**Chapter**

# Root Vegetables Having Medicinal Properties: Their Possible Use in Pharmaceutical and Food Industries

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## Abstract

Root, bulb, or tuber vegetables, which are borne underground, are reported to be dense in essential nutrients and come with several health benefits. Most of these root vegetables are the cultivated ones, but few are still underexploited. The root vegetables are consumed either wholly or partially and raw or after processing. They are high in fiber but low in fat and cholesterol. There are wide varieties of bioactive phytochemicals present in them that may contribute to their medicinal and nutraceutical properties. Although some research work has been conducted to uncover the pharmacological effects of root vegetables, their unlimited potential has yet to be fully exploited. The pharmaceutical industry can develop various health-promoting herbal formulations with medicinal properties. The food industry can employ novel processing technologies to preserve nutrition and prevent degradation of the phytochemicals during processing or for value addition of food products. The information presented in this chapter would be helpful for researchers, nutritional and medical professionals, pharmaceutical companies, and the food industry to design and develop effective medicines, drugs, and value-added food products by exploiting the specific as well as multiple modes of action of the various root vegetables.


**Keywords:** antioxidant, antimicrobial, bio-preservative, curing, food products, medicinal, nutrients, phytochemicals, root vegetables, value addition

## 1. Introduction

An increasing number of root vegetables have received attention due to the presence of bioactive compounds in them. Among them, root crops are important crops with swollen underground edible parts that are rich in carbohydrates, dietary fibers, protein, vitamins, fats, and minerals. The storage roots are enriched with specific bioactive substances that can control one or more metabolic pathways, hence promoting improved health conditions. Numerous bioactive elements found in root vegetables, including glucosinolates, isothiocyanates, phenolic compounds, flavonoids, organic acids, etc., have been discovered to contribute to a variety of health-beneficial effects, reduced risk of non-communicable diseases, and delayed onset of age-related disorders [1].

The importance of vegetables in our diet is well known. The root vegetables, unlike leaf or fruit vegetables, have a comparatively higher shelf life. They can be stored for a relatively longer time and have a wider consumption pattern. The nutritional value of different root vegetables varies with species, cultivar, cultivation method, maturity stage, and storage and processing conditions. The optimum utilization of the nutrients from root vegetables is, however, dependent on the method of consumption. The root vegetables may be consumed raw in the form of salad or after being cooked alone or in combination with other vegetables. Depending upon their nature and pattern of consumption, they can be freshly preserved, minimally processed, canned, frozen, or dried. The root vegetables are also processed into various novel value-added and shelf-stable food products. The by-products obtained from them or their unutilized peel and pomace can be used by both pharmaceutical and food industries. This chapter will highlight the beneficial medicinal and nutritional properties of some of the widely cultivated and underutilized root vegetable crops. To widen the scope of discussion, the vegetables having the edible part borne underground have been considered as root vegetables, though morphologically, they may not be representing root.

## 2. Different root crops and their health benefits

Different root vegetables are known for their distinctive nutritional and phytochemical constituents. The various phytochemicals present in them have different health benefits and great prospects in nutraceuticals and pharmaceutical industries. The various nutritional and bioactive compounds present along with the associated medicinal uses of different root crops are discussed below in alphabetical order.

### 2.1 Beetroot

Beetroot (*Beta vulgaris*), which belongs to the family Amaranthaceae, is also known as red beet, garden beet, table beet, or beet. Due to the high concentration of physiologically active ingredients including betalain, inorganic nitrates, polyphenols, vitamins, and folates as well as minerals (Na, K, Ca, and Mg) present in its tuberous root, it is consumed as a vegetable all over the world [2]. Its leaves are also edible. The plant also contains carbohydrates, proteins, fatty acids, vitamins, and fibers. The taproots have high sucrose content (15 to 20% of fresh weight), which makes them suitable for the industrial production of sugar [3, 4]. The roots contain phenolic acids (such as caffeic acid, ellagic acid, syringic acid, vanillic acid, and ferulic acid) and flavonoids (such as rutin, myricetin, kampferol, and quercetin) [2]. Beetroot also contains both water- and fat-soluble vitamins. In decreasing order of concentration, the vitamins are: vitamin B2 > > vitamin C > > vitamin B3 > vitamin E > vitamin B5 > vitamin B1 > vitamin B6 > vitamin K [4].

It has been reported by others [4, 5] that *B. vulgaris* has an abundance of a nitrogenous pigment betalain, which is water soluble. Betalain is a member group of secondary phytochemical and phenolic acids. Two major categories of betalains exist in the plant. The first is betacyanin, which is a red pigment, and the second is known as betaxanthin, which is a yellow pigment. The predominant betalains present in the beetroot are betaxanthin, isobetanin, and betanin (betacyanins). Betacyanins, mostly betanin and its isomers, are the major coloring pigments in red beetroot, whereas Vulgaxanthin I is responsible for the yellow pigments in beetroot.

Beetroot is used as a vegetable, and its juice and extracts are commonly used for medicinal and food purposes. However, the oxalic acid constitution of beetroot is relatively abundant (94.6–141.6 mg/100g and 300–525 mg/L). Oxalic acid encourages the development of nephroliths, and hence, beetroot is thought to be unhealthy, especially for people who are prone to kidney diseases [2].

The therapeutic properties of beetroot include antioxidant, antidepressant, antimicrobial, antifungal, anti-inflammatory, diuretic, aphrodisiac, expectorant, and carminative properties as well as anticarcinogenic and cardiovascular health protection [4]. Beetroot juice supplementation has been reported to be a cost-effective strategy in controlling diabetes and insulin hemostasis, blood pressure and vascular function, renal health, and the possible effect on microbiome abundance [6]. Betanin present in the root extract has been found to possess antioxidant activity that is 10 times higher than in tocopherol and three times higher than in catechin [2]. Chen et al. [7] reported that betalains minimize oxidative and nitrative stress by scavenging DPPH, preventing DNA deterioration, and lowering LDL. Nitrate in beetroots lowers blood lipids, glucose, and hypertension in various chronic conditions, enhances athletic performance, and reduces muscle soreness.

### 2.2 Black salsify

Black salsify (*Scorzonera hispanica* L.) is commonly known as Spanish salsify, black oyster plant, serpent root, viper's grass, or simply scorzonera. It belongs to the family Asteraceae. Lendzion *et al.* [8] reported that the scorzonera genus is the source of a wide range of bioactive chemicals that have the properties of wound healing, anti-inflammatory, pain-relieving, antioxidant, and cytotoxic agents against cancer cell lines. The primary benefits of inulin found in the roots of black salsify are its prebiotics and probiotic properties, regulation of lipid metabolism and diabetes, and immunomodulatory qualities. Numerous bioactive substances, such as triterpenoids, sesquiterpenoids, flavonoids, or derivatives of caffeic and quinic acids, have been found in extracts taken from the plant's aerial and subaerial portions. The anti-inflammatory, analgesic, and hepatoprotective effects of black salsify have also been identified, in addition to its antioxidant and cytotoxic capabilities [8].

Scorzonera species have activity against several bacteria and fungi strains. Their effectiveness in wound-healing therapy, treatment of microbial infections, viral infection-induced fever, and poisonous ulcers and as a lactation-inducing and diuretic agent has also been reported [8, 9]. Roots of *S. hispanica* L. have been used as mucolytic agents in pulmonary diseases; appetite stimulation; defeating a cold, and treating carbuncle, inflammation, and fever [10].

### 2.3 Carrot

Carrot (*Daucus carota* L.) is the most important crop of the *Apiaceae* family. Carrot root flesh can have a white, yellow, orange, red, purple, or a very dark purple hue. The majority of varieties of carrot has yellow and orange flesh. The color of the flesh is because of carotenoids. The common yellow carrot is a good source of pro-vitamin A and β- and α- carotene. The yellow color in carrots is due to the presence of lutein. The red color in red carrot is because of a high lycopene content, and the purple color in carrot is due to the presence of a higher concentration of anthocyanins. Meanwhile, carrots with a white flesh have relatively lesser pigments.

Besides being a rich source of vitamins (A, B, and C) and β-carotene, carrot also contains significant amounts of pantothenic acid, folic acid, and vitamins E and H. The pro-healthy nature of carrot is due to the presence of significant amounts of trace elements (K, Na, Ca, Mg, P, S, Mn, Fe, Cu, and Zn) along with vitamins and antioxidants, particularly carotene and phenolic compounds [11].

Carrots contain bioactive polyacetylenes including falcarindiol, falcarindiol-3-acetate, and falcarinol (a synonym for panaxynol) [12, 13]. The antioxidant, anti-carcinogenic, and immunity-boosting properties of carrots are due to the presence of carotenoids, polyphenols, and vitamins. In addition to these properties, carrots help in reducing the cholesterol level, prevent cardiovascular disease, and cure hypersensitivity and diabetes. Carrots also show anti-hypertensive, hepatoprotective, renoprotective, and wound-healing benefits. The carrot taproot and seed extracts are reported to have antibacterial, antifungal, anti-inflammatory, and analgesic properties [14, 15].

### 2.4 Cassava

Cassava, also known as manioc or yucca, belongs to the family Euphorbiaceae and is known for its nutty-flavored, starchy root vegetable or tuber. The varieties *Manihot esculenta* or *Manihot utilissima* (bitter cassava) are popular for their medicinal properties, and *Manihot dulcis* or *Manihot palmata* (sweet cassava) are cultivated for their tuberous roots, which yield important food products. Cassava root has moisture (5.85–7.30%), ashes (0.8–2.4%), proteins (0.25–1.25%), fat (2.01–3.70%), and fiber (0.98–2.31%). Cassava is also rich in calcium and manganese. The common anti-nutritional factors found in plants are cyanide, phytates, nitrates and nitrites, phenolic compounds, and oxalates [16, 17].

It contains carotenes, vitamin C, vitamin A, anthocyanins (flavonoids), saponins, steroids, and glycosides. Additionally, 10 antioxidant substances have been isolated and identified, including coniferaldehyde, isovanillin, 6-deoxyjacareubin, scopoletin, syringaldehyde, pinoresinol, p-coumaric acid, ficusol, balanophonin, and ethamivan [18]. Cassava has been used as a treatment for a variety of illnesses, including diabetes; celiac disease; bone and neurological health; cardiovascular disease; allergies; and issues with the prostate, gastro-intestinal tract, and blood pressure. It has high amounts of fibers and thereby eliminates constipation, bloating, and intestinal pain. However, if cassava is not prepared, processed, or cooked properly, it can be poisonous due to the presence of cyanide and other toxicants [16].

### 2.5 Garlic

Garlic (*Allium sativum* L.) belongs to the family *Amaryllidaceous*, and its bulb with cloves is mostly used for food, spice, and medicinal purposes. The composition of fresh, raw garlic bulbs includes 66% water, 27% carbohydrates, 2.5% protein, 1.3% amino acids, 1.6% fiber, fatty acids, phenols, trace minerals, and 2.4% sulfur-containing compounds [19].

Garlic contains various widely recognized types of phytochemicals. These bioactive compounds have the potential to treat a wide range of diseases and are essential for maintaining human health. Garlic has a unique nutritional profile with particular emphasis on its many bioactive components, which may be employed in various diet-based treatments of various ailments that are tied to a certain lifestyle. Polyphenols, amino acids, benzenoids, sulfur-containing substances, fatty acyls, glycerophospholipids, heteroaromatic substances, indoles, phenol lipids, pyrrolizines, quinolines, steroid derivatives, tetrahydrofurans, and other substances make up the majority of the phytochemicals. As shown in **Figure 1**, garlic consists of active compounds such as alliin, allicin, methiin, S-allylcysteine, diallyl sulfide, S-allymercapto cysteine, diallyl disulfide, diallyl trisulfide, and methyl allyl disulfide [19, 20]. The sulfur-containing compounds allicin, diallyl sulfide, diallyl disulfide, diallyl trisulfide, alliin, S-allylcysteine, and S-allylmercaptocysteine present in garlic are reported to cure cancer [21]. The beneficial effects of the consumption of garlic on health and the treatment of cancer have also been attributed to the seleno-compounds (Se-compounds) present in garlic [22].

Allicin is not produced *de novo* in fresh garlic; rather, an unstable compound known as alliin (S -3- (2-propenylsulfinyl)-l-alanine-) and a proteinous enzyme alliinase are *in situ*. On injury of the plant, alliinase converts alliin to allicin, which gives garlic its characteristic aroma. Allicin is also unstable and gets easily decomposed on heating to allyl and methyl sulfide derivatives (diallyl mono-, di-, and trisulfide). The allyl sulfur-based compounds, which are the product of the stream decomposition of allicin, are the major components of garlic oil [23]. Alliin, allicin, methiin, S-allylcysteine, diallyl sulfide, S-allymercapto cysteine, diallyl disulfide, diallyl trisulfide, and methyl allyl disulfide are the major bioactive compounds responsible for the oral health benefits of garlic bulbs [20]. In certain cases, allergies are caused by allyl methyl sulfide [19].

There are various commercially available garlic-based products in the market with certain health benefits. These products are divided into four main groups, that is, aged garlic extract, dried garlic powder, garlic oil, and garlic oil macerate. Garlic exhibits a range of anti-inflammatory, antibacterial, antifungal, immunomodulatory, hepatoprotective, digestive system protective, anti-cancer, anti-diabetic, anti-obesity, neuroprotective, renal protective, anti-Alzheimer, and antioxidant properties [23, 24]. The antioxidant and antibacterial effects of stored garlic are higher as compared to

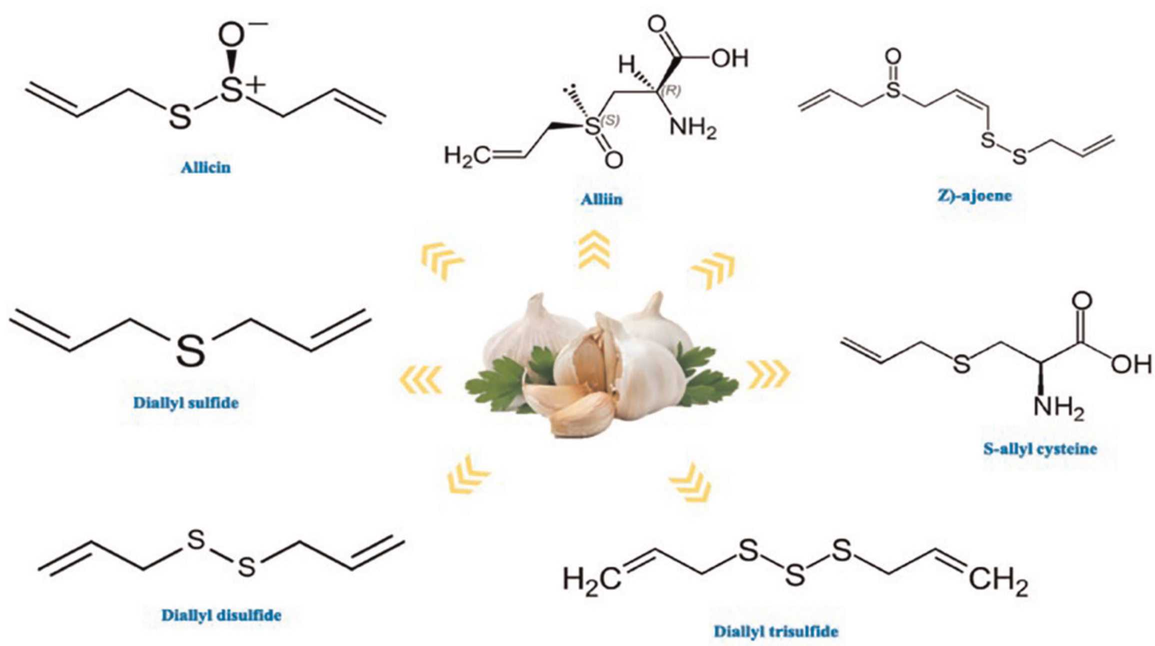


**Figure 1.**
*Structure of the important bioactive constituents present in garlic [20].*

those of freshly harvested garlic. Aged garlic shows more potent antioxidant and antibacterial effects than fresh garlic [25]. For use as a diuretic, diaphoretic, expectorant, and stimulant, garlic is prepared and offered in a variety of ways, including extract, decoct, infusion, tincture, and syrup. Easy-to-use allicin-based products such as chewing gum, garlic gel, mouth fresheners, and various confectionary products have also been developed [20].

### 2.6 Ginger

Ginger (*Zingiber offcinale* Roscoe) belongs to the Zingiberaceae family. The rhizomes of ginger are widely used for culinary and medicinal purposes. Fresh ginger rhizomes are mostly composed of water (80.7%), minerals (1.2%), protein (2.3%), fiber (2.4%), and fat (1.0%). Ginger contains the minerals calcium, magnesium, iron, phosphorus, sodium, and potassium [26]. Shoaib *et al.* [27] reviewed and reported that ginger contains 1–3% volatile oils, and these substances are also responsible for its flavor and scent. Dry ginger has a different scent and flavor from fresh ginger because the volatile aromatic components of ginger are lost during drying or heat processing. The three primary compounds in ginger's volatile oil are zingiberene, curcumene, and farnesene. A total of 40 distinct molecules are also found, with 1,8-cineole, linalool, borneol, neral, and geraniol being the most prevalent. The main ingredients in non-volatile oil include zingerone, paradols, shogaols, and gingerols, which give off a fiery taste or hot sensation in the tongue. Abdullahi *et al.* [28] reported that the volatile phytochemicals of domestic ginger are α-zingiberene (18.56%), geranial (13.88%), neral (10.75%), trans-caryophyllene (9.64%), eucalyptol (5.05%), β-phellandrene (5.51%), camphene (5.34%), α-pinene (2.05%), and heptan-2-ol (1.05%).

The primary polyphenols in fresh ginger are gingerols, including 6, 8, and 10-gingerol, which are the bioactive ingredients in ginger that exhibit a variety of health advantages. Gingerols can be changed into corresponding shogaols by heat treatment or extended storage. On hydrogenation, the shogaols can be converted into paradols. The other phenolic components found in ginger are quercetin, zingerone, gingerenone-A, and 6-dehydrogingerdione. In addition to these, ginger contains a number of terpene elements, including bisabolene, curcumene, zingiberene, farnesene, and sesquiphellandrene, which are thought to be the primary components of ginger essential oils. In addition to these, ginger also contains polysaccharides, lipids, organic acids, and raw fibers [29]. Along with hepatoprotective and antiallergic effects, antioxidant, anti-inflammatory, antibacterial, anticancer, neuroprotective, cardiovascular protective, respiratory protective, anti-obesity, antidiabetic, anti-nausea, and antiemetic are just a few of the biological effects of ginger.

The essential oils (EOs) of ginger have been reported to possess antimicrobial properties. Abdullahi *et al.* [28] reported that even at a lower concentration (1 ml/ml), EOs exhibited considerable inhibition of fungal pathogens. *Fusarium oxysporum* exhibited the highest inhibition, and the lowest was *Ganoderma boninense*. The order of the sensitivity (descending order) was *Fusarium oxysporum* > *Colletotrichum falcatum* > *Pyricularia oryzae* > *Rigidoporus microporus* > *Ganoderma boninense*. Similarly, ginger EOs showed significant antibacterial activity at a concentration range of 100 to 500 ml/ml. It was the most effective against *Xanthomonas oryzae* pv, oryzae strain A, *X. oryzae* pv. oryzae strain B, *Ralstonia solanacearum*, and *Klebsiella sp*. and least effective against *Bacillus* sp. Thus, ginger EOs are among the natural products that can serve as an alternative to natural antimicrobials because of their broad metabolite spectrum, which might open the door for new and more powerful compounds for controlling plant diseases. The nano-emulsion ginger essential oils have also been incorporated into gelatin-based films to produce activated films with improved physical properties and with antimicrobial and antioxidant activities [30].

## 2.7 Jerusalem artichoke

The Jerusalem artichoke (*Helianthus tuberosus*), also called sunchoke, belongs to the Asteraceae family. It is known for its carbohydrate-rich tubers, which can vary significantly in their size, shape, and color. The dried Jerusalem artichoke tubers contain crude protein (8.26%), crude fiber (5.92%), ash (6.82%), and inulin (73.50%) [31, 32].

Jerusalem artichoke tubers are used to obtain inulin, which is a chain of 1,2-D-fructose with a glucose terminal. When ingested or used in food products, inulin has a number of positive health effects. Inulin is not digestible by the human digestive system due to its distinct structure of fructose and glucose molecules. When it enters the large intestine and is fermented by microbes, its advantages become apparent. Prebiotic and probiotic benefits are stimulated by this process, which boosts the development of helpful bacteria and supports better digestive health. In addition, inulin may replace sugar or fat in diet and even makes it easier for the body to absorb minerals in the large intestine. Dietary inulins are hard to digest for humans, and hence, they serve as an ideal bulking agent, increase stool frequency, and show hypolipidemic functions [31].

A number of bioactive compounds have been isolated from the aerial parts of Jerusalem artichoke, demonstrating antifungal, antioxidant, anticancer activities, and other medicinal properties [32]. The various food, pharmaceutical, and chemical industries' applications of Jerusalem artichoke are presented in **Figure 2**.

## 2.8 Onion

Onion (*Allium cepa L.*), also known as bulb onion, belongs to the family of Amaryllidaceae. Based on color, there are 3 different types of onions: red, yellow, and white. Each has a unique flavor and level of pungency, ranging from moderate to extremely strong. Its underground bulbs are widely used for food and pharmaceutical purposes; however, young green leaf tops are also used for culinary purposes. Sami *et al.* [33] reported that onion bulbs were rich in proteins (9.22–13.21 g/100 g FW), with low fiber (1.7 g/100 g FW) and sugar (4.2 g/100 g FW) contents. Red and yellow

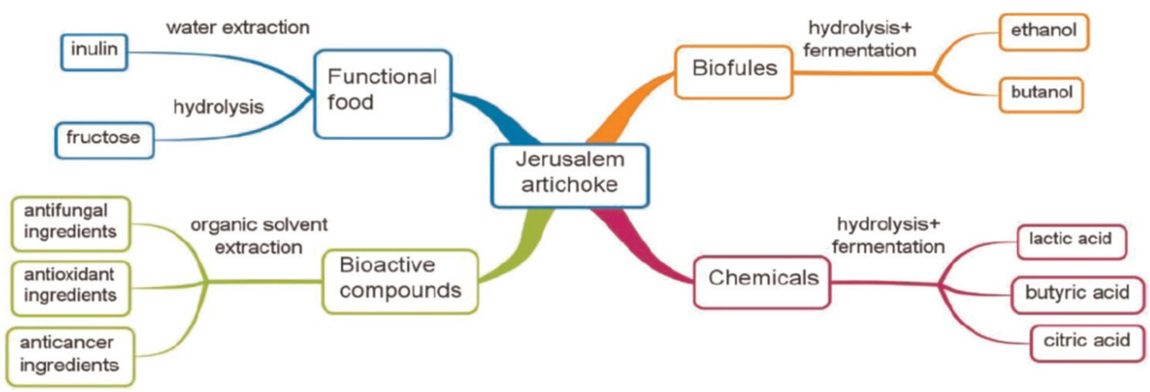


**Figure 2.**
*Food and non-food applications of Jerusalem artichoke [31].*

varieties showed high vitamin C (45.07 mg/100 g FW) and carotenoid (1.44 μg/mL FW) contents, respectively. The major amino acid was arginine, followed by glutamic and aspartic acids. The major elements present were calcium, iron, and sulfur.

Onions provide not only flavor but also health-promoting phytochemicals. The amounts of phytonutrients have been reported to be more in brown as compared to white and red onions. The four different diallyl sulfides, viz., diallylmonosulfide, diallyldisulfide, diallyltrisulfide, and diallyltetrasulfide, are the major organosulfur compounds that are present in onions [34]. Flavonoids, a subgroup of the polyphenol family, are abundant in onions. A major and important dietary flavonoid found in onions, quercetin, is a member of the flavonol subclass of flavonoids. In addition to quercetin, onions have also been shown to contain additional flavonols such as kaempferol and isorhamnetin [35]. The organo-sulfur compounds are attributed to the antibacterial, antiallergenic, anti-inflammatory, and antithrombotic properties of onion. In addition to having important biological functions for maintaining health, flavonols found in onions, such as quercetin and kaempferol, also protect the brain and have antiviral, antibacterial, anti-inflammatory, and anticancer properties [35, 36]. Onion contains sufficient amounts of ascorbic acid as antioxidant and fructo-oligosaccharides and prebiotics. These fructo-oligosaccharides retard the growth of potentially harmful bacteria, thus reducing the risk of emerging tumors in the colon, and also as work as prebiotics to promote the growth of healthy *Bifidobacterium* [37]. According to Zhao *et al.* [38], onion powder, juice, and extracts are beneficial for managing and preventing a number of illnesses, including obesity, hypertension, leukemia, heart disease, nephritis, respiratory issues, colitis, and sterility. They also showed that the ethanolic extract from onion peel might prevent some harmful bacteria from growing and retard oxidation in cooked beef [35]. Onion peels' antibacterial and antioxidant properties help in the inhibition of cancer cell growth [36].

The detailed effects of postharvest primary processing treatments on the bioactive compounds of onion have been reviewed by other workers [37, 39]. The processes involving damage of the tissue, viz., minimal processing, and unit operations including peeling, slicing, dicing, and chopping have been found to decrease the bioactive components of the onion. Similarly, drying and other secondary processing treatments also decreased the content of bioactive components [37], which has been summarized in **Table 1**.

### 2.9 Potato

Potato is a member of the Solanaceae family and is a major food crop grown all over the world for its starchy tubers. Raw potato comprises 2% protein, 17% carbs (88% of which is starch), 79% water, and hardly any fat. The vitamins C and B6 as well as the minerals potassium, magnesium, and iron are among the many vital nutrients found in potatoes [40]. Amylopectin, a branched chain glucose polymer, and amylose, a straight chain glucose polymer, make up the majority of potato starch in a comparatively constant 3:1 ratio. Potato starch, which makes up a minor part of total starch, is resistant starch (RS) and acts as a prebiotic by promoting the growth of beneficial colonic bacteria [41]. Two of the five types of resistant starch (RS) categories are found in potatoes: RS2, which is mostly present in raw potatoes, and RS3, which is generated when potatoes are processed and chilled enough for the starch to gelatinize and retrograde [42]. The peel or the thick periderm skin of the tubers is also rich in nutrients such as potassium, iron, riboflavin, folate, and vitamins [43].

DOI: http://dx.doi.org/10.5772/intechopen.108875

| Postharvest/ processing practices | Parameters/conditions | Effect on bioactive compounds |
|---|---|---|
| Curing | The onions were cured under different conditions such as drying at 24°C, 20°C, and 28°C for three and six days, respectively, exposing to fluorescent light for three days. | Different curing treatments resulted in an increase in quercetin, quercetin glucosides, and anthocyanin levels in onion and decrease in flavanol content. |
| Minimal processing | The minimal processing treatments such as onion maceration for 5 h, peeling, chopping, trimming, and cutting were applied | The application of various minimal processing treatments resulted in decrease in flavanols and quercetin glucosides level. |
| Freezing | Diced onion frozen at −18°C and stored for 3, 4, and 5 months | The freezing temperature resulted in an increase in total flavanols and total anthocyanin content. |
| Frying | The different frying conditions were applied for frying of onions, i.e., in olive oil for 4–8 min at 180°C, in oil for 4–8 min, 5–15 min at 180°C, and sauteing for 5 minutes. | The frying in olive oil will not affect the bioactive compounds and flavonoids, but frying in any other oil for different time durations resulted in a decrease in quercetin content, and sauteing will result in decrease in flavonoid content. |
| Boiling | Boiling of onions for 10–60 min at 90–100°C | The boiling of onions resulted in a decrease in flavonoids, bioactive compounds, and quercetin content. |
| Heating | Various heating treatments such as blanching onion for 60 or 70°C for 3 or 1 min, respectively; pressure processing 400 MPa pressure at 5 °C temperature for 5 min; sterilization at 100 °C for 11–17 min; microwave heating for 4 min.; and heating between 36 and 120°C in the time range of 30 to 96 hrs. | The various heating treatments resulted in a decrease in quercetin and its derivatives, quercetin glucosides, and flavonoids and an increase in the total phenol content. |
| Roasting | Roasting for 15–30 min between 180 and 270°C | The roasting of onions resulted in a decrease in flavonoid content with no effect on the total quercetin. |
| Drying | Freeze-drying of onion slices at −70°C and 4.2 Pa pressure for 24 h and dehydration of onions at 70°C | The freeze-drying and dehydration resulted in an increase in flavonoid content and anthocyanin content and a decrease in ascorbic acid. |
| Irradiation | Peeled onion were treated with UV-irradiation at low (1.2 $KJ/m^2$) and medium (6.0 $KJ/m^2$) doses, gamma irradiation at 1.5 kGy and 1.0 kGy and 0.1% sodium benzoate treatment, and stored for 16 days. | The irradiation treatments resulted in a decrease in flavanol content and the total ascorbic acid and an increase in quercetin content, total phenols, polyphenols, and flavonoid content. |

**Table 1.**
*Effect of postharvest practices and minimal processing and conditions on bioactive compounds of onion [37].*

Several phytonutrients, including phenolic acids and carotenoids, are also present in potatoes. For every 100 g of fresh weight potatoes, the carotenoid content ranges from 35 μg to 795 μg. Compared to white flesh cultivars, dark yellow cultivars have 10 times more carotenoid content. Arylated petunidin glycosides (purple potatoes) and acylated pelargonidin glycosides (red and purple potatoes) are the anthocyanins found in potatoes in the highest concentrations. Up to 80% of the total phenolic content of potato tubers is made up of the colorless polyphenol chlorogenic acid [41]. The bioactive compounds present in potatoes have favorable impacts on human health. Potato anthocyanins, glycoalkaloids, and lectins are helpful as anti-tumor agents, while potato protein, resistant starches, and phosphorylated starches contribute cholesterol-lowering properties [44]. Antioxidants in particular have been linked to decreasing inflammation, a risk factor for diabetes, cardiovascular disease, and cancer [42]. Antioxidants present in potatoes are reported to reduce inflammation, cardiovascular disease, and cancer [45].

### 2.10 Radish

Radish (*Raphanus sativus L.* var. *niger*) belongs to the *Brassicaceae* family. The taproot is used for culinary and medicinal properties. It has significant amounts of minerals, vitamin C, and by-products. Radish is a low-caloric food but a good source of calcium, magnesium, copper, manganese, potassium, vitamin B6, vitamin C, folate, polyphenols, sinapine, raphanusanins, isoperoxidases, peroxidases, and alkaloids [46]. The anthocyanin pigments are responsible for the red color of roots, and the distinctive and pungent flavor is a result of their high potential to form isothiocyanates [47]. Pelargonidin and delphinidin are the predominant anthocyanidins in the red and pink radish cultivars, respectively, whereas cyaniding is the main anthocyanidin in the purple radish variant [48]. It contains glucosinolates and/or their derivatives (isothiocyanates, nitriles, and cyano-epithioalkanes), essential oils, flavonoids, and other polyphenolic compounds. Radish microgreens contain significantly greater concentrations of glucosinolates (3.8-fold) and isothiocyanates (8.2-fold) than mature radish taproots.

Radish is recommended as a hepatoprotectant, diuretic, antimicrobial, antioxidant, anti-inflammatory, anti-thrombotic, anti-scorbutic, expectorant, and astringent, while it is also used in urinary and syphilitic complaints, dysuria, calculus, and bronchial and chest troubles [49]. Radishes have also been found to possess anticancer and anxiety-reducing effects [46]. Lugasi et al. [50] reported that radish is a natural remedy for stomach bloating, inadequate digestion, gallstone prevention, and promotion of bile production and bile function.

### 2.11 Sweet potato

Sweet potato (*Ipomoea batatas* L.) belongs to the Convolvulaceae family. In addition to a variety of micronutrients including manganese, copper, potassium, iron, vitamin B complex, vitamin C, vitamin E, and provitamin A, its roots are also rich in macronutrients like starch and dietary fibers. The yellow- and orange-fleshed varieties are also rich in carotenoids. The amounts of protein and fat are quite low. The flesh may be white, cream, yellow, orange, or purple, whereas the skin is often brown, beige, red, or purple [51].

The sweet potato roots are a rich source of phytochemicals such as carotenoids, tocopherols, phenolic compounds, tannins, flavonoids, saponins, and anthocyanins; the concentration, however, varies with flesh color and varieties. Sweet potato is also rich in dietary fiber and resistant starch [52]. Grebla-Al-Zaben *et al.* [53] found that cianidine is a more common anthocyanin than peonidin. Polyphenols are composed of chlorogenic acid, caffeic acid, and their derivatives. From the coumarins family of chemicals, scopoletin, esculetin, and umbeliferon are also present in sweet potatoes. Triterpenes and calistegines are found in comparatively lesser concentrations [52].

Anthocyanin, polyphenolic compounds, coumarins, calystegines, and triterpenes in sweet potatoes stimulate immune function, act as antioxidants, reduce cardiovascular disease risk, suppress cancer cell growth, prevent and improve symptoms of diabetes and hypoglycemia, suppress HIV symptoms, and act as hepatoprotective agents [53]. These bioactive phytochemicals present in sweet potatoes, individually and together, also have bowel-regulating qualities and neuroprotective and anti-inflammatory capabilities [52].

### 2.12 Turmeric

Turmeric (*Curcuma longa* L., sometimes known as *Curcuma domestica* Valeton) belongs to the family Zingiberaceae and is widely cultivated in Asia's tropical regions. Its root (rhizome), in both processed and raw forms, is the part that is most frequently utilized for food and medicinal purposes (**Table 2**). Turmeric has a lot of fiber and carbohydrates. Additionally, it has certain proteins and lipids but no cholesterol and minerals, thus rendering it among the naturally occurring foods with a high nutritional value [54, 55]. Among the bioactive components, the major component is curcumin (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione), followed by other significant components including curcuminoids atlantone, dimethoxycurcumin, diarylheptanoids, tumerone, and flavonoid curcumin. Curcumin can act as antioxidant, antimicrobial, analgesic, anti-inflammatory, antiseptic, anticarcinogenic, antiobesity, hypolipidemic, and cardioprotective [54]. Additionally, it protects against several forms of cellular injury. In addition to offering neuroprotection, turmeric and its ingredients are also helpful in controlling the pathology of neurological conditions like Parkinson's and Alzheimer's diseases and shield COVID-19 patients from developing lung damage brought on by cytokine storms [56].

Turmeric powder with milk is known for its good healing capability. As a remedy for dysentery, roasted turmeric powder is consumed. Both herbal toothpaste and powders have turmeric as one of the ingredients. The advantage of oral use of turmeric and curcumin is that it is safe even at high levels. However, in a few cases,

| Product name | Description | Uses |
|---|---|---|
| Whole rhizome | *Appearance*: orange-brown, red-yellow, or pale yellow<br>*Chemical composition*: it may contain 3–15% curcuminoids and 1.5 to 5% essential oils | Medicinal purposes |
| Turmeric powder | *Appearance*: yellow or red-yellow<br>*Chemical composition*: curcuminoids and essential oils | Spices, dyes, medicines, and dietary supplements |
| Turmeric oil | *Appearance*: yellow to brown oil<br>*Chemical composition*: essential oils mostly contain monoterpenes and rhizomes oil (sesquiterpenes) | Spices, dyes, medicines, and dietary supplements |
| Turmeric oleoresins | *Appearance*: Dark yellow, reddish brown<br>*Chemical composition*: 25% essential oil and 36–56 percent curcuminoids | Food colorant, medicine, and dietary supplement |
| Curcumin | *Appearance*: yellow to orange-red crystalline powder<br>*Chemical composition*: bisdemethoxy- and demethoxy-derivatives | Medicines and dietary supplements |

**Table 2.**
*The main products of turmeric, their chemical composition, and uses [54].*

itching, redness of the tongue, tachycardia, and gastrointestinal problems (such as flatulence, diarrhea, nausea, and constipation) have been reported [57]. Besides curcumin, various volatile oils specifically atlantone, turmerone, and zingiberone are found to be the other active constituents of turmeric. The fresh juice and essential oils from turmeric can be used as biopesticides, as it is reported to possess pesticidal properties and also repellent properties against mosquitos [58].

Wada *et al*. [59] reported the antimicrobial action of extracts of turmeric against *Staphylococcus aureus*, *Escherichia coli,* and *Klebsiella pneumoniae*. Earlier, Kurhekar [60] had reported that the aqueous extract of turmeric was effective in inhibiting the growth of Gram-positive *Bacillus subtilis, S. aureus, Enterococcus fecalis*, and fungal pathogen *Candida albicans* and Gram-negative isolates, *E. coli, Salmonella typhi, Shigella flexneri, Pseudomonas aeruginosa*, and *Proteus vulgaris*. Lakmina *et al.* [61] reported that both turmeric methanolic extract and turmeric powder samples were effective against *Salmonella* spp. and *E. coli* spp.

The low solubility of curcumin in water has restricted its systemic bioavailability and therapeutic potential. However, Yong *et al.* [62] reported that fermentation with *Lactobacillus fermentum* significantly increased the curcumin content by 9.76% and showed no cytotoxicity. In comparison to unfermented turmeric, higher concentrations of curcumin, demethoxycurcumin, bisdemethoxycurcumin, phenolic compounds, and total flavonoid-curcuminoid were observed after solid-state fermentation of wild turmeric (*Curcuma aromatica*) with *Rhizopus oligosporus* for 5 days.

### 2.13 Turnip

*Brassica rapa* L., commonly known as turnip, belongs to the family of Brassicaceae and is known for its white fleshy taproot. Turnip root has low calorie but is a good storehouse of minerals (Cu, Fe, Ca, and Mn), vitamins, dietary fiber, and antioxidants. The major organic acids present in turnip in higher concentrations are malic, sinapic, ferulic, and their derivative acids. Turnip greens and tops have been shown to contain flavonoids, mostly in the form of derivatives of quercetin, kaempferol, and isorhamnetin, but not the roots. In addition to being a great source of vitamin K, turnip greens are also rich in antioxidants such as carotenoids, xanthins, lutein, vitamin A, and vitamin C. The turnip's top greens are rich in vitamin B complex, which includes riboflavin, pantothenic acid, and thiamine [63].

Turnip is mostly composed of glucosinolates and isothiocyanates, particularly 2-phenylethyl, 4-pentenyl, and 3-butenyl derivatives, which have a variety of bioactivities, particularly for the prevention of cancer. In addition, bioactive volatiles, indoles, phenolics, and flavonoids are found in turnip roots. **Table 3** lists the numerous phenolic substances that may be found in turnips. In traditional Chinese therapy, turnips are used to treat a variety of ailments, including gonorrhea, syphilis, rheumatism, oedemas, and rabies. It has antitumor, antihypertensive, antidiabetic, antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, and nephroprotective effects. Hexahydrofarnesylacetone present in it is known for bactericidal effects. The anticancer property of turnip is associated with its 2-phenylethyl isothiocyanate, phenylpropionitrile, brassicaphenanthrene A, 6-paradol, and *trans*-6-shogaol [64, 65].

### 2.14 Yam

*Dioscorea* species, popularly known as yam, belong to the family of Dioscoreaceae. Yams are cultivated for the consumption of their starchy tubers. The species are

| **Phenolic compounds** |
|---|
| Kaempferol 3-O-sophoroside-7-O-glucoside |
| Kaempferol 3-O-(feruloyl/caffeoyl)-sophoroside-7-O-glucoside |
| Kaempferol 3,7-di-O-glucoside |
| Isorhamnetin 3,7-O-diglucoside |
| Sinapic acid |
| Hydroxycinnamoyl gentiobiosides |
| Kaempferol-3-O-glucoside |
| Quercetin-3-O-(sinapoyl)-sophotrioside-7-O-glucoside |
| Hydroxycinnamoylmalic acids |
| Hydroxycinnamoylquinic acids |
| Kaempferol 3-O-sophoroside-7-O-glucoside |

**Table 3.**
*Turnip phenolic compounds [63].*

known for their food values, medicinal values, and low anti-nutritional factors. Yam has many medicinal uses and is used as a post-pregnancy tonic, in piles and dysentery, and as an antidiabetic agent [66].

The underground and/or aerial tubers represent valuable sources of proteins, fats, and vitamins. The presence of different bioactive compounds in various *Dioscorea* species has been reviewed by other workers [67, 68]. The secondary metabolites of yams include steroids, clerodane diterpenes, quinones, cyanidins, phenolics, diarylheptanoids, and nitrogen-containing compounds. They are low in phytates. The most common secondary metabolites are saponins, and there are more than 100 steroidal saponins (based on aglycon part as stigmastanol, furostanol, spirostanol, cholestanol, ergostanol, and pregnanol glycosides). Tubers and roots contain steroidal sapogenins, mostly diosgenin as well as volatile compounds [68].

*Dioscorea* species are used as a cure for different diseases and ailments (cough, cold, stomach ache, leprosy, burns, fungal infections, dysentery, skin diseases, rheumatism, arthritis, etc.), stomach pain (colic), menstrual disorders, birth control, and a disease caused by parasitic worms known as schistosomiasis [66, 69]. Yam is also known for its hypolipidemic, antioxidant, anti-inflammatory, antimicrobial, hypoglycemic, androgenic, estrogenic, contraceptive, and antiproliferative activities [67].

## 3. Uses in food and food industry

Depending upon the availability and nutritional profile, several traditional food dishes of root vegetables, alone or in combination with other vegetables in raw or cooked form, are prepared and consumed. However, there are some novel value-added foods products that are also prepared from these vegetables. The advances and value addition for the routine culinary usages have been briefly discussed in the following sections for the individual root vegetables.

### 3.1 Beet root

Chauhan *et al.* [70] have enumerated food uses of beetroot. The deep-red roots of beetroot can be eaten raw, boiled, steamed, and roasted. It is a popular salad in raw and shredded forms, alone or in combination with other salad vegetables. Fermented and non-fermented pickles are made from boiled and spiced beets. Betanin is a natural pigment in beet juice and is used as a red food colorant for processed products like tomato paste and sauces, desserts, ice cream, sweets, jam and jellies, and spices. Beetroot is also used in manufacturing a food coloring agent known as E162 [2, 71]. It is used to impart a rich red color to dairy products (e.g., milk, ice cream, and yogurt), beverages (juices, wines, and vinegar), fruit candies, and bakery products (cookies, desserts, and cakes). Red beet itself can be used to prepare rich red, Burgundy-style wines.

Dhawan *et al.* [72] developed phytochemical rich and organoleptically acceptable beetroot *Barfi* and *Kanjhi* by incorporating beetroot flour at 1% and 4%, respectively. Similarly, Ashraf *et al.* [73] developed a beetroot-enriched energy booster drink and flavored milk that contained high antioxidant activity, high proteins and fats, and low carbohydrates but adequate total energy content. Beetroot peels' (waste left out during the processing of beetroots) powder, which is rich in antioxidant content, has been used as a natural ingredient in several value-added emulsions, including mayonnaise, dressings, sauces, and creams [74]. In meat products, red beet can be an efficient replacer of nitrate to preserve the red color [2].

### 3.2 Black salsify

The roots and aerial parts of black salsify are used for food purposes. Petkova [75] reported that the leaves are eaten in fresh or blanched forms in salads. The leaves are rich in vitamin C but lack inulin. The roots are long, blackish from the outside and white, milky on the inside. The roots are bitter in taste, but boiling can remove the bitterness and develop an oyster-like taste as salsify. The fresh (raw, seasoned, or cooked) roots can be consumed as such or processed and canned. It can also be dried and used later to be cooked as a vegetable. Roots contain about 17% polysaccharides, of which 13–16% is inulin, 3–5% is pectin, and 1.5–2.5% is fiber. Powder of black salsify roots can be added at 3–4% in ice cream for fiber fortification. Because of high levels of inulin in roots, they can also be roasted as a coffee substitute for diabetic patients. The inulin can be also used for encapsulation purposes, especially in oregano oil, catechins, or thyme extracts as an active ingredient [76].

### 3.3 Carrots

The presence of the coloring pigments anthocyanins and carotenoids and the sufficient quantity of bioactive compounds in carrots have resulted in an increased interest in the food use of carrots. Carrot roots can be consumed fresh, steamed, blanched, or cooked in stews and soups and stuffed in baked products like cakes and pies. Different carrot-based products like dehydrated carrots are used as an ingredient in making instant soups and healthy snacks without oil. *Kanji*, a naturally fermented probiotic appetizer drink popular in North India, is typically prepared using black carrots. The high anthocyanin content and associated high antioxidant activity make the black carrot a suitable raw material for the preparation of functional foods like jams and marmalades. Carrot powder when incorporated in *chapatti*, cake, and *halwa* increases their nutritional value and fiber content [77]. *Gazrella* is a traditional and popular Indian sweet that is made by cooking carrot shreds with condensed milk and cane sugar. Carrot oil, canned baby carrots, pickle, dessert mix, juice, and candy are some of the other promising high-value products made from carrots.

The high nutritional content, sweet taste, and bright color of carrot juice have resulted in an increased popularity of carrots. It is also mixed with other fruit beverages. From carrots, baby foods are also prepared. Riaz *et al.* [78] prepared the value-added products from carrots and reported that β-carotene content and antioxidant activity were higher in carrot jam, followed by carrot candies and carrot–orange juice. Varshney and Mishra [15] reported that carrot pomace, a waste of the carrot food industry which contains approximately 50% carotene and is rich in dietary fibers, may be used to enhance the quality of the cake, bread, and biscuits as well as to make a diversity of other useful ready-to-eat snacks, carrot crispy chips, etc.

### 3.4 Cassava

The roots of cassava have abundant starch content. Zekarias et al. [16] reported that its tubers contain 32–35% carbohydrate on fresh weight (FW) and 80–90% on dry matter (DM) basis, of which 80% is starch and about 17% sucrose. In its starch, 83% is amylopectin and 17% is amylose. Though cassava roots are energy rich, they have limitations in their usage as food. They can be highly toxic if not properly prepared, processed, or cooked. Cassava contains cyanide and other toxic substances that are harmful to humans. Fermentation followed by boiling and drying can, however, significantly reduce the anti-nutritional factors and ensure its nutritional quality [79].

Both fermented and unfermented products are traditionally prepared from cassava. Fermented cassava flour and starch, cassava bread, *fufu, lafun, akyeke* (or attieke), *agbelima*, and *gari* are some of the popular fermented products, whereas unfermented cassava flour and starch, cassava chips, and pellets are the unfermented products [80]. Ukwuru *et al.* [81] discussed the production of biofuel and ethanol, iodine-supplemented and protein-enriched high-quality cassava flour (HQCF), and processed products. The use of HQCF as a raw material for the production of modified starch, monosodium glutamate, cassava bread, pies, chips, cookies, biscuits, noodles, etc. has also been discussed. The functional properties of cassava starch have been extensively reviewed by Lambebo *et al.* [17]. Since the residue obtained from cassava tubers have high quantity of organic matter, it serves as a suitable substrate for microorganisms for the production of organic acids and flavor and aromatic compounds. According to Airaodion *et al*. [79], the microorganisms primarily responsible for fermentation are *Neurospora sitophila, Geotrichum candidum*, and *Rhizopus oryzae.* They observed a 95% reduction in cyanogen levels by heap fermentation of cassava roots followed by sun drying.

### 3.5 Garlic

Garlic is a vegetable that is widely used as a seasoning, flavoring, food dish, and functional food. The use of garlic is popular due to its excellent effectiveness, less side effects, low cost, and easy availability. Bioactive compounds present in it are effective in promoting health and developing functional foods or nutritional supplements. However, highly unstable thiosulfinates, such as allicin, are destroyed during processing and are quickly converted into various organosulfur components [24, 82].

Therefore, the efficiency and safety of garlic products and food supplements are influenced by the processing methods used. Different value-added processed products like minimally processed, osmotically dehydrated flakes, freeze dried powder, paste, pickle, oil, etc. have been prepared from garlic.

The distinctive flavor of fresh garlic is attributed to a variety of thiosulfinates and volatile compounds like S-alkyl substituted cysteine sulfoxide derivatives, alkyl canthiosulfinates, pyruvate, and ammonia produced by the action of allinases (EC4.4.1.4). The enzyme action starts as soon as garlic tissues are disrupted. Allinase enzyme, which is involved in thiosulfate conversion, gets inactivated by pH below 3.5 or by heat [23, 83]. Microwave radiation for even 1 minute inactivates allinase. The diallyl thiosulfinate (allicin) formed by enzyme action accounts for approximately 60–80% of the total thiosulfinates in garlic. The half-life of allicin is up to 16 hours at room temperature and 2.5 days when stored in a juice or crushed form. Fresh garlic and garlic powder, garlic oil, and steam-distilled garlic do not have significant amounts of alliin or allicin but instead contain various products of allicin transformation [83].

Black garlic, which is fermented white garlic, is prepared by heat treatment of fresh garlic without additives to reduce the pungent odour and taste. Fresh garlic is exposed to high temperature (60–90°C) and high humidity (60–80%) for 60–90 days. The black garlic that is produced is richer in various bioactive components; however, it has a reduced pungent smell and taste of garlic. Ma *et al.* [84] studied the potential of probiotic fermentation to further improve the quality of black garlic. It was reported that the pH was significantly lowered, and total acids, amino nitrogen, total polyphenols, and total flavonoids increased by *Lactobacillus* fermentation. The content of 5-hydroxymethylfurfural (a carcinogenic component) was reduced by 25.10–40.81%. The contents of furfural, 2-acetylfuran, 5-methylfurfural, etc. responsible for unpleasant baking flavor were decreased, while an increase was observed for green grass, floral, and fruit aromas. The *Lactobacillus* fermentation resulted in increased contents of functional components like Gly-Pro-Glu, sorbose, lactic acid, and α-CEHC (3,4-dihydro-6-hydroxy-2,5,7,8-tetramethyl-2H-1-benzopyran-2-propanoic acid).

The exogenous addition of garlic-derived organosulfur compounds in ground beef was found to be a more effective antioxidant than the α-tocopherol. It significantly reduced total aerobes and inhibited the growth of five inoculated pathogenic bacteria: *S. typhimurium, E. coli O157:H7, Listeria monocytogenes, S. aureus*, and *Campylobacter jejuni* [85]. Similarly, Kanza Aziz et al. [86] reported that garlic fortification improved the stability and sensory attributes of chicken bites.

### 3.6 Ginger

Ginger is used either fresh or after drying the whole or chopped ginger. As the moisture content in fresh ginger is high, it causes difficulty in its drying and converting it into dry spice. Dried ginger is a highly wrinkled product with low volatile oil content. Various value-added products that can be prepared from ginger are ginger candies and preserve, ginger puree and paste, ginger powder and sticks, ginger beer and wine, and ginger oil and oleoresin [87]. It is also used as a flavoring substance in foods, curries, and beverages (such as ginger ales); in the confectionery industry in products such as pickles, chutneys, vinegar, and marmalades; and in bakery products. Other new products that can be made from ginger are skin/stick, osmotically dried appetizing ginger flakes, ginger drinks, and ginger starch [88].

Amer *et al.* [89] developed value-added extruded maize enriched with ginger extract at 3%. The product had better functional and sensory properties. Kaushal *et al.* [71] developed ginger fruit bars and ginger appetizing tablets, which have significantly higher antioxidant activity, total phenolics, and crude fiber. Tanweer *et al.* [90] prepared value-added meatballs by adding 10% dried ginger powder. The product was yellowish due to the presence of shogaol, had higher total phenolics and antioxidant potential, and had acceptable organoleptic quality.

### 3.7 Jerusalem artichoke

Due to the high nutritive value and proportion of fructans and low content of nitrates, the flour of Jerusalem artichoke tubers may be fully utilized as functional food [31]. Nadir *et al.* [91] obtained concentrated gluten by washing wheat flour and replacing the removed starch with flour and inulin extract obtained from Jerusalem artichoke. Compound flour was used to prepare pasta. It was observed that the volume of cooked pasta increased with increasing levels of flour and inulin extract. The appearance, color, taste, fragility, and stickiness of the pasta improved with increasing levels of Jerusalem artichoke flour up to 30%. Previously, Shin *et al*. [92] developed quality noodles by replacing 25% of wheat flour with Jerusalem artichoke flour.

Inulin extracted from Jerusalem artichoke tuber powder (JATP) in the form of oligosaccharides is used as a sugar substitute and in prebiotics. The conventional enzymatic method of inulinases for the extraction of inulin from JATP is limited by the narrow temperature range of enzyme activity, complicated processes, low substrate solubility, longer reaction times, and high operating costs. Bui *et al.* [93] developed a method using a combination of microwave heating and HCl as a catalyst to extract most of the carbohydrate content of JATP and selectively convert it to fructo-oligosaccharides. The method required a low reaction temperature and a relatively short reaction time. Bakr *et al.* [94] produced Bio-Labneh probiotic from cow's milk using Jerusalem artichoke tuber powder inoculated with *Lactobacillus acidophilus* LA-5. The most organoleptically acceptable Bio-Labneh was produced with 1% JATP, while 3% JATP obtained the highest overall score and *L. acidophilus* growth.

### 3.8 Onion

Onion, also referred to as the "queen of the kitchen," is known for its extremely valuable flavor, aroma, and distinctive style. Onion is eaten raw as salad or used as an ingredient in a diverse variety of foods by enhancing their flavor and taste. If consumed in raw form, it provides health benefits due to the direct intake of phytochemicals. The good fiber and higher flavonoids in bulbs and the various by-products obtained from it have tremendous scope for food application. Fresh onion and its dried powder when added to various food products have been reported to increase the shelf life of processed food products due to onion's antifungal, antibacterial, and antioxidant properties [95]. Sulfur containing volatile oils (allicin, ajoene, and alliin) present in onion can be extracted and used as a flavoring substance and preservative and also as a health-promoting bioactive compound. As onions are rich in sugars and other nutrients, they can also be processed into value-added products like onion vinegar, wine, paste, and sauce [96].

### 3.9 Potato

Potato is consumed mainly as a carbohydrate source. The starch from raw potato is nearly indigestible but is more easily digestible from cooked potato. Raw, peeled potatoes after cooking are one of the common most ingredients in food dishes. The potatoes are also processed into several groups of food products like potato flour and starch, potato flakes, granules and dried products, potato chips and french fries, frozen potato products, canned potatoes, and fabricated french fries and chips [97]. It may be noted that the normal potato tubers that have been properly grown and stored have small quantities of glycoalkaloids, safe enough for human health. However, if exposed to light, the sprouts and skin of the tuber accumulate high concentrations of glycoalkaloids, which have harmful effects on human health. The tubers exposed to light also produce solanine, a toxin harmful to human consumption. Anti-nutrients in raw and baked potatoes include glycoalkaloids and acrylamides [98].

The potato-processing industry, depending on the product produced and the employed peeling method, generates potato peel or skin at 15–40% of the tubers' fresh weight. The potato peel/skin can be a potential source of fiber and other phytochemicals (**Figure 3**). Arora and Camire [99] prepared cinnamon muffins and cookies using extruded and non-extruded potato skins at 25% as a substitute for wheat flour. Baked products with skin had reduced contents of glycoalkaloids and peroxides; they were darker, more resistant to compression, and lower in height and possessed increased fiber content.

### 3.10 Radish

The taproot of radishes is consumed worldwide in the form of pickled vegetables, salads, and curries. The leaves and sprouts are usually eaten raw as part of salads. Radish juice is not palatable because of its pungent taste. Kaur *et al.* [100] developed a

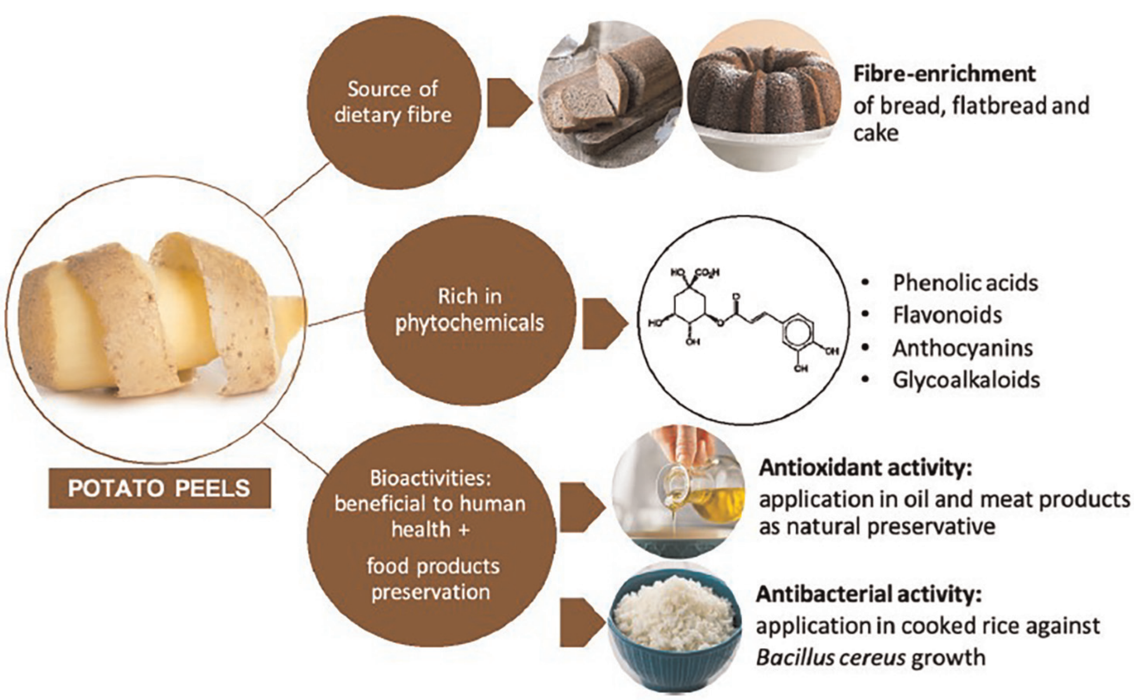


**Figure 3.**
*Potato peels and their food uses [43].*

high-acceptability nutritional drink by mixing radish juice with 30% sugarcane juice, 1 percent herbal extract (mint juice/coriander juice/citric acid in a ratio of 1:1:1 v:v:w), and 1.5% salt concentration (black salt/white salt in a ratio of 1:1). Lugasi *et al.* [50] reported no glucosinolates in pressed black radish root juice, as it got completely destroyed and converted into polyphenolic compounds by the pressing process and storage. Tanaka and Ohmiya [101] reported that anthocyanin derivatives from red radish can be used as a stable natural food colorant. The brick red/scarlet, red/ magenta, and violet/blue color of radish are due to the presence of pelargonidin-, cyanidin-, and delphinidin-based anthocyanins, respectively.

### 3.11 Sweet potato

Sweet potatoes can be converted to several functional ingredients, food, and industrial products that have been summarized by Truong *et al.* [102] and presented in **Figure 4**.

Mitiku et al. [103] developed bread by blending of sweet potato flour with wheat flour. The developed bread was lower in protein but richer in ash, crude fiber, carbohydrates, iron, zinc, phosphorus, and vitamin A contents. The tannin and phytate contents of the composite bread were low. Similarly, Gracia et al. [104] developed a healthy cake by replacing 20% of maida (refined wheat flour) base with oven-dried *Ipomea batatas* powder. As compared to pure maida cake, the developed cake was high in fiber content and scored better organoleptically for color and taste.

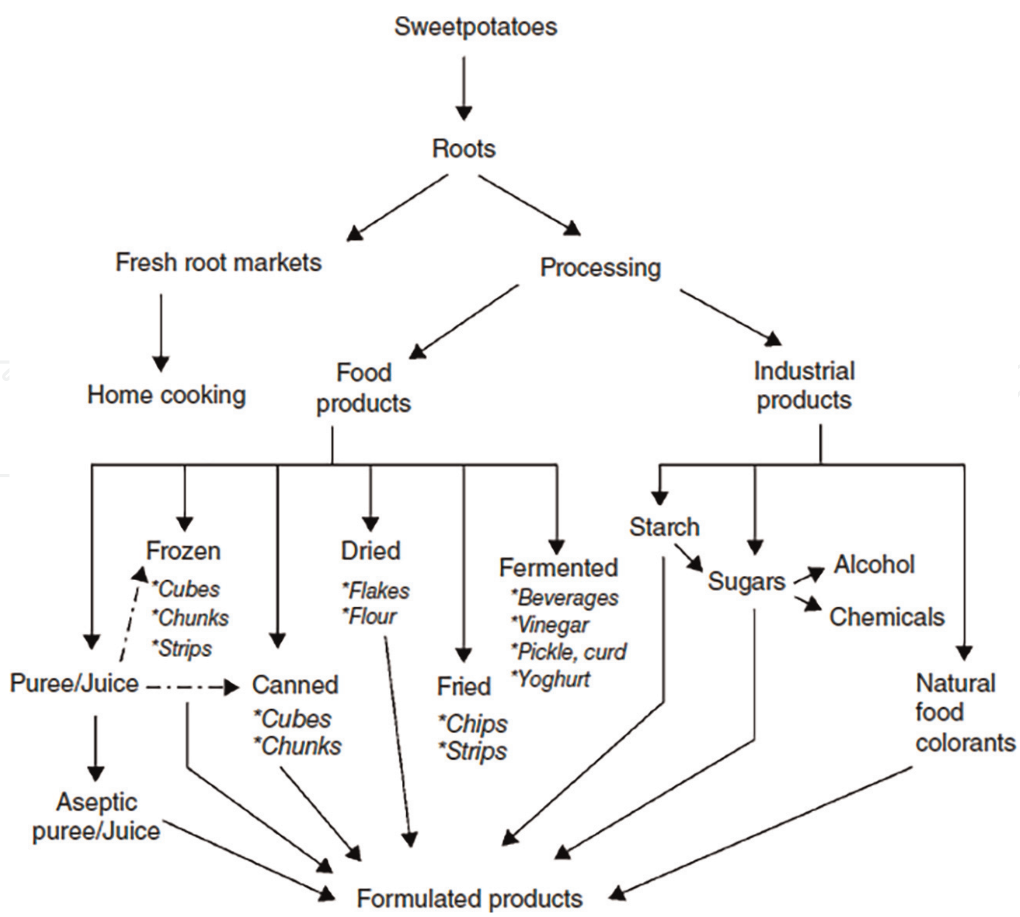


**Figure 4.**
*Processing and utilization of sweet potatoes [102].*

Supplemental foods based on root or tuber crops have an advantage of having significantly lower phytate content (by 3–20%) than the foods based on grains and legumes. Amagloh *et al.* [52] developed a complementary food for infants using sweet potato, soybean meal, soybean oil, and fish powder or skimmed milk powder. It was reported that sweet potato-based formulations had phytate and fructose levels superior to commercially available Weanimix.

### 3.12 Turmeric

The dried root powder of turmeric is used as a spice, food preservative, and flavoring and food-coloring agent. Turmeric is used in smoked meats, pickles, seafood, soups, rice, and various vegetable dishes. Turmeric extends the shelf life of seafood products by maintaining nutritional quality and attractiveness due to its antioxidant, antimicrobial, coloring, and flavoring properties [105]. Turmeric tea can be made from grated, dried, or powdered turmeric. The brewing methods such as hard, soft, and ambient infusion were tested to characterize the antioxidant potential of the turmeric tea. Among them, hard infusion shows the highest antioxidant potential as compared to soft and ambient infusion [106]. Ipar *et al.* [107] developed a ready-to-use turmeric latte by an innovative approach using microencapsulated turmeric oleoresin with a blend of gum acacia, maltodextrin, and dairy whitener with bio-enhancers. The microencapsulated powder obtained exhibited high encapsulation efficiency, wettability, dispersibility, superior antioxidant activity, and oral bioavailability. It showed the release of >95% of curcumin at pH 1.2. Choi *et al.* [108] observed that a novel processing technique of high-pressure gun puffing increased the brown color and porous structures of turmeric. Puffing also enhanced its antioxidant activity.

### 3.13 Turnip

Turnips have a shelf life longer than that of potatoes. Turnips can be stored for 4–5 months at a temperature of 0°C and relative humidity of 95–98%. Around the world, many types of dishes are prepared with turnips, especially from raw, boiled, or steamed roots, alone or with other vegetables or meat. Turnip roots are diced and frozen or dried and stored in a powder form. The traditional turnip dishes belong to the food groups of soups, stuffed turnips, baked goods, rice pilaf, salads, and juices. It can also be used as salad and garnishes. The greens of this vegetable are used in soups, stews, and various value-added food products [109].

Some new turnip root products have also been developed. Xue *et al.* [110] evaluated different methods such as hot air drying, explosion drying, infrared drying, and freeze drying (FD) to produce turnip chips from roots. It was observed that FD chips retained the most starch, total sugar, vitamin C, and volume ratio by maintaining better brittle values and rehydration rate. Tripathi and Yadav [111] reported that replacing wheat flour and refined flour with 15% turnip powder to make traditional Indian *Chappati, Namakpara,* noodles, etc. resulted in their improved Ca and Fe contents.

### 3.14 Yam

The white and yellow yams in West Africa are consumed by boiling the peeled yam tubers and then mashing them (sometimes together with cooked bananas) into a doughy paste to make a traditional dish of "pounded yam", locally called *Fufu*, *Foutou*, or *Iyan* [69]. Leng *et al.* [112] studied the nutritional composition and antioxidant activity of a yam-based formulated weaning feed. Dried yam slice flours purchased from the local market were enriched with soybean paste and groundnut to create a balanced diet. Carrots and eggshells were added as fortifying sources of micronutrients. The nutritional content and antioxidant properties of the flour mixtures indicated that the developed weaning feed met the recommended energy and macronutrient requirements according to the established standards. Dos Santos *et al.* [113] prepared Greek-type goat yogurt with added yam aqueous extract and goat milk casein powder. It was reported that the yam-fortified yogurt has increased yield, water-holding capacity, viscosity, sensory acceptance, and purchase intention score.

## 4. Conclusion and future prospects

Root vegetables have a distinct nutritional profile with special reference to their various bioactive components having innumerable medicinal properties. These bioactive components can be used in different pharmaceutical formulations or diet-based therapies to cure various ailments and disorders. Their advantages over traditional medicines are lower cost and fewer side effects. The endogenous synthesis of the nutrients and phytochemicals in these root vegetables, however, is also affected by pre-harvest farm practices adopted and biotic and abiotic stresses faced by the crop. The effect(s) of these factors on the quality and quantity of various bioactive compounds need to be studied in detail. Besides, further identification and characterization of newer bioactive compounds; the selection of proper cultivar or variety rich in bioactive component(s); development of effective methods of extraction; improvement in the technologies for stabilizing the formulations; use of encapsulation, microsome, liposomes, and nano-formulation strategies, etc. are some of the approaches that can be helpful to pharmaceutical industries in producing effective herbal drugs and herbal antibiotics with improved efficiencies. The phytoconstituents' bioavailability and compatibility with other phytonutrients; the safe dosage with respect to a person's age; and the potential risk of the formulations for persons suffering from ailments like bile stone, hypertension, diabetics, allergies, etc. are some of the other important aspects to be studied further to develop effective drugs from root vegetables.

Besides the routine culinary usage of root vegetables, there is tremendous scope for their utilization by food industries. The quality of traditional foods prepared from the local root vegetables can be improved and maintained to make them available and acceptable globally. The essential oils extracted from root vegetables like garlic, turmeric, ginger, etc. can serve as potential food bio-preservatives because of their antimicrobial properties. The pigments from beetroot, turmeric, carrot, etc. can serve as food-grade natural coloring agents. The food industry can utilize modern non-thermal processing technologies to preserve the bioactive components during processing to develop pharma foods, possessing higher quantities of essential bioactive nutrients and phytochemicals than naturally existing processed food products. Further technologies need to be developed to utilize left-out peel and pomace of the root vegetable-processing industries to develop by-products and then utilize those by-products in the development of functional foods. The reduction of pesticide residue, heavy metals and microbial contamination, nitrate, and anti-nutrient contents are some of the important aspects that should be given due consideration by the food industries utilizing root vegetables. The development of newer varieties of root vegetables suitable for processing, studies of changes in nutrients during storage, and development of non-thermal technologies to preserve the nutrients' loss during processing can be the future line of work for the researchers engaged in root vegetables' production, utilization, and related aspects.



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## References

[1] Ülger TG, Songur AN, Çırak O, Çakıroğlu FP. Role of vegetables in human nutrition and disease prevention. In: Asaduzzaman M, Asao T, editors. Vegetables-Importance of Quality Vegetables to Human Health. London, UK: IntechOpen; 2018. pp. 7-32. DOI: 10.5772/intechopen.77038

[2] Ceclu L, Nistor O. Red beetroot: Composition and health effects—A review. Journal of Nutritional Medicine and Diet Care. 2020;**6**(1):1-9

[3] Getz H. Sucrose accumulation and synthesis in sugar beet. In: Developments in Crop Science. Vol. 26. Amsterdam, Netherlands: Elsevier; 2000. pp. 55-77

[4] Afiomah CS, Iwuozor K. Nutritional and phytochemical properties of *Beta vulgaris* Linnaeus (Chenopodiaceae)–a review. Nigerian Journal of Pharmaceutical and Applied Science Research. 2020;**9**(4):38-44

[5] Masih D, Singh N, Singh A. Red beetroot: A source of natural colourant and antioxidants: A review. Journal of Pharmacognosy and Phytochemistry. 2019;**8**(4):162-166

[6] Mirmiran P, Houshialsadat Z, Gaeini Z, Bahadoran Z, Azizi F. Functional properties of beetroot (*Beta vulgaris*) in management of cardio-metabolic diseases. Nutrition & Metabolism. 2020;**17**(1):1-15

[7] 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

[8] Lendzion K, Gornowicz A, Bielawski K, Bielawska A. Phytochemical composition and biological activities of Scorzonera species. International Journal of Molecular Sciences. 2021;**22**(10):5128

[9] Wu QX, Su YB, Zhu Y. Triterpenes and steroids from the roots of *Scorzonera austriaca*. Fitoterapia. 2011;**82**:493-496

[10] Zhu Y, Wu QX, Hu PZ, Wu WS. Biguaiascorzolides a and B: Two novel dimeric guaianolides with a rare skeleton, from *Scorzonera austriaca*. Food Chemistry. 2009;**114**:1316-1320

[11] Bystrická J, Kavalcová P, Musilová J, Vollmannová A, Tomáš T, Lenková M. Carrot (Daucus carota L. ssp. sativus (Hoffm.) Arcang.) as source of antioxidants. Acta agriculturae Slovenica. 2015;**105**(2):303-311

[12] Ergun M, Süslüoğlu Z. Evaluating carrot as a functional food. Middle East Journal of Science. 2018;**4**(2):113-119

[13] Ahmad T, Cawood M, Iqbal Q, Ariño A, Batool A, Tariq RM, et al. Phytochemicals in *Daucus carota* and their health benefits. Food. 2019;**8**(9):424

[14] Silva Dias JC. Nutritional and health benefits of carrots and their seed extracts. Food and Nutrition Sciences. 2014;**5**(22):2147-2156

[15] Varshney K, Mishra K. An analysis of health benefits of carrot. International Journal of Innovative Research in Engineering & Management. 2022;**9**(1):211-214

[16] Zekarias T, Basa B, Herago T. Medicinal, nutritional and anti-nutritional properties of cassava (*Manihot esculenta*): A review. Academic Journal of Nutrition. 2019;**8**(3):34-46

[17] Lambebo T, Deme T. Evaluation of nutritional potential and effect of processing on improving nutrient content of cassava (*Mannihot esculenta* crantz) root and leaves. bioRxiv. 2022;**2**(4):479097. DOI: 10.1101/2022.02.04.479097

[18] Bahekar S, Kale R. Phytopharmacological aspects of *Manihot esculenta* Crantz (cassava)—A review. Mintage Journal of Pharmacy and Medical Sciences. 2013;**2**:4-5

[19] Suleria HAR, Butt MS, Khalid N, Sultan S, Raza A, Aleem M, et al. Garlic (*Allium sativum*): Diet based therapy of 21st century–a review. Asian Pacific Journal of Tropical Disease. 2015;**5**(4):271-278

[20] Sasi M, Kumar S, Kumar M, Thapa S, Prajapati U, Tak Y, et al. Garlic (*Allium sativum* L.) bioactives and its role in alleviating oral pathologies. Antioxidants. 2021;**10**(11):1847

[21] De Greef D, Barton EM, Sandberg EN, Croley CR, Pumarol J, Wong TL, et al. Anticancer potential of garlic and its bioactive constituents: A systematic and comprehensive review. In: Seminars in Cancer Biology. Vol. 73. Amsterdam, Netherlands: Academic Press; 2021. pp. 219-264

[22] Escudero LB, Monasterio RP, Lipinski VM, Filippini MF, Wuilloud RG. Selenized garlic: A future prospect or already a current functional food? Revista de la Facultad de Ciencias Agrarias. 2012;**44**(2):301-318

[23] Ezeorba TPC, Chukwudozie KI, Ezema CA, Anaduaka EG, Nweze EJ, Okeke ES. Potentials for health and therapeutic benefits of garlic essential oils: Recent findings and future prospects. Pharmacological Research-Modern Chinese Medicine. 2022;**5**:100075

[24] Shinde A, Dond S, Diwate V, Pawar S, Katkar R, Darandale S. Historical approach of garlic (*Allium sativum*) in food, spices and it's phytochemicals and therapeutic uses in medicine: A review. World Journal of Pharmaceutical Research. 2021;**10**(1):737-744

[25] Jang H-J, Lee H-J, Yoon D-K, Ji D-S, Kim J-H, Lee C-H. Antioxidant and antimicrobial activities of fresh garlic and aged garlic by-products extracted with different solvents. Food Science and Biotechnology. 2018;**27**(1):219-225

[26] Singletary K. Ginger: An overview of health benefits. Nutrition Today. 2010;**45**(4):171-183

[27] Shoaib M, Shehzad A, Butt MS, Saeed M, Raza H, Niazi S, et al. An overview: Ginger, a tremendous herb. Journal of Global Innovations in Agricultural and Social Sciences. 2016;**4**(4):172-187

[28] Abdullahi A, Khairulmazmi A, Yasmeen S, Ismail I, Norhayu A, Sulaiman M, et al. Phytochemical profiling and antimicrobial activity of ginger (*Zingiber officinale*) essential oils against important phytopathogens. Arabian Journal of Chemistry. 2020;**13**(11):8012-8025

[29] Mao Q-Q, Xu X-Y, Cao S-Y, Gan R-Y, Corke H, Beta T, et al. Bioactive compounds and bioactivities of ginger (*Zingiber officinale* roscoe). Food. 2019;**8**(6):185

[30] Alexandre EMC, Lourenço RV, Bittante AMQB, Moraes ICF, do Amaral Sobral PJ. Gelatin-based films reinforced with montmorillonite and activated with nanoemulsion of ginger essential oil for

food packaging applications. Food Packaging and Shelf Life. 2016;**10**:87-96

[31] Munim A, Rod MR, Tavakoli H, Hosseinian F. An analysis of the composition, health benefits, and future market potential of the *Jerusalem artichoke* in Canada. Journal of Food Research. 2017;**6**(5):69

[32] Yang L, He QS, Corscadden K, Udenigwe CC. The prospects of *Jerusalem artichoke* in functional food ingredients and bioenergy production. Biotechnology reports. 2015;**5**:77-88

[33] Sami R, Elhakem A, Alharbi M, Benajiba N, Almatrafi M, Helal M. Nutritional values of onion bulbs with some essential structural parameters for packaging process. Applied Sciences. 2021;**11**(5):2317

[34] Esienanwan EE, Luavese PA, Ezinne CC, Adepoju IO, Godwin O. Comparative qualitative phytochemical analysis of oil, juice and dry forms of garlic (*Allium sativum*) and different varieties of onions (*Allium cepa*) consumed in Makurdi metropolis. International Journal of Plant Physiology and Biochemistry. 2020;**12**(1):9-16

[35] Greeshma K, Muthulingam S, Thamizselvi R, Venkatamani GP. Phytochemical analysis and a review on biological importance of *Allium cepa*. L. GSC Advanced Research and Reviews. 2020;**2**(2):018-024

[36] Fredotović Ž, Puizina J, Nazlić M, Maravić A, Ljubenkov I, Soldo B, et al. Phytochemical characterization and screening of antioxidant, antimicrobial and antiproliferative properties of allium× cornutum Clementi and two varieties of *Allium cepa* L. peel extracts. Plants. 2021;**10**(5):832

[37] Sagar NA, Pareek S, Benkeblia N, Xiao J. Onion (*Allium cepa* L.) bioactives: Chemistry, pharmacotherapeutic functions, and industrial applications. Food Frontiers. 2022;**3**:135. DOI: 10.1002/fft2.135

[38] Zhao X-X, Lin F-J, Li H, Li H-B, Wu D-T, Geng F, et al. Recent advances in bioactive compounds, health functions, and safety concerns of onion (*Allium cepa* L.). Frontiers in Nutrition. 2021;**8**: 669805

[39] Ren F, Nian Y, Perussello CA. Effect of storage, food processing and novel extraction technologies on onions flavonoid content: A review. Food Research International. 2020;**132**:108953

[40] Khalid MZ, Aziz A, Tariq A, Ikram A, Rehan M, Younas S, et al. Nutritional composition and health benefits of potato: A review. Advanced Food and Nutritional Sciences. 2020;**5**: 7-16

[41] Beals KA. Potatoes, nutrition and health. American Journal of Potato Research. 2019;**96**(2):102-110

[42] McGill CR, Kurilich AC, Davignon J. The role of potatoes and potato components in cardiometabolic health: A review. Annals of Medicine. 2013;**45**(7): 467-473

[43] Sampaio SL, Petropoulos SA, Alexopoulos A, Heleno SA, Santos-Buelga C, Barros L, et al. Potato peels as sources of functional compounds for the food industry: A review. Trends in Food Science & Technology. 2020;**103**:118-129

[44] Camire ME, Kubow S, Donnelly DJ. Potatoes and human health. Critical Reviews in Food Science and Nutrition. 2009;**49**(10):823-840

[45] Jansky S, Navarre R, Bamberg J. Introduction to the Special Issue on the

Nutritional Value of Potato. American Journal of Potato Research. 2019;**96**(2): 95-97

[46] Ghayur MN, Gilani AH. Gastrointestinal stimulatory and uterotonic activities of dietary radish leaves extract are mediated through multiple pathways. Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives. 2005;**19**(9):750-755

[47] Gamba M, Asllanaj E, Raguindin PF, Glisic M, Franco OH, Minder B, et al. Nutritional and phytochemical characterization of radish (*Raphanus sativus*): A systematic review. Trends in Food Science & Technology. 2021;**113**: 205-218

[48] Hanlon PR, Barnes DM. Phytochemical composition and biological activity of 8 varieties of radish (*Raphanus sativus* L.) sprouts and mature taproots. Journal of Food Science. 2011; **76**(1):C185-CC92

[49] 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

[50] Lugasi A, Dworschák E, Blazovics A, Kery A. Antioxidant and free radical scavenging properties of squeezed juice from black radish (*Raphanus sativus* L. var Niger) root. Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives. 1998;**12**(7):502-506

[51] Neela S, Fanta SW. Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin a deficiency. Food Science & Nutrition. 2019;7(6):1920-1945

[52] Amagloh FC, Yada B, Tumuhimbise GA, Amagloh FK, Kaaya AN. The potential of sweetpotato as a functional food in sub-saharan Africa and its implications for health: A review. Molecules. 2021;**26**(10):2971

[53] Grebla-Al-Zaben B, Babalau-Fuss V, Biris-Dorhoi SE, Talos I, Tofana M. A review of the composition and health benefits of sweet potato. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca Food Science and Technology. 2021; **78**(1):1-10

[54] Ahmad RS, Hussain MB, Sultan MT, Arshad MS, Waheed M, Shariati MA, et al. Biochemistry, safety, pharmacological activities, and clinical applications of turmeric: A mechanistic review. Evidence-based complementary and alternative Medicine. 2020;**14**: 7656919. DOI: 10.1155/2020/7656919

[55] Enemor VHA, Ogbodo UC, Nworji OF, Ezeigwe OC, Okpala CO, Iheonunekwu GC. Evaluation of the nutritional status and phytomedicinal properties of dried rhizomes of turmeric (*Curcuma longa*). Journal of Biosciences and Medicines. 2020;**8**(08):163

[56] Ismail Z, Mazuki NAN. An overview of Golden Spice's (turmeric) medicinal properties for future development potential. Malaysian Journal of Science Health & Technology. 2020;**6**:53-57

[57] Soleimani V, Sahebkar A, Hosseinzadeh H. Turmeric (*Curcuma longa*) and its major constituent (curcumin) as nontoxic and safe substances. Phytotherapy Research. 2018;**32**(6):985-995

[58] Damalas CA. Potential uses of turmeric (*Curcuma longa*) products as alternative means of pest management in

crop production. Plant omics. 2011;**4**(3): 136-141

[59] Wada NM, Ambİ AA, Ibrahİm AA, Bello SK, Umar A, James DT. Mediterr J Infect Microb Antimicrob. 2021;**10**:6

[60] Kurhekar JV. *Curcuma longa* and *Allium sativum* as prebiotics. Bionano Frontier. 2013;**6**(2):327-329

[61] Lakmina D, Ranasinghe M, Abeyrathne E, Jayasena D. Antimicrobial activity of turmeric (*Curcurna longa*) against *salmonella* spp and *E. coli* Spp. In: Proceeding of the 2nd International Research Symposium. Badulla, Sri Lanka: Uva Wellassa University; 2018. p. 313

[62] Yong C, Yoon Y, Yoo H, Oh S. Effect of lactobacillus fermentation on the anti-inflammatory potential of turmeric. Journal of Microbiology and Biotechnology. 2019;**29**(10): 1561-1569

[63] Javed A, Ahmad A, Nouman M, Hameed A, Tahir A, Shabbir U. Turnip (*Brassica rapa* L.): A natural health tonic. Brazilian Journal of Food Technology. 2019;**22**:e2018253. DOI: 10.1590/1981-6723.25318

[64] Paul S, Geng CA, Yang TH, Yang YP, Chen JJ. Phytochemical and health-beneficial progress of turnip (*Brassica rapa*). Journal of Food Science. 2019;**84**(1):19-30

[65] Cao Q, Wang G, Peng Y. A critical review on phytochemical profile and biological effects of turnip (*Brassica rapa* L.). Frontiers in Nutrition. 2021;**8**: 721733

[66] Guchhait KC, Singh G, Sardar S, Kumbhojkar V, Marndi S, Kumar S. Yams of India and their medicinal values. Medico-Biowealth of India. 2022;**Vol V**:59

[67] Salehi B, Sener B, Kilic M, Sharifi-Rad J, Naz R, Yousaf Z, et al. Dioscorea plants: A genus rich in vital nutra-pharmaceuticals-a review. Iranian Journal of Pharmaceutical Research: IJPR. 2019;**18**(Suppl. 1):68

[68] Obidiegwu JE, Lyons JB, Chilaka CA. The Dioscorea genus (yam)—An appraisal of nutritional and therapeutic potentials. Food. 2020;**9**(9):1304

[69] Andres C, AdeOluwa OO, Bhullar GS. Yam (*Dioscorea* spp.)-a rich staple crop neglected by research. In: Encyclopedia of Applied Plant Sciences. Vol. 2. San Diego, USA: Academic Press; 2017. pp. 435-441

[70] Chauhan S, Chamoli K, Sharma S. Beetroot-a review paper. Journal of Pharmacognosy and Phytochemistry. 2020;**9**(2S):424-427

[71] Sawicki T, Wiczkowski W. The effects of boiling and fermentation on betalain profiles and antioxidant capacities of red beetroot products. Food Chemistry. 2018;**259**:292-303

[72] Dhawan D, Sharma S, Scholar D. Exploration of the nourishing, antioxidant and product development potential of beetroot (*Beta vulgaris*) flour. International Journal of Health Sciences & Research. 2019;**9**(6):280

[73] Ashraf S, Sayeed SA, Ali R, Vohra F, Ahmed N, Alam MK. Assessment of potential benefits of functional food characteristics of beetroot energy drink and flavored milk. BioMed Research International. 2022;**2022**:1971018. DOI: 10.1155/2022/1971018

[74] Lazăr S, Constantin OE, Horincar G, Andronoiu DG, Stănciuc N, Muresan C, et al. Beetroot by-product as a functional ingredient for obtaining value-added mayonnaise. PRO. 2022;**10**(2):227

[75] Petkova N. Characterization of inulin from black salsify (*Scorzonera hispanica* L.) for food and pharmaceutical purposes. Asian Journal of Pharmacy and Clinical Research. 2018;**11**:221-225

[76] Beirão-da-Costa S, Cl D, Bourbon I, Pinheiro A, Januário M, Vicente A, et al. Inulin potential for encapsulation and controlled delivery of oregano essential oil. Food Hydrocolloids. 2013; **33**:199-206

[77] Akubor PI, Eze JI. Quality evaluation and cake making potential of sun and oven dried carrot fruit. International Journal of Biosciences. 2012;**2**(10):19-27

[78] Riaz N, Yousaf Z, Yasmin Z, Munawar M, Younas A, Rashid M, et al. Development of carrot nutraceutical products as an alternative supplement for the prevention of nutritional diseases. Frontiers in Nutrition. 2021;**8**: 787351. DOI: 10.3389/fnut.2021.787351

[79] Airaodion AI, Airaodion EO, Ewa O, Ogbuagu EO, Ogbuagu U. Nutritional and anti–nutritional evaluation of garri processed by traditional and instant mechanical methods. Asian Food Science Journal. 2019;**9**(4):1-13

[80] Falade KO, Akingbala JO. Utilization of cassava for food. Food Reviews International. 2010;**27**(1):51-83

[81] Ukwuru M, Egbonu S. Recent development in cassava-based products research. Academia Journal of Food Research. 2013;**1**(1):1-13

[82] Amagase H, Petesch BL, Matsuura H, Kasuga S, Itakura Y. Recent advances on the nutritional effects associated with the use of garlic as a supplement. Journal of Nutrition. 2001; **131**(3):955S-962S

[83] Fesseha H, Goa E. Therapeutic value of garlic (*Allium sativum*): A review. Advances in Food Technology and Nutritional Sciences. 2019;**5**(3):107-117

[84] Ma L, Zhao C, Chen J, Zheng J. Effects of anaerobic fermentation on black garlic extract by lactobacillus: Changes in flavor and functional components. Frontiers in Nutrition. 2021;**8**:645416

[85] Yin MC, Cheng WS. Antioxidant and antimicrobial effects of four garlic-derived organosulfur compounds in ground beef. Meat Science. 2003;**63**(1): 23-28

[86] Kanza Aziz A, Masood Sadiq B, Faiza A, Rasul HA, S. Storage stability of garlic fortified chicken bites. Journal of Food Chemistry and Nanotechnology. 2017;**3**(2):80-85

[87] Kaushal M, Gupta A, Vaidya D, Gupta M. Postharvest management and value addition of ginger (*Zingiber officinale* Roscoe): A review. International Journal of Environment, Agriculture and Biotechnology. 2017; **2**(1):397-412

[88] Kaushal M, Vaidya D, Kaushik R, Verma A, Gupta A. Standardization of formulation for development of ginger supplemented confectionary products. International Journal of Bio-Resource and Stress Management. 2018;**9**(2): 237-242

[89] Amer SA, Rizk AE. Production and evaluation of novel functional extruded corn snacks fortified with ginger, bay leaves and turmeric powder. Food Production, Processing and Nutrition. 2022;**4**(1):1-17

[90] Tanweer S, Chughtai MFJ, Zainab S, Mehmood T, Khaliq A, Junaid-Ur-Rahman S, et al. Comparative study of

physicochemical and hedonic response of ginger rhizome and leaves enriched patties. Czech Journal of Food Sciences. 2021;**39**(5):402-409

[91] Nadir AES, Helmy I, Kamil MM. Effect of using Jerusalem artichoke and inulin flours on producing low carbohydrate high protein pasta. Australian Journal of Basic and Applied Sciences. 2011;**5**(12):2855-2864

[92] Shin J-Y, Byun M-W, Noh B-S, Choi E-H. Noodle characteristics of Jerusalem artichoke added wheat flour and improving effect of texture modifying agents. Korean Journal of Food Science and Technology. 1991; **23**(5):538-545

[93] Bui CV, Siriwatwechakul W, Tiyabhorn W, Wattanasiritham T, Limpraditthanont N, Boonyarattanakalin S. Conversion of *Jerusalem artichoke* tuber powder into fructooligosaccharides, fructose, and glucose by a combination of microwave heating and HCl as a catalyst. Thammasat International Journal of Science and Technology. 2016;**21**(3):31-45

[94] Bakr ASHT, Elkot WF, Hussein AKHA. Impact of using *Jerusalem artichoke* tubers powder and probiotic strains on some properties of labneh. Journal of Food Technology & Nutrition Sciences. 2021;**3**(1):1-7

[95] Arshad MS, Sohaib M, Nadeem M, Saeed F, Imran A, Javed A, et al. Status and trends of nutraceuticals from onion and onion by-products: A critical review. Cogent Food & Agriculture. 2017;**3**(1): 1280254

[96] Gorrepati K, Khade YP. Mouth-watering value-added products of onion and garlic. Indian Horticulture. 2017;**62**(6):86-87

[97] Stearns LD, Petry TA, Krause MA. Potential Food and Nonfood Utilization of Potatoes and Related Byproducts in North Dakota. Fargo, North Dakota: North Dakota State University; 1994. 1189-2016-94269

[98] Wijesinha-Bettoni R, Mouillé B. The contribution of potatoes to global food security, nutrition and healthy diets. American Journal of Potato Research. 2019;**96**(2):139-149

[99] Arora A, Camire ME. Performance of potato peels in muffins and cookies. Food Research International. 1994;**27**(1): 15-22

[100] Kaur G, Kumar V, Goyal A, Tanwar B, Kaur J. Optimization of nutritional beverage developed from radish, sugarcane and herbal extract using response surface methodology. Nutrition & Food Science. 2018;**48**: 733-743. DOI: 10.1108/NFS-11-2017-0247

[101] Tanaka Y, Ohmiya A. Seeing is believing: Engineering anthocyanin and carotenoid biosynthetic pathways. Current Opinion in Biotechnology. 2008; **19**(2):190-197

[102] Truong V, Avula R, Pecota K, Yencho G. Sweetpotato production, processing, and nutritional quality. In: Saddiq M, Mark A, editors. Handbook of Vegetables and Vegetable Processing. Vol. 2. New Jersey, USA: John Wiley & Sons Ltd; 2018. pp. 811-838

[103] Mitiku DH, Abera S, Bussa N, Abera T. Physico-chemical characteristics and sensory evaluation of wheat bread partially substituted with sweet potato (*Ipomoea batatas* L.) flour. British Food Journal. 2018;**120**: 1764-1775. DOI: 10.1108/BFJ-01-2018-0015

[104] Gracia J, Anitha D, Jayalakshmi M. Nutrient analysis of *Ipomoea batatas*

flour and sensory property of the formulated product. Journal of Emerging Technologies and Innovative Research. 2022;**9**(2):810-813

[105] Güneri N. A review on turmeric (*Curcuma longa* L.) and usage in seafood. Marine science and technology. Bulletin. 2021;**10**(1):71-84

[106] Mahjoob M, Stochaj U. Curcumin nanoformulations to combat aging-related diseases. Ageing Research Reviews. 2021;**69**:101364

[107] Ipar VS, Singhal RS, Devarajan PV. An innovative approach using microencapsulated turmeric oleoresin to develop ready-to-use turmeric milk powder with enhanced oral bioavailability. Food Chemistry. 2022; **373**:e131400

[108] Choi Y, Ban I, Lee H, Baik MY, Kim W. Puffing as a novel process to enhance the antioxidant and anti-inflammatory properties of *Curcuma longa* L. (turmeric). Antioxidants. 2019; **8**(11):506. DOI: 10.3390/antiox8110506

[109] Badem A. Traditional turnip meals of Konya. Journal of Tourism and Gastronomy Studies. 2021;**9**(2):725-743

[110] Xue Y-L, Chen J-N, Han H-T, Liu C-J, Gao Q, Li J-H, et al. Multivariate analyses of the physicochemical properties of turnip (*Brassica rapa* L.) chips dried using different methods. Drying Technology. 2020;**38**(4):411-419

[111] Tripathi D, Yadav L. Formulation and quality evaluation of turnip green (*Brassica rapa*) powder incorporated food products. The Pharma Innovation Journal. 2021;**10**(4):653-657

[112] Leng MS, Tobit P, Demasse AM, Wolf K, Gouado I, Ndjouenkeu R, et al. Nutritional and anti-oxidant properties of yam (*Dioscorea schimperiana*) based complementary food formulation. Scientific African. 2019;**5**:e00132

[113] dos Santos RA, de Lima RR, de Lima MBD, do Nascimento EB, de Carvalho AMB, de Almeida Gadelha CA, et al. Influence of aqueous yam extract and goat milk casein powder on the characteristics of goat Greek-style yogurt. International Journal of Gastronomy and Food Science. 2022;**27**: e100465