# Influence of Root Vegetables on Health

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Root vegetables are characterized by high nutritional value due to their richness in dietary fiber, vitamins, and minerals. One of their most important features is their high content of bioactive compounds, such as polyphenols, phenols, flavonoids, and vitamin C. These compounds are responsible for antioxidant potential. Moreover, root vegetables are characterized by several health-promoting effects, including the regulation of metabolic parameters (glucose level, lipid profile, and blood pressure), antioxidant potential, prebiotic function, and anti-cancer properties. However, due to the type of cultivation, root vegetables are vulnerable to contaminants from the soil, such as toxic metals (lead and cadmium), pesticides, pharmaceutical residues, microplastics, and nitrates. Vegetables can be classified based on their botanical origin, hardiness or temperature, and plant part used, i.e. leaves, fruits, or roots. Root vegetables include carrot, radish, potato, yam, ginseng, celery, parsley, and horseradish.

Keywords: root vegetables ; polyphenols ; betalains ; carotenoids ; dietary fiber ; contaminants ; microplastic ; heavy metals

## 1. Morphological Structure of Root Vegetables

Holding the plant in the ground and taking up water and mineral salts are the primary functions of roots [1]. The root can also develop into a storage organ and additionally act as a store of spare substances. Such a situation especially occurs in carrots, parsley, beetroots, radishes, celery, turnips, and horseradish, which are the focus of this publication. The ability to accumulate substances is a distinguishing feature of root vegetables. This is of critical importance with regard to the problem of contamination.

Storage roots have strong secondary growth. They are characterized by a small number of xylem elements and a large amount of storage parenchyma to which they owe their shape [2]. Storage roots are most often found in biennial plants. In the first year of growth, these plants produce vegetative organs and store nutrients in their roots. Only in the second year do they produce generative organs, using reserves from the root. The vegetables described here are biennial plants, with vegetables for consumption being harvested from the fields in the first year of the plant's development. The exception is horseradish, which is a perennial. However, production plantings are carried out as annuals, and only on rare occasions as biennials [2].

The described vegetables belong to different botanical families, i.e., *Apiaceae*, *Amaranthaceae*, and *Brassicaceae*. The anatomical structure of the storage root can be determined from the outside by a transparent cork, under which the phelloderm is located. In carrots, the phelloderm accumulates spare materials and carotene. Beneath the phelloderm, there is a ring of phloem composed of parenchyma and arranged sieve tubes. The middle part of the root is occupied by the xylem, separated from the phloem by the cambium [1].

An abnormal secondary structure of the root is found in beetroot. The growth of the beetroot in thickness is abnormal [1][2]. Unlike other root vegetables, beetroot has several cambial rings. Subsequent rings form outside the first. The second and subsequent cambial rings produce small bundles of phloem and secondary xylem, as well as large amounts of parenchyma filled with spare sugars [1].

The different taxonomic orders are not reflected in the way roots grow in thickness. Parsley and carrots belong to the same order and to the same family of *Apiaceae*, but different tissues form the main layers that accumulate reserve substances. In parsley, it is the secondary wood crumb, while in carrots, it is the secondary phloem parenchyma [3]. A large core is, therefore, an undesirable trait in carrots, as studies have shown that it is less nutrient-rich and accumulates more nitrates. As in parsley, the radish cambium produces a thin layer of phloem and a thick layer of secondary wood. The secondary wood contains few vessels and lacks fibers, while by volume, there is a large amount of crumb tissue [4].

# 2. Composition and Antioxidant Potential of Root Vegetables

## 2.1. Carrot

Carrots (*Daucus carota* L.) have been cultivated for more than 1,000 years and are one of the most popular vegetables worldwide. Currently, they are mainly grown in Europe and Asia [5]. In 2020, the greatest producers of carrots and turnips in Europe were the United Kingdom of Great Britain and Northern Ireland (799,715 tons), and Poland (689,100 tons). In Asia, Indonesia (675,760 tons) and Japan (601,016 tons) were ranked as major producers [5]. This vegetable has an average water content of 69.06%–75.3%, depending on the specific variety. The average amounts of protein, carbohydrates, and fiber are as follows: 8.59%, 7.09%, and 7.95% of dry matter, respectively. The fat content is even lower—1.97–4.31% of dry weight (d.w.)—depending on the variety [6][7].

*Daucus carota* is characterized by a high quantity of antioxidant compounds, such as carotenoids. This is a group of isoprenoids synthesized by all photosynthesizing organisms and those that do not carry out this process (selected bacteria and fungi) [8]. The amount of carotenoids in carrots, including lutein and lycopene and their mutual ratio, determines the color of the ripe vegetable. The greater their content, the more intense the color. The average content of this compound in carrots was determined to be within the range of 5.5–10 mg/100 g of fresh weight (f.w.) [9][10].

Polyphenols are other compounds showing biological activity in carrots. The main compound is hydroxycinnamic acid. It has a content of 3351.5 mg/kg f.w. and represents 93–99% of the total polyphenols [11]. Furthermore, antioxidant compounds, such as polyphenols, in purple Polignano carrots (*Daucus carota L. var. sativus*) were found to increase during storage in a refrigerator and due to factors such as light or temperature. However, the level of ascorbic acid decreases in such situations, but it does not have a negative effect on the overall antioxidant activity [12]

## 2.2. Celery

Celery (*Apium graveolens* L.) includes three botanical varieties. The most common is rapaceum, or common (root) celery, whose cultivation in Europe in 2019 reached more than 500 tons [13]. Among other root vegetables, celery is characterized by a high sodium content (100 mg/100 g) and relatively high content of carbohydrates (9.2 g/100 g). Moreover, it is a good source of potassium (K) (300 mg/100 g).

Celery is a plant with a high antioxidant potential, which is due to the presence of many compounds, such as phenols, including flavonols (apigenin, kaempferol, and luteolin) and phenolic acids (caffeic acid, ferulic acid, and p-coumaric acid) [14]. The most potent free-radical scavengers are compounds from the flavonol group, which were detected at a level of 4.19 mg/100 g d.w., including luteolin (0.81 mg/100 g d.w.) and apigenin (3.39 mg/100 g d.w.) [15]. The total antioxidant activity of ethanolic extracts of different varieties of this vegetable, measured by the DPPH (2,2-diphenyl,1-picryl-hydrazyl-hydrate) assay, ranged from 79.54 to 105.79 µM Trolox equivalent per 100 g d.w. (TE/100 g d.w.), and the average Trolox equivalent antioxidant capacity (TEAC) value amounted to 92.54 µM TE/100 g d.w. [16]. Pretreatment by washing or soaking shredded celery in water confirmed a reduction in the phenolic content of 30% compared with untreated samples [17].

## 2.3. Parsley

The most common consumer choice of parsley (*Petroselinum crispum* Mill.) is its leaves. However, there are countries, especially in south and east Europe, where the root of parsley is universally used in gastronomy. In Poland, parsley crops are measured in thousands of tons. The root of parsley is usually used to enrich the taste of meals or as a minor component of dishes, e.g., in chicken soup [18]. Among all root vegetables, parsley is characterized by a significant content of K (399 mg/100 g) and calcium (Ca) (43 mg/100 g). Moreover, it is also rich in folates (180 µg/100 g). The consumption of 100 g of parsley covers the daily need for folic acid by 30–40% [19].

Apigenin is one of the most renowned parsley components because of its health properties, especially its antioxidant potential [20]. The amount found in parsley leaf is 3.69 mmol apigenin-7-O-(2″-O-apiosyl)glucoside per 100 g of product [21]. Parsley is also characterized by its content of many phenolic acids, such as luteolin, p-coumaroyl, and isorhamnetin [22]. Due to the presence of these compounds, this vegetable exerts a strong antioxidant effect. The degradation of parsley's bioactive compounds, particularly from the flavonoid group, has been reported during frying or other technological processes with high temperatures. However, a reduction in the amount of cholesterol oxidation products (COPs) in fried omelets was noted when parsley was added [23][24]. Parsley leaves can serve as a nutraceutical to enrich other products in antioxidants. The addition of powdered leaves to wheat pasta resulted in a 67% increase in the phenolic content, 146% greater antiradical capacity, and 220% increased reducing power. The antioxidant potential of methanol parsley extracts examined by DPPH, FRAP (free-radical scavenging capacity), and ORAC (oxygen-radical absorbance capacity) amounted to 58.8%, 19.7 mg (TE/100 g d.w.), and 993.2 mg TE/100g d.w., respectively.

## 2.4. Beetroot

Beetroot (*Beta vulgaris* L.) is of great interest to consumers in the 21st century due to its pleiotropic health-promoting properties [25]. Among all root vegetables, beetroot is characterized by high quantities of carbohydrates (9.56 g/100 g) and fiber (2.8 g/100 g) [26]. Beetroot is commonly considered a source of iron (Fe), but among root vegetables, it is parsley that contains greater amounts of this microelement [9]. The most abundant element is K (356 mg/100 g in organic beetroots). Moreover, it has been reported that organic beetroots are characterized by higher contents of mineral compounds, such as K, phosphorus (P), Mg, and Ca, than conventional ones [26].

One of the characteristic features of beetroot is the presence of betalains, i.e., betacyanins (e.g., betanin, betanidin, and isobetanin) and betaxanthins (vulgaxanthin I and dopamine–betaxanthin) [27][28]. Higher concentrations of these substances were found in the peel than in the flesh of the beetroot [26]. Besides their antioxidant potential and anti-inflammatory activity, betalains determine the color of beetroot and can be used as a food pigment [29]. Beetroots contain other bioactive substances, i.e., gallic acid, caffeic acid, p-coumaric acid, and quercetin [30]. When comparing the contents of betalains, phenolic compounds, and antioxidant capacity in conventional and organically grown beetroots, higher concentrations were found in organic beetroots [30]. The presence of compounds from the flavonoid group, saponins and glycosides, was also noted in beetroot. However, the antioxidant properties of beetroot juices, particularly their iron-reducing ability, depend on the betalain content in the product [31]. Additionally, the antioxidant potential increases with higher selenium content [32]. The total phenolic content (TPC) of beetroot methanol extract was to be 313.8 mg gallic acid equivalent per 100 g d.w. (GAE/100 g d.w.). The total content of phenolic compounds, as well as antioxidant potential, can be further increased by storage at 4 °C for 10 days [33]. Another process that affects the content of bioactive substances is fermentation, as the amount of betalains in fermented beetroot is 61–88% lower than that in fresh samples [34].

## 2.5. Radish

Radish (*Raphanus sativus* L.*)*, like the other root vegetables described, has a high antioxidant potential and a significant content of biologically active compounds. The TPC was determined to be 68 mg GAE/100 g f.w. [35]. Flavonoids are the most abundant substances of all antioxidant compounds (38.8%), followed by non-flavonoid polyphenols (8.4%), terpenes and derivatives (8.2%), glucosinolates (GLS) and their breakdown products (5.6%), and hydrocarbons (4.6%) [36]. Glucosinolates are decomposed by myrosinase in Brassicaceae vegetables. This enzyme is activated during plant tissue damage, for example, during cooking or cutting [37]. Isothiocyanates and thiocyanates are breakdown products of GLS with glucoraphasatin, which is found in the highest concentration (163.1 mg/100 g d.w.). Sulforaphane is the main product of GLS breakdown (5.26 mg/100 g d.w.) [36]. The bioavailability of these compounds ranges between 12 and 80% of all GLS present after the consumption of a fresh sample. The large variation between these two values mostly depends on the amount of myrosinase present in the ingested plant and structural properties of each GLS [37].

Flavonoids are the major pigment molecules responsible for the color of radish. Pelargonidin-based anthocyanins (callistephin and pelargonin) are mainly found in red radishes, and acylated cyanidin has been identified in purple ones. Moreover, cyanidin o-syringic acid is abundant only in purple radishes [38].

## 2.6. Turnip

Turnip *(Brassica rapa* L.*) is* characterized by a multitude of varieties. The roots can range in color from white to green and to an intense purple. This depends on the concentration of anthocyanins, which are responsible for the intensity of the color [39]. The most common anthocyanins are pelargonidin and cyanidin. In their absence, the root is white [40]. As among all *Brassica* vegetables, turnips are characterized by the presence of GLS. The average quantity of GLS in turnips amounted to 2.74 mmol/100 g d.w. [68]. However, sinigrin is not present in these roots [41].

Like other root vegetables, turnips are also rich in compounds that increase the plant’s antioxidant potential, such as phenols and flavonoids. The TPC was determined to be 241.27 mg GAE/g, while the total flavonoid content (TFC) was estimated to be 4.45 mg quercetin equivalent per gram (QE/g). Compounds such as catechin (42 µg GAE/g), ferulic acid (265 µg GAE/g), and p-hydroxybenzoic acid (151.25 µg GAE/g) were measured with the highest amounts. Simultaneously, protocatechuic acid (5.60 µg/g d.w.), biochanin A (12.77 µg/g d.w.), and m-coumaric acid (17.95 µg/g d.w.) were measured with the lowest amounts. The oxidative activity of turnips, measured using the DPPH method, was estimated to be 47.5%.

### 2.7. Horseradish

Horseradish (*Armoracia rusticana* G. Gaertn. et al.) is distinguished by the highest energy value among all root vegetables described (81 kcal/100 g). This is due to its low content of water (75%). The contents of protein (4.5 g/100 g) and carbohydrates (18.1 g/100 g) are also responsible for its high caloric value.

*Armoracia rusticana*, like other root vegetables of the *Brassicaceae* family, is characterized by a high content of GLS. Their amount in horseradish was determined to be in the range of 0.2–2.9 mmol/100 g d.w. Synigrin was the most abundant compound, accounting for as much as 83% of all GLS [42]. Isothiocyanates formed from the breakdown of GLS are responsible for most of the properties of *Armoracia rusticana*, including its taste and smell. Allyl isothiocyanate is the main compound causing the pungent taste and lacrimation [43]. These are volatile substances; therefore, the storage of horseradish, even in a cool room (5 °C), causes a reduction in their levels, even up to 50% [43][44]. Due to the presence of these compounds, horseradish exhibits strong antioxidant properties. The antioxidant potential measured by the DPPH method for the aqueous extract was 48%, while the EC50 value (reducing power) was determined to be 8.6 mg/mL [44].

## 3. Influence of Root Vegetables on Health

### 3.1. Carrot

Carrots may exhibit prebiotic potential [45]. It was found that, during the digestion of carrot powder in vitro, polyphenols had low recovery up to the large intestine. However, in the colon, fermentation of polyphenols was observed, including conjugated ones. The polyphenols that were released demonstrated antioxidant activity, as well as the ability to inhibit α-galactosidase. At the same time, the composition and diversity of the gut microbiota were regulated by the fermented carrot powder. Such a relationship demonstrated the importance of carrot polyphenols for the colonic microbiota and, thus, for gastrointestinal health.

Carrots are one of the vegetables rich in carotenoids. The effect of consuming a mix of vegetables and fruits rich in these compounds on their content in the body was studied. It was found that the level of carotenoids increased, but there was no effect on internal lipid oxidation, cholesterol, or triacylglycerols [46]. A strong antioxidant effect of carotenoids was achieved in people by the supplementation of these components [47]. Carrot intake might be inversely associated with cancer, especially prostate, bladder, and breast cancer [48][49][50].

### 3.2. Celery

Celery affects health mainly in terms of metabolic parameters. Its extracts can exhibit hypotensive effects, as shown both in vitro and in vivo in spontaneously hypertensive rats. In addition, celery extract is able to relax the aortic smooth muscle by blocking the entry of calcium (Ca) ions into calcium channels [51].

A substance extracted from celery, 3-n-butylphthalide (NBP), exhibits potent antioxidant activity. It reduced interleukin 6 (IL-6) and tumor necrosis factor-α (TNF-α), and played an important role in oxidative stress in a rat model of chronic renal failure [52]. 3-n-butylphthalide additionally exhibited diuretic and vasodilatory effects, thus lowering blood pressure [53]. In an animal model of fructose-induced hypertension, celery leaf extract may not have only reduced blood pressure, but also improved cardiovascular parameters and the lipid profile [54].

Celery may reduce the risk of hyperglycemia. Elevated rates of inflammation have been shown to predispose the development of diabetes, and the antioxidant effects of celery compounds may counteract this [55][56]. Additionally, luteolin in celery has been shown in vitro to enhance insulin action through the increased expression of peroxisome proliferator-activated receptor γ (PPARγ) and decreased TNF-α mRNA levels [57].

### 3.3. Parsley

Unfortunately, there is a lack of research examining the relationship between parsley root and health. Studies have focused on parsley leaves and concerned cell lines or animals. Therefore, future research should focus on roots and compare their effects with those exerted by leaves, described below.

Parsley leaves exhibit anti-fatigue effects. There were noted improvements in serum fatigue indices among swimming mice that were administered ethanol extracts from this plant. In addition, the same study described the effect of fatigue and the administered extracts on the mice’s microbiota. Among the control group, there was a reduction in the *Firmicutes* to *Bacteroidetes* (F/B) ratio and a decrease in the Shannon index, indicating reduced microbial diversity. Despite fatigue, there were no negative changes in the microbiota in the group of mice receiving compounds isolated from parsley. In addition, *Bifidobacterium* and *Lactobacillus* were detected in higher abundance in the group not subjected to fatigue [58]. Parsley leaves have also exhibited antimicrobial properties in vitro. It was reported that aqueous–methanol extracts of parsley leaves had strong antimicrobial activity. This type of functionality has been noted for microorganisms such as *Listeria monocytogenes, Bacillus cereus*, and *Escherichia coli* [59].

Parsley is also known for its diuretic effect. The consumption of this vegetable may be useful in prevention and intervention for people with kidney stones [60]. Moreover, the intake of 20 g parsley/10 KJ total energy/day decreases apigenin excretion and increases the activity of certain antioxidant enzymes, such as superoxide dismutase (SOD) [61].

### 3.4. Beetroot

Due to the presence of nitrates, beetroot and supplements made from this vegetable are recognized for their support in improving the respiratory and cardiovascular systems [26][62]. However, the consumption of beetroot has better health properties than supplementation with nitrates [26]. Beetroot juice may support the treatment of asthma and psychological stress by protecting against respiratory infections [63]. It was found that beetroot juice rich in nitrates did not significantly improve the systolic and diastolic blood pressure, heart rate, or the six-minute walk test [64]. However, this preparation increased the score of the Borg Rating of Perceived Exertion (RPE) scale, reflecting higher levels of exercise and physical activity among a group of patients with chronic obstructive pulmonary disease [65].

### 3.5. Radish

The most popular health-promoting use of radish is its impact on glucose levels in diabetic patients. Radish sprouts, due to the presence of isothiocyanates, can reduce the activity of α-amylase and α-glucosidase. As a result, a reduction in glucose absorption and lower blood glucose levels in *Drosophila melanogaster* were noted [66]. Similar changes were observed in rats fed with radish sprouts at 0, 2.5, and 5% of the total diet. Animals in the test group not only had lower blood glucose levels, but also lower insulin and total cholesterol levels [67].

### 3.6. Turnip

The consumption of turnips can have cardiorespiratory benefits. Their consumption in a powdered form by healthy individuals for seven days affects hypoxia tolerance. Interestingly, improvements were noted only among women, but not men [68]. It would be interesting to research this aspect with a larger group of study subjects.

Another function of turnips and their components is their cytotoxicity against cancer cells. This is related to the presence of GLS. The IC50 values for the tested varieties are directly proportional to the content of these compounds in the plant [69].

### 3.7. Horseradish

Horseradish has been used since ancient times for its flavorful qualities. In addition, its health-promoting properties were noticed thousands of years ago, and it has been used as a medicinal plant [70]. Its components, GLS and thiocyanates, show pleiotropic effects on health, the most important of which is the antioxidant activity and anticancer function [71]. This was investigated in rats in the context of bladder cancer [37][71]. Allyl isothiocyanate (AITC), found abundantly in horseradish, has a stimulating effect on the activity of phase II detoxification enzymes, such as quinone reductase (QR) and glutathione S-transferase (GST). High doses of AITC (100–200 µg/kg b.w./day) were found to increase QR and GST activity in many organs, while at low doses (5–50 µg/kg b.w./day), the change was observed only in bladder tissues [71].

## 4. Contaminants

The biological value of root vegetables consumed may be lower due to the content of contaminants, i.e., substances that can be harmful to human health. The accumulation of particular contaminants in root vegetables depends on many factors, such as the pH, ionic strength, soil texture and quality, organic matter content, and time [72]. Heavy metals, nitrates and nitrites, organic compounds, pesticide residues, and mycotoxins may be present in these vegetables [73]. Root vegetables constitute a group particularly vulnerable to the presence of contaminants, as soil can be polluted through sewage sludge or fertilizers [72]. A common soil contaminant is also microplastics, which can migrate inside plants [74].

Among the most dangerous contaminants to human health are organic pollutants, such as pharmaceutical residues or polychlorinated biphenyls (PCBs), and other industrial and urban waste materials, such as coal ash, etc., which enter the soil with sewage [75]. Toxic metals, such as lead (Pb) and mercury (Hg), take the same pathway as PCBs to enter soils [72].

### 4.1. Nitrate and Nitrite

The contents of nitrates and nitrites depend on the soil properties, light conditions, moisture content, growing season, planting density, geographic region, fertilization, harvest date, species, or variety of vegetable [76][77]. These compounds are characteristic of root vegetables, especially beetroot. The adequate daily intake (ADI) of nitrates has been set at 3.7 mg/kg body weight/day, whereas, for nitrites, it has been established at 0.06 mg/kg body weight/day [78]. Nitrates and nitrites are useful as food additives. The maximum permitted level (MPL) of these substances was set at a range of 10–500 mg/kg for a product [79]. What is important is that it has been shown that the consumption of beetroot, unlike supplements, does not pose a risk of exceeding the ADI established for these compounds [26].

The concentration of nitrates also varies in different parts of the plant [80]. Carrots, especially early varieties, tend to accumulate these compounds. Most nitrates are stored in the head and apex of the root, more in the axial cylinder than in the primary cortex. The content of both compounds is higher in the superficial layers of some root vegetables, e.g., beetroot, than in the central parts. Such a relationship does not exist in carrots, in which higher amounts of nitrates and nitrites are found in the core of the root [81]. Moreover, during the cooking process, the level of nitrates decreases significantly [82].

### 4.2. Heavy Metals

The contamination of vegetables is mainly determined by the pollution of the environment. Soil along the Msimbazi River valley in the city of Dar es Salaam (Tanzania) was examined and the levels of chromium (Cr)(VI), Pb, copper (Cu), and cadmium (Cd) were determined. The highest concentrations were found for Cr (1.14 mg/L) and Pb (1.113 mg/L). The concentration of Pb was higher than the limits for rivers set at 0.01mg/L by the Food and Agricultural Organization and the World Health Organization (FAO/WHO). The study showed that the metal content was higher in the surface layers of the soil [83].

In addition, soil quality depends on many factors, with the most important being the location and irrigation method. Selected vegetables harvested from different geographic areas were examined. The same plants grown in different soils were characterized by various Cd levels. Its level in turnips grown in soil irrigated with wastewater was 0.78 mg/kg, while that in turnips grown near the Dabaoshan mine in Guangdong, China, amounted to 2.9 mg/kg, and that in turnips grown near the same mine, but in Zhongxin City, was 0.28 mg/kg [84].

The toxicity of these metals includes the production of reactive oxygen species, reduction in antioxidant defenses, inactivation of enzymes, and increased oxidative stress [85]. Moreover, together with higher urbanization, vegetables are more exposed to heavy metals due to environmental pollution. Therefore, there is a need for the constant evaluation of vegetable contamination and human risk assessment.

### 4.3. Pesticides

Residues of plant-protection products can be found in vegetables, including root vegetables. Their content in vegetables should not exceed the maximum residue levels (MRLs). However, incidental cases of MRLs being exceeded in root vegetables were found in random crops [86][87]. However, the application of pesticides, as recommended in field tests, resulted in no exceedance of the MRLs [86]. Root vegetables appear to be safe in terms of pesticide residues.

### 4.4. Polycyclic Aromatic Hydrocarbons

PAHs constitute another example of organic compounds that contaminate root vegetables. The most dangerous PAHs include benzopyrene (BaP), which, like other PAHs, can be absorbed by plant roots [88]. The compounds' accumulation is not the same for all root vegetables. Ashraf and Salam (2012) found a lower total PAH content in turnips (9.26 µg/kg f.w.) compared with carrots (11 µg/kg f.w.). Moreover, the scientists noted that more PAHs were accumulated in the peel than the core [89].

### 4.5. Microplastics

Plastic particles can enter terrestrial ecosystems and accumulate in the soil [90]. They affect the enzymatic activity of the soil and the microorganisms present within it [91]. Plastic pollution of cultivated soils is mainly related to agricultural activities, such as the use of plastic tunnels, compost fertilization, and the use of sewage sludge [92][93]. The MP contents in soils from different regions of the world, such as Spain, Brazil, and China, were analyzed and found to be 2000 [93], 10,782 [94], and 52,081.7 particles/kg [95]. It has been found that polyethylene (PE) and polypropylene (PP) particles are the most commonly found MPs in soil [94][96]. These contaminants are usually in the form of fibers and fragments [90][96][97]. Microplastics can migrate from the soil into plants. They are capable of penetrating seeds, roots, stems, leaves, and fruits, depending on the type and size of the particles, and the plant species [97][98]. The uptake of plastic particles is inversely proportional to their size [99].

Microplastics can be a contaminant of edible vegetables, including the common carrot *Daucus carota*. Plastic particles, ranging in size from 1.36 to 2.00 µm, have been found in this vegetable in amounts of 72,175 to 130,500 particles/g [100][101]. The MP particles are absorbed into the carrot root from the environment. The area of absorption is increased by microscopic hairs located on the outer side of the epidermis of the central root of *Daucus carota* [100]. Polystyrene (PS) particles of 1 µm can accumulate in the intercellular layer after entering the carrot root, but are unable to penetrate cells. However, particles of 0.2 µm can migrate into the leaves. They destroy the tertiary structure of pectin methylesterase in carrots, which is involved in the synthesis of cell wall components, contributing to the loss of the vegetable's crunchiness. Microplastics reduce the nutritional value of *Daucus carota* and pose potential risks to human health [102][103].

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