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Vegetables of Temperate Climates: Carrot, Parsnip, and Beetroot

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Sources and Production

Carrots (*Daucus carota* L.), parsnips (*Pastinaca sativa* L.), and beets (*Beta vulgaris* L.) are horticultural crops that are grown on a relatively small scale compared with staple foods crops, such as rice, maize, and wheat. Unlike cereal grains and dry legumes, many horticultural crops have a relatively short shelf life, requiring ready access to cold storage, which limits their long-distance distribution, especially in less-developed countries. Nonetheless, because all of these vegetables are root crops, their shelf life is long when kept in cold storage, unlike leafy green vegetables, such as spinach and lettuce, although the leaves of carrots and beets can also be consumed.

Plants contain vascular systems that allow them to move water (xylem) and nutrients (phloem) throughout the plant. Besides orange, carrots are found in other colors. In unusually pigmented carrots and beets, the xylem and phloem are readily identifiable (Figure 1). Carrots and beets with more than one color are sometimes referred to as functional foods or designer vegetables. Purple color in carrots is usually darker in the outer phloem of the root and sometimes only on the root surface.

Carrots are available around the world (Table 1) and do well in cooler climates. The first definite records of carrots being used as a root crop are in Afghanistan and surrounding regions of Central Asia around 1100 years ago, when purple and yellow carrots were described. There are some indications that carrot may have been a root crop in the Roman Empire, but records are ambiguous. The color of carrots is an important part of the history of this crop. Orange carrots were first recorded in Europe in the 1500s and are the predominant color of the crop in all growing regions of the world today. Red carrots are primarily of Asian origin and are still common today. Purple carrots predate orange carrots and were one of the first types to be consumed by humans in Central Asia and the Middle East. Although no longer widely grown, white carrots, which lack pigment, were developed as a fodder crop for feeding livestock in Europe.

Biofortification is the process of breeding crops for enhanced nutritional value. Biofortification of orange carrots has resulted in carrots with high levels of α- and β-carotene (Figure 2) with an emphasis on breeding for deeper uniform orange color. Studies have shown that these carrots provide a little extra vitamin A when fed at similar levels in animals and humans, but substantial extra amounts of α- and β-carotene, which both have antioxidant activity, are made available to tissues. Other color combinations have been bred and include purple-white, purple-yellow, purple-orange, purple-red, purple-orange-red, red-orange, and orange-yellow.

Parsnip is a vegetable plant in the family Apiaceae. The plant was domesticated in the Mediterranean and was consumed in Roman times. Some confusion exists in historical accounts of this vegetable due to its similarity with carrot, to which it is related. White carrots exist but are not the same vegetable as parsnips. Parsnip is biennial and produces a rosette of leaves and a swollen taproot during the first season of growth. It is well adapted to cool growing regions and substantial production occurs in Canada.

Table beet was domesticated in the Mediterranean and originally used as a leaf crop. In its earliest forms, the crop did not have a swollen root and was only consumed for its leaves and petioles. Swiss chard most likely resembles this early form of the crop. As beet moved throughout the Mediterranean region and spread north, selection occurred for a swollen root that could be stored throughout the winter. This process of selection resulted in swollen rooted forms that became the modern, pigmented table beet. Selection among the swollen rooted forms also resulted in two additional crops: fodder beet and sugar beet; the former is used for livestock and the latter as an industrial source of sucrose. Sugar beet was developed in the eighteenth century from white fodder beets. A sugar beet is about 30 cm (12 in.) long and weighs 1–2 kg (2–5 pounds) at harvest.

Patterns of Consumption

Carrots, parsnips, and beets, like other root vegetables, store well and can be eaten throughout the winter when many other vegetables are out of season. They will keep best when stored in the refrigerator, in the crisper drawer, or in plastic bags and will last for 1 month or more.

Carrots are a popular vegetable, especially in Europe and the United States, and fresh-market carrot consumption in the United States has increased recently due in part to the introduction of ‘cut-and-peel’ carrots. Cut-and-peeled carrots offer a convenience to consumers in their ready-to-eat form that comes in a variety of package sizes. In the United States, ~4 kg (9 pounds) are available per capita each year (Figure 3 (a)). Orange carrots are likely the highest source of α- and β-carotene in the diet of many people in the United States, and thus, modern orange carrots are a significant source of vitamin A.

Carrot leaves are consumed in parts of Asia, used either fresh in a salad or cooked in other dishes. The young tender leaves are occasionally used as a stir-fried herb in China and Japan. Carrot leaves have a similar appearance to some of its wild relatives that are not carrots, and some of these wild relatives, such as hogweed or cow parsnip, have toxic compounds in their leaves. Carrot top consumers should avoid leaves from these wild plants. In the leaves, the carotenoids are located in the photosystems of the inner chloroplast membrane usually associated with lipids. Carrot leaves have a different carotenoid profile than the roots.

Parsnips can be eaten raw but are usually cooked. Taproots of parsnips have a mild and very pleasant flavor and are prized as an ingredient in soups and stews because of their rich flavor.
They contain more sugar and starch than other vegetable members of the *Apiaceae* family, such as carrot, and appear to have been used as a source of these compounds prior to the introduction of the potato. Parsnips are sweeter than typical carrots, especially when cooked. Parsnips have sugar content comparable to fruits, such as bananas and grapes. They can be baked, boiled, pureed, and roasted and are sometimes fried to make chips. It is interesting to note that the starch in parsnips converts to sugar when exposed to cold and thus winter parsnips are sweeter than autumn parsnips. Refrigeration will also cause them to develop more sweetness.

The table beet is consumed in a variety of ways. Compared with carrots, however, availability per capita in the United States has tended to decrease over the past few decades (Figure 3(b)). Leaves, particularly small leaves known as ‘baby leaves,’ are consumed as a salad crop. Roots are eaten in salads, placed on sandwiches, pickled, roasted, boiled, or used in soup. A substantial portion of the United States crop is canned. Beet root can be eaten raw and will maintain more of its folate content if not cooked. When table beet roots are consumed, the hypocotyl tissue is also consumed as it is a transitional zone between the root and stem. The root/hypocotyl is actually composed of supernumerary cambia, or zones of xylem and phloem tissue, that increase in size during growth. The root/hypocotyl region also contains storage parenchyma cells, where sucrose is stored. Table beet has long been known as a sweetener and was likely used in Roman times for this purpose.

The sugar beet was developed following the Napoleonic wars when Europe needed a domestic source of sugar that did not depend on the West Indies sugar trade. Sugar beet is a natural source of sucrose, which is not different from cane sugar. Sugar beets contain about 18% sucrose, which is about two to three times higher than table beets. Sugar beet must be processed quickly because it is perishable. Beet sugar represents about 50% of domestically produced sugar in the United States.

### Availability, Absorption, and Metabolism

In general, phytochemicals found in vegetables have putative mechanisms of action in the body including antioxidant effects, modulation of detoxifying enzymes, stimulation of the immune system, modulation of hormone metabolism, and antibacterial and antiviral effects. Brightly colored

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**Table 1** World carrot production and availability, 1965–2011

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Average of 3 years (e.g., 1975 = average of 1974–76).
Source: FAO yearbook production statistics.
vegetables, such as carrots and beets, generally contain high amounts of phytochemicals and nutrients.

In addition to being a significant source of \( \beta \)-carotene, orange carrots are likely the highest source of \( \alpha \)-carotene among all vegetables. Both of these orange compounds from carrots provide vitamin A upon central cleavage. Most mammals, including humans, are able to cleave \( \alpha \)- and \( \beta \)-carotene to vitamin A. \( \alpha \)-Carotene provides one molecule of vitamin A and one molecule of a compound commonly called \( \alpha \)-retinol, while \( \beta \)-carotene can provide two molecules of vitamin A due to its symmetrical structure (Figure 2). Thus, orange, red, and some purple carrots are great sources of vitamin A. Vitamin A is essential for healthy eyes, cell growth, and reproduction. It is also important in strengthening the immune system by keeping the skin, lungs, and intestinal tract mucosa healthy. When carrots are eaten, not only do they provide vitamin A, but also the excess carotenoids can be absorbed and circulated intact in the human body. In circulation, \( \alpha \)-carotene and \( \beta \)-carotene are predominantly associated with low-density lipoproteins. Therefore, some animals that have higher-density lipoproteins, such as gerbils and chickens, may not circulate much \( \beta \)-carotene in the blood.

Carrots of other colors have a different carotenoid profile. Yellow carrots contain lutein, which is bioavailable to humans, in addition to small amounts of \( \beta \)-carotene. Lutein is a xanthophyll carotenoid, which means it is partially oxygenated. Because it contains hydroxyl groups on both sides of the molecule (Figure 2), lutein cannot be cleaved by mammals to form molecules of vitamin A. A human study demonstrated that lutein from yellow carrots was 65% as bioavailable as that from a lutein supplement dissolved in oil.

Red carrots accumulate lycopene, a common pigment in red tomatoes, in addition to high amounts of \( \beta \)-carotene. Like \( \alpha \)- and \( \beta \)-carotene, lycopene is a hydrocarbon carotenoid, but it does not have any cyclic rings, making it quite different structurally from the other well-known carotenoids in carrots (Figure 2). Lycopene from red carrots is about 40% as bioavailable as that from tomato paste. For consumers who do not like tomatoes, red carrots are another food source of lycopene. Consumers in India actually prefer red-pigmented carrots to orange ones.

Other phytochemicals present in purple carrots include flavonoids, such as red or blue anthocyanins (Figure 4), and purple carrots may, or may not, contain carotenoids. Anthocyanin pigmentation develops independently of carotenoid colors, so some purple carrots contain \( \alpha \)- and \( \beta \)-carotene. Purple color may mask the appearance of carotenoids. The purple anthocyanins found in carrots are sometimes used as food colorants. Some of the carrot anthocyanins have an acyl chemical group, while some do not. The acylated anthocyanins of carrot are more stable when used as a food colorant, but the nonacylated anthocyanins are more bioavailable. Some strains of purple carrot are sometimes referred to as ‘black’ carrot because the anthocyanins are so concentrated that they have deep purple color in the phloem and xylem. Efforts to breed carrots of several colors have been on the rise, and within the past decade, purple-orange-red carrots have been bred for increased red color. These particular carrots would have anthocyanins, \( \alpha \)- and \( \beta \)-carotene, in addition to lycopene (Figure 1). A common name for these types of carrots is ‘rainbow carrots.’ Through outreach efforts, rainbow carrot seeds have been distributed to community and youth gardeners to build awareness and to use the harvested carrots to demonstrate the diversity of pigments in vegetables.

Lastly, carrots also contain phenolic acids that have a single aromatic ring. The main phenolic acids are chlorogenic acids.
(Figure 4), which are hydroxycinnamic acid derivatives formed by the esterification of cinnamic acids with quinic acid. These compounds contribute to the organoleptic properties of fresh and processed carrots. Approximately 30% of chlorogenic acids are absorbed by the intestine and the remainder is extensively metabolized by colonic microflora.

Although typical parsnips are white, they contain compounds known as polyacetylenes, which may impart beneficial properties to this vegetable. Plants synthesize polyacetylenes to protect them against pathogens and pests. They are derived from unsaturated fatty acids. One type of polyacetylene called falcarinol is highly bioavailable in humans, being rapidly absorbed after ingestion (Figure 4). Interestingly, falcarinol was viewed as a potentially undesirable component of food in the 1980s, and now, it is viewed by some as desirable.

Table beet is colored by betalain pigments (Figure 5). The betalains are a unique class of alkaloid pigments found in plant species in the order Caryophyllales and in some fungi. Tyrosine is converted to l-DOPA via hydroxylation and subsequently to betalamic acids via the extradiol ring cleavage reaction. Betalains are ultimately formed via spontaneous chemical conversion. Recently, the R locus that controls betalain pigment production in table beet was identified as a novel cytochrome P450. This protein provides the cyclo-DOPA moiety that is required for all red betacyanin pigments. Selection has been effective at increasing betalain concentration in table beet. Betalains are water-soluble, fairly easy to extract, and a commonly used source of natural colorants. After ingestion, betalains are thought to be degraded in the stomach and absorbed in the gut, possibly through passive diffusion. An estimated 50% of betalain is lost during digestion, and urinary betalain ranges between 0.3% and 1% after consumption of beet juice or extract, which may reflect low absorption. Food processing also affects betalain absorption, with lower bioavailability from the whole beet matrix compared with purified beet juice or extract.

Health Effects

Root vegetables provide energy through their carbohydrate content and are naturally low in fat. Root vegetables are a good source of fiber, ranging from 3 g fiber in 100 g of raw carrots and beets to 5 g in 100 g of parsnips. Cooking tends to lower the fiber content in beets and parsnips. Carrot fiber is highly regarded and has become of interest to food processors.
due to the large quantities of carrot waste, known as pomace, created in the cut-and-peel and juice industries. The insoluble fibers, primarily cellulose and hemicellulose, constitute the greatest portion of the total dietary fiber with small amounts of lignin. The soluble fibers include fermentable hemicellulose and pectin. The fiber composition of dried carrot pomace differs from whole carrot and depends on the processing method.

Raw root vegetables are also a good source of water ranging from 80% in parsnips to 88% in carrots and beets. Boiling the vegetables does not appreciably change the water content (<2%) when based on a 100 g serving. While cooking breaks down some nutrients, both carotenoids and anthocyanins of carrot are quite stable with light cooking. Root vegetables are also a good source of potassium providing ~ 350 mg in 100 g.

Research has focused on the numerous health benefits of phytochemicals, including those that are found in the root vegetables. Carrots, in particular, have been studied for nutritive benefits and color components and are widely considered a ‘functional food.’ The pigments in carrots serve an important role because they have been associated with reduced risks of atherosclerosis, cancer, and inflammation. Carrots have antioxidant capacity because both α-carotene and β-carotene are antioxidants, which are important to trap free radicals and fight against heart disease. Both carotenoids have been reported to have anticancer potential. Yellow carrots contain lutein, which has been implicated in improved eye health. Specifically, lutein and zeaxanthin are concentrated in the macula of the eye and may be important in preventing macular degeneration. Lutein has also been implemented in preventing some forms of cancers and reducing the risk of atherosclerosis. Intake of dietary lycopene, as found in red and some purple carrots, has been associated with a reduced incidence of some forms of cancer. Lycopene, which has much higher antioxidant potential than β-carotene, is also associated with a reduced risk of serum lipid oxidation and heart disease.

When carrots or carrot juice are consumed at a high level in the diet, a condition known as hypercarotenemia can occur. This is due in part to the downregulation of biochemical conversion of the provitamin A carotenoids to vitamin A as a way to protect the human body from hypervitaminosis A due to high vegetable intake. The carotenoids will accumulate in the adipose tissue and the yellow pigmentation of the palms is usually first noticeable. This is thought to be a benign condition.

Eleven different phenolic acids in orange, purple, yellow, and white carrots have been identified. Total concentration of all identified phenolic acids is greatest in the purple carrots followed by orange, white, and yellow. In particular, chlorogenic acid consumption has been associated with reductions in several chronic diseases.

Anthocyanins in purple and black carrots act as powerful antioxidants to sequester harmful free radicals in the body; however, human data are lacking. Anthocyanins may prevent heart disease by acting as anti-inflammatory agents and reducing lipid oxidation. Solid-colored purple carrots contain the most phenolic compounds and therefore may have higher antioxidant capacity in the human body.

Parsnips are a better source of vitamin C than carrots and beets. Parsnips and beets provide more folate than carrots. Falcarinol may be involved in carrot and parsnip beneficial effects on health.
health effects including anti-inflammatory, antiplatelet aggregation, and potential anticancer activity. While falcarnicol can cause allergic skin reactions, contact dermatitis from *Apiaceae* family vegetables is rare, likely due to the relatively low concentrations of falcarnicol in the species commonly consumed or sensitization from oral intake.

Parsnip leaves also contain furanocoumarins, which can cause photodermatitis if they are touched or brushed up against the skin in the presence of light. Burns caused by these compounds can be serious and can leave scars that do not easily disappear. Parsnips are therefore difficult to handle and individuals handling the crop require substantial protection during production. Parsnip root contains photocarcinogenic psoralens, which are not destroyed by cooking. However, the effect and potential toxicity of these chemicals from normal human consumption are not known.

Beet greens by weight have even more micronutrients than beetroot, including vitamin A as β-carotene, vitamin C, vitamin K, calcium, iron, magnesium, potassium, copper, and manganese. Beet leaves also contain a substantial amount of lutein and zeaxanthin and thus have health benefits associated with those carotenoids as detailed earlier for carrots.

Beets are among the vegetables with the highest antioxidant content. Betalain pigments are among the antioxidants in beets and may be associated with cancer prevention. Betalains in beet extract reduced tumors associated with skin and lung cancer in mice, but no human studies have been done to date that demonstrate substantial health benefits. Betalains have a large nonpolar surface area that allows them to interact with lipid membranes and low-density lipoprotein particles in the blood reducing oxidation.

Oxalic acid is related to the formation of kidney stones and has other antinutritive properties. Table beet is considered a high oxalate food, and therefore, breeding to decrease oxalic acid levels is an area of interest. In a collection of table beet cultivars, mean values were from 722 to 1909 mg in 100 g of leaf tissue and 553 to 1679 mg in 100 g leaf tissue for total and soluble oxalate levels, respectively. Root-soluble oxalate values ranged from 103 to 171 mg in 100 g of root tissue, and total oxalate values ranged from 95 to 142 mg in 100 g of root tissue. These findings confirm relatively high levels of oxalate in table beet.

Many people are familiar with ‘beeturia,’ or the excretion of red urine following beet consumption. This occurs in 10–14% of the population and seems to be a harmless idiosyncratic reaction relating to digestion of the beet pigments. The occurrence of beeturia is probably related more to an individual’s physiological conditions (such as stomach acidity), nutritional status, type of beet, and amount consumed, rather than genetics as previously thought.

Summary

Root vegetables are a source of energy in the form of carbohydrates and a good fiber source. They contain essential nutrients as well as a variety of classes of phytochemicals associated with optimal health.

See also: Antioxidants: Role on Health and Prevention; Bioavailability of Nutrients; Carotenoids: Occurrence, Properties and Determination; Colors: Properties and Determination of Natural Pigments; Dietary Fiber: Determination; Functional Foods; Phenolic Compounds: Bioavailability and Health Effects; Phenolic Compounds: Occurrence, Classes, and Analysis; Salad Crops: Root, Bulb, and Tuber Crops; Sugar Alcohols; Tannins.

Further Reading


