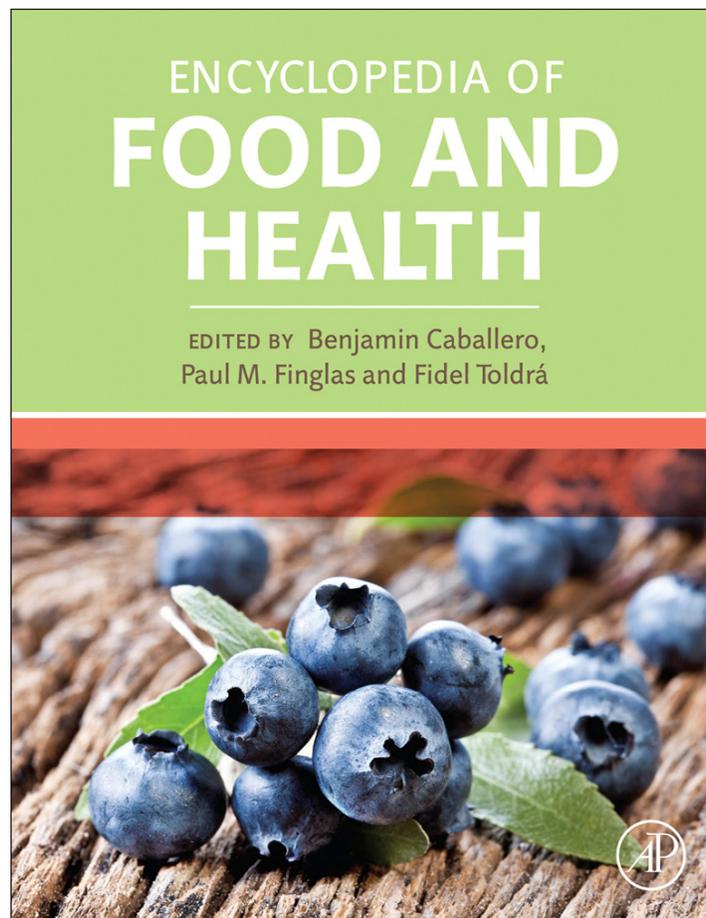


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Brassica: Characteristics and Properties

JW Fahey, Johns Hopkins University, Baltimore, MD, USA; Johns Hopkins University, Bloomberg School of Public Health, Baltimore, MD, USA

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Background

The brassicas comprise a large and diverse group of widely consumed vegetables. *Brassica* is the Latin name of a genus that is taxonomically placed within the Brassicaceae (Cruciferae), which is one of the ten most economically important plant families in the world. The genus *Brassica* includes, but is not limited to, the following vegetables: bok choy, broccoli (calabrese and sprouting broccoli), Brussels sprouts, cabbage, cauliflower, Chinese cabbage, kale, kohlrabi, mizuna, swede (rutabaga), and turnips. Rapeseed or canola, one of the world's most widely grown oilseed crops, is also a nonvegetable *Brassica* species and is discussed elsewhere. Other closely related vegetables within the Brassicaceae family (also known as brassica or cruciferous vegetables, crucifers, cole crops, or mustards) include radish (*Raphanus sativus*), watercress (*Nasturtium officinale*), arugula (*Eruca sativa*), horseradish (*Armoracia rusticana*), maca (*Lepidium meyenii*), mashua (*Tropaeolum tuberosum*), wasabi (*Wasabia japonica*), and cress (*Lepidium sativum*). One of the common characteristics of brassica vegetables is that they all contain glucosinolates, sulfur-containing compounds that are hydrolyzed to produce the so-called mustard oils, which impart characteristic tastes and odors to these vegetables.

Vegetables are considered to be an essential part of a balanced diet. The brassica vegetables in particular add considerable visual or aesthetic appeal to a meal, since many of them are leafy and green. They are rich sources of dietary fiber, and many are good sources of calcium, carotenoids (provitamin A), vitamin C, and certain beneficial phytochemicals. They also have distinctive flavors and textures, which enhance palatability in the eyes of many consumers, though they evoke quite violent negative emotions in others.

Historical Origins of Modern Brassica Vegetables

Most scholars place the wild cabbage at the head of the family tree that has led to the development of the 400 or so varieties of *Brassica oleracea*. Although there is still considerable disagreement among scientists as to precisely how all of the modern brassica vegetables arose, there are widespread references to these vegetables in writings dating back many centuries. Their taxonomy, too, is a subject of considerable debate and should be regarded as being in a state of flux. Genus, species, variety, subspecies, botanical group, and cultivar designations are frequently interchanged in the descriptive literature. Commonly recognized taxonomic designations are used herein, wherever possible.

It is widely agreed that there are six major vegetable *Brassica* species. Three are monogenomic, and three are amphidiploid (being diploid for two genomes, each originally contributed by a different species). These major categories are thus commonly

designated as having A, B, or C genomic compositions, and their relationships are shown in [Table 1](#).

The ancestral wild cabbage was almost certainly a seaside plant of northern European or Mediterranean origin. All of the wild brassicas today occur in cliffs and rocky islets in fairly isolated places. Wild *B. oleracea* varieties still grow as perennials along the coasts of northern Spain, western France, and southern and southwestern Britain. Over time, some 400 varieties have been created, which include cabbages, kohlrabi, oilseed rape, Brussels sprouts, cauliflower, and broccoli. Cabbages were not eaten by the Hebrews or the Egyptians. None of the crucifers are mentioned in the Old Testament, and the only crucifer mentioned in the New Testament (Mark 4:30–32) is mustard seed. The ancient Romans and Greeks, however, were quite familiar with cabbages and cauliflower and believed that eating cabbage during a banquet would prevent one from becoming drunk. Dietary cabbage intake was discussed in the writings of Pythagoras, Diogenes, and Cato, to name a few. Cato, for example, recommended cabbage in the diet to prevent disease and prolong life and claimed to owe his procreative prolificacy (he had 28 sons) to cabbage. In the Middle Ages, cabbage plasters were used for medicinal purposes, and cabbage was used for cough syrup and wound dressings. In the 1700s, they were used aboard ships for their vitamin C content and were used as dressings to combat gangrene.

Broccoli (from the Italian 'brocco,' arm or branch) is widely presumed to have developed from the wild cabbage that was native to coastal Europe and spread through the Near East to the Orient between 2000 and 2500 years ago. Some authorities consider that sprouting broccoli (something resembling modern-day broccoli) was first domesticated and cultivated in Italy during ancient Roman times. A vegetable that was probably broccoli was described by the Roman botanist Pliny (first century CE). There is no consensus, however, on the translation of the early name 'cyma,' and there is concern that the writings of early botanists may have confused 'broccoli' and 'cauliflower' as we know them today. Others maintain that early selection and domestication of broccoli may have been made in Asia Minor, with a cultivated form being brought to Italy by early traders in the 1500s. What is certain, however, is that broccoli (also known at that time as Italian asparagus or sprouting broccoli) was introduced to England around the 1720s. The following passage from Stephen Switzer's *The Practical Kitchen Gardiner* (1727) illustrates the point:

As for the broccoli, there are three kinds of it, one of which yields sprouts button'd at their points, or headed like small collyflowers; another sort with curl'd leaves, which produce sprouts button'd on the points like asparagus; and a third with curl'd leaves of a pale green colour, which yield sprouts like the red kind; the two are to be had at several places about London; but the first is very rare to be had, but from some few gentlemen that have them yearly from Italy...

Table 1 Haploid chromosome number and genomic compositions of the six major *Brassica* species

Species	Haploid chromosome number	Genome
<i>B. rapa</i>	10	A
<i>B. nigra</i>	8	B
<i>B. oleracea</i>	9	C
<i>B. juncea</i>	18	AB
<i>B. napus</i>	19	AC
<i>B. carinata</i>	17	BC

By the late 1700s, broccoli was introduced to the American colonies, where it was grown by Italian immigrants on the East Coast of the United States but was otherwise little known until the 1920s. In 1912, the Stokes Seeds company brought broccoli seed into the United States and started selling to growers in 1918. In 1923, the D'Arrigo Brothers Company initiated field trials in California and, by 1925, was shipping ice-pack freight car loads of broccoli back to the east coast.

Commonly Cultivated Brassica Vegetables

Broccoli, Including Broccoli Sprouts (*B. oleracea* var. *italica*)

This is also known as calabrese or sprouting broccoli. The most valued portions of broccoli plants are the heads, which are inflorescences consisting of immature fully differentiated flower buds and tender upper stems. Both primary and secondary inflorescences are eaten, and lower stems are eaten too, but are not as prized due to their tough outer 'rind.' Broccoli is available commercially as fresh or frozen florets and is used raw in salads or as vegetable crudité. It is also frequently cooked and served by itself as well as being a component of many cooked and stir-fried dishes. There are over 100 commercial hybrid cultivars of broccoli, derived from a limited number of landraces or open pollinated cultivars that include purple sprouting, purple cape, purple Sicilian, white sprouting, and calabrese or green sprouting broccoli. Cut broccoli shoots or florets are very perishable and must thus be cooled (e.g., vacuum cooling) very soon after picking. Crushed ice or an ice slurry is typically blown into cartons of broccoli within a few hours of their being picked. California and Mexico in North America and Italy, France, and Spain in Europe are the major production areas. Consumption of broccoli in the United States has been steadily climbing since about 1970. In 1970, the total per-capita consumption was about 0.7 kg and is presently (2012 figures) about 3.6 kg. The development of hybrids in the late 1970s and their subsequent marketing by the vegetable seed companies were responsible for much of the increased consumption in the 1970s and 1980s. Impetus for the dramatic increase in consumption over the past 20 or so years has come from the health aura, which broccoli has recently enjoyed. Broccoli and kale are regularly identified as the vegetables eaten most often for health reasons, including cancer prevention and high-fiber, vitamin C, folate, and calcium content. Broccoli sprouts (seeds germinated in water, without soil, and grown as green sprouts for a few days) have added further evidence to the literature on broccoli's health

benefits and are currently being evaluated in clinical trials for their ability to mitigate or prevent a wide spectrum of chronic diseases.

Broccoli Raab (*B. rapa* var. *rapa*)

Broccoli raab is also known as broccoli rabe, broccoli babe, rapini, broccoletti di rape, broccoletto, turnip broccoli, cima di rapa, Italian turnip, sparachetti, or taitcat. Broccoli raab has also been classified botanically as *B. campestris* or *B. ruvo*. It is a bitter-tasting vegetable similar in appearance to Chinese kale but non-heading and with thinner stems and smaller flowers than broccoli. It is long been considered a delicacy in Italy, typically lightly sautéed with garlic. It has recently gained interest in the United States and is considered a 'new' vegetable by some.

Brussels Sprouts (*B. oleracea* var. *gemmifera*)

Brussels sprouts are a relatively young member of the brassica family. They originated in Belgium in the 1500s and by the 1700s were appearing on tables around the world. Brussels sprouts grow as a tall (~1 m) single-stem biennial from which the axillary buds, resembling miniature cabbage heads, are harvested. They are generally eaten after cooking (steaming or boiling) and are available commercially either fresh or frozen. Brussels sprouts require a long growing season, and vegetable quality is adversely affected by warm weather.

Cabbage (*B. oleracea* var. *capitata*)

Cabbage has been cultivated, and even revered, as a vegetable by the ancient Greeks as far back as 2600 years ago, and it has also had a long history of medicinal use. There are scores of references to its use for such diverse purposes as the prevention of drunkenness, headache, stomach ailments, and even cancer. Cabbage leaves have long been used as poultices for application to tumors, and even in modern times, they have been under investigation as a means for preventing or treating breast engorgement in nursing mothers.

All cabbages have heads formed from tightly packed leaves. There are many distinct head types, the most common being Wakefield (with small, early, white, pointed heads; for fresh market), red (leaf surfaces are pigmented and they have medium very firm, round heads; for fresh market and storage), Danish Ballhead (round, very firm heads and light green leaves; for fresh market and storage), and Savoy (some authorities designate this *B. oleracea* var. *sabauda*) (round, loose heads with crinkled or blistered leaves; for fresh market and storage). Cabbage is typically eaten fresh, processed into a salad-like dish called coleslaw, and boiled or eaten as a fermented and pickled product called sauerkraut. Cabbages are important as a fresh market crop as well as a processing crop in most parts of the world and rank in the top ten vegetables in both sales and volume in North America and much of Europe.

Cauliflower (*B. oleracea* var. *botrytis*)

The edible portion or head of cauliflower is composed of tightly clumped, undifferentiated shoot apices on top of

hypertrophied, highly branched fleshy stem tissue commonly referred to as curds. Referred to by Mark Twain as “nothing but a cabbage with a college education,” cauliflower curds, unlike broccoli, are actually degenerate shoot tips that are most frequently white in color (lacking chlorophyll), although purple, green, and orange cultivars now exist. Cauliflower is not as cold-tolerant as many other brassica vegetables. It is grown commercially in France, Italy, the United Kingdom, and North America, and it is eaten in the same manner as broccoli as well as being pickled. It is available commercially as fresh or frozen curds.

Charlock (*B. kaber*, also *B. arvensis*, or *Sinapis arvensis*)

Charlock is also known as kaber. The seeds of this plant, likely of Mediterranean origin, are used as a condiment, and the leaves are eaten as a potherb. The seeds are not as pungent as those of other mustards.

Chinese Cabbage (*B. rapa* var. *pekinensis*)

Chinese cabbage is also known as napa, napa cabbage, pe-tsai, wongbok, or chihli. This is a vegetable of major importance in China (over 300 000 ha grown), Korea, Taiwan, and Japan. Grown as an annual crop, most cultivars are biennial and produce tight, compact, cylindrical heads. This vegetable has been cultivated in China for over 1600 years and accounts for a major fraction of the total vegetable consumption in certain (northern) areas of the country. In Korea, it is fermented to produce (preserved) kimchi, which is thus a yearlong, ubiquitous commodity in that country.

Chinese Kale (*B. oleracea* var. *alboglabra*)

This is also known as gai lan, Chinese broccoli, gai lon, gai lam, kai laan, white-flowered broccoli, or fat-shan. Compared to broccoli, Chinese kale has more, slender, dark green leaves, longer stems, and very few florets, which are similar to those of broccoli. Flower buds, flower stalks, and young leaves are consumed, primarily in salads and stir fries. Chinese kale is relatively new to Japan, western Europe, and US cuisines but extensively grown in Taiwan, Southeast Asia, and China. It is relatively fast growing and heat-tolerant.

Chinese Mustards (*B. rapa* ssp. *chinensis*)

These include bok choy, pak choi, choy sum, and Shantung cabbage and are also known as Chinese white cabbage and celery mustard. Pak choi and bok choy are sometimes errantly referred to as Chinese cabbages. *B. rapa* ssp. *parachinensis*, also known as mock pak choi, choy sum, cai tai, or saishin, has been cultivated since the fifth century CE in Asia and continues to be very important vegetables, especially in China. Pak choi is the more leafy cultivar, and bok choy is notable for its massive leaf midribs, which are white and fleshy. This subspecies is a biennial, which is grown as an annual for its edible leaves. Plants can reach 0.6 m tall and can weigh over 2 kg. Leaves are usually consumed fresh but are also dried after blanching, for use through periods when fresh vegetables are not plentiful.

Collards (*B. oleracea* var. *sabellica*)

Available commercially as fresh, canned, or frozen leaves, collard greens are popular in the southern United States, where they are grown along the eastern portion of the country. As such, it is a much more heat-tolerant crop than its close relative, kale. The plants are nonheading and up to 1.25 m tall, and the broad, flat, or slightly furrowed leaves form as a rosette on a minimal stem.

Colza (*B. napus* var. *napus*)

Colza is also known as vegetable rape, xi yang you cai, and chou navet. Colza oil (expressed from seeds) is commonly consumed in India and China. Foliage and sprouted seeds are eaten in salads or as a potherb; inflorescences are prepared like broccoli.

Kale (*B. oleracea* var. *acephala*)

There are many ‘kales,’ some of which are classified taxonomically into other *Brassica* species or varieties. Kale includes kitchen kale, green kale, dwarf Siberian kale, marrow stem kale, tronchuda kale, curly leaf kale, Scotch kale, tree kale, and borecole. Although highly variable, kale is characterized by a nonheading rosette-like whorl of foliage; a short, erect stem; and large, upright, curly leaves. They are used mainly for their edible foliage and are generally eaten cooked, but are sold fresh, canned, and frozen, or used as garnish. Among the commonly grown kales are the following:

- Branching bush kales (sometimes classified as *B. oleracea* var. *fruticosa*): also known as cow kale or borecole (sometimes classified as *B. oleracea* var. *selenesia*), these were often cultivated in the past for their edible foliage and have been used extensively for animal fodder.
- Thousand-headed kale (*B. oleracea* var. *ramosa* or *B. oleracea* var. *millecapitata*).
- Inflorescence kales (a term used by some to describe cauliflower, broccoli, and related brassica vegetables).
- Galega kale (also known as couve galega): a traditional and widely grown Portuguese nonheading kale with long petioles, large midribbed leaves, and an elongated stem that can reach 3 m; leaves are picked one by one and used for traditional soups or for animal feed.
- Marrow stem kale (*B. oleracea* var. *medullosa*): a particularly prolific type of kale used exclusively for animal feed.
- Siberian kale (also classified as *B. napus* var. *pabularia*): also known as Hanover salad, a leafy vegetable, similar to collards, which is used fresh in salads and cooked as a potherb.

Kohlrabi (*B. oleracea* var. *gongylodes*)

This is also known as knol khol or turnip cabbage. The edible portion of kohlrabi is the fleshy, swollen, tuber-like enlargement of the short, unbranched stem, which may be white, green, or purple and develops just above the surface of the soil. This vegetable developed in northern Europe about five centuries ago. It resembles turnip and rutabaga in flavor and texture but becomes highly fibrous if not harvested at peak maturity.

Mizuna (*B. rapa* ssp. *japonica*)

Also known as mibuna, curled mustard, or Japanese greens, mizuna is a cool-tolerant relative of the leafy turnips that has recently been introduced to the West.

Mustard (Various Latin Binomials)

Plants from this diverse group have been used worldwide for centuries as a condiment (mustard seed; also known as black mustard, brown mustard, and *B. nigra*) and as a vegetable (mustard greens; *B. juncea*). Most well known among the mustards are

- white or yellow mustard (*B. hirta*, *B. alba*, or *Sinapis alba*),
- Chinese mustard (*B. japonica*),
- black mustard (*B. nigra* or *Sinapis nigra*) and field mustard (*B. campestris*),
- Ethiopian mustard and Abyssinian mustard (*B. carinata*).

Many of the so-called brown mustards (*B. juncea*) have been assigned unique variety names. Common English and Chinese names are as follows:

- *B. juncea* var. *capitata* (capitata mustard, jie qiu jie)
- *B. juncea* var. *crassicaulis* (bamboo shoot mustard, sun zi jie)
- *B. juncea* var. *crispifolia* (cut-leaf mustard and curled mustard, mi tuo jie)
- *B. juncea* var. *foliosa* (small-leaf mustard, xiao ye jie)
- *B. juncea* var. *gemmifera* (gemmiferous mustard, bao zi jie)
- *B. juncea* var. *involuta* (involute mustard, juan xin jie)
- *B. juncea* var. *latipa* (wide petiole mustard, kuan bing jie)
- *B. juncea* var. *leucanthus* (white-flowered mustard, bao hua jie)
- *B. juncea* var. *linearifolia* (line mustard, feng wei jie)
- *B. juncea* var. *longepetiolata* (long petiole mustard, chang bing jie)
- *B. juncea* var. *megarrhiza* (tuberous-rooted mustard, dal tou jie)
- *B. juncea* var. *multiceps* (tillered mustard, fen nie jie)
- *B. juncea* var. *multisecta* (flowerlike leaf mustard, hua ye jie)
- *B. juncea* var. *rugosa* (large-leaf mustard, brown mustard, Indian mustard, and mustard greens; rai and dai ye jie)
- *B. juncea* var. *strumata* (strumous mustard, tsatsai and zha cai)
- *B. juncea* var. *tumida* (swollen stem mustard, jing liu jie)
- *B. juncea* var. *utilis* (peduncled mustard, tai jie)
- *B. rapa* var. *narinosa* (broad-beaked mustard, wu ta cai and taasai)

Swede (*B. napus* var. *napobrassica*)

Also known as rutabaga in the United States, swede is considered a 'root crop,' though, technically, this is not accurate. It is an annual crop grown as animal fodder and consumed by human beings after cooking or pickling. It has been grown for about three centuries, originating in Sweden and spreading throughout Europe. The flesh is white or orange and similar in flavor and texture to turnips with equivalent, excellent storage characteristics but low commercial value. Swede not only is much more hardy than the turnip but also takes much longer to mature. The leaves are used as a potherb.

Tendergreen (*B. rapa* ssp. *perviridis*)

Also known as spinach mustard, mustard spinach, or komatsuna, this leafy relative of the turnip is reasonably cold-tolerant, surviving temperatures as low as -15°C . It has large, dark green, mildflavored foliage, which is eaten fresh and pickled, primarily in Korea, Taiwan, and Japan.

Texsel Greens (*B. carinata*)

Of Ethiopian origin, the early growth of this plant is valued for its high protein and vitamin C content and is eaten raw in salads or lightly boiled as a spinach substitute. It has a milder flavor than collards or mustard greens.

Tronchuda Cabbage (*B. oleracea* var. *costata*)

Also known as Portuguese cabbage, couve tronchuda, Galician cabbage, braganza, or sea-kale cabbage, these are loose-headed cabbages that have large leaves with succulent midribs. It is believed that the many landraces of this vegetable arose from an initial hybridization of cabbage and kale.

Turnip (*B. rapa* var. *rapifera*)

Turnip is very similar to rutabaga in that it is a 'root crop' (technically incorrect) that produces high amounts of biomass per hectare, is high in starch content, and has very favorable storage characteristics. It appears to have been around for about 4000 years, originating in eastern Europe and Siberia and gradually spreading across Europe. As with swedes, turnips are generally eaten after cooking and can also be processed for use in pickled or mixed vegetables. Turnip greens are eaten in season as a fresh leafy green vegetable.

Turnip Rape (*B. campestris* var. *oleifera*)

The seeds of this plant produce an oil that is sometimes used in cooking, and it has relatively high levels of unsaturated lipids. It is becoming more popular as an oilseed but is distinct from the very widely grown oilseed rape (*B. napus* var. *oleifera*). The foliage of the plant is used as a potherb and garnish.

'New' Brassica Vegetables

A number of 'new' brassica vegetables have been produced under trade names, primarily by cross hybridization between existing taxa. These include the following:

- Broccolini: a cross between Chinese kale and broccoli trademarked by Mann Packing Co. (California, the United States)
- Asparation: a cross between Chinese kale and broccoli trademarked by Sakata Seed Inc. (California, the United States)
- Broccoflower (*B. oleracea* var. *botrytis*): a bright green cauliflower originating in Holland and trademarked by T & A (Tanimura & Antle, California, the United States) about two decades ago

Regional Preferences

Brassica vegetables are a large group of primarily herbaceous plants that includes a number of the world's most commonly cultivated vegetables. Though the progenitor species likely originated in the Mediterranean region, the cultivated brassica vegetables are of cosmopolitan distribution. Cultivars have been adapted for worldwide production, from the tropics to the Arctic Circle. The largest cabbages in the world have, in fact, been grown near Fairbanks, Alaska, the United States.

Brassica vegetables include a large number of taxonomically closely related, but morphologically and organoleptically diverse, plants. These species have been cultivated for many centuries and have been extensively crossed and hybridized. Many cultivars have been developed in microenvironments or very small geographic regions where they have remained essentially isolated for decades, or even centuries. For example, certain small villages or regions in Italy have their own very distinctive broccoli cultivars. Since these vegetable gene pools have remained isolated for hundreds of generations of

selection, there has been considerable development of phenotypes that diverge from a common ancestor. The relationships of some of the more common brassicas are detailed in Figure 1.

Dietary and Commercial Importance

From a nutritional standpoint, these vegetables are perhaps best recognized as excellent sources of vitamin C, fiber, calcium, and certain phytochemicals such as carotenoids (provitamin A) and glucosinolates (which have been the source of considerable recent scientific research as cancer protective agents). The contents of vitamins, minerals, and phytochemicals are, however, highly dependent on both genetic and environmental variables. Plant cultivar or variety; the environment in which the plant is grown (e.g., amount of sunlight, drought stress, and temperature); the conditions under which it is harvested, stored, and transported to market; and the way in which it is prepared for the table and consumed all play key

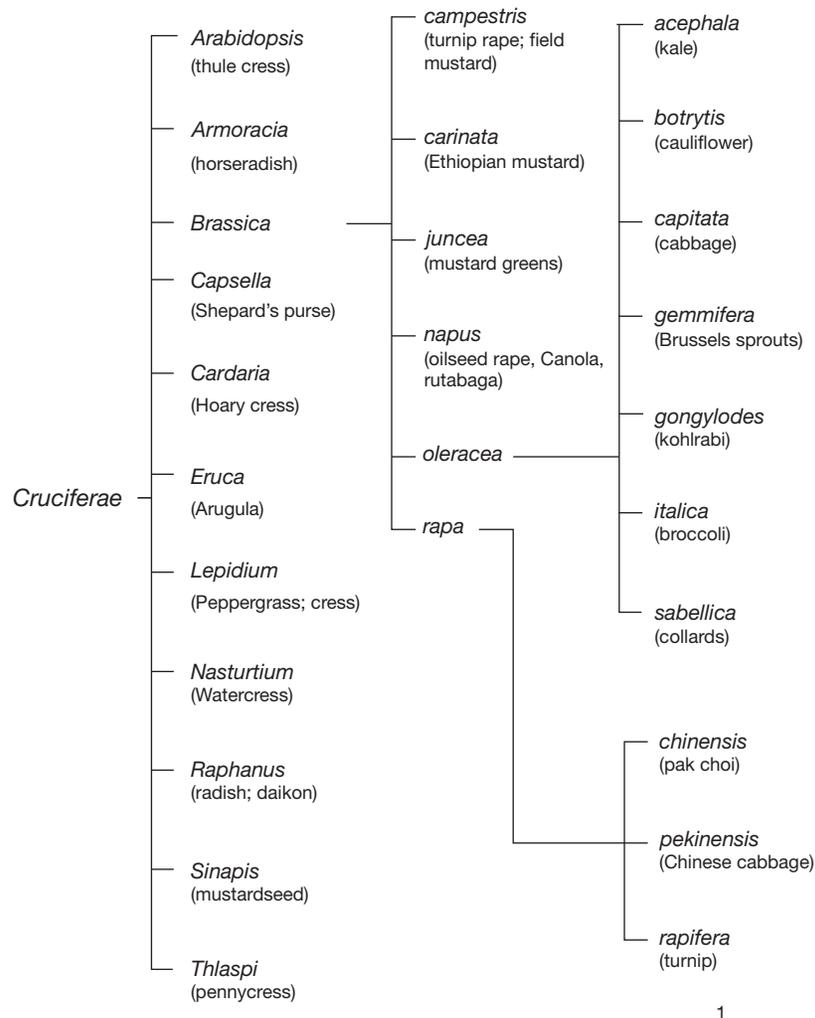


Figure 1 The world's most commonly known brassicas. Note that there are many hundreds of edible brassica species. Three of the well-known species are not commonly eaten, *Arabidopsis* (a genetic 'model organism'), *Capsella*, and *Cardaria*, which actually contains a pervasive and invasive weed in western US rangeland in which the phytochemical sulfuraphane was first identified.

roles in the ultimate nutritional value of that vegetable. Water-soluble components such as vitamin C and glucosinolates (see succeeding text) are easily leached out in the pot liquor during cooking. These and other beneficial chemicals can exhibit a tremendous gradient from one portion of the plant to another, and it is often quite difficult to assess these differences without performing sophisticated chemical analyses. Nonetheless, the brassica vegetables remain among the best sources of the dietary components mentioned earlier and should be consumed regularly as part of a diet rich in fruits and vegetables.

In the West, broccoli, Brussels sprouts, cauliflower, cabbage, and kale are the most significant brassica components of the diet. In the East, the so-called oriental brassicas (Chinese cabbage, tendergreen (spinach mustard), bok choy, pak choi, mizuna, celery mustard, and Chinese mustard) as well as spinach mustard and mizuna greens, Chinese kale (Chinese broccoli), and daikon (Japanese radish – a cruciferous root crop) are the main brassica vegetables of commercial and dietary importance.

Cultivation and Postharvest

The brassica vegetables are hardy, cool-season vegetables that grow best in temperatures in the range of 15–20 °C and have similar cultural requirements. Cabbage plants that have been hardened off can tolerate temperatures as low as –4 °C for short bursts, and broccoli and cauliflower plants thrive in light frosts. Almost all cole crops decline in quality when temperatures are in excess of 26–27 °C. Under irrigation (guaranteed water supply), broccoli crops can be harvested in 10–15 weeks from direct seeding, cabbage crops in 13–17 weeks, and cauliflower crops in about 13–16 weeks, depending on the temperature and climate. Brassica vegetables can be grown on a wide range of soil types, and in addition to direct seeding, many crops are now grown from glasshouse transplants. All brassica vegetables are more or less susceptible to the same diseases and insect pests. More specific agronomic advice is beyond the scope of this article.

Although some brassica crops do not need cooling after harvest, broccoli and cauliflower require immediate pre-chilling to 4 °C. These crops are typically hydrocooled or immersed in an ice slurry. They must be refrigerated for transport and storage and have a storage life of about 2 weeks (broccoli), to 4 weeks (cauliflower), to as much as 6 months for some cabbage varieties grown in cooler climates.

Nutritional Value and Chemical Composition

Table 2 summarizes the nutritional value and chemical composition of broccoli, Brussels sprouts, cabbage, red cabbage, Savoy cabbage, Chinese cabbage, cauliflower, collards, cress, kale, kohlrabi, mustard greens, tendergreen, and swede.

Vitamin A, Vitamin C, Selenium, Calcium, and Fiber

The brassica vegetables are excellent sources of calcium, fiber, vitamin A (in the form of β -carotene) or provitamin A, and vitamin C (especially broccoli, kale, and tendergreen). The

element selenium can be incorporated into the tissues of brassica vegetables (in particular broccoli), where it can reach rather high levels, and the vegetable may be of therapeutic value as a source of this antioxidant element due to its special availability from such tissues.

Phytochemical Attributes (e.g., Glucosinolates/Isothiocyanates, Carotenoids, and Flavonoids)

All of the brassica vegetables contain glucosinolates, at concentrations of up to 3% by weight in the seeds of some plants. These sulfur-containing compounds and their breakdown products have long been known for their fungicidal, bactericidal, nematocidal, and allelopathic properties, as well as for the goitrogenic or antinutritional glucosinolates in the protein-rich, defatted meal from widely grown oilseed crops (e.g., rapeseed) and in some domesticated brassica vegetables (e.g., Brussels sprouts). When used as animal feed, rapeseed meal can have pronounced deleterious health consequences on livestock due to ingestion of excessive quantities of 'progoitrin' (e.g., when livestock are fed a meal produced from defatted rapeseed containing the progoitrin), which may interfere with thyroxine production, drastically reducing iodine supply to the thyroid gland and resulting in the development of goiter and other associated problems. Recently, however, other members of this large group of compounds (e.g., glucoraphanin, sulforaphane, phenethyl isothiocyanate, benzyl isothiocyanate, crambene, and indole-3-carbinol) have attracted intense research interest because of their cancer chemoprotective and antioxidant attributes. Certain compounds (e.g., sulforaphane) have been shown to be potent inducers of mammalian detoxication enzymes, which facilitate the deactivation and excretion of many carcinogens from the body. The use of a number of these compounds in a dietary strategy for cancer prevention is now being investigated in clinical trials worldwide, particularly as very young plants (e.g., broccoli sprouts).

The brassica vegetables are generally very rich sources of the antioxidant and provitamin A carotenoids (e.g., lutein, zeaxanthin, and β -carotene). These compounds are long-chain, fat-soluble substituted hydrocarbons, which are the light-gathering accessory pigments typically found in the leaves, stems, and inflorescences of most plants. Since these are typically the plant organs that are eaten, they can be regarded as typical 'dark green leafy vegetables' and good sources of such compounds (**Table 2**). Certain *Brassica* vegetables, such as kale and broccoli, are particularly rich in these compounds, and the edible head of cauliflower is devoid of them. A mutant, orange cauliflower plant was found growing in a Canadian field about 40 years ago, however, which is currently being investigated as a very potent source of β -carotene and a very useful system for scientists to unravel some of the biochemical and molecular mysteries still surrounding carotenoid production in plants. Though an orange cauliflower is now being marketed, the application of this research may result ultimately in the introduction of higher-carotenoid varieties of some of the world's staple crops and a reduced incidence of vitamin A deficiency (which can be reduced by the ingestion of β -carotene-rich foods).

The brassica vegetables, though not unique in this respect, are also good sources of various flavonoids and their

Table 2 Nutrient composition per 100 g serving of selected raw brassica vegetables^a

Nutrients	Broccoli	Brussels sprouts	Cabbage	Red cabbage	Savoy cabbage	Pak choi	Pe-tsai	Cauliflower	Collards	Cress	Kale	Kohlrabi	Mustard greens	Tendergreens	Swede
<i>Gross composition</i>															
Water (g)	86.00	86.00	92.18	90.39	91.00	95.32	94.39	92.07	89.62	89.4	84.04	91.00	90.70	92.20	89.43
Energy (kcal)	34	43	25	31	27	13	16	25	32	32	49	27	27	22	37
Protein ($N \times 5.95$) (g)	2.82	3.38	1.28	1.43	2.00	1.50	1.20	1.92	3.02	2.60	4.28	1.70	2.86	2.20	1.08
Total lipid (g)	0.37	0.30	0.1	0.16	0.10	0.20	0.20	0.28	0.61	0.70	0.93	0.10	0.42	0.30	0.16
Carbohydrate (g)	6.64	8.95	5.80	7.37	6.10	2.18	3.23	4.97	5.42	5.50	8.75	6.20	4.67	3.90	8.62
Fiber, total dietary (g)	2.6	3.8	2.5	2.1	3.1	1.0	1.2	2.0	4.0	1.1	3.6	3.6	3.2	2.8	2.3
Ash (g)	0.87	1.37	0.64	0.64	0.80	0.80	0.98	0.76	1.32	1.80	2.01	1.00	1.36	1.40	0.71
Sugars, total (g)	1.7	2.2	3.2	3.83	2.27	1.18	1.41	1.91	0.46	4.4	2.26	2.6	1.32	– ^b	4.46
<i>Minerals</i>															
Calcium (mg)	47	42	40	45	35	105	77	22	232	81	150	24	115	210	43
Iron (mg)	0.73	1.4	0.47	0.8	0.40	0.80	0.31	0.42	0.47	1.30	1.47	0.40	1.64	1.50	0.44
Magnesium (mg)	21	23	12	6	28	19	13	15	27	38	47	19	32	11	20
Phosphorus (mg)	66	69	26	30	42	37	29	44	25	76	92	46	58	28	53
Potassium (mg)	316	389	170	243	230	252	238	299	213	606	490	350	384	449	305
Sodium (mg)	33	25	18	27	28	65	9	30	17	14	38	20	20	21	12
Zinc (mg)	0.44	0.42	0.18	0.22	0.27	0.19	0.23	0.27	0.21	0.23	0.56	0.03	0.25	0.17	0.24
Copper (mg)	0.049	0.070	0.19	0.017	0.062	0.021	0.036	0.039	0.046	0.170	0.499	0.129	0.165	0.075	0.032
Manganese (mg)	0.21	0.337	0.16	0.243	0.180	0.159	0.19	0.155	0.658	0.553	0.659	0.139	–	0.407	0.131
Selenium (μg)	2.5	1.6	0.3	0.6	0.9	0.5	0.6	0.6	1.3	0.9	0.9	0.7	0.9	0.8	0.7
<i>Vitamins</i>															
Vit C (mg)	89.2	85.0	36.6	57.0	31.0	45	27	48.2	35.3	69	120	62	70.0	130	25
Vit B ₁ (mg)	0.071	0.139	0.061	0.064	0.070	0.040	0.040	0.05	0.054	0.080	0.110	0.050	0.080	0.068	0.090
Vit B ₂ (mg)	0.117	0.090	0.040	0.069	0.030	0.070	0.050	0.060	0.130	0.260	0.130	0.020	0.110	0.093	0.040
Niacin (mg)	0.639	0.75	0.234	0.418	0.300	0.500	0.400	0.507	0.742	1.000	1.00	0.400	0.800	0.678	0.700
Pantothenic acid (mg)	0.573	0.309	0.212	0.147	0.187	0.088	0.105	0.667	0.267	0.242	0.091	0.165	0.210	0.178	0.160
Vit B ₆ (mg)	0.175	0.219	0.124	0.209	0.190	0.194	0.232	0.184	0.165	0.247	0.271	0.150	0.180	0.153	0.100
Folate (μg)	63	61	43	18	80	66	79	57	129	80	141	16	12	159	21
Vit B ₁₂ (μg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vit A (IU)	623	754	98	1116	1000	4468	318	0	5019	6917	9900	36	3024	9900	2
Vit A, RE (μg)	31	38	5	56	56	223	16	0	251	346	500	2	151	495	0
Vit D (IU)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vit E, α -TE (mg)	0.78	0.88	0.15	0.11	0.17	0.09	0.12	0.08	2.26	0.70	1.54	0.48	2.01	1.704	0.30
Vit K (μg)	101.6	177	76	38.2	68.8	45.5	42.9	15.5	437.1	541.9	704.8	0.1	257.5	–	0.3
<i>Lipids</i>															
Saturated, total (g)	0.039	0.062	0.034	0.021	0.013	0.027	0.043	0.013	0.055	0.023	0.091	0.013	0.010	0.015	0.027
Monounsaturated (g)	0.011	0.023	0.017	0.012	0.007	0.015	0.023	0.034	0.030	0.239	0.052	0.007	0.092	0.138	0.025
Polyunsaturated (g)	0.038	0.153	0.017	0.08	0.09	0.096	0.072	0.031	0.201	0.228	0.338	0.048	0.038	0.057	0.088

(Continued)

Table 2 (Continued)

<i>Nutrients</i>	<i>Broccoli</i>	<i>Brussels sprouts</i>	<i>Cabbage</i>	<i>Red cabbage</i>	<i>Savoy cabbage</i>	<i>Pak choy</i>	<i>Pe-tsai</i>	<i>Cauliflower</i>	<i>Collards</i>	<i>Cress</i>	<i>Kale</i>	<i>Kohlrabi</i>	<i>Mustard greens</i>	<i>Tendergreens</i>	<i>Swede</i>
Cholesterol (mg)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–
<i>Pigments (carotenoids)</i>															
β-Carotene (μg)	361	450	42	670	600	2681	190	0	2991	4150	5927	22	1790	–	1
Lutein/zeaxanthin (μg)	1403	1590	30	329	77	40	48	1	4323	12500	8198	0	3730	–	19
Lycopene (μg)	0	0	0	20	0	0	0	0	0	0	0	0	0	–	14
<i>Refuse^c (% of total)</i>	39	10	20	20	20	12	7	61	43	29	28	54	7	7	15

^aData from USDA Nutrient Database for Standard Reference, Food Group 11, Release SR27 (2014; <http://www.ars.usda.gov/Services/docs.htm?docid=8964>).

^bNo data provided.

^cRefuse is some combination of the total biomass, which is typically not used in food preparation, for example, stems; crowns; spoiled, damaged croute leaves; leaf stalks; cores; trimmings; or root base.

conjugates to which significant antioxidant activity has been ascribed. For example, the prevention of lipid peroxidation for which these compounds appear to be reasonably well suited may be an important mechanism for reducing the severity of age-related degenerative diseases such as arthritis, cardiovascular disease, and cancer.

See also: Antioxidants: Role on Health and Prevention; Cancer: Diet in Cancer Prevention; Food–Herbal Medicine Interface; Functional Foods; Glucosinolates from the Brassica Vegetables and Their Health Effects; Mustard; Papayas; Pesticides and Herbicides; Pesticides and Herbicides: Residue Determination; Pesticides and Herbicides: Types of Pesticide; Pesticides and Herbicides: Types, Uses, and Determination of Herbicides; Rapeseed Oil/Canola; Salad Crops: Root, Bulb, and Tuber Crops; Vegetarian Diets.

Further Reading

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Relevant Websites

- http://www.agmrc.org/commodities__products/vegetables/ – Agricultural Marketing Resource Center – USDA and Iowa State University.
- <http://clinicaltrials.gov/> – A registry and results database of publicly and privately supported clinical studies of human participants conducted around the world. It is a service of the US National Institutes of Health.
- <http://www.ers.usda.gov/topics/food-choices-health/food-consumption-demand.aspx> – The USDA's Economic Research Service.