids, betalains: betacyanins and betaxanthins [9].

Betalains are water-soluble nitrogen-containing pigments exhibiting red-violet and yellow-orange colors. Due to glycosylation and acylation of the hydroxyl groups in the molecule betalains have a great structural diversity. Betanin (betanidin-5-O-β-glucoside) is the most represented betacyaninin plants. It is also one of the few natural compounds that were approved for use as colorant in the food industry, cosmetics and pharmaceuticals (trade name: E162). Betanin is a strong reactive oxygen species (ROS) scavenger and exhibits gene-regulatory activity via Nfr2 (nuclear factor erythroid-derived 2)-like-dependent signaling pathway that triggers the induction of phase II enzymes synthesis and antioxidant defense mechanisms. It has been suggested that betanin may also prevent LDL oxidation and DNA damage [10].

The type of beetroot processing has a considerable influence on the antioxidant power displayed by this vegetable. Thus, it was found that fresh, dried and pureed beetroot exhibited the highest antioxidant power, as expressed by the total phenolic content. Moreover, the liquid nitrogen method of beetroot processing resulted in the highest bioavailability of biologically active compounds. Beetroot active compounds have shown antitumor activity in vitro cell culture and animal model experiments.

Among all vegetables beetroot has the highest amount of nitrate (2.8 g/100 g wet weight). Nitrate as such has no biological effects but its metabolization product nitric oxide ($NO^{\bullet}$) has. Nitrate is absorbed in the upper part of duodenum but some 25% ends up in entero-salivary cycle where bacteria in the mouth convert it to nitrite. This nitrite is further reduced in the GI tract by several reductases to nitric oxide. Nitric oxide is a vasodilator (relaxes the smooth muscle cell in the vasculature) causing the vessels to widen hence prevent an increase in blood pressure. A decrease in nitric oxide supply leads to endothelial dysfunction, which is the primary risk for cardiovascular diseases (CVD). Clinical studies on healthy subjects demonstrated that beetroot juice intake was protective against endothelial dysfunction induced by an acute ischemic insult caused by brachial artery occlusion [11]. Beetroot juice supplementation significantly reduced systolic and diastolic blood pressure. Accumulating evidence suggest that several conditions such as hypertension, atherosclerosis, T2D and inflammation (chronic or acute) benefit from beetroot consumption. Betalains appear to interfere with the proinflammatory signaling cascade in which NF-κB plays a critical role by activating the transcription genes that regulate and amplify the inflammatory response.

Animal model experiments indicated that beetroot supplementation had a protective effect against drug-induced liver and kidney injury. The mechanisms likely involved are the anti-inflammatory, antioxidant and anti-apoptotic activities. In humans, beetroot supplementation was shown to improve hemoglobin status in adolescent anemic girls [12]. In another study involving healthy subjects it was shown that daily consumption of a 10% beetroot juice beverage resulted in a 34% decrease in plasma glucose level after 4 weeks of supplementation suggesting an improved glucose metabolism [13].

2.2 Carrots

Carrots are a food source rich in micronutrients, phytochemicals and fiber. The main macronutrients are represented by carbohydrates (6.6–7.7 g/100 g), protein (0.8–1.1 g/100 g) and lipids (0.2–0.5 g/100 g). Carrots contain several B group vitamins (thiamine, niacin, folic acid, in sub milligram range), vitamin C (21-775 mg/100 g between cultivars) and minerals Na, K, Ca, Mg, Cu, Zn in milligram range). The fiber is represented by insoluble fiber (cellulose, hemicellulose and lignin) whereas the soluble fiber consists of pectin, gums and mucilage [14]. Carrots are a significant source of phenolic compounds, carotenoids and polyacetylenes [15].

Phenolic compounds are widely present in the plant kingdom and include phenolic acids, flavonoids, tanins, lignans, curcuminoids and stilbenoids. The concentration of phenolic compounds increases in the direction xylem toward peel (periderm) as they are released through the exudate into the surrounding medium of the root. Phenolic compounds play an important role in the acquisition of metal ions and the facilitation of microbes – root interactions. There is a large body of evidence that phenolics exert a host of health benefits including antioxidant, anti-inflammatory and antiproliferative properties. In so doing they decrease the risk of cardiovascular diseases, diabetes, inflammatory conditions and slow down the aging process. Anthocyanins from black carrot root were found to possess anti-proliferative activity in cell culture and animal model experiments. Unfortunately, epidemiological studies in humans failed to demonstrate clear cut benefits in cancer patients [16]. Most clinical studies however, had a short duration, insufficient to draw a definite conclusion on the subjects. It is worth mentioning here that in 2014 in U.S. some 40% of all cancer cases were attributable to risk factors such as smoking, alcohol consumption, bad diet, low physical activity and the rest of 60% were caused by DNA replicative errors that led to gene mutations [17]. It is therefore of paramount importance to pay attention to a diet rich in phytochemicals such as fresh fruits and vegetables in order to reduce the risk of cancer.

Isoprenoid precursors through a series of reactions yield lycopene, which is further processed to yield α- and β-carotene. α-carotene is converted to lutein whereas β-carotene is turned into zeaxanthin. In humans, conversion of β-carotene into vitamins A occurs mainly in the gut and liver and much less in other tissues. The efficiency factor for the conversion of dietary β-carotene to vitamins A is 12:1 by weight. Epidemiological data indicate that diets rich in carotenoid-containing foods are associated with a reduced risk of developing chronic diseases such as CVD, diabetes, cancer and age-related macular degeneration [18, 19]. Retinol in vitamins A has been shown to play a central role in these processes. The major factors affecting bioavailability of carotenoids and their conversion to vitamin A are food matrices, food preparation and the fat content of meals.

The third group of phytochemicals in carrots are polyacetylenes. They are non-volatile compounds comprising at least two conjugated triple C-C bonds [15]. There is evidence to suggest that these compounds have the potential to improve human health due to their antifungal, antibacterial and anti-inflammatory properties.

2.3 Celery

Celery plant parts (leaves, stalk, and root) have been used since Antiquity for medicinal purposes in the treatment of conditions such as joint pain, gout, and fever cause by bacterial infection, constipation, heartburn, etc. Celery is rich in vitamins (A, C, D, E, K, B group), minerals (K, Mg, Ca, Zn, Fe, Cu, Se) and phytochemicals (carotenes, phenolic acids (ferulic acid, caffeic acid, chlorogenic acid, *p*-hydroxybenzoic acid), flavonoids (apigenin, luteolin, kaempferol), anthocyanins fiber and volatile oils (in seeds). Mannitol, glucose and fructose are the major monosaccharides in celery. In a study on the nutrient, biomass, minerals and antioxidant distribution in different plant parts between six celery genotypes belonging to leafy, stalk and root types it was found that all celery types exhibited the highest level of antioxidants in leaves [20]. Polyphenols and flavonoids content in roots was slightly lower than that in leaves and stalks. Minerals show a selective distribution among celery parts. For instance, Se, Cu, Zn and K were found in slightly lower amount in roots than in leaves. Both celery stalks and root are consumed either raw or cooked. They share the same type of nutrients in slightly different proportions. The nutritional value is the same for stalks and root.

Celery seeds and root extracts exhibited anti-proliferative and pro-apoptotic activity against several human cancer cell lines. These extracts also reduced the ability of dendritic cells to proliferate during lipopolysaccharide stimulation. As a result, there was no decrease in the pro-inflammatory TNF-α and IL-6 levels but a reduced production of the anti-inflammatory IL-10. Interestingly, it has been recently shown that during severe cases of COVID-19 infections there was a spike in the production of anti-inflammatory IL-10 but for some unknown reason IL-10 failed to suppress COVID-associated cytokine storm that causes increased inflammation. The IL-10 level in COVID patients has been linked to disease severity and prognosis [21]. Regular consumption of celery has been consistently shown that it leads to decreased inflammation, oxidative stress and reduced risk of developing hypertension and coronary heart disease. Apigenin in celery was shown in animal model experiments to help improve liver function by increasing the antioxidant power and hepatoprotective activity [22].

2.4 Ginger

Ginger has been used for a long time as a spice rather than a food staple. It is consumed raw or pickled. It is rich in polyphenols (gingerols, shogaols, paradols), flavonoids and several terpenoids, which are the main constituents of ginger essential oils. Ginger roots also contain polysaccharides, lipids, organic acids and fiber. Due to its high content in polyphenols ginger possesses a strong antioxidant activity. Dried ginger appears to have the highest antioxidant power. Cell culture experiments revealed that ginger extracts protected against oxidative stress as it stimulated the expression of antioxidant enzymes that reduce ROS generation and lipid peroxidation. The antioxidant activity was mediated through the Nrf2 signaling pathway [23].

Ginger extracts were shown, in animal model experiments to alleviate the severity of inflammatory bowel disease. The polyphenols in these extracts inhibit the inflammation signaling pathways represented by the NF-κB and MAPK pathways. Cell culture and mice model experiments using ginger-derived nanoparticles have shown that this novel therapeutic approach could be a promising way for the treatment/prevention of inflammatory bowel diseases [24, 25].

Ginger extracts were also shown to be cytotoxic to breast, cervical, colorectal and prostate cancer cells. The 6-gingerol from ginger may exert its effect on cancer cells via the inhibition of proliferation and the induction of apoptosis in these cells. Apoptosis is induced by the decreased expression of genes involved in the Ras/ERK and PI3K/Akt signaling pathways. Interestingly, a natural ginger extract exhibited a 2.4-fold higher inhibition of tumor growth than a mixture of 6-shogaol, 6-gingerol, 8-gingerol and 10-gingerol [26].

In a cross-sectional observational study involving 4628 participants, age 18 to77, it has been found that daily ginger consumption was associated with a decreased risk of hypertension and atherosclerosis [27].

Animal model experiments indicated that administration of ginger extracts to rats fed a high-fat diet resulted in improved plasma lipid profiles and increased plasma HDL-C level, thus reducing the risk of atherosclerosis. Ginger treatment decreased the activity of angiotensin-1 converting enzyme and increased $NO^{\bullet}$ in hypertensive rats. Mice fed a high-fat diet treated with 6-paradol from ginger exhibited a significantly lower blood glucose level. 6-gingerol treatment of diabetic rats improved glucose tolerance by increasing glucagon-like peptide-1 expression and increased the transport of GLUT4 to cell membrane. In a clinical observational study ginger intake led to reduced levels of fasting plasma glucose, HbA1c, insulin, triglycerides in T2D patients [28]. In a RCT on gestational diabetes mellitus women it was found that ginger tablet supplementation for 6 weeks resulted in reduced fasting blood glucose, fasting insulin and HOMA index. However, there was no change in the 2 hours post-prandial blood glucose level [29]. Ginger intake, in line with a long tradition to treat respiratory disorders was shown to possess bronchodilating activity and anti-hyperactivity. This effect was due probably to the relaxation of smooth muscle cells of the airways as animal model experiments demonstrated. Ginger phytochemicals could also improve symptoms of allergic asthma by reducing allergic airway inflammation [30].

A recent systematic review of over 100 randomized controlled clinical trials on the effects of ginger consumption on a host of human disorders found that conditions such as inflammation, metabolic syndrome, irritable bowel disease, some cancers and pain relief for arthritis, chemotherapy-induced nausea and vomiting showed clear health benefits while others such as diabetes, cardiovascular disease and neurological disorders were not significantly helped by ginger intake [31]. In the realm of pain relief it was reported that ginger intake was helpful in alleviating primary dysmenorrhea pain and was as effective as medications such as ibuprofen and mefenamic acid. Ginger's mode of action involves the suppression of cyclooxygenase and lipoxygenase responsible for the production of pro-inflammatory prostaglandins and leukotrienes, respectively.

Like in all RCT (randomized clinical trials) to date, the wide spectrum of trial designs, number of participants, dosage of active compounds administered, standardization of methodology, etc. makes it difficult to fully assess the effectiveness of natural products from plants in the treatment/prevention of human diseases. Better designed trials will be able to address the shortcomings encountered so far.

2.5 Curcuma longa (turmeric)

Turmeric has been long used by the folk medicine as adjuvant for liver obstruction and jaundice, ulcers and inflammation as well as a host of other ailments such as cold, digestive problems, skin infections, wound healing, asthma, tumors and others. Turmeric was also used as a spice, food preservative and coloring agent. The plant part most important for health is the tuberous rhizome from which turmeric is formed. The main bioactive compound in turmeric is curcumin, also known as diferuloylmethane [32]. Chemically, it is a diarylheptanoid, which is a phenolic pigment responsible for the yellow color of turmeric. Besides the macronutrients (proteins, lipids and carbohydrates), turmeric rhizome contains minerals (Mn, Ca, Mg, Cu, Fe, Zn, P, Na, K), vitamins (B, A, E, K, C), polyphenols, terpenoids, alkaloids, fiber and resins. Monoterpenes are predominant in the essential oils of flowers and leaves whereas sesquiterpenes are predominant in the oils of roots and rhizome. Curcumin makes up 0.3–5.4% of raw turmeric and is the most investigated compound from this plant to date.

Animal model experiments and human clinical studies showed that curcumin may be an important adjuvant therapy in conditions such as gastrointestinal and respiratory disorders, inflammatory disorders, diabetes, CVD and cancer (colorectal, pancreatic and lung cancer). In T2D patients curcumin improved insulin sensitivity, enhanced adiponectin secretion and lowered leptin, resistin, IL-6, IL-1β and TNF-α levels. A meta-analysis of RCT found that curcumin supplementation led to lower blood lipid profiles in CVD patients [33]. One type of cancer that currently has a poor prognosis and survival rate is glioblastoma (GBM). Several cellular signaling pathways such as p53, MAPK, PI3K/Akt, JAK/STAT and NF-κB were found to be dysregulated in GBM.

Curcumin appears to modulate these pathways as in vitro and in vivo experiments suggested. Unfortunately, there was only one clinical trial on the possible anti-tumor effect of curcumin in GBM patients. Using the micellar curcumin formulation it was found that the intra-tumoral curcumin concentration was too low to cause a short-term anti-tumor effect. This was likely due to the small dose of curcumin administered to patients [34]. Due to its chemical structure curcumin has low solubility at neutral and acidic pH, hence reduced bioavailability. In the duodenum curcumin undergoes rapid metabolization via the formation of glucuronides and sulfates that are excreted. Free curcumin was not detected in the serum of GBM patients. It is important therefore to increase the solubility and absorption of this bioactive compound. To that effect efforts are underway to encapsulate curcumin in micelles, nanoparticles, liposomes to make sure it is delivered to the target tissue. There is evidence that curcumin-loaded nanoparticles could suppress the viability, proliferation and migration of glioma stem cells through the induction of cell cycle arrest and apoptosis [34].

In an effort to improve the efficacy of conventional drugs for the treatment of amyotrophic lateral sclerosis (ALS) curcumin nanoparticles were added to standard therapy for this condition. It was found that curcumin was safe and well tolerated [35]. In another RCT curcumin reduced oxidative stress, improved aerobic metabolism and slowed down the progression of the disease [36].

Since the antiviral activity of curcumin is well documented it has been recently speculated that curcumin might be used as adjuvant therapy in the treatment of SARS-CoV-2 infections [37].

2.6 Horseradish

Horseradish (*Armoracia rusticana* L.) is a perennial crop of the Brassicaceae family, indigenous to Eastern Europe and Mediterranean. Upon cutting or shredding the root releases a strong pungent, burning and lachrymatory odor. Horseradish roots (HR) have been used since ancient times as a culinary spice recognized for its nutritional value. Its other uses include food preservative, antiseptic and fermenter. Its folk medicinal use includes the treatment of gout, kidney stones, asthma, bladder infections as well as a possible remedy against rheumatic pain, headache and high blood pressure. The root contains small amounts of macronutrients, fiber, vitamins (C, folate), minerals (Mg, Ca, K, Zn, Mn, Se). It is rich in sulfur-containing glycosides known as glucosinolates [37]. Upon grating glucosinolates (GLS) are hydrolyzed by the enzyme myrosinase to volatile oils such as isothiocyanates, nitriles and thiocyanates. Isothiocyanate sulforaphane is the predominant volatile oil in broccoli. The sharp taste and odor of HR is mainly due to sinigrin-derived allyl isothiocyanate (AITC). AITC is a well-known safe and non-toxic food-borne antimicrobial agent. HR essential oils were shown to possess potent antifungal activity. Thus, essential oils in the vapor phase could control a honey bee larvae disease caused by the fungus *Ascosphaera apis* [38].

There is evidence to suggest that HR oils have potential anti-cancer effects against lung, colorectal, ovarian, oral, prostate cancer as well as glioblastoma. Recent cell culture experiments using cisplatin-resistant oral cancer cells demonstrated that AITC can inhibit Akt/mTOR proliferation signaling pathway and promote mitochondria-dependent apoptotic pathway via AITC-enhanced activity of caspase-3 and caspase-9 in these cells [39].

A study back in 2007 using a HR preparation on patients with acute sinusitis, acute bronchitis and acute urinary tract infection showed that HR was just as effective as the standard treatment with antibiotics and displayed a significantly lower potential for adverse events [40]. In another cell culture experiment, *E. coli* LPS-treated murine macrophages were incubated with HR extracts. It was found that there was a significant reduction in the inflammatory markers TNF-α and IL-6 through the inhibition of NF-κB and p65 activation [41]. HR extracts also reduced ROS production and increased heme oxygenase-1 expression, which meant an enhanced cellular protection during inflammation.

Despite promising results from in vitro and in vivo studies of the health benefits of HR oils there are no RCT to date on the use of HR extracts in clinical settings.

2.7 Radish

Like in the case of horseradish, radish roots have been used for centuries for the treatment of conditions such as stomach pain, constipation, fever, urinary tract infections, liver inflammation, ulcers and cardiac disorders. More recently, in vitro and animal model experiments reported antibacterial, antioxidant and anxiety lowering effects [42].

Radish contains carbohydrates, protein, fiber, vitamins (B group and C) and minerals (Ca, Mg, Fe, Zn, Mn, K, P). Besides the macro-and micronutrient arsenal radish contains secondary metabolites such as polyphenols, isothiocyantes (sulforaphane, sulforaphene, indole-3-carbinol) and glucosinolates (GSL) similar in composition with those in HR. GSL are found exclusively in cruciferous vegetables. They can be classified in three major classes: aliphatic GSL (derived from Met, Ileu, Leu, Val), aromatic GSL (derived from Phe, Tyr) and indolic GSL (derived from Trp). They are sulfur-rich secondary metabolites involved in plant's defense mechanisms against herbivores and pathogens. GSL occur in pungent plants of the Brassicaceae order. To date more than 200 types of GSL have been identified [43].

Selenium (Se) has long been recognized as being essential to animal and human nutrition. Although Se is not considered essential to plants is nevertheless thought as a beneficial element. Low Se soil levels translate in low Se levels in crops used for human consumption. Se as selenate (Na_2SeO_4) is absorbed by plants via sulfur transporters and is incorporated into selenocysteine (SeCys) and seleno-methionine (SeMet). SeCys is part of the seleno-glutathione peroxidase, a powerful antioxidant enzyme. SeMet and methyl-selenocysteine were found to have anticarcinogenic properties.

Because of the importance of Se for human health efforts were made to increase Se uptake by root veggies like radish. Schiavon et al. [44] have shown that Se biofortification in radish resulted in enhanced nutritional value through accumulation of methyl-selenocysteine and secondary metabolites such as glucosinolates, polyphenols and amino acids. The method of Se fertilization and the dosage of selenate applied to plants is important as excess Se may interfere with cysteine and methionine biosynthesis and can also affect negatively glucosinolate accumulation in plants. This is because Se and sulfur share the same uptake pathway. Nitrogen assimilation may also be affected by a high Se concentration in the fertilizer as Se may interfere with molybdenum (Mo) uptake. Mo is a cofactor in the enzyme nitrate reductase that converts nitrate to nitrite, the first reaction in nitrate assimilation by plants. Nitrite is further reduced to ammonia by nitrite reductase. At higher Se dosage the concentration of GSH in roots was lower than at low Se dosage because of a lower entry of sulfate into the sulfur assimilation pathway. The foliar Se spray of radishes grown in soil yielded a higher production of cysteine and GSH in roots. The study of Schiavon et al. [44] also revealed that Se foliar spray resulted in higher levels of all types of glucosinolates in roots including the glucoraphanin, a powerful anticarcinogen. The authors concluded that Se foliar fertilization is a better way to achieve a higher Se and other bioactive compounds in the roots than the hydroponic method.

In the following we will examine some of the properties that make radish such a valued vegetable in terms of nutrition and health enhancement promoter. Turmeric has been long used by the folk medicine as adjuvant for liver obstruction and

a. Antioxidant activity

Radish contains a large selection of phytochemicals that includes carotenoids, GSL, isothiocyanates, phenolic acids, polyphenols, flavanol, flavanone and anthocyanins. Some are present in only one tissue (GSL and carotenoids in sprouts) while others occur in more than one tissue, e.g. anthocyanin, in root and leaves. The leaves have a higher amount of polyphenols than the root. The leafy part constitutes an excellent source compounds with antioxidant power. Hence, it is recommended that all parts of the radish plant be consumed, including the sprouts. The flavonoids in radish have the ability to chelate iron, thus blocking iron-catalyzed generation of reactive oxygen species (ROS).

b. Detoxification activity

Cell culture and animal model experiments revealed that radish extracts attenuated the chemically-induced rat liver injury by decreasing lipid peroxidation caused by oxidative stress (OS). There is evidence to suggest that administration of radish extracts to rats upregulated the expression of cytochrome P450, Nrf-2/HO-1 signaling pathway, which are known to activate the expression of antioxidant enzymes. Besides fresh extracts some studies employed fermented radish in presence of *Lactobacillus spp*. Apparently, fermentation helps disassociate fibers in vegetables and that facilitate the release of bioactive compounds. Thus, fermented Spanish black radish had a hepatoprotective effect in CCl4-induced rat liver injury [45]. In another paper from the same group it was shown that the administration of fermented black radish to mice challenged with methionine and choline deficient diet significantly attenuated the increase in serum enzymes associated with hepatic cell injury such as alanine aminotransferase and aspartate aminotransferase [46]. Liver fibrosis and inflammation were also mitigated by treatment with fermented black radish.

Radish extracts proved helpful in the detoxification of xenobiotics. Thus, a single center, open label, pilot study investigated black radish supplementation to healthy males who received a controlled dose of acetaminophen (ibuprophen). The results showed that changes over a 4 week period of the ibuprophen metabolite and estradiol-17β suggested that there was an upregulation of phase I and phase II detoxification enzymes [47].

c. Anticancer activity

There is some evidence to suggest that indole-3-carbinol and its metabolite 3,3′-diindolyl-methane could suppress the growth and proliferation in tumor cell lines. These compounds target several features of cancer cell metabolism such as cell cycle regulation and survival including NF-κB/Akt signaling pathway, estrogen receptor signaling, caspase activation and endoplasmic reticulum stress [48]. Several studies reported the anti-cancer properties of GSL and isothiocyanates [42]. Thus, extracts of Spanish black radish inhibited the proliferation of HepG2 human tumor cells in vitro by up-regulating the phase I and II detoxification system. Apparently, the anti-cancer effect was due to the GSL compounds glucoraphasatin and 4-methylthio-3-butenyl isothiocyanate [49]. Sulforaphane and sulforaphene in Thai rat-tailed radish extract exhibited a strong cytotoxic effect against colon tumor cell line HCT116 [50]. The mechanism of action involved the increased production of ROS in these cells and the disruption of microtubule polymerization, hence affecting cell cycle regulation. A prospective EPIC-Heidelberg cohort study comprising 11,405 subjects and a mean follow-up time of 9.4 years found that a high GSL intake from cruciferous vegetables including radish was inversely associated with prostate cancer risk.

A very interesting use of radish extracts with the goal of obtaining cytotoxic agents against cancer cells is the reduction of graphene oxide (GO) in the presence of mild reductants such as those in radish extracts. GO is generated by the exfoliation of graphene from graphite in the presence of strong acids and bases. For biomedical applications GO is reduced by eco-friendly compounds such as polyphenols and flavonoids in plants such as radish. It has been found that reduced GO could significantly inhibit the proliferation of human breast and lung cancer cell lines [51].

d. Potential anti-diabetic properties

Unlike other medical conditions discussed above the potential of radish extracts to exert an anti-diabetes activity has been investigated so far only by using in vitro or in vivo (animal model experiments) systems. Thus, radish extracts administered to streptozotocin-induced diabetic rats caused a significant reduction in blood glucose, insulin and triglycerides levels [52]. Radish extracts also reduced the starch-induced postprandial glycemic load suggesting that is has a potent anti-diabetic activity. It has been speculated that the hypoglycemic effect was due to an improved insulin sensitivity rather than increased insulin output. The phenolic compounds in radish may also assist in reducing oxidative stress via production of ROS, which are known to be elevated in diabetes. In addition, isothiocyanates in radish were shown to induce phase II antioxidant enzymes such as glutathione transferase, heme oxygenase-1, NAD(P)H-quinone reductase and UDP-glucuronosyl transferase. In vitro studies, demonstrated that aqueous radish extracts inhibited the activity of α-amylase and α-glucosidase, hence a decreased absorption of poly-and oligosaccharides in the GI tract.

2.8 Parsnip

Like the other root vegetables discussed above parsnip has been a staple for humans since ancient times. Parsnip is rich in vitamins and minerals (particularly potassium), phytochemicals (polyphenols, flavonoids, polyacetylenes, terpenes), essential oils and fiber. 100 g of parsnip provide about 75 kcal. A typical parsnip root contains 80% water, 5% carbohydrates, 1% protein, 0.3% lipids and 5% fiber.

Traditionally, parsnip has been used by folk medicine, particularly in the old Persian medical practice for topical and oral treatment of headaches, stomatitis, dermatitis, kidney stones and fever as well as recommended as gastric tonic, laxative and diuretic [53].

We cannot emphasize strongly enough the importance of fiber intake for a healthy life because of the proven health benefits of a fiber-rich diet. The dietary fiber comprises cellulose, hemicellulose, lignin, pectin and β-glucans. According to WHO and FAO dietary fiber consists of ten or more monomeric units that are neither digested nor absorbed in the small intestine and they are labeled as complex carbohydrates. Fruits and vegetables contain soluble and insoluble fiber. The former includes pectins, gums, insulin-type fructans and some hemicellulose. The latter comprises lignin, cellulose, some hemicellulose, resistant starches and analogous carbohydrates such as methyl cellulose. The content of dietary fiber in parsnip is 30% of the dry matter, composed mainly by neutral sugars (18%), pectic compounds (10%) and Klason lignin (1.92%). Klason lignin represents the insoluble residue portion left after removing the ash by acid hydrolysis of the plant tissue [54, 55].

When designing a healthy meal one should bear in mind the potential interplay between soluble fiber and fat. Experiments on mice indicated that mice fed a high fat diet that included soluble fiber exhibited a weight gain [56]. This outcome might be due to increased short chain fatty acids production after fermentation in the colon and subsequent increase in energy absorption.

Regular intake of soluble fiber has been associated with lower cholesterol and glucose levels, increased mass of friendly gut bacteria and a lower risk of developing metabolic syndrome, T2D and CVD. An observational study comprising healthy subjects found an inverse association between fiber intake and the concentration of serum C reactive protein. In another study on T2D patients it was shown that a higher fiber intake led to a decrease in the levels of circulating pro-inflammatory cytokine IL-18. It is well documented that high levels of circulating pro-inflammatory cytokines are associated with an increased risk for diabetes and CVD so a diet rich in fiber lowers the risk of getting T2D or CVD. Dietary fibers also decrease blood glucose excursions and lower insulin response.

The phytochemicals in parsnip root have been shown to possess a wide spectrum of pharmacological properties, which made them useful in tackling conditions such as neurological, respiratory, gastrointestinal, liver, skin, heart and urogenital disorders [54]. In vitro cell culture experiments have also shown cytotoxic effects of parsnip phytochemicals on cancer cell lines. A parsnip furanocoumarin such as xanthotoxin was shown to prevent memory impairment induced by injection of scopolamine in mice suggesting that xanthotoxin has neuroprotective effects on the cholinergic neurotransmission and also reduced oxidative stress in the brain [57].

2.9 Garlic

Garlic (*Allium sativum* L.) has been used for centuries both as food and as remedy in many cultures for a number of ailments such as cold, influenza, snake bites, bacterial and fungal infections and hypertension. Traditional medicine has also used garlic for the treatment of indigestion, respiratory and urinary tract infections and heart disorders. Epidemiological data indicated that Allium species extracts reduce the risk of diabetes and heart disease, activate the immune response when challenged by microbial and fungal pathogens and also show anti-aging, anti-diabetic and anti-cancer properties. Bulbs of garlic contain hundreds of phytochemicals including sulfur-containing compounds, polyphenols (alliin, allicin, diallyl disulfide, S-allylcysteine, S-allylmercaptocysteine, etc) such as quercetin, luteoline and apigenin, saponins, tanins and polysaccharides. When garlic is chopped or crushed alliin (allyl thiosulfinate), the main cysteine sulfoxide is converted into allicin by the enzyme allinase. The enzyme has pyridoxal phosphate as cofactor and it turns alliin into aminoacrylic acid and allyl sulfenic acid. Two molecules of allyl sulfenic acid (highly reactive) form allicin (2-propenylthiosulfinate). Allicin readily crosses cell membranes and reacts with thiol groups [58].

There have been numerous observational and clinical trials in the last two decades assessing the therapeutic effects of garlic preparations on pathologies such as diabetes, CVD, hypertension, metabolic syndrome, skin disorders, cancer, bacterial and fungal infections due mainly to the antioxidant, anti-inflammatory and lipid lowering effects shown by these preparations [59]. Garlic compounds were shown to elicit a number of biological responses such as the modulation of several cell signaling pathways (Akt/mTOR, MAPK, Nrf2, protein kinase B, 5'-AMP-activated protein kinase) as well as the activity of cytokines, intercellular adhesion molecules, cyclooxygenase, inducible NO synthase and others). Many studies were hampered by the low bioavailability and fast metabolization of garlic compounds in the human body and that affected the interpretation of the results. For example, the effect of garlic treatment on people with elevated blood pressure showed mixt results. One study indicated that the treatment resulted in slight improvement in cases of mild hypertension whereas another study showed no effect. Moreover, aged garlic extracts contain mainly water-soluble organosulfur compounds such as S-allyl cysteine and S-allylmercaptocysteine, which show other pharmacokinetics properties than oil-soluble S-containing compounds and that may influence the outcome of garlic supplementation.

Table headings list study design, medical condition examined, number of patients, type of intervention, duration of study and outcome. The clinical trials on T2D patients receiving garlic preparations with or without standard medication indicated that in general there was a significant reduction in blood glucose and HbA1c levels as well as an improved plasma lipid profile. Patients with gastric lesions supplemented with garlic preparations over a long period of time showed a decreased risk of developing gastric cancer incidence and mortality. On the other hand, patients with liver, prostate and colon cancer supplemented with 4 capsules of garlic preparation daily for 6 months did not show an improvement of their condition and the quality of life. Garlic preparations were found useful in reducing the level of oxidative stress and the production of pro-inflammatory cytokines such as IL-6 and CRP commonly associated with most human pathologies. Garlic preparations were found helpful for combating microbial infections. There was an inverse association between oral bacteria level and a lime-containing garlic extracts mouth wash in children with severe early caries. The inhibitory effect of garlic may include morphological alterations in bacterial cell wall and inhibition of microbial adherence to the epithelial cells of the host.

In general, garlic therapy yielded mixed results suggesting that not all pathologies are alike and not all patients respond in the same way to garlic supplementation. Better garlic formulations together with the standard therapy and a healthy diet and lifestyle should improve the outcome of treatment and reduce the risk of developing the conditions in the first place.

2.10 Onions

Onion (*Allium cepa*) has been used for centuries as food and spice as well as traditional medicine for a host of conditions such as fever, headache, dropsy, dyspnea, chronic bronchitis, cough and arthritis. The health benefits of eating onions are thought to be due to their antioxidant, immunomodulatory and anti-inflammatory activity [60–62].

Onions contain vitamins (B_1, B_2, B_6, folate, vitamin C), minerals (Mg, Ca, K, P), phenolic acids (gallic acid, ferulic acid, protocatechuic acid), flavonoids (flavanones, flavonols, flavanonols, kaempferol, anthocyanins), sulfur-containing compounds (diallyl sulfide, diallyl disulfide, S-methyl cysteine sulfoxide, etc), organic acids (citric, tartric, malic, oxalic, succinic), monosaccharides (glucose, fructose), fructooligosaccharides, phytoalexins and saponins. The main flavonol in onion is qercetin, in free form and as glucoside.

In an elegant randomized double-blind, placebo-controlled cross-over clinical trial it was found that supplementation with 162 mg/d quercetin from onion skin extract powder to overweight-to-obese patients for 6 weeks resulted in a modest drop in blood pressure (BP) in hypertensive but not in pre-hypertensive individuals [63]. These findings suggest that a threshold of higher BP might be necessary in order to detect a BP-lowering effect of quercetin. In addition, in the clinic's office where the BP measurements were performed no significant effects of quercetin supplementation on systolic BP were recorded and only about 50% of the participants showed a decrease in systolic BP. In contrast to animal model studies showing that quercetin attenuated hypertension and vascular dysfunction in a $NO^{\bullet}$-dependent fashion, in the human trial above the biomarkers of endothelial function such as plasma endothelin-1, soluble vascular cell adhesion molecule-1, reactive hyperemia index were not affected by quercetin supplementation. The marker of inflammation CRP and angiotensin converting enzyme activity were also unaffected by quercetin treatment. The authors of the study concluded that for the hypertensive patients quercetin could decrease the 24 h systolic BP but without affecting the markers associated with inflammation and endothelial function. For the time being the molecular mechanisms underlying the BP-lowering effect of quercetin remain unclear.

In another RCT study it was found that onion extracts containing 50 mg quercetin increased the circulating endothelial progenitor cells and improved the flow-mediated dilation while BP and blood lipid profile were not affected.

It is also worth mentioning here that a meta-analysis of several RCTs on the effect of quercetin on BP indicated that a significant anti-hypertensive effect was only apparent at doses above 500 mg/day taken for longer than 8 weeks.

Platelet aggregation constitutes an aggravating factor in atherosclerosis. In vitro experiments using rat platelets have demonstrated that methanol extracts of onion skins were able to inhibit platelet aggregation. Quercetin and quercetin glucosides as well as organosulfur compounds appear to be involved in this inhibition. Allicin in onions was found to be a potent inhibitory factor toward ADP, arachidonic acid and collagen-induced platelet aggregation. It has been proposed that quercetin and organosulfur compounds from onion may be included in a preparation to be used for the prevention/management of atherosclerosis.

Most studies on the effect of onion compounds on cancer have been carried out on cancer cell lines and animal models. The polyphenols and S-containing compounds were mainly responsible for the observed effects. Quercetin glucosides in onion extracts were shown to possess antiproliferative activity against human breast, colorectal and prostate cancer cell lines. One possible mechanism is the inhibition of the PI3K/Akt signaling pathway, which results in apoptosis. Diallyl-trisulfide from onion was shown to trigger cancer cell cycle arrest at G2/M phase and the release of ROS that promote apoptosis and restrict tumor cell formation and development.

Onion extracts have been investigated in animal model experiments in relation to their potential use as anti-diabetic agents. For instance, STZ-induced diabetic rats treated with *A. cepa* bulb juice exhibited a 50% reduction in the fasting blood glucose level. C57BL/6 J mice treated with red onion extracts showed a decreased high fat diet-induced mass accumulation and insulin resistance. Flavonoids such as quercetin and S-methylcysteine in onions are mainly responsible for the hypoglycemic activity. These compounds were shown to decrease blood glucose levels, plasma lipids, oxidative stress and lipid peroxidation as well as modulating insulin secretion. Preliminary clinical trials demonstrated the blood glucose lowering effect of onion extracts.

Onion constituents show clear benefits against respiratory and allergic disorders. Experiments with allergic asthma guinea pigs indicated that onion quercetin significantly alleviated asthma symptoms. The mechanism of action includes β2-adrenoreceptors stimulation, inhibition of Ca channel blocking, histamine H1 receptors and phosphodiesterase activity. Protective effects of onion extracts were demonstrated by epidemiological and population case–control studies. Onion extracts as well as purified thiosulfinates and kaempferol acted by relaxing tracheal smooth muscles hence, improving clinical symptoms and reducing the severity of asthmatic attacks.

Biological active compounds in onions were shown in vitro experiments to possess antimicrobial activity. Red onion extracts were more effective antimicrobial agents than those from white and yellow onions. The bacterial species tested included *E. coli*, *Salmonella typhimurium*, *Klebsiella* spp. Onion extracts in ethanol, chloroform or water were also effective against fungi and molds. In a vivo study on broiler chickens it was found that onion powder-containing chicken feed had an effect on the gut microflora in that the number of *E. coli* was reduced whereas the number of *Lactobacillus* spp. was increased, which has a positive effect on chickens' health.

3. Conclusions

The last 30 years or so have been marked by an impressive progress in our knowledge about the chemical composition and the mode of action of biologically active compounds in fruits and vegetables, both wild and cultivated. In the present chapter we focused on the biochemistry and the potential benefits of compounds occurring in the roots and bulbs of some cultivated vegetables that have been for thousands of years part of human staple in all cultures. These chemicals are synthesized by plants to help attract friendly bacteria and/or ward off pathogens as well as increasing the absorption of vital nutrients including minerals.

All of the vegetable roots discussed in this chapter contain a wealth of bioactive compounds such as phenolic acids, polyphenols, sulfur-containing compounds, isothiocyanates, glucosinolates, mono- and polysaccharides, phytosterols, saponins, fiber and others. These chemicals have been extensively studied by using a variety of in vitro and in vivo experimental systems. Numerous clinical trials tried to assess the usefulness of either isolated compounds from roots and bulbs or whole extracts from these tissues for the treatment of major diseases such as diabetes, cardiovascular disease, cancer, allergies as well as bacterial infections either alone or in conjunction with standard therapies. In most cases there was a significant improvement in the condition of patients and quality of life. If total cure could not be achieved at least these natural compounds can assist in the prevention of many diseases in the first place. It is hoped that based on the knowledge accumulated so far the nutraceutical industry will come up with better product formulation regarding these bioactive compounds so there will be a better outcome for the patients. Besides supplementation with plant-based products, a diet rich in fruits and vegetables, an active lifestyle with physical activity and stress management will ensure a good health and a happy life.

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References

[1] McNear DH Jr. The rhizosphere – Roots, soil and everything in between. Nature Education Knowledge. 2013;**4**(3):1

[2] Liu A, Contador CA, Fan K, Lam HM. Interaction and regulation of carbon, nitrogen and phosphorus metabolisms in root nodules of legumes. Frontiers in Plant Science. 2018;**9**:1860. DOI: 10.3389/fpls.2018.01860

[3] Abdel-Latif K, Bogusz D, Hocher V. The role of flavonoids in the establishment of plant roots endosymbioses with arbuscular mycorrhiza, rhizobia and Frankia bacteria. Plant Signaling & Behavior. 2012;**7**(6):636-641. DOI: 10.4161/psb.20039

[4] Vannier N, Agler M, Hacquard S. Microbiota-mediated disease resistance in plants. PLoS Pathogens. 2019;**15**:e1007740. DOI: 10.1371/journal.ppat.1007740

[5] Pascale A, Proietti S, Pantelides IS, Stringlis IA. Modulation of the root microbiome by plant molecules: The basis for targeted disease suppression and plant growth promotion. Frontiers in Plant Science. 2019;**10**:1741. DOI: 10.3389/fpls.2019.01741

[6] Schmidt H, Günther C, Weber M, Spörlein C, Loscher S, Böttcher C, et al. Metabolome analysis of *Arabidopsis thaliana* roots identifies a key metabolic pathway for iron acquisition. PLoS One. 2014;**9**(7):e102444. DOI: 10.1371/journal.pone.0102444

[7] Chen W, Tang L, Eang J, Zhu H, Jin J, Yang J, et al. Research advances in the mutual mechanisms regulating response of plant roots to phosphate deficiency and aluminum toxicity. International Journal of Molecular Science. 2022;**23**(3):1137. DOI: 10.3390/ijms23031137

[8] Parra-Almuna L, Diaz-Cortez A, Ferrol N, Luz MM. Aluminum toxicity and phosphate deficiency activates antioxidant systems and up-regulates expression of phosphate transporters in ryegrass (*Lolium perenne* L.) plants. Plant Physiology and Biochemistry. 2018;**130**:445-454. DOI: 10.1016/j.plaphy.2018.07.031

[9] Chen L, Zhu Y, Hu Z, Wu S, Jin C. Beetroot as a functional food with huge health benefits: Antioxidant, antitumor, physical function and chronic metabolomics activity. Food Science & Nutrition. 2021;**9**(11):6406-6420. DOI: 10.1002/fsn3.2577

[10] Esatbeyoglu T, Wagner AE, Schini-Kerth VB, Rimbach G. Betanin – A food colorant with biological activity. Molecular Nutrition & Food Research. 2015;**59**(1):36-47. DOI: 10.1002/mnfr.201400484

[11] Webb AJ, Patel N, Loukogeorgakis S, Okorie M, Aboud Z, Misra S, et al. Acute blood pressure lowering, vasoprotective and anti-platelet properties of dietary nitrate via bioconversion to nitrite. Hypertension. 2008;**51**:784-790. DOI: 10.1161/HYPERTENSIONAHA.107.103523

[12] Priya NG, Malarvizhi M, Jothi AJ. Beetroot juice on hemoglobin among adolescent girls. Journal of Nursing and Health Science. 2013;**2**:9-13

[13] Olumese FE, Oboh HA. Effects of daily intake of beetroot juice on blood glucose and hormones in young healthy

subjects. Nigerian Quarterly Journal of Hospital Medicine. 2016;**26**:455-462

[14] Sharma KD, Karki S, Thankur NS, Attri S. Chemical composition, functional properties and processing of carrot – A review. Journal of Food Science and Technology. 2012;**49**(1):22-32. DOI: 10.1007/s13197-011-0310-7

[15] Ahmad T, Cawood M, Iqbal Q, Arino A, Batool A, Tarid RMS, et al. Phytochemicals in *Daucus carota* and their health benefits – Review article. Food. 2019;**8**(9):424. DOI: 10.3390/foods8090424

[16] Wang LS, Stoner GD. Anthocyanins and their role in cancer prevention. Cancer Letters. 2008;**269**(2):281-290. DOI: 10.1016/j.canlet.2008.05.020

[17] Islami F, Sauer AG, Miller KD, Siegel RL, Fedewa SA, Jacobs EJ, et al. Proportion and number of cancer cases and deaths attributable to potentially modifiable risk factors in the United States. CA: A Cancer Journal for Clinicians. 2017;**68**(1):31-54. DOI: 10.3322/caac.21440

[18] Del Rio D, Rodriguez-Mateos A, Spencer JPE, Tognolini M, Borges G, Crozier A. Dietary (poly)phenolics in human health: Structures, bioavailability and evidence of protective effects against chronic diseases. Antioxidants & Redox Signaling. 2013;**18**(14):1818-1892. DOI: 10.1089/ars.2012.4581

[19] Tang G. Bioconversion of dietary provitamin a carotenoids to vitamin a in humans. The American Journal of Clinical Nutrition. 2010;**91**(5):1468S-1473S. DOI: 10.3945/ajcn.2010.28674G

[20] Golubkina NA, Kharchenko VA, Moldovan AI, Koshevarov AA, Zamana S, Nadezhkin S, et al. Yield, growth, quality, biochemical characteristics and elemental composition of plant parts of celery leafy, stalk and root types grown in the northern hemisphere. Plants (Basel). 2020;**9**(4):484. DOI: 10.3390/plants9040484

[21] Islam H, Chamberlain TC, Mui AL, Little JP. Elevated interleukin 10 levels in COVID-19: Potentiation of pro-inflammatory responses or impaired anti-inflammatory action? Frontiers in Immunology. 2021;**12**:677008. DOI: 10.3389/fimmu.2021. 677008

[22] Wang E, Chen F, Hu X, Yuan Y. Protective effects of apigenin against furan-induced toxicity in mice. Food & Function. 2014;**5**(8):1804-1812. DOI: 10.1039/c4fo00038b

[23] Mao QQ, Xu XY, Cao SY, Gan EY, Corke H, Beta T, et al. Bioactive compounds and bioactivities of ginger (*Zingiber officinale* roscoe). Food. 2019;**8**(6):185. DOI: 10.3390/foods8060185

[24] Bologa C. Foods that promote health. In: Hulea SA, Ahmadi M, editors. Foods That Harm, Foods That Promote Health: A Biochemical and Nutritional Perspective in Health and Disease Prevention. Irvine, CA, USA: Universal Publishers Inc.; 2021. pp. 181-213

[25] Zhang M, Viennois E, Prasad M, Zhang Y, Wang L, Zhang Z, et al. Edible ginger-derived nanoparticles: A novel therapeutic approach for the prevention and treatment of inflammatory bowel disease and colitis-associated cancer. Biomaterials. 2016;**101**:321-340. DOI: 10.1016/j.biomaterials.2016.06.018

[26] Gundala SR, Mukkavilli R, Yang C, Yadav P, Tandon V, Vangala S, et al. Enterohepatic recirculation of bioactive ginger phytochemicals is associated with enhanced tumor growth

inhibitory activity of ginger extract. Carcinogenesis. 2014;**35**(6):1320-1329. DOI: 10.1093/carcin/bgu011

[27] Wang Y, Yu H, Zhang X, Feng Q, Guo X, Li S, et al. Evaluation of daily ginger consumption for the prevention of chronic diseases in adults: A cross-sectional study. Nutrition. 2017;**36**:79-84. DOI: 10.1016/j.nut.2016.05.009

[28] Arablou T, Aryaeian N, Valizadeh M, Sharifi F, Hosseini AF, Djalali M. The effect of ginger consumption on glycemic status, lipid profile and some inflammatory markers in patients with type 2 diabetes mellitus. International Journal of Food Sciences and Nutrition. 2014;**65**:515-520. DOI: 10.3109/09637486.2014.880671

[29] Hajimoosayi F, Sadatmahalleh SJ, Kazemnejad A, Pirijani R. Effect of ginger on the blood glucose level of women with gestational diabetes mellitus with impaired glucose tolerance test (GTT): A randomized double-blind placebo-controlled trial. BMC Complementary Medicine and Therapies. 2020;**20**(1):116. DOI: 10.1186/s12906-020-02908-5

[30] Khan AM, Shahzad M, Asim MBR, Imran M, Shabbir A. *Zingiber officinale* ameliorates allergic asthma via suppression of Th2-mediated immune response. Pharmaceutical Biology. 2015;**53**(3):359-367. DOI: 10.3109/13880209.2014.920396

[31] Anh NH, Kim SJ, Long NP, Min JE, Yoon YC, Lee EG, et al. Ginger on human health: A comprehensive systematic review of 109 randomized controlled trials. Nutrients. 2020;**12**(1):157. DOI: 10.3390/nu12010157

[32] Fuloria S, Mehta J, Chandel A, Sekar M, Rani NNIM, Begum MY, et al. A comprehensive review on the therapeutic potential of *Curcuma longa* Linn. in relation to its major active constituent curcumin. Frontiers in Pharmacology. 2022;**13**:820806. DOI: 10.3389/fphar.2022.820806

[33] Qin S, Huang L, Gong J, Shen S, Huang J, Ren H, et al. Efficacy and safety of turmeric and curcumin in lowering blood lipid levels in patients with cardiovascular risk factors: A meta-analysis of randomized controlled trials. Nutrition Journal. 2017;**16**(1):68. DOI: 10.1186/s12937-017-0293-y

[34] Wong SC, Kamarudin MNA, Naidu R. Anticancer mechanism of curcumin on human glioblastoma. Nutrients. 2021;**13**(3):950. DOI: 10.3390/nu13030950

[35] Ahmadi M, Agah E, Nafissi S, Jaafari MR, Harirchian MH, Sarraf P, et al. Safety and efficacy of nanocurcumin as add-on therapy to riluzole in patients with amyotrophic lateral sclerosis: A pilot randomized clinical trial. Neurotherapeutics. 2018;**15**(2):430-438. DOI: 10.1007/s13311-018-0606-7

[36] Chico L, Ienco EC, Bisordi C, Gerfo AL, Petrozzi L, Petrucci A, et al. Amyotrophic lateral sclerosis and oxidative stress: A double-blind therapeutic trial after curcumin supplementation. CNS & Neurological Disorders Drug Targets. 2018;**17**(10): 767-779. DOI: 10.2174/1871527317666180720162029

[37] Lunz K, Stappen I. Back to roots – An overview of the chemical composition and bioactivity of selected root essential oils. Molecules. 2021;**26**(11):3155. DOI: 10.3390/molecules26113155

[38] Kloucek P, Smid J, Flesar J, Havlik J, Titera D, Rada V, et al. In vitro inhibitory activity of essential oil vapors against

Ascosphaera apis. Natural Product Communications. 2012;7:253-256. DOI: 10.1177/1934578X1200700237

[39] Chang PY, Tsai FJ, Bau DT, Hsu YM, Yang JS, Tu MG, et al. Potential effect of allyl isothiocyanate on inhibiting cellular proliferation and inducing apoptotic pathway in human cisplatin-resistant oral cancer cells. Journal of the Formosan Medical Association. 2021;**120**(1): 515-523. DOI: 10.1016/j.jfma.2020.06.025

[40] Goos KH, Alberecht U, Schneider B. On-going investigations on efficacy and safety of a herbal drug containing nasturtium herb and horseradish root in acute sinusitis, acute bronchitis and acute urinary tract infection in children in comparison with other antibiotic treatments. Article in German. Arzneimittel-Forschung. 2007;**57**(4): 238-246. DOI: 10.1055/s-0031-1296611

[41] Marzocco S, Calabrone L, Adesso S, Larocca M, Franceschelli S, Autore G, et al. Anti-inflammatory activity of horseradish (*Armoracia rusticana*) root extracts in LPS-stimulated macrophages. Food & Function. 2015;**6**(12):3778-3788. DOI: 10.1039/C5FO00475F

[42] Manivannan A, Kim JH, Kim DS, Lee ES, Lee HE. Deciphering the nutraceutical potential of *Raphanus sativus* – A comprehensive overview. Nutrients. 2019;**11**(2):402. DOI: 10.3390/nu11020402

[43] Wang J, Qui Y, Wang X, Yue Z, Yang X, Chen X, et al. Insights into the species-specific metabolic engineering of glucosinolates in radish (*Raphanus sativus* L.) based on comparative genomic analysis. Scientific Reports. 2017;**7**:16040. DOI: 10.1038/s41598-017-16306-4

[44] Schiavan M, Berto C, Malagoli M, Trentin A, Sambo P, Dall'Acqua S, Pilon-Smits EAH. Selenium biofortification in radish enhances nutritional quality via accumulation of methyl-selenocysteine and promotion of transcripts and metabolites related to glucosinolates, phenolics and amino acids. Frontiers in Plant Science. 2016;**7**:1371. DOI: 10.3389/fpls.2016.01371

[45] Kim J, Ahn M, Kim SE, Lee HS, Kim HK, Kim GO, et al. Hepatoprotective effect of fermented black radish (*Raphanus sativus* L. var. niger) in CCl4-induced liver injury in rats. Journal of Preventive Veterinary Medicine. 2017;**41**(4):143-149. DOI: 10.13041/jpvm.2017.41.4.143

[46] Ahn M, Kim J, Choi Y, Ekanayake P, Chun JY, Yang DW, et al. Fermented black radish (*Raphanus sativus* L. var. *niger*) attenuates methionine and choline deficient diet-induced nonalcoholic fatty liver disease in mice. Food Science & Nutrition. 2019;**7**(10):3327-3337. DOI: 10.1002/fsn3.1200

[47] Evans M, Paterson E, Barnes DM. An open label pilot study to evaluate the efficacy of Spanish black radish on the induction of phase I and phase II enzymes in healthy male subjects. BMC Complementary and Alternative Medicine. 2014;**14**:475. DOI: 10.1186/1472-6882-14-475

[48] Weng JR, Tsai CH, Kulp SK, Chen CS. Indol-3-carbinol as a chemopreventive and anti-cancer agent. Cancer Letters. 2008;**262**(2):153. DOI: 10.1016/j.canlet.2008.01.033

[49] Hanlon PR, Webber DM, Barnes DM. Aqueous extract from Spanish black radish (*Raphanus sativus* L. var. *niger*) induces detoxification enzymes in the HepG2 human hepatoma cell line. Journal of Agricultural and

Food Chemistry. 2007;**55**:6439-6446. DOI: 10.1021/jf070530f

[50] Pocasap P, Weerapreeyakul N, Barusrux S. Cancer preventive effect of Thai rat-tailed radish (*Raphanus sativus* L. var. *caudatus Alef*). Journal of Functional Foods. 2013;**5**:1372-1381. DOI: 10.1016/j.jff.2013.05.005

[51] Punniyakotti P, Aruliah R, Angaiah S. Facile synthesis of reduced graphene oxide using *Acalypha indica* and *Raphanus sativus* extracts and their in vitro cytotoxicity activity against human breast (MCF-7) and lung (A549) cancer cell lines. 3. Biotech. 2021;**11**(4):157. DOI: 10.1007/s13205-021-02689-9

[52] Banihanni SA. Radish (*Raphanus sativus*) and diabetes. Nutrients. 2017;**9**(9):1014. DOI: 10.3390/nu9091014

[53] Lattimer JM, Haub MD. Effects of dietary fiber and its components on metabolic health. Nutrients. 2010;**2**(12):1266-1289. DOI: 10.3390/nu2121266

[54] Kenari HM, Kordafshari G, Moghimi M, Eghbalian F, Taher KD. Review of pharmacological properties and chemical constituents of *Pastinaca sativa*. Journal of Pharmacopuncture. 2021;**24**(1):14-23. DOI: 10.3831/KPI.2021.24.1.14

[55] Castro A, Bergenståhl B, Tornberg E. Parsnip (*Pastinaca sativa* L.): Dietary fiber composition and physicochemical characterization of its homogenized suspensions. Food Research International. 2012;**48**(2):598-608. DOI: 10.1016/j.foodres.2012.05.023

[56] Isken F, Klaus S, Osterhoff M, Pfeiffer AFH, Weickert MO. Effects of long-term soluble vs insoluble dietary fiber intake on high fat diet-induced obesity in C57BL/6J mice. The Journal of Nutritional Biochemistry. 2010;**21**:278-284. DOI: 10.1016/j.jnutbio.2008.12.012

[57] Skalicka-WozniakK,BudzynskaB,BialaG, Boguszewska-Czubara A. Scopolamine-induced memory impairment is alleviated by xanthotoxin: Role of acetylcholinesterase and oxidative stress processes. ACS Chemical Neuroscience. 2018;**9**(5):1184-1194. DOI: 10.1021/acschemneuro.8b00011

[58] Batiha GE, Beshbishy AM, Wasef LG, Yha E, Al-Sagan A, MEA E-H, et al. Chemical constituents and pharmacological activities of garlic (*Allium sativum* L.): A review. Nutrients. 2020;**12**(3):872. DOI: 10.3390/nu12030872

[59] Ansary J, Forbes-Hernandez TY, Gil E, Cianciosi D, Zhang J, Elexpuru-Zabelata M, et al. Potential health benefits of garlic based on human intervention studies: A brief overview. Antioxidants (Basel). 2020;**9**(7):619. DOI: 10.3390/antiox9070619

[60] Chakraborty AJ, Uddin TM, Zidan BMRM, Mitra S, Das R, Nainu F, et al. *Allium cepa*: A treasure of bioactive phytochemicals with prospective health benefits. Evidence-based Complementary and Alternative Medicine. 2022;**2022**:4586318. DOI: 10.1155/2022/4586318

[61] Marrelli M, Amodeo V, Statti G, Conforti F. Biological properties and bioactive components of *Allium cepa* L.: Focus on potential benefits in the treatment of obesity and related comorbidities. Molecules. 2019;**24**(1):119. DOI: 10.3390/molecules24010119

[62] Beigoli S, Behrouz S, Zia AM, Ghasemi SZ, Boskabady M, Marefati N, et al. Effects of *Allium cepa* and its constituents on respiratory and allergic disorders: A comprehensive

review of experimental and clinical evidence. Evidence-based Complementary and Alternative Medicine. 2021;**2021**:5554259. DOI: 10.1155/2021/5554259

[63] Brüll V, Burak C, Stoffel-Wagner B, Wolffram S, Nickenig G, Muller C, et al. Effects of a quercetin-rich onion skin extract on 24h ambulatory blood pressure and endothelial function in overweight-to-obese patients with (pre-) hypertension: A randomized double-blinded placebo-controlled cross-over trial. The British Journal of Nutrition. 2015;**114**(8):1263-1277. DOI: 10.1017/S0007114515002950