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Nutritional attributes of* Brassica *vegetables

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Contents

1 Executive summary

1.1 Introduction

The Brassicas, particularly broccoli and broccoli sprouts, have been the subject of much scientific interest over the past 15 years. Most relates to the discovery that the compounds that cause these vegetables' distinctive mustardy taste have strong health benefits. Most research has focused on their ability to protect against various cancers. It appears that this is achieved through a range of mechanisms, and that these protective effects are relatively long lasting. More recently, research has widened to include their effects upon other health problems such as *Helicobacter pylori* infection.

In addition to these compounds, many Brassicas contain other phytochemicals that can help prevent chronic disease. Many *Brassica* species have been shown to have antioxidant activity, which may account for some of these health attributes.

1.2 Composition

In general, the green leafy Brassicas have a wider array of micronutrients and phytochemicals than the root types, with vitamin C, vitamin A precursors, vitamin K, folate, vitamin E and fibre being the most important. However, of greatest interest nutritionally is the fact that they all contain glucosinolates, whose breakdown products cause their pungent taste and which have particular anti-cancer properties different from those in other vegetables. These breakdown products, formed when the plant cell is ruptured, are the result of enzymatic conversion and are isothiocyanates, indoles, thoicyanates or nitriles, depending on the parent glucosinolate and the enzymes present. The isothiocyanate sulforaphane, formed from glucoraphanin, the most abundant glucosinolate in broccoli, has been the most intensively studied. An indole, indole-3-carbinol (I3C), from the glucosinolate glucobrassicin is also important.

1.3 Health benefits

1.3.1 Core nutrients

Brassica vegetables contain micronutrients such as vitamin C, vitamin A precursors, vitamin K, folate, fibre and vitamin E. Amounts vary from generally small for the root vegetables to large for Brussels sprouts and Chinese broccoli.

1.3.2 *Isothiocyanates*

Isothiocyanates are thought to protect against cancer both as cancer blockers and cancer suppressors. One of their most important features is they can induce phase 2 enzymes, which are involved in protecting cells against DNA damage from carcinogens or free radicals. Rather than quenching radicals themselves, isothiocyanates behave as indirect antioxidants. They act on a genetic level to increase the production of phase 2 enzymes, which in turn either attack the radicals or other potential carcinogens directly, or render them inert and promote their elimination from the body. In addition, they can help stop the progression of cancerous cells, by encouraging cell cycle arrest and apoptosis. Some isothiocyanates also have anti-inflammatory activity, which is important as inflammation can be involved in both cancer development and atherosclerosis.

To date *Brassica* consumption is best known to lessen the risk of lung and colorectal cancers. Newer research is investigating the effect of sulforaphane and *Brassica* consumption on the bacteria *H. pylori.*

1.3.3 *Indoles*

Indoles are also glucosinolate breakdown products, though they are structurally different from isothiocyanates. The most nutritionally important of these, indole-3-carbinol from glucobrassicin, has been studied particularly in relation to hormone-sensitive cancers such as prostate and breast, because of its effect on oestrogen activity and metabolism. Results, however, are somewhat inconsistent.

1.3.4 *Other phytochemicals*

The leafy, stalky vegetables especially contain good amounts of phytochemicals, such as the antioxidant pigments β-carotene, lutein and zeaxanthin, and anthocyanins (red cabbage only) as well as flavonoids. Broccoli has particularly large amounts of the latter in the form of kaempferol and quercetin. These phytochemicals are believed to help protect against chronic diseases such as heart disease and cancer, as well as health problems associated with ageing, and this is largely attributed to their antioxidant activity.

1.4 *Factors affecting heath benefits*

Numerous factors affect the nutrient profile of a plant food and thus the health benefits that it delivers. These include such variables as genus, cultivar, growing conditions, agronomy, season, level of maturity, storage, processing and cooking. There are reasonably large differences in composition between genera and also between cultivars of the same species. Postharvest treatment and processing, including cooking, have strong effects upon many nutrients in Brassicas, including the glucosinolates. Eating them raw or minimally cooked with as little water as possible is recommended for delivering maximum isothiocyanates.

Another more recently recognised factor in terms of how compounds are metabolised is human genetics. In the metabolism of *Brassica* isothiocyanates, some people benefit more than others from *Brassica* consumption, due to the absence of a gene that promotes the transit of isothiocyanates in the body. This may also account for some of the apparent inconsistencies in research findings.

2 Background

This report provides material for incorporation into one of a series of promotional and educational booklets for the various Horticulture New Zealand sector groups. We have gathered relevant literature, including medical research and scientific papers, and, where possible, included information specific to New Zealand. This report focuses on the nutritional attributes of vegetables belonging to the *Brassica* genus – broccoli, cauliflower, cabbage, Brussels sprouts, broccoflower, Asian varieties of cabbage and broccoli, turnips and swedes. Brief reference may also be made to other vegetables within the Brassicaceae, but belonging to a different genus e.g. radish, watercress, rocket. The depth of information available varies considerably; it is sparser for the lesser known or newer vegetables such as broccoflower. Factors that may influence the nutritional profile of these vegetables, such as agronomy, cooking or processing, and storage, are covered. Some additional material of general interest has also been included.

Since the major functional components are common to all in this group, the *Brassica* genus will be dealt with collectively, rather than individually, though characteristics of individual species will be described if noteworthy.

2.1 Introduction

Brassicas are vegetables about which people usually have strong opinions, possibly because of their strong taste and smell. Unfortunately too, in the past they were not cooked to their best advantage; boiled too long, their colours turned insipid, their texture transformed from crisp to pulpy and, with more volatile components driven off, only a flat mustardy taste and smell remained. This mixed reputation is unfortunate, as this family has almost unique and powerful health protective qualities.

Most research into Brassicas has focused upon their potential to protect against cancer, and there is good evidence to support this. In a comprehensive review of diet and cancer, the World Cancer Research Fund concluded that diets rich in Brassicas probably protected specifically against cancers of the colon, rectum and thyroid, and when part of a diet rich in other types of vegetables, generally against other kinds of cancers too (World Cancer Research Fund (1997) cited in Mithen et al. (2000)).

Broccoli is considered the star of the Brassicas, and it has certainly received most research and media attention. However, the main reason why it was initially chosen by one of the pioneering research groups in this area, and probably by others subsequently, was because it was popular. Although other Brassicas might be just as deserving on a scientific basis, the researchers believed that there was little point in studying less popular genera, such as kale, since those would have little dietary relevance to the majority of the population. However, the interest in broccoli has given rise to considerable effort into developing cultivars and products with large amounts of health-giving components. Broccoli is certainly nutritious, but other *Brassica* genera are likely to be equally so, although they have not been as extensively studied. Brussels sprouts, for example, deserve a much higher profile nutritionally.

Brassica nomenclature is somewhat confusing, and this is added to by Asian vegetables, for which there are often more than one name and which seem to be inconsistently spelt. The Brassicaceae, formerly known as Cruciferaceae and colloquially as the mustard or cabbage family, is the wider group to which these plants belong. Brassicas are a genus within the large Brassicaceae family. Within this genus there are several species, within each species there are different varieties, and within these there are different cultivars (Table 1). Many of the newly available Asian "greens" are Brassicas, as are many of the sprouted seeds and some components of salad mixes.

Table 1 shows that there are some vegetables, such as watercress and rocket, which are members of the Brassicaceae family but not members of the *Brassica* genus, although they share many of the compounds behind the health benefits of Brassicas. Watercress and rocket have been discussed in more detail in *Crop & Food Research Confidential Report No. 1473*, Nutritional attributes of salad vegetables.

Table 1: Common and botanical names of Brassica *vegetables (IHD 2006; Wikipedia 2006).*

Common name	Other names	Genus	Specific epithet	Variety
Kale		*Brassica*	*oleracea*	*acephala*
Collards		*Brassica*	*oleracea*	*acephala*
Chinese broccoli	Chinese kale, gai laan, kailan	*Brassica*	*oleracea*	*alboglabra*
Cabbage		*Brassica*	*oleracea*	*capitata*
Brussel sprout		*Brassica*	*oleracea*	*gemmifera*
Kohlrabi		*Brassica*	*oleracea*	*gongylodes*
Broccoli		*Brassica*	*oleracea*	*italica*
Broccoflower	Caucoli, broccoli romanesco	*Brassica*	*oleracea*	*italica* x *botrytis*
Broccoli romanesco		*Brassica*	*oleracea*	*botrytis*/*italica*
Cauliflower		*Brassica*	*oleracea*	*botrytis*
Wild broccoli		*Brassica*	*oleracea*	*oleracea*

Common name	Other names	Genus	Specific epithet	Variety
Bok choy	Chinese white cabbage, Chinese chard, paktsoi, pak choy	*Brassica*	*rapa*	*chinensis*
Mizuna		*Brassica*	*rapa*	*nipposinica*
Broccoli rabe		*Brassica*	*rapa*	*parachinensis*
Flowering cabbage	Chinese flowering cabbage, choy sum	*Brassica*	*rapa*	*parachinensis*
Chinese cabbage	Napa cabbage, Celery cabbage, wong bok, pe tsai	*Brassica*	*rapa*	*pekinensis*
Turnip root; greens		*Brassica*	*rapa*	*rapifera*
Rutabaga		*Brassica*	*napus*	*napobrassica*
Siberian kale		*Brassica*	*napus*	*pabularia*
Canola/rape seeds; greens		*Brassica*	*napus*	*oleifera*
Wrapped heart mustard cabbage		*Brassica*	*juncea*	*rugosa*
Mustard seeds, brown; greens		*Brassica*	*juncea*	
Mustard seeds, white		*Brassica*	*hirta*	
Mustard seeds, black		*Brassica*	*nigra*	
Tatsoi	Spinach mustard, spoon mustard	*Brassica*	*rosularis*	
Ethiopian mustard		*Brassica*	*carinata*	
Radish		*Raphanus*	*sativus*	
Daikon	White radish	*Raphanus*	*sativus*	*longipinnatus*
Horseradish		*Armoracia*	*rusticana*	
Japanese horseradish (wasabi)		*Wasabia*	*japonica*	
Arugula	Rocket	*Eruca*	*vesicaria*	
Watercress		*Nasturtium*	*officinale*	
Cress		*Lepidium*	*sativum*	

3 Composition

The factors that combine to determine the amounts of core nutrients and other phytochemicals in a food include the variety/cultivar of the plant, issues relating to the agronomy involved – soils, cultivation protocols (irrigation, pest control, use of fertiliser), degree of maturity at harvest – and processing practices (harvesting, storage, method of processing). In addition, there can be issues such as the form in which the food was analysed – raw, fresh, canned, boiled, frozen – as well as analytical techniques and variations between the laboratories doing the analysis. These factors can lead to inconsistent results. They may also lead to large differences in core nutrient levels, and even greater differences in terms of phytochemicals.

The extent and effect of this variation will be discussed in section 5, "Factors affecting health benefits".

3.1 Micronutrients

Where available, fuller detail on the macro and micronutrients in Brassicas is presented in Appendix 1. Table 2 summarises the main micronutrients (also known as core nutrients) in this genus. It is probable that they all also contain a lesser known vitamin, K, in large or very large amounts, though data are not given here as this is not routinely documented in the New Zealand database. Potassium, calcium, iron and phosphorus are also present in many of this group, but only in small amounts. Unfortunately data on many of the newly popular Asian varieties are not available. These vegetables are likely to have a similar range of nutrients, though amounts may differ.

It is interesting that Brussels sprouts are well endowed with nutrients, though this is not generally appreciated. Also the paler vegetables appear generally to have lower levels of nutrients than the more colourful.

Table 2: Major micronutrients in Brassica *vegetables (Athar et al. 2004; USDA 2005).*

	Total vitamin A equivalents (μg)	Vitamin C (mg)	Vitamin E (mg)	Folate, total (μg)	Dietary fibre (g)
Broccoli,raw	68	57	0.06	75.4	3.8
Broccoli, Chinese, cooked (gaai laan)*	82	28	1.08	99	2.5
Brussels sprouts, inner leaves, raw	72	97.3	0.2	119	3.4
Cabbage, Chinese, raw (variety unidentified, maybe bok choi)	32	20	0.2	72	1.2
Cabbage, Peking (Pe tsai) raw*	16	27	0.2	79	1.2
Cabbage, Red, inner leaves, raw	3	55	0.2	90	2.8
Cabbage, Savoy, inner leaves, raw	50	60	0.02	90	2.6
Cabbage, White, inner and outer leaves, raw	2	21	0.01	44	1.9
Cauliflower, raw	2	60	0.2	55	2.2
Swede, flesh, raw	T	36	0.41	37	2.5
Turnip, flesh, raw	0	25	T	12	1.8

* USDA data, T = trace.

3.2 Other phytochemicals

The term "phytochemicals" literally means "plant chemicals", but has come to mean plant-derived compounds that have bioactivity in ways other than preventing diseases of deficiency or being essential for the maintenance of normal body function. Rather, they are believed to help prevent chronic diseases and age-related health problems, such as cardiovascular disease and cancer. Many in this category could be classified as what are popularly known as "antioxidants". As presented in Table 3 below, those present in the broccoli and other greens in the *Brassica* genus include glucosinolates, chlorophyll, lutein, β-carotene, D-glucaric acid, caffeic acid, quercetin, α-lipoic acid, and lignans (Joseph et al. 2002). Swedes and turnips do not contain chlorophyll.

Table 3: Phytochemicals in Brassicas (Joseph et al. 2002; O'Hare et al. 2005; USDA 2005).

	β-carotene	Lutein/Zeaxanthin	Anthocyanins	Flavonoids	Phenolic acids	Lignans	Glucaric acid	Chlorophyll	Phytosterols	Glutathione	Glucosinolates
Broccoli	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Brussels sprouts	✓	✓		✓	✓		✓	✓	✓		✓
Cabbage	✓	✓		✓	✓			✓	✓		✓
Chinese broccoli	✓	✓						✓			✓
Chinese cabbage	✓	✓						✓			✓
Red cabbage	✓	✓	✓								
Cauliflower				✓			✓		✓		✓
Kale	✓	✓		✓				✓			✓
Turnip/swede									✓		✓

3.2.1 *Glucosinolates*

The glucosinolate content of Brassicas is particularly distinctive nutritionally. Glucosinolates are sulphur-containing compounds (β-thioglucoside-*N*-hydrodxy sulfates), all with a β-D-glucopyranose moiety and an aliphatic, aromatic or an indole side chain (Tian et al. 2005). Over 120 different glucosinolates have been identified, mostly in plants of the Brassicaceae (Fahey et al. 2001). Structures of the major glucosinolates appear in Appendix II.

Glucosinolates and their breakdown products are present in the plant as part of a defence mechanism against pest attack. The glucosinolates themselves are not beneficial, but the breakdown products to which they are hydrolysed, either immediately by the enzyme myrosinase or later by intestinal flora, are beneficial. These same compounds are also believed to cause the anti-cancer activities and other beneficial health properties observed through the consumption of plants rich in glucosinolates or their purified extracts. They also have fungicidal, bactericidal and nematocidal properties (Fahey et al. 2001).

In the plant, the glucosinolates and the enzyme that catalyses their hydrolysis, myrosinase, are physically separated. However, when the plant is bitten into by a predator, or cut or chewed, the cell is disrupted and the two compounds interact to form these breakdown products. As already mentioned, a wide variety of glucosinolates is present in the Brassicaceae and each is broken down into a different product, depending both upon the parent glucosinolate and the enzymes present. Major isothiocyanates, their parent glucosinolates and food sources are listed in Table 4.

Table 4: Food sources of selected isothiocyanates and their glucosinolate precursors (Higdon 2005).

Isothiocyanate	Glucosinolate (precursor)	Food sources
Allyl isothiocyanate (AITC)	Sinigrin	Broccoli, Brussels sprouts, cabbage, horseradish, mustard, radish
Benzyl isothiocyanate (BITC)	Glucotropaeolin	Cabbage, garden cress, Indian cress
Phenethyl-isothiocyanate (PEITC)	Gluconasturtiin	Watercress
Sulforaphane (SFN)	Glucoraphanin	Broccoli, Brussels sprouts, cabbage

The isothiocyanate sulforaphane is most commonly associated with broccoli or broccoli sprouts, in which it acts as a particularly powerful phase 2 enzyme inducer, the mechanism behind those foods' purported health benefits. However, each member of the *Brassica* genus contains several glucosinolates, whose associated isothiocyanates also have anti-cancer potential. For example, O'Hare et al (2005) predictably found large amounts of glucoraphanin, but also glucoberteroin, glucoerucin and 4-hydroxyglucobrassicin, in broccoli seeds. Glucoerucin was also the major glucosinolate in rocket seeds, and present too in those of kohlrabi, kale and mizuna. The full table of the glucosinolate composition and concentrations in the seeds of as vegetables is reproduced in Appendix III.

Table 5 lists total glucosinolate content for some of the Brassicaceae. In this regard too, Brussels sprouts appear to contain particularly large amounts.

Table 5: Glucosinolate content of selected Brassicaceae (Higdon 2005).

Food (raw)	Serving	Total glucosinolates (mg)
Brussels sprouts	½ cup (44 g)	104
Garden cress	½ cup (25 g)	98
Mustard greens	½ cup, chopped (28 g)	79
Turnip	½ cup, cubes (65 g)	60
Cabbage, savoy	½ cup, chopped (45 g)	35
Kale	1 cup, chopped (67 g)	34
Watercress	1 cup, chopped (34 g)	32
Kohlrabi	½ cup, chopped (67 g)	31
Cabbage, red	½ cup, chopped (45 g)	29
Broccoli	½ cup, chopped (44 g)	27
Horseradish	1 tablespoon (15 g)	24
Cauliflower	½ cup, chopped (50 g)	22
Bok choi (pak choi)	½ cup, chopped (35 g)	19

To confuse the issue, another feature of some Brassicas is that they contain a compound called epithiospecifier protein (ESP) which operates as a enzyme co-factor with myrosinase, but which steers the glucosinolate conversion away from isothiocyanates to isothiocyanate nitrile, a compound with no anti-cancer activity. One study showed that this occurred in some of the vegetables tested (broccoli, cabbage, garden cress), though not with others (daikon and white mustard) (Matusheski et al. 2004). However, complicating matters further, different cultivars within the same vegetable type can have more or less ESP than others.

Another major issue relating to cruciferous vegetables is that myrosinase is destroyed by heating. Although some conversion of glucosinolates to their isothiocyanates or indoles takes place via bacteria in the gut, this is not an efficient conversion (Shapiro et al. 2001). Also, glucosinolates are water-soluble and thus can leach into cooking water.

3.2.2 *Indoles (Indole-3-carbinol)*

Like isothiocyanates, indoles are formed from the hydrolysis of glucosinolates, but unlike isothiocyanates they do not contain sulphur. The indole that has received most scientific interest is indole-3-carbinol (I3C), derived from glucobrassicin. Initially the hydrolysis of glucobrassicin by myrosinase at neutral pH results in an unstable indole isothiocyanate that degrades to form indole-3-carbinol and a thiocyanate ion (Higdon 2005). (See Appendix III for diagram of this conversion.) Glucobrassicin occurs widely in the Brassicaceae, but as with other glucosinolates, amounts can vary considerably both between cultivars of the same genus and between different *Brassica* genera (Kushad et al. 1999; O'Hare et al. 2005). In the acidic environment of the stomach, I3C is rapidly broken down into further bioactive products known generally as acid condensation products, including 3,3'-diindolylmethane (DIM) and a cyclic trimer (TM), and although their bioactivity is different to that of I3C, it is usually attributed to it.

Brussels sprouts are a particularly good source of glucobrassicin, though it is present in other Brassicas, including broccoli, cabbage, cauliflower and kale (Kushad et al. 1999).

3.2.3 *Carotenoids*

The carotenoids are a group of yellow-orange-red pigments, found in a variety of fruits and vegetables as well as in algae, fungi and bacteria. Carotenoids cannot be synthesised in the body and are present solely as a result of ingestion from other sources, either from a plant itself or a product from an animal that has consumed that plant source, e.g. egg yolks are yellow because of the carotenoids they contain. Often the colours of the carotenoids present in plants are masked by chlorophyll, to the extent that some of the largest amounts of carotenoids are found in dark green leafy vegetables, such as kale and spinach.

Carotenoids consist of a long-chain hydrocarbon molecule with a series of central, conjugated double bonds. (See Appendix II for structural diagrams of the major carotenoids in Brassicas.) These conjugated (alternating) double bonds confer colour and the compounds' antioxidant properties. These compounds are especially effective in quenching singlet oxygen and peroxyl radicals. They appear to act synergistically with other carotenoids and other antioxidants. In plants, these pigments assist in the light-capturing process in photosynthesis and protect against damage from visible light. In humans, one of their various benefits is believed to be protecting the skin and the macula lutea of the eye against photoxidative damage (Sies & Stahl 2003).

There are two general classes of carotenoids – the carotenes, and their oxygenated derivatives, the xanthophylls. The two groups are almost structurally identical, except that the xanthophylls have a terminal hydroxyl group. Their structure determines their properties and thus also their activities and physiological roles. The body can convert α-carotene, β-carotene and β-cryptoxanthin into retinol, or vitamin A. The carotenes are non-polar and hence tend to be located on the periphery of cell membranes. Lycopene and the xanthophylls, lutein and zeaxanthin, have no vitamin A capacity. The xanthophylls, being more polar, are believed to span cell membranes, with their hydrophobic hydrocarbon chain inside the lipid bilayer and their hydrophilic hydroxyl groups emerging on the other side (Gruszecki & Sielewiesiuk 1990). Because of their similarity, amounts of the two compounds are often reported as a combined total.

Because carotenoids are fat-soluble they are best absorbed in the body if accompanied by some form of oil or fat in the meal. Chopping and cooking assists in releasing carotenoids from the food matrix and this also increases their bioavailability.

The carotenoid content of some common Brassicas is shown in Table 6. There is considerable variation between genera, but even the largest amounts are significantly smaller than those in other vegetables such as kale (β-carotene 9226, lutein and zeaxanthin 39 550) and spinach (β-carotene 5626, lutein and zeaxanthin 12 198).

Table 6: Major carotenoids in assorted Brassica *vegetables (mcg/100 g) from USDA National Nutrient Database for Standard Reference Release 18, 2005 (USDA 2005).*

Food	β-carotene	α-carotene	Lutein + zeaxanthin
Broccoli, raw	361	25	1403
Broccoli, Chinese, cooked (gaai laan)	983	0	912
Brussels sprouts, inner leaves, raw	450	6	1590
Cabbage, Chinese, raw (bok choi)	2681	1	40
Cabbage, Peking (Pe tsai) raw	190	1	48
Cabbage, red, inner leaves, raw	670	320	329
Cabbage, savoy, inner leaves, raw	60	0	77
Cabbage, white, inner and outer leaves, raw	90	25	310
Cauliflower, raw	8	0	33
Swede, flesh, raw	1	0	0
Turnip, flesh, raw	0	0	0

3.2.4 *Phenolic compounds*

Phenolics are a group of over 4000 compounds occurring widely in the plant kingdom, usually divided into two subgroups — the flavonoids and phenolic acids. In the plant they serve a variety of purposes including protection against fungal disease, insect attack and strong sunlight as well as attracting pollinators and seed dispersers. Often these compounds impart taste (often bitter or astringent) and some also provide aroma and colour. Anthocyanins, a subgroup of the flavonoids, give the red, blue and purplish colours to some fruit and vegetables, including red cabbage.

Structurally phenolics all contain at least one phenol ring and at least one hydroxyl group, which is important as these confer antioxidant activity. (See Appendix II for structural diagrams of some of the phenolics in Brassicas.) They are water-soluble, which affects some of their functional properties. The phenolics in Brassicas include the flavanols (kaempferol and quercetin) some flavones (apigenin and luteolin) and (in red cabbage only) anthocyanins. Many Brassicas also contain the phenolic acids chlorogenic, α-lipoic, D-glucaric and caffeic acids (Joseph 2003).

In measuring the levels of phenolic compounds in a food, the kinds or classes of compounds are identified along with their antioxidant activity, to provide an indication of the health benefits a food may have (see Table 7). However, it is difficult to arrive at conclusions when the data vary so considerably (several-fold between authors). It would be possible to generalise though, that in comparison with other vegetables, Brassicas contain small to medium amounts of phenolics, which is around average for vegetables, though these amounts are much smaller than those in fruits. For example, the study by Chun et al. (2005) gives a range of 4.5 to 64.15 mg GAE (100 mg/100 g fresh weight) for vegetables (median amount of around 25 mg GAE), and a range for fruit of 11.45 to 368.66 GAE (median of around 110 mg GAE).

Table 7: Reported total phenolic content of raw fresh Brassicas.

Vegetable	mg GAE/100 g FW	Author
Broccoli	25.02	Chun
	128	Turkmen
	337	Wu
Cabbage	45.28	Chun
	203	Wu
Cabbage, red	254	Wu
Cauliflower	10.4	Chun
	274	Wu
Radish	29.45	Chun
	110	Wu

The kinds and amounts of individual flavonoids identified in various Brassicas are listed in Table 8. Clearly broccoli has much larger amounts than the other vegetables, with good amounts of both quercetin and kaempferol. These kinds of compounds are higher in vegetables such as onions, kale and leeks, but broccoli nonetheless ranks as a good source (Higdon 2005). Note: no anthocyanin content has been listed for red cabbage in this database, though Higdon (2005) lists anthocyanins in red cabbage at 25 mg per 100 g fresh weight.

Table 8: Flavonoid content of selected Brassicas mg/100 g edible portion (USDA 2003).

Vegetable	Flavonoid	Quantity
Broccoli, raw	Kaempferol	6.16
	Quercetin	3.21
Brussels sprouts, inner leaves, raw	Luteolin	0.34
	Kaempferol	0.95
Cabbage, Chinese, raw (bok choi)	Apigenin	0.1
	Luteolin	0.6
	Kaempferol	0.37
	Quercetin	0.01
Cabbage, Red, inner leaves, raw	Apigenin	0.01
	Luteolin	0.06
	Quercetin	0.37
Cabbage, White, inner and outer leaves, raw	Apigenin	0.01
	Luteolin	0.04
	Kaempferol	0.12
	Quercetin	0.01
Cauliflower, raw	Luteolin	0.08
	Kaempferol	0.25
	Quercetin	0.03

3.2.5 *Chlorophyll*

Chlorophyll is well known as the pigment that gives plants and algae their green colour, and it is the primary compound in photosynthesis. Two different types of chlorophyll (chlorophyll a and chlorophyll b) are found in plants, each absorbing light at slightly different wavelengths.

3.2.6 *Lignans*

Structurally, plant lignans are diphenolic compounds that are transformed into enterolignans by intestinal flora in the human body (Lampe 2003; Milder et al. 2005). They are widely distributed in the plant kingdom, occurring in roots, rhizomes, woody parts, stems, leaves, seeds and fruit of vascular plants (Lampe 2003). The mammalian lignans, enterodiol and enterolactone, into which they are converted, can have weak oestrogenic activity, and it is for this reason that they are termed phytoestrogens. They are present in a variety of foods, but are particularly concentrated in seeds such as flax and sesame. In comparison with these, amounts in Brassicas seem relatively small (see Table 9). Although this is true, most brassicas contain more than other vegetables and fruit too. In the Brassicas studied, amounts decrease in the order curly kale > broccoli > white cabbage > Brussels sprouts > red cabbage > cauliflower at 2321, 1325, 787, 747, 276, and 185 µg/100 g fresh weight respectively (Milder et al. 2005). The most studied lignans are secoisolariciresinol and matairesinol, because they were the first identified, but the major lignan precursors in Brassicas are pinoresinol and lariciresinol (Milder et al. 2005).

Table 9: Lignan content of selected foods (Higdon 2005).

Food	Serving	Total lignans (mg)
Flax seeds	1 oz	85.5
Sesame seeds	1 oz	11.2
Curly kale	½ cup, chopped	0.8
Broccoli	½ cup, chopped	0.6
Apricots	½ cup, sliced	0.4
Cabbage	½ cup, chopped	0.3
Brussels sprouts	½ cup, chopped	0.3
Strawberries	½ cup	0.2
Tofu	¼ block (4 oz)	0.2
Dark rye bread	1 slice	0.1

4 *Health benefits*

Brassicas have a wide assortment of nutrients and phytochemcicals that can potentially benefit many aspects of human health. However, with *Brassica* vegetables, the focus has been particularly on protecting against cancer, because the bioactivity of glucosinolate breakdown products, in terms of human foods, are almost unique to the Brassicaceae. Other compounds with anti-cancer potential in Brassicas include vitamin C, fibre, carotenoids, and flavonoids, and it is likely that some of these compounds work synergistically. The health benefits of many of these are not confined to protecting against cancer, to the extent that many *Brassica* phytochemicals have a beneficial effect upon many other chronic diseases as well. Many Brassicas also provide good amounts of important core nutrients.

4.1 Core nutrients

The major functions of the various micronutrients are well established and are summarised in Table 10 below.

Table 10: Main micronutrients in Brassicas and their physiological functions (Adapted from Medscape 2004; BUPA 2006).

Name	Major function
Vitamin A Retinol (animal origin) Some carotenoids (plant origin, converted to retinol in the body)	Important for normal vision and eye health Involved in gene expression, embryonic development and growth and health of new cells Assist in immune function May protect against epithelial cancers and atherosclerosis
Vitamin C Ascorbic acid	Necessary for healthy connective tissues – tendons, ligaments, cartilage, wound healing and healthy teeth Assists in iron absorption A protective antioxidant - may protect against some cancers Involved in hormone and neurotransmitter synthesis
Vitamin E A group of tocopherols and tocotrienols Alpha tocoferol most common and biologically active	Provides dietary support for heart, lungs, prostate, and digestive tract Reduces peroxidation of fatty acids Non-specific chain-breaking antioxidant May protect against atherosclerosis and some cancers
Vitamin K Occurs in various forms including phyllo- and menaquinone	Coenzyme in the synthesis of proteins involved in blood clotting (prothrombin and other factors) and bone metabolism Involved in energy metabolism, especially carbohydrates May also be involved in calcium metabolism
Folate Generic term for large group of compounds including folic acid and pterylpolyglutamates	Coenzyme in DNA synthesis and amino acid synthesis. Important for preventing neural tube defects Key role in preventing stroke and heart disease, including reducing blood homocysteine levels with vitamin B_{12} May protect against colonic and rectal cancer
Calcium	Structural component of bones and teeth Role in cellular processes, muscle contraction, blood clotting, enzyme activation, nerve function

Name	Major function
Iron	Component of haemoglobin and myoglobin in blood, needed for oxygen transport Role in cellular function and respiration
Potassium	Major ion of intracellular fluid Maintains water, electrolyte and pH balances Role in cell membrane transfer and nerve impulse transmission
Phosphorus	Structural component of bone, teeth, cell membranes, phospholipids, nucleic acids, nucleotide enzymes, cellular energy metabolism pH regulation Major ion of intracellular fluid and constituent of many essential compounds in body and processes
Fibre (insoluble)	Adds bulk to stool and thus helps to prevent bowel problems such as bowel cancer, irritable bowel syndrome and diverticulitis

4.2 *Isothiocyanates*

4.2.1 *Epidemiological studies*

Numerous studies link diets rich in fruits and vegetables with lower incidences of cancer, but it is often difficult for researchers to separate whether the effect is due to *Brassica* vegetables themselves or to vegetable consumption in general. However, an early review of epidemiological studies of *Brassica* vegetable consumption (cabbage, kale, broccoli, Brussels sprouts and cauliflower) and cancer incidence showed inverse associations in the majority (67%) of cases (Verhoeven et al. 1996) and it was postulated that their protective effect may at least in part have been due to glucosinolate content. After reviewing the results of 87 case control studies and seven cohort studies, the authors of that review concluded that high *Brassica* vegetable consumption was most strongly associated with a decreased risk of lung, stomach, colon and rectal cancer, and least strong for cancers of the prostate, ovaries and endometrium. However, the authors noted that various factors lead to inconsistent results in epidemiological studies, including study design, with retrospective case-control studies most likely to be distorted by selection bias and dietary recall. More recently too, human genetics have been found to play an important role in the metabolism of these compounds, and thus there are differences in the health effects that they are able to exert.

Both these issues may help to explain some of the mixed results in more recent studies. Three prospective studies (Dutch men and women, US women, Finnish men) found that higher intakes of Brassicas of more than three servings per week were linked with a lower risk of lung cancer. Conversely, two other prospective studies (US men and European men and women) found no such association (Higdon 2005).

Contradictory results are also evident for colorectal cancer. Early case-control studies suggested that people with colorectal cancer were more likely to have lower *Brassica* consumption than those without the disease, but later prospective cohort studies did not find similar inverse associations. An exception to this was a Dutch study in which the group of men and women with the highest *Brassica* intake (around 58 g/day) had a significantly lower risk of developing colorectal cancer than those with the lowest intake (around 11 g /day). Surprisingly, a further finding in this study was that for women, higher *Brassica* intake was associated with an increased risk of colorectal cancer (Higdon 2005).

Several studies of breast and prostate cancer, have given more inconsistent results. There are many factors that could lead to confusing results, including genetic factors and research continues into this.

Laboratory studies have supported these findings to some extent, with *Brassica* vegetable consumption reducing the incidence of mammary tumours, liver tumour size and number, tumour frequency and lung tumour metastases in rodents, either before or after the administration of a carcinogen (Verhoeven et al. 1996).

4.2.2 Biological activities of isothiocyanates

Mechanistic studies have shown that these *Brassica*-derived compounds may have both anticarcinogenic and anti-cancer effects. That is, they may both block potentially carcinogenic substances from inflicting damage and may also suppress the progression of cancers by disrupting the chain of events that would otherwise lead to cancer. They have many modes of operation; they may inhibit carcinogen-activating (phase 1) enzymes, stimulate the activation of detoxifying (phase 2) enzymes, promote cell cycle arrest (the damage repair mechanism within growing cells) and induce apoptosis (the suicide of aberrant, non-repairable cells) (Talalay & Zhang 1996; Gamet-Payrastre et al. 2000; Zhang et al. 2005; Zhang et al. 2006). In addition, unlike direct antioxidants that lose their efficacy once they have reacted with a free radical, isothiocyanates have a long lasting effect, possibly for several days, and this can continue even after the initiating compound itself has been eliminated from the body.

Some isothiocyanates also enhance the transcription of tumour suppressor proteins (Higdon 2003). Other studies have shown them to have anti-inflammatory activity. This is important because inflammation is implicated in the development of cancer through the promotion of cellular proliferation and the inhibition of apoptosis and heart disease, where the inflammation of vascular tissue is part of the progression of atherosclerosis.

One of the most recent areas of research has been into sulforaphane's possible antibacterial activity. Fahey et al. (2002) showed that sulforaphane inhibited the gastric bacteria *H. pylori*, which is thought to be implicated in the development of stomach cancer.

In summary, to date there is most evidence to support the hypothesis that large intakes of *Brassica* vegetables are associated with lower rates of lung and colorectal cancer.

4.3 *Indole-3-carbinol*

I3C does induce phase 2 enzymes, but it does so less efficiently than sulforaphane, for example (Joseph 2003). However, it does have other bioactivity and has been researched particularly in relation to hormone-based cancers.

4.3.1 *Biological activities*

As mentioned above, I3Cs are metabolised to form various acid condensation products. These condensation products may also increase the activity of phase 2 enzymes and thus promote the elimination of potential carcinogens and toxins. However, they may also enhance phase 1 enzyme activity, with potentially harmful effects as some procarcinogens are transformed by phase 1 enzymes into active carcinogens (Higdon 2005).

4.3.2 *Cancer prevention*

The most researched area of I3C activity is in oestrogen-sensitive breast cancer. The acid condensation products of I3C block the oestrogen receptors in breast cancer cells, preventing the oestrogen from exerting a deleterious effect. I3C also is thought to direct oestrogen synthesis away from the form of oestrogen that is believed to be instrumental in initiating breast cancer (16α-hydroxtoestrone), towards one that is less likely to promote the proliferation of oestrogen-sensitive cancer cell lines (2-hydroxyoestrone).

IC3 also has ability to induce cell cycle arrest and apoptosis, particularly in relation to hormone-related cancers such as prostate (Sarkar & Li 2004). There is also some evidence from cell culture experiments to show that I3C or its acid condensation products might prevent tumour invasion and angiogenesis (the growth of new blood vessels to support tumour growth) (Higdon 2005).

Some recent studies have investigated the potential of I3C to prevent cervical cancer through its effect upon the human papilloma virus, infection with which is implicated in the development of cervical cancer. Both an animal model and a small clinical trial showed encouraging preliminary results. I3C is also being trialled in recurrent respiratory papillomatosis, caused by infection of the respiratory tract with human papilloma virus.

The effect of I3C upon oestrogen has also led to research into the autoimmune disease systemic lupus erythematosus. This disease is believed to be related to oestrogenic activity. Results from an animal trial were encouraging, but those from a small trial in people were not conclusive.

By contrast, some studies using animals or animal tissues have shown that although I3C administered as a pure compound (as opposed to being contained in a food source) can inhibit a number of cancers, in some cases it has appeared to have actually initiated or enhanced cancer (Higdon 2005).

4.4 *Antioxidant activity*

Epidemiological studies have shown that large intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing, and this is generally attributed to their phytochemical content. One of the most important ways in which they are believed to exert this protective effect is through antioxidant activity.

Antioxidants deactivate free radicals and other oxidants, rendering them harmless. Free radicals are highly unstable molecules, present in the body both from external sources (e.g. pollution, smoking, carcinogens in the environment) and internal sources, the result of normal physiological processes. If uncontrolled, free radicals can damage cell components, interfering with major life processes. For example they may damage DNA, leading to cancer, or oxidise fats in the blood, contributing to atherosclerosis and heart disease. Although the body produces antioxidants and has other defence mechanisms, it is thought that antioxidants from the diet also have an important role.

The major antioxidants in Brassicas are vitamin C, the carotenoids and various phenolic compounds. There are a number of different methods for measuring antioxidant activity and to give a full picture, a range of these methods should be used. However, many researchers use the ORAC method (oxygen radical absorbance capacity, measured in µmol trolox equivalent or TE) as a convenient yardstick for comparing different foods. Table 11 lists results from various studies. It is obvious that absolute values vary considerably, and the reasons for these kinds of variations have already been discussed. However, to put them in some sort of context, ORAC values for an assortment of common vegetables vary from 115 to 9409 µmol TE/100 g according to Wu et al. (2004), with most of these vegetables having average or moderate activity.

Table 11: Antioxidant activity of some raw brassica vegetables (μmol TE/100 g fresh weight).

Vegetable	Author	Oxygen radical absorbance capacity (ORAC) value
Broccoli (calabrese)	Ninfali et al. 2005.	352
Broccoli	Wu et al. 2004	1590
Broccoli	Ou et al. 2002	1348
Cabbage (green)	Ninfali et al. 2005	856
Cabbage (common)	Wu et al. 2004	1359
Cabbage (white)	Ou et al. 2002	479
Cabbage (savoy)	Ninfali et al. 2005	2050
Cabbage (red)	Wu et al. 2004	2252
Cauliflower	Ninfali et al. 2005	925
Cauliflower	Wu et al. 2004	647
Cauliflower	Ou et al. 2002	825
Radish	Ninfali et al. 2005	3602
Radish	Wu et al. 2004	954

Note: where necessary, figures have been adapted from dry weight to fresh weight using USDA data.

4.5 *Carotenoids*

α- and β-carotene differ only very slightly in terms of structure. They are very common antioxidants, as well as having other potential health benefits. As mentioned earlier, both can be converted into vitamin A by the body, though β-carotene has about twice the provitamin A activity as α-carotene. Sometimes, carotenoid content is measured as retinol (pre-formed vitamin A) equivalents; β-carotene has 1/6 the vitamin A activity of retinol, with α-carotene and β-cryptoxanthin having each about 1/12.

Note: Although there is some international controversy over the carotenoid/retinol conversion rate, the rates above are used in New Zealand and Australia in accordance with the FAO/WHO decision (Health 2004).

β-carotene has been the focus of most research. Carotenoid-rich foods have been associated with health benefits for some time and this has been attributed largely to the β-carotene they contain. It was hypothesised that β-carotene might help prevent the formation of lesions that led to cancer, and *in vitro* cell experiments have indicated that carotenoids have properties consistent with anti-cancer activity, e.g. they may play an important role in the cell communication that leads to the removal of pre-cancerous cells. However, results have been somewhat inconsistent. For example, although a review of case control studies looking at diet and breast cancer found a significant inverse association between β-carotene intake and breast cancer in four studies, five studies found no association and seven studies found only a loose association, which was not statistically significant (Cooper et al. 1999). Similarly, although early studies observed a protective effect of β-carotene on lung cancer, more recent studies have found no significant association between dietary β-carotene intake and lung cancer risk. A study evaluating the effect of β-carotene supplements on lung cancer risk in smokers and other at-risk groups showed that the risk of developing lung cancer actually increased in those taking supplements. However, no such effect has been found in studies in which the β-carotene was consumed as part of a food rather than as a supplement in which the compound is isolated and concentrated. Mixed results have also been reported from studies of prostate and colorectal cancer.

The effect of dietary β-carotene on cardiovascular disease is also unclear. It has been established that the development of cardiovascular disease involves the oxidation of low-density lipoprotein (LDL) and its subsequent uptake by foam cells in the vascular endothelium, where it can lead to the development of atherosclerotic lesions. It was hypothesised that β-carotene, which itself is carried in LDL, might help prevent this oxidation, as several *in vitro* studies had shown it capable of scavenging potentially damaging radicals. However, some research has shown higher plasma levels of carotenoids to be associated with better vascular health and lower cardiovascular disease risk, but other studies have shown no effect (Higdon 2005; Cooper et al. 1999). Further, some recent studies have produced contradictory results on the ability of β-carotene to stabilise LDL against oxidation (Cooper et al. 1999).

4.6 Phenolic compounds

Phenolic compounds are primarily of interest because of their antioxidant activity. Because of their structure, they are very efficient scavengers of free radicals and are also metal chelators (Shahidi & Naczk 1995). In addition to the antioxidant characteristics of flavonoids, other potential health-promoting bioactivities include anti-allergic, anti-inflammatory, anti-microbial and anti-cancer properties (Cody et al. 1986; Harbourne 1993). There are many ways in which flavonoids may act to prevent cancer, including inducing detoxification enzymes, inhibiting cancer cell proliferation and promoting cell differentiation (Kalt 2001). Some flavonoids are also beneficial against heart disease because they inhibit blood platelet aggregation and provide antioxidant protection to LDL (Frankel et al. 1993). Studies on the health benefits of the phenolic acids to date have largely focused on their antioxidant activity.

4.7 Chlorophyll

Relatively little is known of the health effects of chlorophyll. Some research suggests that it may be important in protecting against some forms of cancer by binding to the mutant DNA to prevent it proliferating. A recent study found that chlorophyll has phase 2 enzyme-inducing potential and, although its activity was relatively weak, its high concentrations in so many edible plants may cause some of the protective effects observed in diets rich in green vegetables (Fahey et al. 2005).

4.8 Lignans

Lignans are of most nutritional interest because of their oestrogenic activity. with speculation that this may protect against hormone-related cancers, such as breast, endometrial, ovarian and prostate. However, studies have not been able to substantiate this, as they are generally unable to separate the beneficial effects of foods rich in lignans from the effects of the lignans themselves. A similar problem appears for cardiovascular disease risk; flax seeds, for example, are a rich source of lignans but also contain other heart-protective compounds including polyunsaturated fatty acids and fibre. A limited amount of research into the effect of lignans on osteoporosis has produced inconsistent results (Higdon 2005). As with the metabolism of isothiocyanates, there are large variations in serum and urinary lignans between individuals. There are several possible explanations for this, such as the effects of other dietary components, the colonic environment and sex differences, and it is again possible that this could explain some of the inconsistencies in study results (Lampe 2003).

Most research into the effect of lignans has involved flax seeds, and no published material was found specifically on the effects of *Brassica* lignans.

5 Factors affecting health benefits

5.1 Human genetic factors

Research in the relatively new field of human genetics has identified a genetic factor that influences the extent of the health benefits of isothiocyanates. There are genetic variations affecting the enzymes (glutathione-S-transferases or GSTs) that metabolise isothiocyanates, encouraging their elimination from the body. Some people are unable to produce these enzymes, and are exposed for longer to isothiocyanates than those with the enzymes who eliminate isothiocyanates more quickly. Thus, those without these genes benefit from the protective effects of isothiocyanates for longer. Further credence has been attached to this theory by the observation in epidemiological studies that eating cruciferous vegetables produced a more marked protective effect in people without these genes (Higdon 2005).

5.2 Bioavailability

Bioavailability broadly addresses the issue of how well a compound is absorbed to be used by the body and made available at the site of physiological activity. Absorption may be determined by a range of variables, such as the chemical structure and nature of the compound, the amount consumed, the food matrix in which it is contained, the presence of other compounds within the meal and the nutrient status of the subject.

5.2.1 *Glucosinolate products*

The structural diversity and differences in reactivity of glucosinolates present challenges in understanding glucosinolate metabolism, but it is closely related to the presence of myrosinase. When myrosinase is present, glucosinolates are rapidly hydrolysed in the upper gastrointestinal tract, but if they are lacking (e.g. through deactivation as a result of cooking), glucosinolate metabolism takes longer and occurs in the lower gastrointestinal tract via a surprisingly wide variety of intestinal bacteria (Mithen et al. 2000; Mithen et al. 2003). Human studies have shown urinary excretion of glucosinolate breakdown products of between 30 and 67% within 24 hours, suggesting reasonable bioavailability of these chemicals (Mithen et al. 2000).

5.2.2 *Carotenoids*

The large difference between the numbers of carotenoids ingested as plant material and those absorbed into human plasma indicates selective uptake.

Carotenoids occur in plants in three forms:

- as part of the photosynthetic apparatus, where they are complexed to proteins in chromoplasts and trapped within the cell structures, and are thus protected from absorption (in green, leafy vegetables);
- dissolved in oil droplets in chromoplasts, which are readily extracted during digestion (mango, papaya, pumpkin and sweet potato) (West & Castenmiller 1998);
- as semi-crystalline membrane-bound solids (carrot, tomato), which, though soluble in the intestinal tract, probably pass through too quickly to allow much solubilisation.

These differences in location and form strongly affect absorption and explain differences in bioavailability in different food matrices (Galeotti et al. 1990). Particle size and cooking, which breaks down the cell matrix of the food, also influence uptake, presumably by making the carotenoid more available for absorption in the lumen.

It should be noted that hydrocarbon carotenoids (e.g. β-carotene, lycopene) are absorbed differently from xanthophylls (e.g. lutein, zeaxanthin). Within the intestinal lumen, the non-polar carotenes are thought to locate in the hydrophobic core of lipid emulsions and bile salt micelles, whereas the more polar xanthophylls are thought to locate at the surface (Galeotti et al. 1990).

The presence of fat or oil, either as part of the meal (e.g. in whole milk, cheese or a dressing) or used in cooking, also positively affects absorption. Because carotenoids are fat-soluble compounds they are absorbed in parallel with fat metabolism, and it has been estimated that a fat intake of at least 5 g of fat per day is necessary for an adequate uptake of dietary carotenoids (West & Castenmiller 1998). Polyunsaturated fatty acid-rich dietary fat increases serum response to β-carotene more than does mono-unsaturated fatty acid-rich dietary fat. The solubility of β-carotene and zeaxanthin decreases with increased chain length in triglyceride fatty acids.

Protein present in the small intestine also assists absorption through the stabilisation of fat emulsions and enhanced micelle formation with associated carotenoid uptake (West & Castenmiller 1998). Lecithin may also promote the absorption of fat-soluble vitamins and carotenoids as well as triglycerides through facilitating micelle formation. Similarly, long-chain fatty acids, which increase cholesterol absorption, may also increase the absorption of solubilised lipophilic phytochemicals (West & Castenmiller 1998).

Dietary fibre has a negative effect on β-carotene bioavailability. It is thought that fibre may entrap carotenoids and, through its interaction with bile acids, lead to increased excretion of bile acids. This, in turn, may result in a reduction in the absorption of fats and fat-soluble substances, including carotenoids (Hammond et al. 1997). The presence of soluble fibre, in the form of citrus pectin, reduces the increase in β-carotene absorption after ingestion of a β-carotene capsule (Rock & Swendseid 1992, cited in West & Castenmiller 1998). Similarly, Hoffmann et al. (1999) showed that dietary fibre, pectin, guar and cellulose supplementation decreased antioxidant activity of a carotenoid and α-tocopherol mixture (Hammond et al. 1997).

High bioavailability

- Formulated carotenoids in water-dispersible beadlets (natural or synthetic)
- Carotenoids – oil form (natural or synthetic)
- Fruits (peach, apricot, melon)
- Tubers (sweet potato, yam, squash)
- Processed juice with fat-containing meal (e.g. tomato)
- Lightly cooked yellow/orange vegetables (carrots, peppers)
- Raw juice without fat (tomato)
- Raw yellow/orange vegetables (carrots, peppers)
- Raw green leafy vegetables (spinach, silver beet)

Low bioavailability

Figure 1: Relative bioavailability of carotenoids according to food matrix (adapted from Boileau et al. 1998; Lister 2003).

5.2.3 Phenolic compounds

There have been few studies on the bioavailability of hydroxycinnamic acids, and not specifically those in sweet potato. However, in two studies reviewing the bioavailability of dietary polyphenols, phenolic acids were among the best absorbed (Scalbert et al. 2002; Karakaya 2004). Anthocyanins, conversely, were the least well absorbed, but this area has not been thoroughly investigated and it is possible that anthocyanin metabolites have not yet been identified.

5.2.4 *Lignans*

Using the enterolignans enterdiol and enterolactone as biomarkers, it has been shown that a substantial amount of the ingested plant lignans are available for use in the body (Higdon 2005). However, as mentioned earlier, there is also considerable interindividual variation in both serum and urinary excretion of lignans. Explanatory factors include the dietary constituents and form of the food, the colonic environment of the subject, antibiotic use by the subject, possibly contraceptive use or stage of menstrual cycle for women and differences in metabolism and excretion between sexes (Lampe 2003).

5.3 *Genus*

Besides the different micronutrients they contain (Table 2), different Brassicaceae genera contain different phytochemicals in different amounts. These include glucosinolates, which are then converted to different hydrolysis products (Kushad et al. 1999; Bennett et al. 2002; McNaughton & Marks 2003; O'Hare et al. 2005; Tian et al. 2005; Nilsson et al. 2006). The variation in glucosinolate amounts from a large number of studies is extensively documented in McNaughton & Marks (2003).

5.4 *Cultivar*

There is also a large body of research documenting wide variations in micronutrients and phytochemicals, including glucosinolates, between different cultivars (e.g. Bennett et al. 2002; Jeffery et al. 2003; Vallejo et al. 2003; Schonhof et al. 2004; Nilsson et al. 2006).

5.5 *Growing conditions*

Several studies document how growing conditions such as hours of sunlight or temperature, and agronomical practices such as the application of fertilisers, can affect nutrients in plants. For example, Schreiner (2005) showed that glucosinolate content in broccoli and radish increased with the availability of sulphur as well as with a reduced supply of nitrogen or water. Sulphur supply did not affect cauliflower glucosinolates, but lower water and nitrogen availability increased glucosinolates, as also occurred with broccoli and radish.

Growing conditions can also alter between seasons to affect nutrient levels. Nilsson et al. (2006) showed how amounts of the major glucosinolates in white cabbage, curly kale and cauliflower all varied somewhat between different growing seasons, but the extent to which they differed were significant for some glucosinolates but not for all. Differences in cauliflower glucosinolates were in fact more pronounced than in those in white cabbage or curly kale samples. Broccoli harvested in spring or autumn had higher antioxidant activity than that harvested in winter or summer (Schreiner 2005).

5.6 Part of plant

Nilsson et al. (2006) also found distinct differences in the amounts of bioactive components in different parts of the plant. Total glucosinolates were approximately 60% higher in the flower of the cauliflower than in the stalk and, similarly, the outer leaves of white cabbage contained around 30% more than the inner leaves. Levels of individual glucosinolates also varied.

5.7 Level of maturity

Seeds and sprouted seeds of broccoli have particularly high concentrations of glucosinolates, and this is likely to be the case with other vegetables. Three-day-old broccoli sprouts have 10-100 times more glucoraphanin by weight than the mature heads (Fahey et al. 1997). Investigating amounts of various bioactives in broccoli heads at different stages of maturity, Vallejo et al. (2003) found that amounts of vitamin C, flavonoids and phenolic acids all increased steadily with age, reaching a maximum when the head was at the "over mature" stage. In contrast, glucosinolates peaked in the second or third of the five stages, depending on the degree of sulphur fertilisation and cultivar. The stage at which most broccoli is harvested for market was stage 4.

5.8 Processing

Some studies report losses of glucosinolates and/or hydrolysis products as a result of cooking (Jeffery et al. 2003). Because they are water-soluble, glucosinolates may leach into cooking water, with boiling for 9 to 15 minutes reducing glucosinolate content in some brassicas by 18 to 59% (Higdon 2005). Thus, cooking methods that require little or no water, such as stir frying, steaming or microwaving, may preserve more glucosinolates. However, as already mentioned, heating destroys the enzyme myrosinase, which is important in converting glucosinolates to isothiocyanates and other hydrolysis products, with the result that although the glucosinolates remain, they cannot be optimally converted because myrosinase is not present. Although some conversion can take place through the action of gut bacteria, it is believed that this is a less effective process. The presence of ESP further complicates the picture, as discussed in section 3.2.1. If present, the conversion of glucosinolates is directed towards the formation of nitrile analogues, which appear to have no useful bioactivity, rather than towards isothiocyanates. ESP is a heat-sensitive protein and by heating broccoli florets and sprouts to 60°C, Matusheski et al. (2004) found that the formation of the sulforaphane nitrile decreased, but sulforaphane increased. However, at temperatures above 70°C, the formation of sulforaphane in the florets decreased, though interestingly this was not seen in the sprouts. This would suggest that a mild heat treatment would allow optimal sulforaphane production, by destroying ESP, and leaving myrosinase intact. Rouzaud et al. (2004) similarly demonstrated that microwaving cabbage (8 minutes at full power in a 850 W oven) resulted in less isothiocyanate production after eating than when the cabbage was eaten raw. In contrast, however, antioxidant activity increased by similar amounts (approximately 16%) in broccoli after boiling for 5 minutes, steaming for 7.5 minutes or microwaving for 1.5 minutes. Phenolic content in broccoli dropped slightly when boiled, but increased with steaming and microwaving (Turkmen et al. 2005).

6 Quotes and trivia

- The ancient Romans are believed to have first cultivated the Calabrese broccoli, (still the most popular variety today) and valued it highly. The son of the Emperor Tiberius apparently ate it to such excess that his urine turned green Centuries later, Catherine de Medici is reported to have insisted on taking it, along with her favourite chefs, to France when she married Henry II.
- Julius Caesar would apparently eat collard greens in order to prevent indigestion after attending royal banquets.
- The first President Bush very publicly announced his aversion to broccoli – by contrast to Thomas Jefferson, the third president of the United States, who recorded growing it in his extensive garden in Virginia some 200 years earlier.
- Cauliflower – “cabbage with a college education” (Mark Twain).
- Cabbage – a Korean equivalent of sauerkraut, kimchi, is being investigated for providing protection against avian flu, because of the lactic acid bacteria it contains.
- Brussels sprouts have been grown by farmers in Belgium since the 16th Century, although they did not originate there.
- Daikon can grow up to a metre long and weigh up to 40 kg, although they are usually harvested at 1 to 5 pounds.
- Broccoli and cauliflower (and their crosses) are unusual in being plant foods where the flower is the part most commonly eaten.
- Swedes are also known as rutabagas and belong to the same family as rape, whose seeds are used for canola oil. They may be a cross between turnips and cabbage and are thought to have originated in the Middle Ages.
- The Scottish eat turnips with their haggis referring to them as "bashed neeps”. Turnips were originally called "neeps”, from the Latin word for turnip, *napus*. The prefix “turn” refers to their spherical shape.
- In northern Europe, turnip leaves are also eaten and are known as turnip greens.
- The word broccoli comes from the Italian *brocco* meaning "arm", or "branch".
- The Brassicaceae family was formerly called the Crucifers due to the four-petalled flowers in the shape of a cross.

- Very large intakes of *Brassica* feed crops cause hypothyroidism in animals, though there have been no instances of this in humans.

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Appendices

Appendix I Nutritional information on assorted Brassica *vegetables (per 100 g edible portion) from FOODfiles 2004*

Broccoli, raw		
Water	g	88
Energy	kcal	32
Protein	g	4.38
Total fat	g	0.6
Carbohydrate, available	g	2.3
Dietary fibre (Englyst, 1988)	g	3.8
Ash	g	1.1
Sodium	mg	5
Phosphorus	mg	104
Potassium	mg	487
Calcium	mg	42
Iron	mg	1.2
Beta-carotene equivalents	µg	410
Total vitamin A equivalents	µg	68
Thiamin	mg	0.09
Riboflavin	mg	0.35
Niacin	mg	0.5
Vitamin C	mg	57
Cholesterol	mg	0
Total saturated fatty acids	g	0.099
Total monounsaturated fatty acids	g	0.044
Total polyunsaturated fatty acids	g	0.308
Dry matter	g	12
Total nitrogen	g	0.7
Glucose	g	1
Fructose	g	1.2
Sucrose	g	0.1
Lactose	g	0
Maltose	g	0
Total available sugars	g	2.3
Starch	g	T
Alcohol	g	0
Total niacin equivalents	mg	1.3
Soluble non-starch polysaccharides	g	1.5
Insoluble non-starch polysaccharides	g	2.2
Energy	kJ	134
Magnesium	mg	17
Manganese	µg	362
Copper	mg	0.06
Zinc	mg	0.7
Selenium	µg	0.29
Retinol	µg	0
Potential niacin from tryptophan	mg	0.8
Vitamin B6	mg	0.205
Folate, total	µg	75.4
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.06

Brussel sprouts, inner leaves, raw		
Water	g	87.1
Energy	kcal	39
Protein	g	4.33
Total fat	g	1.12
Carbohydrate, available	g	2.9
Dietary fibre (Englyst, 1988)	g	3.4
Ash	g	1.1
Sodium	mg	4
Phosphorus	mg	70
Potassium	mg	411
Calcium	mg	35
Iron	mg	0.76
Beta-carotene equivalents	µg	433
Total vitamin A equivalents	µg	72
Thiamin	mg	0.108
Riboflavin	mg	0.15
Niacin	mg	0.757
Vitamin C	mg	97.3
Cholesterol	mg	0
Total saturated fatty acids	g	0.234
Total monounsaturated fatty acids	g	0.087
Total polyunsaturated fatty acids	g	0.576
Dry matter	g	12.9
Total nitrogen	g	0.69
Glucose	g	1.3
Fructose	g	1.1
Sucrose	g	0.4
Lactose	g	0
Maltose	g	0
Total available sugars	g	2.8
Starch	g	0.1
Alcohol	g	0
Total niacin equivalents	mg	1.56
Soluble non-starch polysaccharides	g	1.8
Insoluble non-starch polysaccharides	g	1.6
Energy	kJ	162
Magnesium	mg	20.5
Manganese	µg	168
Copper	mg	0.109
Zinc	mg	0.54
Selenium	µg	0.116
Retinol	µg	0
Potential niacin from tryptophan	mg	0.807
Vitamin B6	mg	0.303
Folate, total	µg	119
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.08

Cabbage, white, inner and outer leaves, raw		
Water	g	92
Energy	kcal	31
Protein	g	1.25
Total fat	g	0.2
Carbohydrate, available	g	6.1
Dietary fibre (Englyst, 1988)	g	1.9
Ash	g	0.6
Sodium	mg	5
Phosphorus	mg	39
Potassium	mg	215
Calcium	mg	41
Iron	mg	0.4
Beta-carotene equivalents	µg	11
Total vitamin A equivalents	µg	2
Thiamin	mg	0.05
Riboflavin	mg	0.04
Niacin	mg	0.1
Vitamin C	mg	21
Cholesterol	mg	0
Total saturated fatty acids	g	0.026
Total monounsaturated fatty acids	g	0.015
Total polyunsaturated fatty acids	g	0.097
Dry matter	g	8
Total nitrogen	g	0.2
Glucose	g	2.9
Fructose	g	3.2
Sucrose	g	0
Lactose	g	0
Maltose	g	0
Total available sugars	g	6.1
Starch	g	0.04
Alcohol	g	0
Total niacin equivalents	mg	0.3
Soluble non-starch polysaccharides	g	0.7
Insoluble non-starch polysaccharides	g	1.2
Energy	kJ	129
Magnesium	mg	10
Manganese	µg	121
Copper	mg	0.01
Zinc	mg	0.12
Selenium	µg	0.1
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.1
Folate, total	µg	44
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.01

Cauliflower, raw		
Water	g	92.2
Energy	kcal	27
Protein	g	2.2
Total fat	g	0.3
Carbohydrate, available	g	3.8
Dietary fibre (Englyst, 1988)	g	2.22
Ash	g	0.8
Sodium	mg	7.8
Phosphorus	mg	53
Potassium	mg	340
Calcium	mg	25
Iron	mg	0.4
Beta-carotene equivalents	µg	9
Total vitamin A equivalents	µg	2
Thiamin	mg	0.07
Riboflavin	mg	0.09
Niacin	mg	0.5
Vitamin C	mg	60
Cholesterol	mg	0
Total saturated fatty acids	g	0.048
Total monounsaturated fatty acids	g	0.021
Total polyunsaturated fatty acids	g	0.146
Dry matter	g	7.8
Total nitrogen	g	0.35
Glucose	g	1.5
Fructose	g	1.6
Sucrose	g	0.2
Lactose	g	0
Maltose	g	0
Total available sugars	g	3.3
Starch	g	0.5
Alcohol	g	0
Total niacin equivalents	mg	1
Soluble non-starch polysaccharides	g	0.76
Insoluble non-starch polysaccharides	g	1.45
Energy	kJ	111
Magnesium	mg	10
Manganese	µg	162
Copper	mg	0.03
Zinc	mg	0.3
Selenium	µg	0.129
Retinol	µg	0
Potential niacin from tryptophan	mg	0.537
Vitamin B6	mg	0.214
Folate, total	µg	55
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.41

Turnip, flesh, raw		
Water	g	93.3
Energy	kcal	21
Protein	g	0.8
Total fat	g	0.3
Carbohydrate, available	g	3.7
Dietary fibre (Englyst, 1988)	g	1.8
Ash	g	0.62
Sodium	mg	58
Phosphorus	mg	28
Potassium	mg	240
Calcium	mg	59
Iron	mg	0.4
Beta-carotene equivalents	µg	0
Total vitamin A equivalents	µg	0
Thiamin	mg	0.04
Riboflavin	mg	0.05
Niacin	mg	0.6
Vitamin C	mg	25
Cholesterol	mg	0
Total saturated fatty acids	g	0.04
Total monounsaturated fatty acids	g	0.03
Total polyunsaturated fatty acids	g	0.18
Dry matter	g	6.7
Total nitrogen	g	0.12
Glucose	g	1.9
Fructose	g	1.4
Sucrose	g	0.2
Lactose	g	0
Maltose	g	0
Total available sugars	g	3.5
Starch	g	0.2
Alcohol	g	0
Total niacin equivalents	mg	0.8
Soluble non-starch polysaccharides	g	0.7
Insoluble non-starch polysaccharides	g	1.1
Energy	kJ	86
Magnesium	mg	7
Manganese	µg	165
Copper	mg	0.07
Zinc	mg	0.2
Selenium	µg	0.23
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.11
Folate, total	µg	12
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	T

Swede, flesh, raw		
Water	g	88.3
Energy	kcal	29
Protein	g	1.4
Total fat	g	0.1
Carbohydrate, available	g	5.6
Dietary fibre (Englyst, 1988)	g	2.5
Ash	g	0.8
Sodium	mg	44
Phosphorus	mg	26
Potassium	mg	314
Calcium	mg	54
Iron	mg	0.5
Beta-carotene equivalents	µg	T
Total vitamin A equivalents	µg	T
Thiamin	mg	0.08
Riboflavin	mg	0.05
Niacin	mg	1.5
Vitamin C	mg	36
Cholesterol	mg	0
Total saturated fatty acids	g	0.013
Total monounsaturated fatty acids	g	0.007
Total polyunsaturated fatty acids	g	0.061
Dry matter	g	11.7
Total nitrogen	g	0.22
Glucose	g	3
Fructose	g	2
Sucrose	g	0.3
Lactose	g	0
Maltose	g	0
Total available sugars	g	5.3
Starch	g	0.3
Alcohol	g	0
Total niacin equivalents	mg	1.8
Soluble non-starch polysaccharides	g	1.2
Insoluble non-starch polysaccharides	g	1.3
Energy	kJ	120
Magnesium	mg	14
Manganese	µg	201
Copper	mg	0.031
Zinc	mg	0.22
Selenium	µg	0.19
Retinol	µg	0
Potential niacin from tryptophan	mg	0.3
Vitamin B6	mg	0.27
Folate, total	µg	37
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	T

Watercress, leaves & upper stem, raw		
Water	g	93
Energy	kcal	16
Protein	g	2.76
Total fat	g	0.42
Carbohydrate, available	g	0.2
Dietary fibre (Englyst, 1988)	g	1.4
Ash	g	1.07
Sodium	mg	16.6
Phosphorus	mg	33.3
Potassium	mg	180
Calcium	mg	52.7
Iron	mg	2.24
Beta-carotene equivalents	µg	4950
Total vitamin A equivalents	µg	824
Thiamin	mg	0.115
Riboflavin	mg	0.035
Niacin	mg	0.268
Vitamin C	mg	75
Cholesterol	mg	0
Total saturated fatty acids	g	0.129
Total monounsaturated fatty acids	g	0.038
Total polyunsaturated fatty acids	g	0.167
Dry matter	g	7
Total nitrogen	g	0.44
Glucose	g	0.1
Fructose	g	T
Sucrose	g	T
Lactose	g	0
Maltose	g	0
Total available sugars	g	0.1
Starch	g	0.12
Alcohol	g	0
Total niacin equivalents	mg	0.8
Soluble non-starch polysaccharides	g	0.7
Insoluble non-starch polysaccharides	g	0.8
Energy	kJ	65
Magnesium	mg	13.2
Manganese	µg	504
Copper	mg	0.011
Zinc	mg	0.27
Selenium	µg	0.19
Retinol	µg	0
Potential niacin from tryptophan	mg	0.5
Vitamin B6	mg	0.187
Folate, total	µg	80
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.3

Radishes, flesh and skin, raw		
Water	g	93.6
Energy	kcal	19
Protein	g	0.96
Total fat	g	0.5
Carbohydrate, available	g	2.6
Dietary fibre (Englyst, 1988)	g	1.3
Ash	g	0.71
Sodium	mg	56.4
Phosphorus	mg	26
Potassium	mg	229
Calcium	mg	42
Iron	mg	1.81
Beta-carotene equivalents	µg	13
Total vitamin A equivalents	µg	2
Thiamin	mg	0.038
Riboflavin	mg	0.019
Niacin	mg	0.191
Vitamin C	mg	23.9
Cholesterol	mg	0
Total saturated fatty acids	g	0.15
Total monounsaturated fatty acids	g	0.085
Total polyunsaturated fatty acids	g	0.225
Dry matter	g	6.4
Total nitrogen	g	0.15
Glucose	g	1.5
Fructose	g	1.1
Sucrose	g	0
Lactose	g	0
Maltose	g	0
Total available sugars	g	2.6
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	0.3
Soluble non-starch polysaccharides	g	0.6
Insoluble non-starch polysaccharides	g	0.7
Energy	kJ	78
Magnesium	mg	10.5
Manganese	µg	90.7
Copper	mg	0.037
Zinc	mg	0.38
Selenium	µg	0.288
Retinol	µg	0
Potential niacin from tryptophan	mg	0.1
Vitamin B6	mg	0.096
Folate, total	µg	22.9
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	T

Cabbage, Chinese, raw		
Water	g	95.7
Energy	kcal	10
Protein	g	1.1
Total fat	g	0
Carbohydrate, available	g	1.3
Dietary fibre (Englyst, 1988)	g	1.2
Ash	g	0.7
Sodium	mg	6
Phosphorus	mg	36
Potassium	mg	250
Calcium	mg	25
Iron	mg	0.3
Beta-carotene equivalents	µg	190
Total vitamin A equivalents	µg	32
Thiamin	mg	0.03
Riboflavin	mg	0.04
Niacin	mg	0.4
Vitamin C	mg	20
Cholesterol	mg	0
Total saturated fatty acids	g	0
Total monounsaturated fatty acids	g	0
Total polyunsaturated fatty acids	g	0
Dry matter	g	4.3
Total nitrogen	g	0.176
Glucose	g	0.7
Fructose	g	0.6
Sucrose	g	T
Lactose	g	0
Maltose	g	0
Total available sugars	g	1.3
Starch	g	T
Alcohol	g	0
Total niacin equivalents	mg	0.59
Soluble non-starch polysaccharides	g	0.6
Insoluble non-starch polysaccharides	g	0.6
Energy	kJ	40
Magnesium	mg	8
Manganese	µg	280
Copper	mg	0.02
Zinc	mg	0.2
Selenium	µg	0.06
Retinol	µg	0
Potential niacin from tryptophan	mg	0.19
Vitamin B6	mg	0.1
Folate, total	µg	72
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.2

Appendix II Chemical structures of major phytochemicals in Brassicas

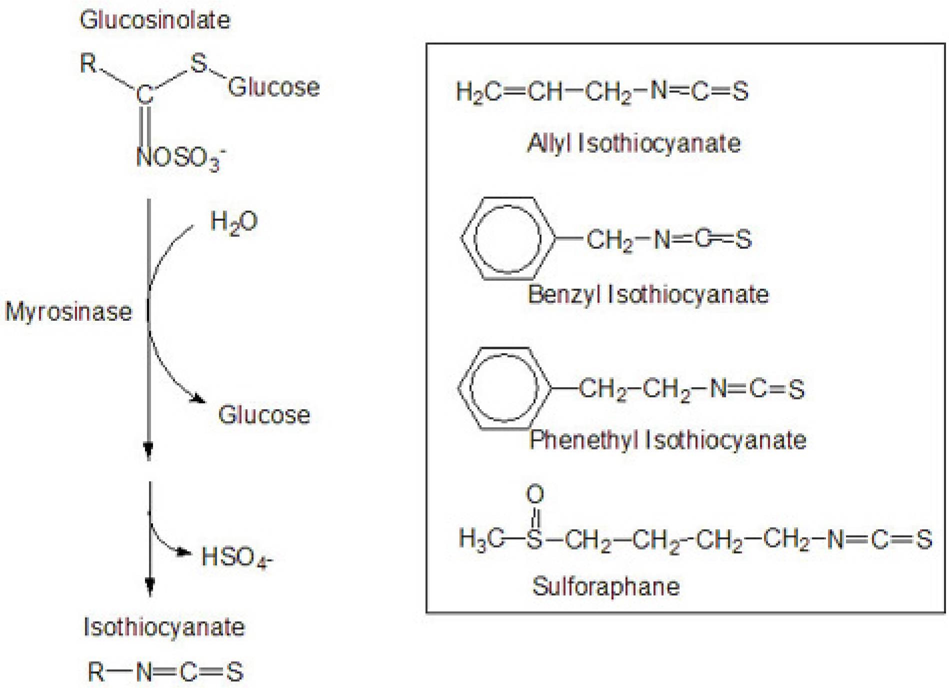

Figure 1: Myrosinase-catalysed glucosinolate hydrolysis and chemical structures of selected isothiocyanates (Higdon 2005).

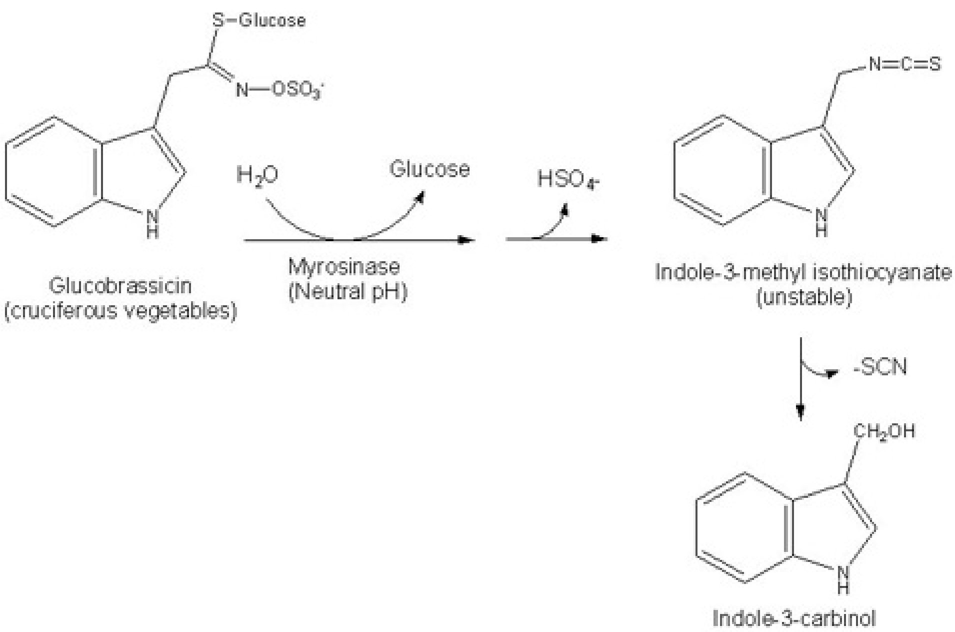

Figure 2: Formation of indole-3-carbinol (Higdon 2005).

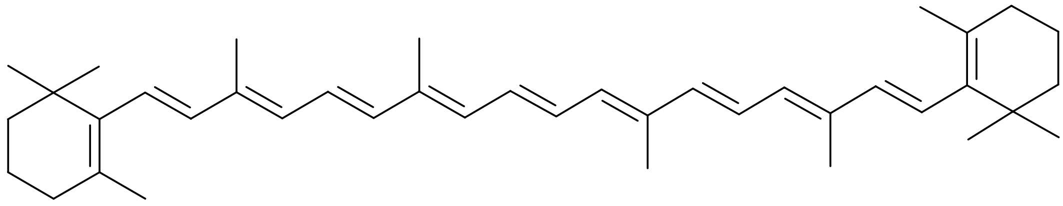

Figure 3: β-carotene.

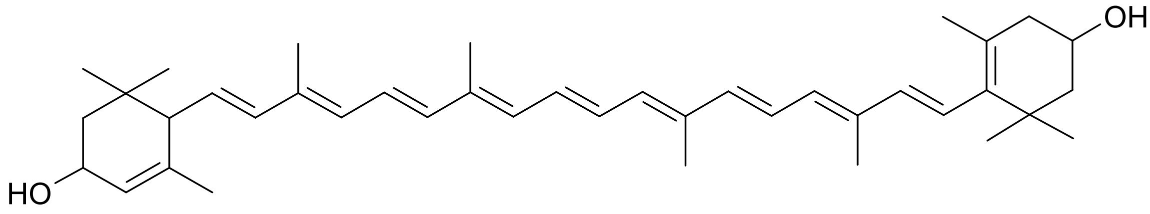

Figure 4: Lutein.

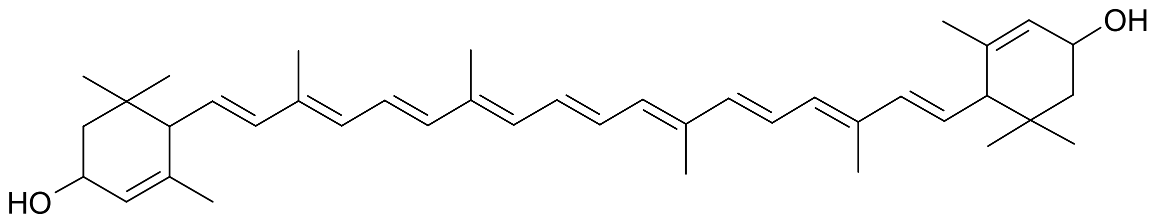

Figure 5: Zeaxanthin.

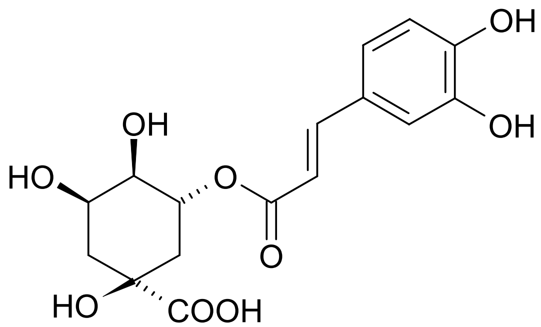

Figure 6: Chlorogenic acid.

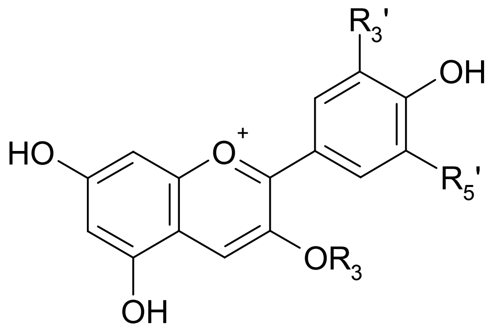

Figure 7: Basic anthocyanin.

Appendix III Glucosinolate composition and concentration (µmol/g) of seeds of Asian and Western vegetables (adapted from O' Hare 2005)

Glucosinolate	Red raddish	Daikon	Broccoli	Kohl rabi	Garden cress	Rocket	Kale	Water cress	Chinese broccoli	Cabbage	Choy sum	Mizuna	Senposai	Red giant mustard	Pak choy	Black mustard	Japanese turnip	Broccoli raab	Tatsoi	Chinese cabbage	Komatsuna	White mustard
Glucosiberin								2.7														
Glucoraphenin	117.4	109.2				1.4																
Glucoraphanin		2.0	102.3	26.4		3.2	9.8				1.0	1.6	1.7		2.7					1.1		
Glucohirsutin								1.3														
Glucoalyssin											2.2	1.0					1.0	3.2	1.0	0.7		
Glucoberteroin			2.6	1.9			1.9			3.1	1.8	2.8						1.6		1.1		
Glucoiberin				14.0			16.8			21.6												
Glucoerucin			29.5	8.1		72.7	3.2					4.7					1.1					
Glucodehydroerucin		5.3																				
Glucotropaeolin					137.4																	
Glucoiberverin				1.7			3.1		1.5	7.4												
Gluconasturtiin								60.8										2.5				
Sinigrin				2.5			25.1		42.7	22.2			20.4	84.3		71.0		1.4				
Gluconapin				0.8			4.6	0.8	98.0		65.0	40.2	37.1	2.8	37.8		59.5	30.4	53.5	16.3	37.1	
Glucobrassicanapin											9.1	4.0			1.4		11.9	16.1	5.2	1.1	4.0	
Gluconapolieferin																		0.4				
Glucosinalbin										0.4								1.3				250.1
4-Hydroxyglucobrassicin	11.0	9.6	8.9	7.0			10.6		6.3	10.5	5.8	6.4	11.2	6.0	5.2	4.1	6.4	7.7	6.0	9.7	6.0	
Progoitrin				4.1			11.8				9.2	1.8	61.9		5.9		1.8	2.2	1.1	6.7	0.7	
Epiprogoitrin													1.3									4.9
Glucobrassicin										0.6										1.2		