Compiling the nutritional and health benefit information for fresh vegetables

Lesley Hedges
Crop & Food Research Institute

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Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

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Summary:
This report focuses on the nutritional attributes of twenty five assorted herbs. Their composition is described and related to their beneficial effects on health. Finally, quotes and facts of general interest are provided.

Crop & Food Research Confidential Report No. 1391

Nutritional attributes of tomatoes

L J Hedges & C E Lister

June 2005

A report prepared for
VegFed

Copy 9 of 9

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

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1 Executive summary

1.1 Background

This report is intended to provide an information resource from which material can be selected for incorporation into promotional and educational booklets for the various VegFed sector groups. We have gathered relevant literature, including medical research and scientific papers, and, where possible, information specific to New Zealand. This report focuses on the nutritional attributes of tomatoes, but also includes factors that may influence these, such as bioavailability, agronomical issues, cooking or processing and storage. Some additional material of general interest has also been included.

1.2 Composition

Tomatoes contain a variety of phytochemicals, the most well known being lycopene. In addition, other carotenoids (e.g. β-carotene, phytoene, phytofluene), phenolics (e.g. coumaric and chlorogenic acids, quercetin, rutin and naringenin), moderate amounts of the antioxidant vitamin C (ascorbic acid) and a little vitamin E (tocopherol) are present. Carotenoids are present in many vegetables and fruit but lycopene is more restricted in its distribution, being concentrated in tomatoes, guava, rosehip, watermelon and pink grapefruit. Lycopene imparts the red colour to these fruits.

1.3 Lyopene and human health

Globally, considerable research is being conducted into the health benefits of lycopene. It is a powerful antioxidant; antioxidants neutralise free radicals, which may cause damage to cell components (e.g. DNA, protein, lipids). It may also have a range of other modes of action. The strongest scientific evidence is for a role of lycopene in reducing the incidence of prostate cancer. Lycopene may also help reduce the incidence of other cancers and cardiovascular diseases, and play a role in eye health.

1.4 The role of other tomato components in human health

There has been less study of the role of other tomato phytochemicals. β-Carotene is an important precursor of vitamin A and, like lycopene, may play a role in cancer prevention. The phenolic compounds, especially the flavonoids, are important antioxidants. Other potential health-promoting bioactivities of the flavonoids include anti-allergic, anti-inflammatory, anti-microbial and anti-cancer properties. The yellow jelly around tomato seeds may stop platelet aggregation and help prevent heart attacks, strokes and blood vessel problems.

1.5 Bioavailability

Lycopene is absorbed in the human body and is one of the most common circulating carotenoids. Other tomato carotenoids may also be bioavailable. Many factors affect the bioavailability of lycopene and other carotenoids, including the nature of the food matrix, thermal processing and presence of fat. Of the phenolics, naringenin from tomatoes has been shown to be bioavailable. Data on other phenolics are lacking.

1.6 Tomato consumption and major disease patterns

New Zealanders would appear to consume fewer tomato and tomato-based products than do Mediterranean peoples and have a higher incidence of prostate cancer. Heart disease mortality figures are also higher. Whether these higher incidences of disease are related to lower tomato consumption remains to be proven, but this association may at least be part of the answer.

1.7 Optimum intake levels

To date there is no clear consensus on the intake of lycopene required to reduce disease risk. Suggestions range from about 5 up to 35 mg lycopene per day. This could be achieved by consuming at least one or two servings of tomatoes or tomato products every day.

1.8 Factors affecting phytochemical levels in tomatoes

Levels of tomato phytochemicals may be affected by cultivar, growing conditions, degree of ripeness and cooking or processing. It may be possible to enhance the levels of lycopene and other phytochemicals in tomatoes and tomato products by managing these factors.

1.9 Promoting nutritional benefits

Since lycopene intake levels are comparatively low in New Zealand compared to in Mediterranean countries, promotion could build on the notion that tomato consumption may reduce disease incidence, particularly that of some cancers and cardiovascular disease. Prostate and skin cancer could be of special interest because of their high levels of occurrence here.

The intense red colour and therefore high lycopene content of some New Zealand-grown tomatoes over the paler Australian imports could be a differentiating factor for promotional purposes.

Consumption of the whole tomato, including skins and seeds, consumed with a little good quality oil optimises the delivery of the potential benefits of tomatoes in general, as well as lycopene specifically. Cooking also enhances lycopene bioavailability, but can also reduce levels of other nutrients, such as vitamin C.

2 Introduction

The much heralded ‘Mediterranean diet’ is widely believed to confer health benefits with respect to preventing particular cancers and cardiovascular disease. It typically contains a significant proportion of fruit and vegetables, cereals, fish, olive oil and red wine. Initially, the general components of this diet were studied and the benefits of the Mediterranean diet attributed variously to the high amounts of fibre, the high vitamin intake, and the omega 3 polyunsaturated fish oils and omega 6 polyunsaturated oils in whole grains and monounsaturated olive oil. More recently, the contributions made by antioxidants and other phytochemicals, such as the sulfur compounds present in the onion family and the phenolics in red wine, have been recognised. More recently still, attention has turned to the ubiquitous tomato and the pigment that gives it the characteristic red colour, lycopene.

Originating from South America, and taken back to Europe by the Spaniards in the early 16th century, the tomato was initially viewed with suspicion in northern Europe and English speaking countries where it was also known as the “wolf peach”. A rough translation of its botanical name, *Lycopersicon,* is “edible wolf peach”, which is an echo of this. Nowadays, however, it is widely cultivated and consumed worldwide, although particularly prominent in Italian, Spanish, Greek and Mexican cuisine. It is frequently consumed fresh as a salad vegetable, but is also processed into a wide range of products including ketchup, soup, puree, paste, pasta sauces; canned in various forms; and combined with various other vegetables, herbs and spices. Salsa is an increasingly popular product. It has been estimated that in the United States more salsa is now consumed than ketchup (Virginia Tech 2003). In the United States and Australia it is the second most commercially important vegetable crop after potatoes (Yeung & Rao 2001; Australian Bureau of Statistics 2003). In New Zealand, consumption of fresh and processed tomatoes is second only to potatoes (VegFed 2005).

There is a large array of commercially available cultivars, reflecting the plant’s adaptability for different growing conditions and end uses. The fruit produced ranges from as small as 1.5 cm in diameter and weighing about 8 g to around 18 cm in diameter and weighing about 800 g (Yeung & Rao 2001 - units converted to metric). They can vary also in colour from white to red to purplish black, including green, yellow and orange, as well as in shape (Yeung & Rao 2001). In red tomatoes some researchers maintain that it is often only the flesh that supplies the red colour, the skin itself often being yellow or orange (Virginia Tech 2003). However, other reports state that the skins contain more lycopene, the red pigment, than the pulp (Sharma & Le Maguer 1996). A New Zealand study of three hydroponically grown greenhouse cultivars. similarly found that on a per weight basis the skins contained more lycopene than the pulp, but that when considering the fruit as a whole, more lycopene was provided by the pulp (Toor & Savage 2005).

This report provides information on the nutritional attributes of tomatoes and their role in a healthy diet. It also describes factors that may affect these attributes. Additional material of general interest is provided in Appendix I.

3 Composition

The major nutritional components of the tomato are shown in Table 1. Further data on the nutritional composition of fresh tomatoes and tomato-based products are given in Appendix II. As can be seen, tomatoes are a good source of vitamin C and vitamin A equivalents (in the form of β-carotene, see Section 3.2) and also provide some vitamin E, folic acid, potassium and other trace elements. Protein and dietary fibre are also present, although the major constituent is water, comprising 94-95% of the fruit by weight (Davies & Hobson 1981). Processed tomatoes may have higher levels of some nutrients because their concentration may be higher in these forms.

Vitamin C is important to prevent scurvy but it is also a powerful antioxidant and may help prevent a range of degenerative diseases. It has been estimated that tomato production in the United States could provide about one-third of the recommended dietary allowance (RDA) for Americans (Pantos & Markakis 1973). The actual contribution to the vitamin C supply is considerably lower than this (12.2% in 1972), but nevertheless only oranges and potatoes contribute more to the American diet (Senti & Rizek 1975). Another nutritionally important component is β-carotene, since it is converted to vitamin A in our bodies. Vitamin A is important for night vision, maintenance of skin, immune function and prevention of infections. Potassium is an essential nutrient for normal health maintenance and growth. Potassium, along with calcium and magnesium, may play a role in reducing high blood pressure. Dietary fibre is important to maintain a healthy digestive system and may also help to control high cholesterol levels in the blood. Tomatoes are a considerable source of fibre, especially when eaten with the skin and seeds.

Table 1: Major dietary components per 100 g red raw tomato.

Nutrient	NZ[1]	USA[2]	Other[3]
Vitamin A	92 µg RAE	31 µg RAE; 623 IU	1000 IU
Vitamin B1 (µg)	20	59	60
Vitamin B2 (µg)	10	48	40
Folic Acid (µg)	14	15	28
Vitamin C (mg)	23.7	19.1	22
Vitamin E (mg)	0.77	0.38	1.2
Potassium (mg)	265	222	290
Calcium (mg)	11	5	21
Magnesium (mg)	12.1	11	14

[1] NZ Food Composition Database (Athar et al. 2001).
[2] USDA National Nutrient Database for standard reference, Release 15 - Year round average.
[3] Data from Yeung & Rao (2001).

In addition to the general nutrients above, tomatoes contain an array of phytochemicals (= plant-derived chemicals). Many of these compounds are antioxidants, substances that inactivate certain harmful reactive compounds in the body (free radicals). There are many different antioxidants, including vitamins C (ascorbic acid) and E (tocopherols), carotenoids, flavonoids and other phenolics, the trace elements selenium and zinc, some sulfur compounds and other individual substances (e.g. lipoic acid and coenzyme Q). These antioxidants are substances that have beneficial effects in the body beyond providing the nutrients necessary to prevent deficiency diseases such as scurvy, pellagra and beriberi. Instead, they are believed to prevent or delay the onset or progression of many chronic diseases, such as cancer and cardiovascular disease. They may deactivate free radicals that may be present in the body through diet, pollution, smoking, exposure to radiation or UV light or merely as part of the body's normal processes. As can be seen from Table 2, tomatoes contain a significant number of these antioxidants and in reasonable quantities. Of these, lycopene is of particular interest since it is available in relatively few other foods, yet is present in tomatoes in reasonable quantities.

The levels of these antioxidant components may vary according to such factors as cultivar (Hayman 1999; Orlowski et al. 2002; Thompson et al. 2000), growing conditions (Lacatus et al. 1995; Zushi & Matsuzoe 1998), method of ripening (Arias et al. 2000), processing (Shi & Le Maguer 2000; Thompson et al. 2000; Takeoka et al. 2001) and storage conditions (Hayman 1999). These agronomic issues will be discussed in greater detail in Section 8. As will be seen, some of these micronutrients are destroyed by processing but with others, such as lycopene, bioavailability may be enhanced.

Table 2: Summary of the levels of the main antioxidant components in tomatoes (data from a range of sources).

Component	Typical concentration (mg/100 g FW)
Ascorbic acid	15-48
Carotenoids (total)	4-24
β-carotene	0.4-1
lycopene	3-18
phytoene	1-3
phytofluene	~1
Phenolic acids	16-29
caffeic acid	0.2-10
chlorogenic acid	1.3-3.8
coumaric acid	0.1-1.6
ferulic acid	0.1-0.7
Flavonoids	
naringenin	0.4-4.2
quercetin glycosides (primarily rutin)	0.3-4.3
kaempferol glycosides	0.02-0.10
Vitamin E	0.04-1.2

3.1 Antioxidant vitamins

Tomatoes contain high levels of vitamin C (Fig. 1) and it has been stated that for Americans tomatoes and tomato products are the third most important source of this, after citrus fruit and potatoes (Senti & Rizek 1975). Besides preventing scurvy, vitamin C is a powerful antioxidant, scavenging practically all free radicals and oxidants, protecting membranes from oxidative damage and working in combination with vitamin E to inhibit low density lipoprotein (LDL) oxidation. It also assists the proper functioning of certain enzymes.

Only a minor amount of vitamin E (Fig. 1) is present in tomatoes, mostly in the seeds. Besides its function as a vitamin, there is increasing evidence of its role as an antioxidant, particularly with respect to protecting against cardiovascular disease. There is evidence that vitamin E has synergistic effects in combination with certain other antioxidants.

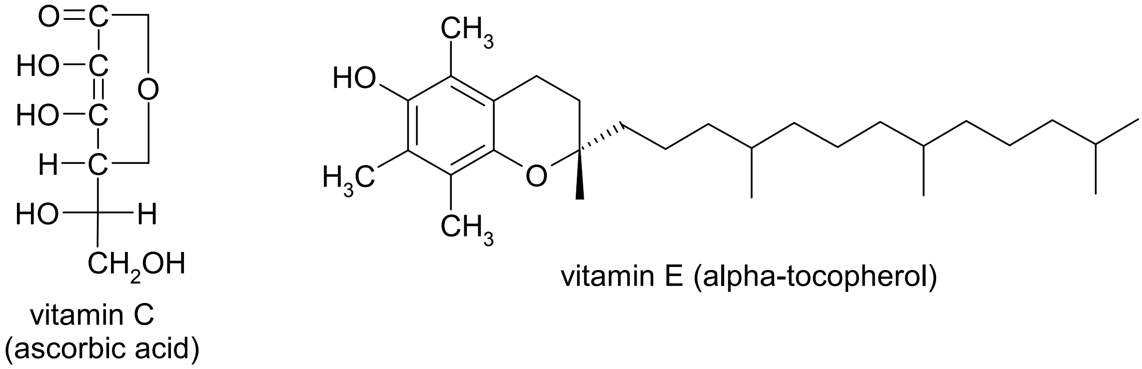


Figure 1: Chemical structures of vitamins C (ascorbic acid) and E (tocopherol).

3.2 Carotenoids

Yellow, orange, and red carotenoids are among the most widespread and important natural pigments. They are found in higher plants, algae, fungi and bacteria, both in nonphotosynthetic tissues and in photosynthetic tissue, (where they accompany the chlorophylls). Their name is derived from the main representative of their group, β-carotene, the orange pigment first isolated from carrots. The carotenoids are classed into two main groups: (1) carotenes that are hydrocarbons ($C_{40}H_{56}$), and (2) their oxygenated derivatives (xanthophylls). Carotenoids are lipids and can specifically absorb light in the UV and specific visible regions of the spectrum, the rest of the spectrum is transmitted or reflected and they appear coloured. The particular structure of individual carotenoid compounds influences their colour.

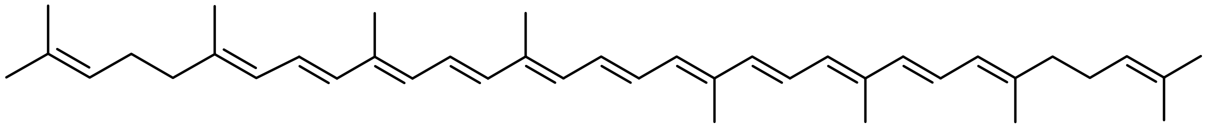
The main carotenoids present in tomatoes are shown in Tables 2 and 3, and the structures of some of these compounds are shown in Figure 2. The red colour of the tomato is due to its major carotene, lycopene, which is present at levels up to 90% of the total carotenoids. A range of other carotenoids is commonly reported including β-carotene, δ-carotene, γ-carotene and neurosporene (Gross 1991), but reports sometimes include other carotenoids. Lycopene epoxide, an oxidation product of lycopene, was reported as the second most predominant carotenoid in tomatoes (Khachik et al. 1992). Abushita et al. (2000) also report that it was present, but at lower levels. The common red tomato also contains the colourless precursors phytoene and phytofluene. Composition of carotenoids does vary considerably between cultivars. Some tomato strains are orange because they do not synthesise lycopene or because other carotenes, such as β-carotene, predominate. The composition of tomato seeds is slightly different than the flesh, with lutein being the main carotenoid followed by β-carotene and lycopene (Rymal & Nakayama 1974).

Table 3: Carotenoid content (mg/100 g FW) of tomatoes and selected tomato products (fresh data from Dumas et al. (2003) and processed data from Tonucci et al. (1995), as given in Beecher (1998)).

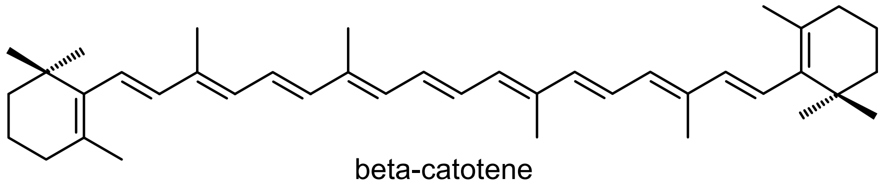
		Tomato product			
Carotenoid	Vitamin A activity[a]	Fresh tomatoes	Canned tomatoes	Tomato catsup	Tomato sauce
Phytoene	-	1.8	1.9	3.4	3.0
Phytofluene	-	1.1	0.8	1.5	1.3
zeta-Carotene	-	0.1	0.2	0.3	0.8
Neurosporene	-	t[b]	1.1	2.6	7.0
Lycopene	-	4.1	9.3	17.2	18.0
gamma-Carotene	+	t[b]	1.5	3.0	3.2
beta-Carotene	++	0.8	0.2	0.6	0.5

[a] Vitamin A activity based on similarity of chemical structure or part of carotenoid molecule to retinal.
[b] Trace.

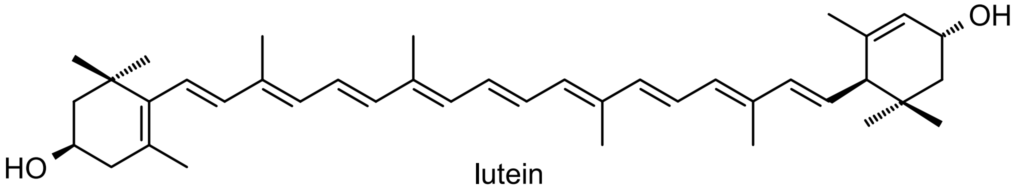
Lycopene comprises a long straight chain, with 11 conjugated double bonds (double bonds on adjacent carbon atoms) (Fig. 2). This structure is not only responsible for conferring colour, but also for its physical properties, chemical reactivity and its biological activity. It exists as various isomers (Fig. 3), but in fresh fruit is usually in the all-*trans* configuration. However, during the heat treatment involved in cooking or processing, exposure to light and some chemical reactions, some lycopene may be converted to the *cis* configuration. This change in the geometry of the molecule is significant because it appears to make lycopene more bioavailable. This is discussed further in Sections 6 and 8.1.4.



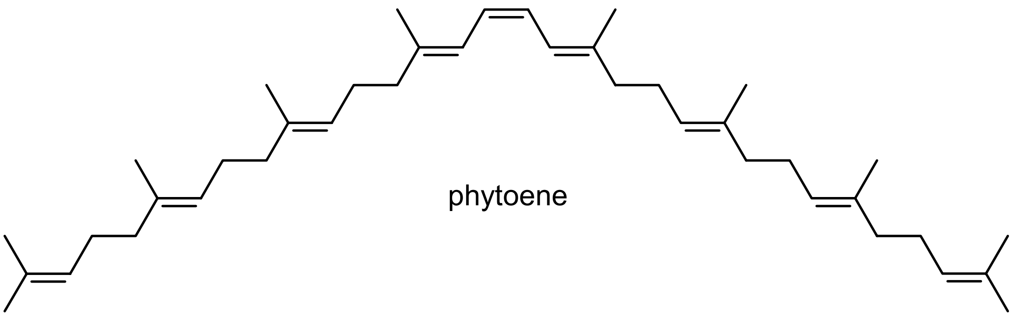
lycopene



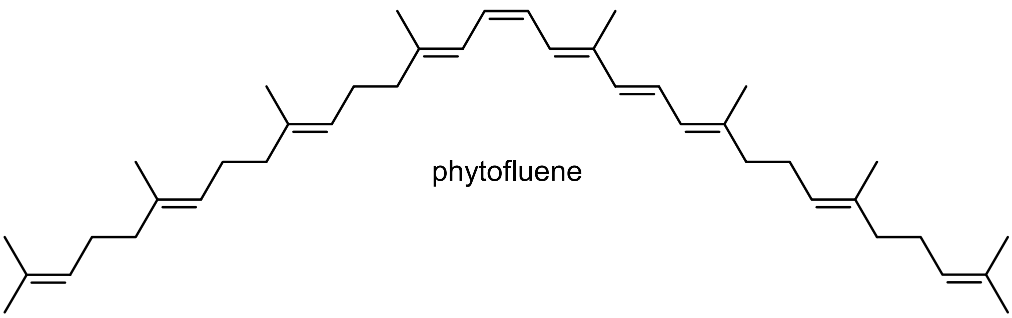
beta-catotene



lutein



phytoene



phytofluene

Figure 2: Chemical structures of lycopene and the other main carotenoids present in tomatoes.

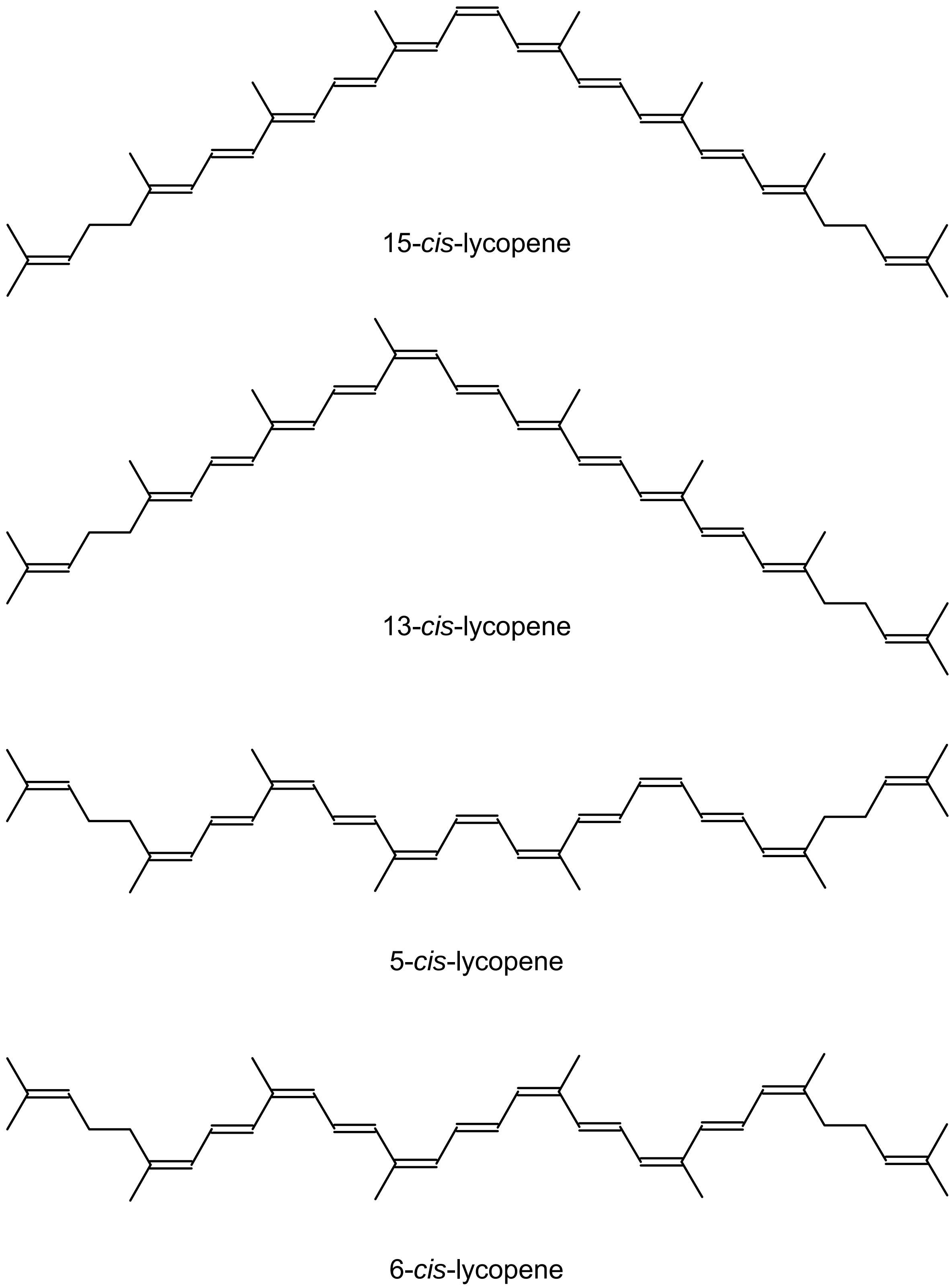


Figure 3: The chemical structure of cis*-isomers of lycopene.*

Lycopene is only present in a few foods, the most common being tomatoes, with watermelon, pink grapefruit, guava, red papaya and rosehips being other sources. Tomatoes, however, are abundant, cheap, versatile and commercially useful, making them by far the most predominant dietary source (Bramley 2000). Table 4 below gives the lycopene content of various foods. The lycopene content of fresh tomatoes can vary from virtually none up to 18 mg/100 g FW, but most values for typical red tomatoes are between 5 and 8 mg/100 g FW (Dumas et al. 2003). Some reports state that lycopene is not present in significant quantities in the tomato skin. However, Sharma & Le Maguer (1996) state that skins contain about five times more lycopene than the pulp (54 mg/100 g FW compared to 11 mg/100 g FW). Toor & Savage (2005) found lycopene in the skin of the three varieties tested averaged around three times more than in the pulp, with a small amount also present in the seeds (although in this study the jelly around the seeds was considered to be 'seed' rather than 'pulp').

Table 4: Lycopene content (mg/100 g FW) of fruit and tomato products (data from Bramley (2000), Holden et al. (1999), Rao & Agarwal (1999), Hart & Scott (1995), Tonucci et al. (1995) and Yeung & Rao (2001).

Food	Lycopene content (mg/100 g FW)
Watermelon	2.3-7.2
Pink guava	5.4
Pink grapefruit	0.5-4.0
Papaya	2.0-5.3
Fresh tomato (raw)	0.9-18.1
Canned tomatoes	4.5-9.7
Tomato sauce	6.2-14.1
Tomato paste	5.4-42.2
Tomato puree	16.7
Tomato juice	5.0-11.6
Tomato ketchup	9.9-17.0
Tomato soup	5.0-7.2
Pizza sauce	12.7

As with many constituent nutrients in plants, levels of lycopene may vary according to cultivar, maturity, growing conditions, harvesting, storage and processing (for more discussion of this see Section 8.1). The levels of lycopene in processed tomato products are significantly higher than in the fresh product. It appears that processing may in fact enhance lycopene content, firstly due to a concentration factor but also by making it more bioavailable (Stahl & Sies 1992). Two major reasons have been postulated for this. Firstly, the act of processing breaks down the food matrix, releasing lycopene for absorption. It is also believed that the *cis*-isomer formed after the thermal energy of cooking or processing is more absorbable than the all-*trans* isomer (Boileau et al. 1999). For further discussion of bioavailability see Section 6.

In addition to lycopene, a range of other carotenoids is present in tomatoes. The most significant of these is probably β-carotene, which attracts considerable interest nutritionally as it can be converted to vitamin A in the human body while lycopene cannot. As mentioned earlier, cultivar has a big influence on the presence/absence of other carotenoids. However, the composition of carotenoids appears to be reasonably consistent over a range of tomato products (Table 5).

Table 5: Carotenoid content (mg/100 g FW) in tomatoes and various tomato products (from Tonucci et al. 1995).

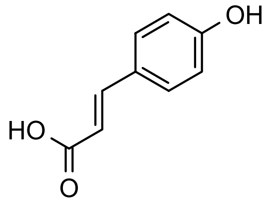
	Carotenoid								
Sample	β-Carotene	γ-Carotene	δ-Carotene	Lutein	Lycopene	Neurosporene	Phytoene	Phytofluene	Lycopene-5,6-diol
Whole tomatoes	0.23	1.50	0.21	0.08	9.27	1.11	1.86	0.82	0.11
Catsup	0.59	3.03	0.33	nd[a]	17.23	2.63	3.39	1.54	0.18
Spaghetti sauce	0.44	3.02	0.34	0.16	15.99	3.15	2.77	1.56	0.17
Tomato paste	1.27	9.98	0.84	0.34	55.45	6.95	8.36	3.63	0.44
Tomato puree	0.41	2.94	0.25	0.09	16.67	2.11	2.40	1.08	0.17
Tomato sauce	0.45	3.17	0.29	t[b]	17.98	2.48	2.95	1.27	0.16

[a] Not detected.
[b] Trace.

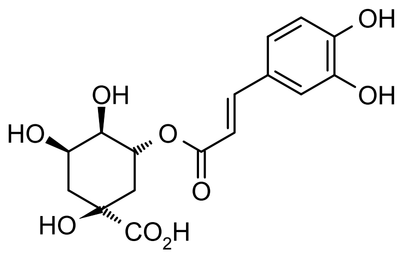
3.3 Phenolic compounds

Other phytochemicals present in tomatoes, though less studied than the carotenoids, are the phenolic compounds. Phenolic compounds are a large group of secondary plant products, present in most if not all plants, that differ in chemical structure and reactivity. The chemical structures range from quite simple compounds like caffeic acid to highly polymerised substances like tannins. Their contribution to the pigmentation of plants is well recognised (the anthocyanins may be red, blue or purple). However, not all phenolics are coloured. There are numerous different groups of phenolics but the most common phenolics found in foods are generally phenolic acids, flavonoids, lignans, stilbenes, coumarins and tannins (Harbourne 1993). The first two of these groups are present in significant amounts in tomatoes.

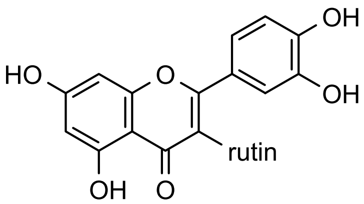
Various total phenolic levels for fresh tomatoes have been reported in the literature: 15.82-22.68 mg/100 g FW (Davies & Hobson 1981), 23 mg/100 g FW (Brune et al. 1991), 25.9-49.8 mg/100 g FW (Martinez-Valverde et al. 2002), and 13.15 mg/100 g FW (Minoggio et al. 2003). There are a number of different groups of phenolic acids present, with the main ones being phenolic acids and flavonols (rutin) (Table 2). The structures of the main phenolics present in tomato fruit are shown in Figure 4. No data were found on the phenolic composition of tomato seeds.



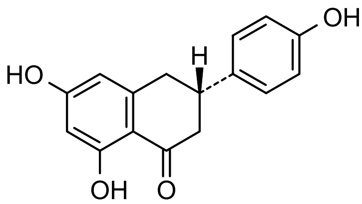
Coumaric acid



Chlorogenic acid



Quercetin-3-rutinoside



Naringenin

Figure 4: Chemical structures of the main phenolics in tomato fruit.

A range of phenolic acids is present, the main ones being caffeic and chlorogenic acids (Table 2). Some authors report that coumaric acid is the main phenolic acid (e.g. Machiex et al. 1990) while others report chlorogenic acid (e.g. Minoggio et al. 2003). These differences could be due to variety/cultivar. Other phenolic acids such as coumaric, ferulic, sinapic, vanillic and salicylic acids may also be present in smaller amounts (Davies & Hobson 1981; Machiex et al. 1990). Cultivars vary in phenolic acid levels and composition (Table 6). There are limited data on the distribution of phenolic acids in the fruit, with most indicating similar contents in flesh and skin. The total hydroxycinnamic acid level of the skin has been reported as 9.4 mg/100 g, while the flesh contains 8.4 mg/100 g (Macheix et al. 1990). However, Herrmann (1973) reported that chlorogenic acid was as high as 50 mg/100 g FW in tomato skin.

Table 6: Content of hydroxycinnamic acids (mg/100 g FW) in tomato cultivars (adapted from Martinez-Valverde et al. 2002).

Tomato cultivar	Phenolic acid			
	Chlorogenic	Caffeic	*p*-Coumaric	Ferulic
Rambo	2.79	0.26	0.11	0.19
Senior	3.28	0.14	0.13	0.17
Ramillete	2.61	1.30	0.40	0.38
Liso	3.28	0.14	nd[a]	0.16
Pera	1.43	1.23	0.25	0.32
Canario	1.70	1.29	0.24	0.27
Durina	2.23	0.99	0.42	0.54
Daniella	1.47	0.59	0.58	0.30
Remate	2.32	0.24	nd[a]	0.19

[a] Not detected.

Tomatoes also contain flavonols, which belong to a sub group of the phenolics family and have been shown to have potent antioxidative activity (Shahidid & Wanasundara 1992). Quercetin glycosides have very high antioxidant activity relative to α-tocopherol (vitamin E) (Hertog et al. 1992). Total flavonol levels for whole tomatoes have been reported to vary between 0.13 and 4.4 mg/100 g FW (Davies & Hobson 1981; Stewart et al. 2000; Martinez-Valverde et al. 2002). However, typical red tomatoes usually contain around 0.5–2 mg/100 g FW of flavonols (Table 7).

Table 7: Content of flavonoids (mg/100 g FW) in tomato cultivars (adapted from Martinez-Valverde et al. 2002).

	Flavonoid		
Tomato cultivar	Quercetin	Kaempferol	Naringenin
Rambo	0.72	nd[a]	0.69
Senior	1.72	nd[a]	0.49
Ramillete	2.87	0.21	0.81
Liso	1.25	nd[a]	0.51
Pera	1.03	0.12	nd[a]
Canario	2.81	nd[a]	0.85
Durina	2.23	nd[a]	0.95
Daniella	4.36	nd[a]	1.26
Remate	2.13	nd[a]	0.45

[a] Not detected.

The main flavonol in tomatoes is a quercetin glycoside, rutin (quercetin 3-rutinoside), but other quercetin and kaempferol glycosides may be present in some cultivars in small amounts (Macheix et al. 1990). As with many phytochemicals, the flavonol content may vary according to many factors including cultivar, the size of the fruit, maturity and environmental/growing conditions (factors influencing the phenolic levels in plants have been reviewed by Parr & Bolwell (2000)) Stewart et al. (2000) showed that the highest concentration of flavonols occurs in tomato skins (Table 8), and thus, in general, smaller tomatoes have higher amounts of this on a per weight basis because of their higher surface area to weight ratio. Purple fruit, which contain anthocyanins, contain much higher levels of flavonols than standard cultivars (Table 9). The rutin level apparently drops during ripening (Macheix et al. 1990). Levels of quercetin glycosides dropped from 1.2-2.4 mg/100 g FW in immature green fruit to 0.3-0.7 mg/100 g FW in red fruit (Davies & Hobson 1981). Woldecke & Herrmann (1974) also reported that the flavonol content, on a per weight basis, decreased during the development of tomato fruits; and it was higher in field-grown than in glasshouse tomatoes. See Section 8.2 for further discussion of factors affecting phenolics in tomatoes, including processing.

Table 8: Distribution of flavonols (mg/100 g FW) in Spanish cherry tomatoes (adapted from Stewart et al. 2000).

Tomato	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol
Whole	0.02	0.05	2.34	0.12	2.53
Skin	0.07	0.04	13.78	0.44	14.33
Flesh	nd[a]	0.01	0.09	0.02	0.12
Seed	0.01	0.02	0.1	0.02	0.15

[a] Not detected.

Table 9: Flavonol content (mg/100 g FW) of skins of different coloured tomatoes (adapted from Stewart et al. 2000).

Tomato cultivar	Skin colour	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol
Noire Charbonneuse	Red/purple	0.39	0.02	40.2	1.42	44.0
Anthocyanin Gainer	Deep red	0.30	0.04	25.2	2.09	27.6
Aubergine	Red/dark patches	0.03	nd[a]	10.3	0.45	10.8
Anthocyanin Free	Red	0.06	0.01	20.6	1.73	22.4
Dark Green	Red/yellow	0.08	nd[a]	18.3	0.49	18.9

[a] Not detected.

Another group of flavonoids present in tomatoes are the flavonones, with the main one being naringenin (Macheix et al. 1990). Some reports state that naringenin is present in the free form only (Wardale 1973), but others clearly show a naringenin glycoside is also present (Hunt & Baker 1980). Hunt & Baker (1980) reported the presence of chalconaringenin (also called naringenin chalcone), naringenin and naringenin-7-glucoside. As with the flavonols, levels of naringenin vary between cultivars (Table 7). Flavan-3-ols are not present and nor are anthocyanins, except in a few unusual lines (Macheix et al. 1990).

It has been postulated that phenolic compounds could be responsible for the antioxidative activity in tomatoes beyond that accounted for by their lycopene content (Takeoka et al. 2001). Other studies, including our own, have found that in many assays the phenolics actually make a greater contribution to antioxidant activity than the carotenoids.

4 Lycopene and human health

Most research on lycopene has been undertaken by researchers working on prostate cancer and cardiovascular disease. As knowledge about this compound has increased, however, so too has interest in its possible effect in a number of health areas, including other cancers (skin, breast, bladder, cervix, lung, digestive tract, and female reproductive organs), osteoporosis, and diabetes. Although it is still too early to draw conclusions, results are promising in many of these areas. In addition, research is continuing to expand our understanding of the metabolism of lycopene and its mode of action.

4.1 Proposed mechanisms of action

Lycopene first caught the interest of the scientific community in the late 1980s when it was found that of all the carotenoids, including the better known β-carotene, it was the most potent quencher of the highly reactive compound, singlet oxygen (Di Mascio et al. 1989). It is also a potent scavenger of peroxyl radicals (Mortensen & Skibstead 1997; Woodall et al. 1997) and nitrogen dioxide (Bohm et al. 1995). By increasing lycopene levels in the body, oxidative stress is reduced and antioxidant potential increased. Antioxidative activities are believed to reduce damage to lipids, both lipoproteins and membrane lipids (Tsuchiya et al. 1993), proteins, particularly enzymes, and DNA (Clinton 1998). There is a range of other possible modes of action for lycopene (Fig. 5). Lycopene may regulate gene functions (Siler et al. 2004), improve intercell gap junction communication (Zhang et al. 1997), moderate hormone function and immune response or regulate metabolic pathways (Rao & Argawal 2000). It is also possible that these mechanisms are interrelated and operate simultaneously. There may also be other modes of action that have not yet been uncovered.

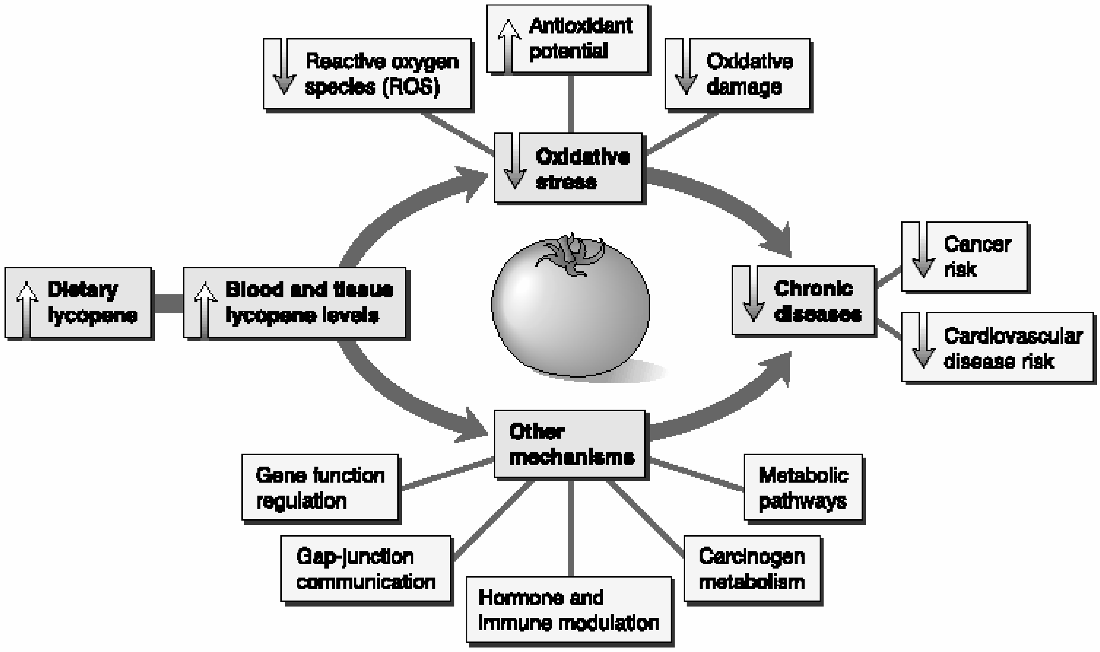


Figure 5: Proposed mechanisms for the role of lycopene in preventing chronic diseases (from Rao & Argawal 2000).

4.2 Prostate cancer

4.2.1 Epidemiologic studies

Epidemiologic studies (also called observational or population studies) look at disease patterns to see if certain diseases are more common in some groups of people than others. Prostate cancer is a leading cause of cancer deaths worldwide, but particularly in developed countries. According to figures obtained from Globocan, a joint initiative between the International Agency for Research on Cancer (IARC), part of WHO, and the European Commission, New Zealand has one of the world's highest age standardised incidence rates at 139.06 per 100 000 people, with Australia at 108 and the USA at 104.33. The rate for the United Kingdom is 40.24, for Italy, 24.89, Spain, 24.23, and Greece 20.17 (International Agency for Research on Cancer, 2000 estimates). Non modifiable risk factors include older age, family history of the disease, and race (Giovannucci 2003). In addition, certain types of prostate cancer appear to be associated with a diet high in red meat and dairy products (Michaud et al. 2001). Other dietary factors may also be important (e.g. trace elements), making it very difficult to precisely determine critical factors relating to the disease. A recent overview of the chemoprevention of prostate cancer details not only results relating to phase III trials of a new pharmaceutical treatment, finasteride, but also potential non-pharmaceutical treatments (Klein & Thompson 2004). The authors conclude that while there is substantial evidence that selenium and vitamin E act as preventative agents with respect to prostate cancer, there is also good epidemiological and molecular support for lycopene, soy, green tea and cyclooxegenase-2 inhibitors having a similar effect. Whilst studies undertaken to date are not unanimous in concluding a beneficial effect of tomatoes in general, and lycopene in particular, and further research is needed, there is strong and growing evidence of both a protective and inhibitory effect of a diet rich in tomatoes and tomato products, with respect to this disease. There are numerous potential reasons for why an actual association could be missed in a study. For example, intake of tomato products or sources of bioavailable lycopene could have been too low to be informative.

Epidemiologic studies vary in approach. Some correlate risk of prostate cancer with either the consumption of tomatoes and tomato products or lycopene itself. These diet-based investigations have been either case-control in which the diet of men prior to prostate cancer diagnosis is compared with that of a group of cancer-free controls, or prospective, where the diet of the sample population is measured at the beginning of the study and the subjects followed for subsequent prostate cancer occurrence.

4.2.2 Prospective studies

An early study, considering the impact of diet and lifestyle on prostate cancer in a population of 14 000 Adventist men, found that a higher tomato intake was statistically significant in lowering the risk of developing prostate cancer (Mills et al. 1989). Later, a Harvard School of Medicine study, involving 47 894 male health professionals, found that, unlike a number of other carotenoids that had no effect, high lycopene consumption lowered the risk of developing prostate cancer by 21% (Giovannucci et al. 1995). Furthermore, high consumption of tomatoes and tomato products (more than 10 servings per week) reduced the risk for all types of prostate cancer by 35%, and advanced prostate cancer by 53%, compared with those who consumed fewer than 1.5 servings per week. Of the tomato-based products, tomato sauces had a high inverse association with prostate cancer risk, with a moderate (inverse) association for fresh tomatoes and pizza and none for tomato juice. Significantly, these gradations of association corresponded to lycopene levels in the plasma of a sample group of the men. Of the 46 food items analysed, tomato sauces were found to confer the greatest protection. A recent follow up to this study, by Giovannucci et al. (2002), evaluated additional data to see if the original associations persisted. It was concluded that whilst frequent consumption of tomato products was associated with a lower risk of prostate cancer, the association was only moderate and so could be missed in a small study, a study with substantial errors in measurement, or one based upon a single dietary assessment. In contrast, a prospective cohort study in the Netherlands, comprising 58 279 men aged between 55 and 69 at baseline in 1986, found no association between lycopene, various other carotenoids, retinal, or vitamins C and E and prostate cancer (Schuurman et al. 2002).

4.2.3 Case-control studies

One of the earliest case-control studies took place in Minnesota from 1976 to 79. In this it was also found that men with prostate cancer had a lower reported tomato intake than men free from prostate cancer (Schuman et al. 1982), although the result was not statistically significant, possibly because the study was relatively small. A later case-control study in Hawaii, using a multi ethnic population and considering the relationship between fruit and vegetable intake and prostate cancer occurrence, found no association between raw or cooked tomatoes and the likelihood of developing cancer (Le Marchand et al. 1991). However, in this study actual intake levels were not reported, nor were processed tomato products, such as tomato-based sauces, specifically considered. Similarly, a case-control study in the United Kingdom (Key et al. 1997) found no relationship between raw or cooked tomatoes and the risk of prostate cancer. However, the strongest diet-related association was found for baked beans, where the beans are generally processed in a tomato sauce in which lycopene is present in a highly bioavailable form. A New Zealand study during 1996-97 found that dietary intake of lycopene and tomato-based products was only weakly associated with a reduced risk of prostate cancer (Norrish et al. 2000). There was approximately a 30% reduction in risk, but it was not statistically significant. In the same study it was found that dietary intake of β-carotene and its major vegetable sources was not protective against prostate cancer. A recent study in China, where the prostate cancer rate is amongst the lowest in the world, similarly found that both lycopene and consuming vegetables and fruits rich in lycopene (as whole cooked tomatoes and watermelon) reduced the risk of developing this disease. A protective effect of other carotenoids and carotenoid-rich vegetables was also observed (Jian et al. 2005).

4.2.4 Clinical studies/blood and tissue studies

As mentioned earlier, lycopene has been shown to concentrate in prostate tissues, with lycopene present in higher levels than any other carotenoid. This has been one of the factors instigating investigation of the relationship between lycopene and prostate cancer. Studies using levels of lycopene in blood and/or tissue have thus investigated both the prospective and actual incidence of prostate cancer and its virulence.

Hsing et al. (1990) used the serum taken from 25 802 people in 1974 to compare levels of various micronutrients between those who developed prostate cancer and those who did not. In this study lycopene was the only carotenoid to be inversely associated with cancer risk. A study at the University of Toronto found that levels of lycopene in serum and prostate tissue were lower in prostate cancer patients than in cancer-free controls (Rao et al. 1999). Gann et al. (1999) used blood samples taken and stored in 1982 when following up on the 578 cases of prostate cancer that had occurred over the following 13 years. Comparing the baseline plasma lycopene level with that of age-matched, cancer-free controls, it was found that a lower risk of prostate cancer was associated with higher levels of plasma lycopene. This was particularly evident in relation to aggressive prostate cancer. A similar study using prediagnostic serum from Japanese Americans in Hawaii found no association between serum lycopene levels and risk of prostate cancer (Nomura et al. 1997). However, other researchers have commented that flaws inherent in this study, such as the use of a single assessment of serum lycopene to characterise a 22-year period and the unusually low serum concentration among the controls, may account in part for the null results (Giovannucci 2002).

Another study, examining how prostate levels of various antioxidants related to plasma levels and self-reported usual dietary intake, found that levels of tocopherols and carotenoids in the prostate correlated best with respect to lycopene, β-carotene and gamma-tocopherol (Freeman et al. 2000). In a case-control study examining the effects of plasma lycopene and various other antioxidants on the risk of prostate cancer, Lu et al. (2001) found inverse associations between plasma lycopene and certain other carotenoids and prostate cancer. A small intervention study, in which a group of 15 randomly selected patients with prostate cancer and awaiting prostatectomy received a twice daily dose of 15 mg lycopene, found an indication that the progression of the disease was reduced in the group under treatment compared with the 11 controls who received no supplementation (Kucuk et al. 2001).

Studies have investigated the higher prostate cancer rates in American Blacks than American Whites, and found that serum lycopene levels were significantly lower in Blacks than Whites (Hayes et al. 1999; Vogt et al. 2002). This raised the possibility that the difference in prostate cancer rates might be attributable to a difference in lycopene exposure. Though not statistically significant, the results were suggestive of serum lycopene being inversely related to risk of prostate cancer in both racial groups (Vogt et al. 2002).

Further evidence for the beneficial effects of lycopene has been demonstrated in a number of laboratory studies. In a cell culture study, Pastori et al. (1998) demonstrated how lycopene in combination with vitamin E prevented the growth of prostate cancer cells. A Japanese *in vitro* study investigated the effects of a number of carotenoids on three lines of human prostate cells and found that, together with neoxanthin from spinach and fucoxanthin from brown algae, the acyclic phytofluenes in the tomato, including lycopene, significantly reduced the viability of these cells (Kotake-Nara et al. 2001).

4.3 *Lycopene and other cancers*

In 1999 a long-time lycopene researcher, Edward Giovannucci, from the Harvard Medical School reviewed 72 epidemiological studies regarding the relationships between tomatoes and tomato-based products, lycopene and cancer (Giovannucci 1999). In 57 of these studies an inverse association between tomato intake or blood lycopene levels and the risk of several types of cancer was shown; in 35 of these, the relationship was statistically significant. The strongest associations were shown for the prostate and stomach. For cancers of the lung, pancreas, colon and rectum, oesophagus, oral mucosa, breast and cervix, the association appeared to be only suggestive. These conclusions were consistent across diverse populations and studies utilising various designs. None of the studies reviewed showed evidence of increased risk of cancer from tomato/tomato-based products/lycopene intake (Giovannucci 1999).

4.3.1 *Skin cancer*

Of great potential interest to New Zealanders, since skin cancer rates here are amongst the highest in the world, are findings relating to a possible protective effect of tomato-based products or constituent tomato phytochemicals. Since the role of carotenoids in plants appears to be primarily to quench oxidative products induced by UV exposure, it is not unreasonable to assume that lycopene could have similar activity in human skin. An early study, considering the effects of solar-simulated light on human skin, showed a 31-46% decrease in the lycopene of exposed skin compared with that of adjacent non-exposed skin in a group of 16 women (Ribaya-Mercado et al. 1995), suggesting that lycopene is actively involved in protecting skin. A small study by Stahl et al. (2001) found that ingesting tomato paste resulted in 40% less erythema formation at the end of a 10-week period compared with a control group. Protection against UV light-induced erythema after regular ingestion of lycopene from tomato paste has also been demonstrated in cell culture (Stahl & Sies 2002). Cesarini et al. (2003), using a lycopene, β-carotene α-tocopherol and selenium mixture, similarly showed a reduction in UV erythemas, as well as in other parameters of epidermal defence, such as a reduction in sun burn cells, in UV-induced p53 expression and in lipoperoxide levels. Andreassi et al. (2004) found a lower UV-induced erythematous response in subjects applying a topical lycopene preparation compared with those using a vitamin C and E preparation and the control group.

In addition to skin cancer, other diseases resulting from photo-oxidative stress induced by UV-radiation may be protected against by carotenoids such as lycopene. These disorders include erythema formation, premature aging of the skin, development of photodermatitis, cataract and age-related macular degeneration (Stahl et al. 2001).

4.3.2 Cancers of the digestive tract

The various cancers of the digestive tract (oesophagus, stomach, colon and rectum) each have individual features in terms of causation and process and thus ideally need specific investigation. The relationship between lycopene and cancer of the oesophagus in northern Iran was the subject of one of the first studies to examine the role of lycopene in relation to human cancer (Cook-Mozaffari et al. 1979). In this case-control study, weekly consumption of tomato-based foods was associated with a 40% reduction in risk for this cancer—a particularly prevalent cancer in this region. Similar results were also shown much later in an Italian case-control study (Franceschi et al. 1994). A case-control study in Uruguay also showed a reduced risk of upper aerodigestive tract (oral, pharynx, larynx and espophagus) cancers with high tomato intake and this related to lycopene content (De Stefani et al. 2000).

With respect to stomach cancer, a number of diversely located studies have again reported a protective effect of a tomato rich diet (Bjelke 1974; Correa et al. 1985; Buiatti et al. 1989; Tsugane et al. 1992; Franceschi et al. 1994). However, others have found no association (Tajima et al. 1985; Ramon et al. 1993). Another study examined the possible relationship between levels of lycopene, α-carotene and β-carotene in the gastric mucosa and the presence of *Helicobacter pylori*, a pathogen thought to provoke an inflammatory response that precipitates the train of events leading to the development of gastric cancer. No difference in the levels of these carotenoids was found between *H. pylori*-infected subjects and controls (Sanderson et al. 1997).

Cancers of the colon and rectum are major health problems in developed countries and have been consistently found to be inversely associated with high dietary intakes of fruits and vegetables. Whilst there are many studies in which tomatoes have not been specifically considered, a number have reported an inverse relationship between the intake of tomatoes and tomato-based products and these health problems (Modan et al. 1981; Maquart-Moulin et al. 1986; Benito et al. 1990). However, a Canadian prospective cohort study of carotenoids (including lycopene) and colorectal cancer risk did not support any association (Terry et al. 2002).

In vitro effects have also been reported for these types of cancer. Lycopene has been shown to inhibit cell proliferation and enhance gap-junction communication in human oral tumour cells (Livny et al. 2002). Antiproliferative effects have also been shown against other digestive cancers (Velmurugan et al. 2002).

4.3.3 Breast cancer

There have been mixed results with respect to the association between lycopene intake and breast cancer. No association was found in studies in the early 1990s by Potischman et al. (1990), London et al. (1992), and Garland et al. (1993), looking at potentially protective effects of carotenoids and antioxidants. A Finnish study of 4697 women equally showed no relationship between consumption of tomato-based products and the risk of developing breast cancer (Jarvinen et al. 1997). More recent Italian (La Vecchia 2002) and Canadian (Terry et al. 2002) studies also showed no consistent association for lycopene and breast cancer. Samples from the Breast Cancer Serum Bank in Missouri were analysed for levels of carotenoids, selenium and retinal, with only lycopene being found to be related to a reduced risk of developing breast cancer (Dorgan et al. 1998). A recent case-control Swiss study investigating the relationship between 17 micronutrients and breast cancer found that lycopene was significantly inversely associated with breast cancer risk (Levi et al. 2001).

Various mechanisms of action against breast cancer have been demonstrated in animal studies or *in vitro*. In a Boston study using induced mammary cancers in a population of rats, it was found that an injection of lycopene-enriched tomato oleoresin appeared to correlate with fewer and smaller tumours in treated animals than in those who were treated either with β-carotene or who were untreated (Zhang et al. 1997). Similarly, another study (Nagasawa et al. 1995) showed that spontaneous mammary tumours were inhibited in mice fed a lycopene-rich diet. Using cell-cultured human mammary cancer cells a 1995 study reported lycopene-inhibited proliferation, whereas other carotenoids, β- and α-carotene, were less effective (Levy et al. 1995).

4.3.4 Ovarian and cervical cancer

A number of studies have also investigated the role of lycopene in preventing ovarian and cervical cancers. A recent population based study of pre- and post-menopausal women found that in both groups lycopene intake was significantly inversely associated with ovarian cancer (Cramer et al. 2001). Of the foods investigated, for raw carrots and tomato ketchup the (inverse) association was strongest. Examining the role of various micronutrients and in the development of cervical cancer, a 1998 study found that of a number of micronutrients, only lycopene was lower in cancer patients than in the controls (Goodman et al. 1998). Similarly, Sengupta & Das (1999) found that higher levels of lycopene were inversely associated with risk, and Kanetsky et al. (1998) found that among black, non-Hispanic women, the risk of developing cervical cancer was reduced by 33% in women with higher blood levels of lycopene. However, again there have been other studies in which no evidence was found between either lycopene intake or serum concentrations and risk (Potischman et al. 1991, 1994; Batieha et al. 1993).

4.3.5 Bladder cancer

As with many other cancers, it has been found that a diet rich in fruit and vegetables is associated too with a protective role against bladder cancer (Block et al. 1992). Looking at tomatoes, lycopene and other micronutrients with respect to bladder cancer risk, Helzlsour et al. (1989) found an inverse association only with lycopene and selenium concentrations. Conversely, however, a laboratory study of induced bladder tumours in mice showed a mild but statistically non significant effect of lycopene or β-carotene on the number of transitional cell carcinomas (Okajima et al. 1997).

4.3.6 Lung cancer

To date, studies considering the relationship between lycopene and lung cancer have not shown strong effects. Holick et al. (2002) found that a diet rich in carotenoids, including tomatoes and tomato-based products, might reduce the risk of cancer. Similarly an English study found that together with fish liver oil, vitamin pills and carrots, tomato juice decreased the risk of contracting lung cancer in a case-control study of smokers (Darby et al. 2001). Kim et al. (2000) found that lycopene inhibited the development of carcinogenises in the lungs of male, but not female mice. Hecht et al. (1999) found that administration of lycopene-enriched tomato oleoresin had no effect on the development of induced lung tumours in mice.

4.4 Cardiovascular disease

Cardiovascular disease (CD) is the leading cause of illness and death in most developed countries. It includes myocardial infarction (heart attack), ischaemic heart disease (narrowing of the arteries) and cerebrovascular disease (stroke), and has been estimated to be responsible for around 40% of deaths in Australasia (Lister 2003). Whilst certain strategies can be adopted to reduce risk factors for this health problem, such as maintaining a healthy body weight, eliminating cigarette smoking and taking more physical exercise, evidence has now accumulated to suggest that dietary factors may also be important. Just as the Mediterranean diet is believed to prevent various cancers, so too is it believed to protect against cardiovascular problems.

The free radicals responsible for initiating the oxidative damage that lead to cancer are also believed to be responsible for the oxidation of the low density lipoproteins (LDL) that carry cholesterol in the bloodstream. Evidence increasingly supports the hypothesis that oxidatively damaged macromolecules derived from the lipoproteins that have been deposited on the blood vessel wall may initiate the cellular and cytokine networks involved in the development of vessel lesions (Ross 1993). This is an early stage in the development of the atherosclerosis that precedes wider cardiovascular health problems. Thus, antioxidant nutrients may retard the progression of this disease by interfering with the oxidative process. In addition, however, mechanisms besides lycopene's antioxidant properties have been shown to reduce the risk of CD. In a small clinical trial and laboratory experiment it was demonstrated by Fuhrman et al. (1997) that lycopene inhibited the activity of a particular enzyme involved in cholesterol synthesis. It has been hypothesised that other activity could include enhanced LDL degradation, LDL particle size, and composition, plaque rupture and altered endothelial functions (Rao 2002).

In the past, many studies have credited the antioxidant activity of vitamin E for providing a protective effect against lipid oxidation (Rimm et al. 1993; Morris et al. 1994). However, this was not confirmed in the Heart Outcomes Prevention Evaluation Study in the United States, which found no evidence of beneficial effects in cardiovascular terms for high risk patients (Hoogwerf & Young 2000). However, other studies specifically examining the effects of consuming tomatoes and tomato products found a decreased risk of CD with intake of these foods. In a multi-centre case-control study, with subjects recruited from 10 European countries, the relationship between antioxidant status and acute myocardial infarction was evaluated. Adipose tissue samples were taken from subjects directly after the infarction and analysed for various carotenoids. These were then compared with matched controls. After statistical adjustment for potentially confounding variables, the only carotenoid that showed a protective effect was lycopene (Kohlmeier et al. 1997). In a small intervention study, Argawal & Rao (1998) examined the effects of various forms of lycopene (tomato juice, spaghetti sauce and tomato oleoresin soft gel capsules) that were added to the diet of the 19 subjects for a period of one week each. All treatments resulted in higher levels of serum lycopene and significantly decreased LDL oxidation and serum lipid peroxidation, but had no effect upon cholesterol levels. In contrast with the latter finding, a study investigating cholesterol metabolism using cell culture and a small clinical trial found that, firstly, incubation of human macrophage cells with lycopene inhibited cholesterol synthesis and augmented macrophage LDL receptors and that, secondly, dietary supplementation of 60 mg lycopene daily in six males over the course of three months resulted in a 14% reduction in plasma LDL cholesterol levels (Elinder et al. 1995). In a study comparing Lithuanian and Swedish men from populations with differing mortality rates from coronary artery disease, it was also found that lower blood lycopene levels were associated with a higher risk of both developing and dying from the disease (Kristenson et al. 1997). The findings of a Finnish study (Rissanen et al. 2003) found greater thickening of the wall of the common carotid artery in men with lower serum lycopene concentrations than in men with higher than median lycopene plasma, although the difference for women was not significant. A second study, by the same group, found that men in the lowest quartile of serum levels of lycopene had a 3.3 fold higher risk of an acute coronary event or stroke than the others.

4.5 AIDS

Many studies have observed reduced levels of micronutrients in HIV patients, despite dietary intakes that would normally be considered adequate. Lower concentrations of serum lycopene were recorded in HIV-positive women (Coodley et al. 1995), and children (Periquet et al. 1995). It has been postulated that this may result from the problem of lipid malabsorption, a common feature of progressive HIV disease (Clinton 1998).

4.6 Diabetes

Type 2 diabetes, in which the body is unable to utilise insulin, is another chronic disease associated with the oxidation of LDL. It is a disease in which, amongst other health outcomes, there is frequently an increased risk of CD. It has been found *in vitro* that high levels of glucose, as present in Type 2 diabetes, increase LDL oxidation (Bierman 1991) and that glycated LDL is particularly prone to oxidation (Semenkovich & Heinecke 1997). Also, diabetic subjects have increased levels of small, dense, LDL which is more readily oxidised than larger LDL (Semenkovich & Heinecke 1997), as well as elevated levels of certain biological markers that suggest stimulation of the inflammatory activity that increases the risk of coronary events (Libby & Ridker 1999). Data analysed form the Third National and Nutrition Examination Survey in the United States found significantly lower levels of lycopene in subjects with impaired glucose tolerance and levels that were lower again in newly diagnosed diabetic patients than in controls with normal glucose tolerance (Ford et al. 1999). Similarly, diabetic Asian Indian physicians living in the USA were found to have lower levels of lycopene than non-diabetic counterparts (Chuang et al. 1998), as did elderly Type 2 subjects in an Italian study (Polidori et al. 2000). In a recent New Zealand clinical trial, involving supplementation with two cups of tomato juice daily in a group of Type 2 diabetic patients, it was found that plasma levels of lycopene markedly increased and that the resistance of localised LDL to oxidation also increased (Upritchard et al. 2000).

4.7 Eye disease

Some carotenoids, such as lutein and zeaxanthin, are well known to play an important role in eye health (Meltzer & Kravets 1998). Less is known about the potential role of lycopene. High concentrations have been reported in certain parts of the eye (ciliary body and retinal pigment epithelium) and so may have some function in protecting against age-related macular degeneration (AMD) and other eye diseases (Khachik et al. 2002). In a population-based, case-controlled study regarding the relationship of AMD and carotenoid levels it was found that individuals with low serum levels of lycopene were twice as likely to have AMD as those with higher serum levels (Mares-Perlman et al. 1995). An Australian study, however, found no evidence of protective effects of lycopene and other antioxidants on the early (within five years) age-related maculopathy (Flood et al. 2002).

A study with rats showed lycopene to have an inhibitory effect on cataract development (Pollack et al. 1996). Lycopene has also been shown to offer protection against galactose-induced cataract changes in lens tissue (Trivedi et al. 2001a) and be protective against selenite-induced stress (Trivedi et al. 2001b).

5 The role of other tomato components in human health

There has been less specific study of the importance of other tomato components on human health, although the groups of compounds themselves have been studied.

5.1 Other carotenoids

Although the above studies have largely focused on lycopene, other carotenoids in tomatoes are likely to contribute to their health benefits. Other carotenoids may have similar effects to lycopene, although some health benefits do seem to be specific to lycopene. Lycopene does have stronger antioxidant activity than many other carotenoids, such as β-carotene (Di Mascio et al. 1989). However, some other carotenoids play important physiological functions that lycopene does not. Those carotenoids with at least one unsubstituted β-ring and an unchanged side change (e.g. β-carotene, α-carotene, cryptoxanthin, γ-carotene) may be converted to vitamin A in the body. Such carotenoids are referred to as having provitamin A activity. Because lycopene does not have the ring structure it cannot be converted to vitamin A.

As with lycopene, most other carotenoids are being considered as potential cancer prevention agents, although there have been mixed results in trials. Studies of β-carotene indicate that its benefits may only occur when it is derived from food and not when it originates from a supplement form. β-Carotene has been used as a so-called oral sun protectant due to its antioxidant properties, and its efficacy has been shown in human studies (Stahl et al. 2000). However, these studies were not with tomatoes. It is unlikely that the level of β-carotene in tomatoes is high enough, alone, to offer this level of protection.

Another group of carotenoids, the xanthophylls (e.g. lutein and zeaxanthin), have specific distribution patterns in human tissue, especially in the retina of the eye (Zaripheh & Erdman 2002). These carotenoids are thought to be important for normal eye function and play a role in the prevention of various eye diseases, including macular degeneration, glaucoma and cataracts (Head 1999, 2001).

5.2 Phenolic compounds

The considerable diversity of the structure of phenolics makes them different from other antioxidants. Several thousands of natural polyphenols have been identified in plants, many of them in plant foods (Shahidi & Naczk 1995), although only a more limited number are at significant levels in most human diets. The chemical structure of polyphenols affects their biological properties: bioavailability, antioxidant activity, specific interactions with cell receptors and enzymes, and other properties. There has been little specific study of the role that tomato flavonoids, and other phenolics, may play in human health. However, this group of compounds has received considerable attention, in general, but particularly those compounds in red wine, tea, chocolate and onions.

Phenolic compounds, because of their structure, are very efficient scavengers of free radicals and they also serve as metal chelators (Shahidi & Naczk 1995). In addition to their antioxidant characteristics, other potential health-promoting bioactivities of the flavonoids 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.

5.3 Other

Research at the Rowett Research Institute in Scotland has identified a component in the yellow jelly around tomato seeds that, it is proposed, stops platelet cells in the blood from clumping together (Dutta-Roy et al. 2001). The aggregation of platelets triggers the cascade of reactions leading to blood clot formation (thrombosis). Heart attacks, strokes and blood vessel problems resulting from thrombosis currently kill or disable more people in developed countries than any other disease. In tests on volunteers, the compound (codenamed P3) from as few as four tomatoes reduced platelet activity by up to 72%. Larger scale studies are necessary to confirm these results but, if successful, P3 could represent a benefit over existing anti-platelet therapy, such as aspirin, which may have side effects such as stomach upsets and bleeding (Dutta-Roy et al. 2001). A Japanese study in 2003 tested various tomato cultivars in relation to anti-thrombotic effects using both *in vitro* and *in vivo* (rat model) methods. One variety showed not only significant anti-thrombotic activity with both methods, but also inhibited thrombus formation as well as having a thrombolytic effect (Yamamoto et al. 2003).

6 Bioavailability of tomato phytochemicals

6.1 Lycopene

A correlation between seven-day food diary lycopene intake and plasma lycopene has been noted (Forman et al. 1993). In contrast it has been found that there is no correlation between plasma lycopene and high fruit and vegetable intake (Campbell et al. 1994). This may be because lycopene only comes from one major food source (tomatoes and tomato products) and a high fruit and vegetable intake may not imply a high lycopene (tomato) intake. It has been shown that plasma lycopene can be increased in a relatively short time by increasing the dietary intake of this carotenoid (Johnson 1998).

It has been demonstrated that dietary lycopene is absorbed and distributed in humans. Its bioavailability depends on various factors such as food processing and co-ingestion of fat (Sies & Stahl 1999). Since lycopene is a fat-soluble compound, it follows the same intestinal absorption path as dietary fat. Absorption is influenced by the same factors that influence fat absorption. Thus, the absence of bile or any generalised malfunction of the lipid absorption system will interfere with the absorption of lycopene.

Lycopene is released from food matrices and solubilised in the gut. This is done in the presence of fat and conjugated bile acids. The efficiency of release is influenced by such factors as disposition of lycopene in the food matrix, particle size after mastication and stomach action, and the efficiency of digestive enzymes (Johnson 1998). Heating of plant foods before ingestion improves the bioavailability of lycopene, partly because protein-carotenoid complexes are weakened (Stahl & Sies 1992).

After absorption into the intestinal musosa, lycopene is transported in the plasma exclusively by lipoproteins (Johnson 1998). Lycopene appears first in the very low density lipoprotein (VLDL) and chylomicron fractions of plasma and later in low density lipoprotein (LDL) and high density liipoprotein (HDL), with highest concentrations in the LDL (Krinsky et al. 1958). The distribution of lycopene among lipoproteins is similar to β-carotene and similar between men and women (Forman et al. 1998; Reddy et al. 1989). Serum concentrations can vary substantially (50 to 900 nM), both within the individual and between individuals (Bramley 2000). It is hydrophobic and is, therefore, generally located within cell membranes. Although lycopene is found in most human tissues, it is not distributed evenly, with substantially larger amounts found in the adrenals and testes (Table 10).

Table 10: Lycopene levels in human tissues (Bramley 2000 - data taken from Schmitz et al. 1991; Stahl et al. 1992; Clinton et al. 1996).

Tissue	Lycopene (nmol/g wet weight)
Adipose	0.2-1.3
Adrenal	1.9-21.6
Brainstem	nd[a]
Breast	0.8
Colon	0.3
Liver	1.3-5.7
Lung	0.2-0.6
Ovary	0.3
Prostate	0.8
Skin	0.4
Stomach	0.2
Testis	4.3-21.4

[a] Not detected.

Cis-isomers of lycopene make up >50% of the total lycopene in human serum and tissues (Stahl et al. 1992; Clinton et al. 1996). This is in contrast to the food sources from which they originate; in tomatoes and tomato-based food products all *trans*-lycopene comprises 79-91% of total lycopene (Clinton et al. 1996). Stahl & Sies (1992) studied the uptake of lycopene and its geometrical isomers from heat-processed and unprocessed tomato juice in humans. Lycopene concentrations in human serum increased only when processed tomato juice was consumed. Lycopene uptake varied with individuals, but peak serum concentrations were always reached between 24 and 48 hours. The carotenoid was eliminated from serum with a half-life of two to three days. The increase in peak serum concentrations was dose-dependent but not linear with the dose. Repeated doses led to a continual rise of lycopene in human serum. Of the different geometrical isomers (all-*trans*, 9-*cis* and 13-*cis*), the *cis*-isomers seemed to be somewhat better absorbed than the all-*trans* form. More detailed studies with ferrets have shown that the *cis*-isomers of lycopene are more bioavailable than *trans*-lycopene, probably because they are more soluble in bile acid micelles and may be preferentially incorporated into chylomicrons (Boileau et al. 1999).

In addition to examining the effect of heat treatment, van het Hof et al. (2000) looked at the effects of the degree of homogenisation on the bioavailability of lycopene. Both additional heat treatment (one hour at 100°C, compared to just heating before serving) and homogenisation increased carotenoid (lycopene and β-carotene) bioavailability from tomatoes (canned, so already had heat treatment during manufacture), although the effect of additional heating was not always significant. Disruption of the tomato matrix also enhanced the ease with which carotenoids could be extracted from the tomatoes. Homogenisation and heat treatment disrupt cell membranes, enhancing extractability, and heat treatment has also been suggested to disrupt further the protein-carotenoid complexes. Homogenisation under high pressure was more effective in increasing carotenoid bioavailability than homogenisation under normal pressure. Thus, the release of carotenoids from cells is a limiting factor in bioavailability.

The bioavailability of lycopene from fresh tomatoes versus tomato paste was compared in human volunteers (Gärtner et al. 1997). The lycopene intake from both the fresh tomatoes or the tomato paste was 23 mg and the meals were ingested together with 15 g of corn oil. The lycopene isomer pattern was the same in both cases. Ingestion of tomato paste yielded much higher peak concentrations and under the curve responses for all-*trans* lycopene and its *cis*-isomers. No difference was observed for the α- and β-carotene response. Porrini et al. (1998) also reported that lycopene from tomato puree (16.5 mg/day) resulted in significantly higher plasma concentrations than fresh tomatoes. Thus, in humans the bioavailability of lycopene is higher from processed tomato products than fresh tomatoes, independent of the doses.

Lycopene serum concentrations increased significantly after ingestion of 39-75 mg/day lycopene from spaghetti sauce, tomato juice and lycopene capsules (Rock & Swendseid 1992). This study did not indicate any significant differences in absorption between the differing food matrices. Lycopene absorption from supplements (oleoresin capsules) and from processed tomato products were comparable (Bohm & Bitsch 1999).

It has further been noted that absorption of carotenoids, including lycopene, is improved when consumed in conjunction with dietary lipids (Bohm & Bitsch 1999). It has been proposed that high-dose intake of a particular carotenoid may antagonise the bioavailability and absorption of other carotenoids. However, one study found that ingestion of a combined dose of β-carotene and lycopene had little effect on the absorption of β-carotene but improved that of lycopene (Johnson et al. 1997). A recent study investigated possible interactions between the transport of β-carotene and lycopene and found that they may compete for the same transport mechanism (Gaziano et al. 1995). When extremely high doses of β-carotene were fed to humans compared to the magnitude of β-carotene uptake into LDL, the concentration of lycopene in LDL reduced. However, the doses fed were well beyond those achieved in a healthy diet.

There are a range of physiologic factors that influence plasma concentrations of carotenoids. For example, for β-carotene plasma concentrations are higher in women than men, although for lycopene there appears to be no sex difference in its absorption or utilisation. Increasing age has been found to be inversely related to plasma lycopene (Brady et al. 1996). One explanation for this observation is that younger individuals consume more of some lycopene-rich foods such as pizza and ketchup. However, it would appear to only partially explain the difference (Johnson 1998). Smoking is well known to decrease plasma β-carotene levels but lycopene seems to be affected to a lesser extent (Johnson 1998). Alcohol intake appears not to affect plasma lycopene levels (LeComte et al. 1994; Forman et al. 1995).

A lycopene formulation where lycopene was entrapped with whey proteins (named "lactolycopene") was shown to be as bioavailable as lycopene from processed tomatoes (Richelle et al. 2002).

6.2 Other carotenoids

The bioavailability of some other carotenoids, especially β-carotene, has been well demonstrated from a variety of fruit, vegetable and supplement sources (Castenmiller & West 1998; van het Hof et al. 2000; Yeum & Russell 2002; Zaripheh & Erdman 2002). As noted with lycopene, various dietary factors have an effect on the bioavailability of carotenoids (Table 11). The type of food matrix in which carotenoids are located is a major factor. The bioavailability of β-carotene from vegetables in particular has been shown to be low (14% from mixed vegetables) compared to when purified β-carotene is added to a simple matrix (e.g. salad dressing), whereas for lutein, the difference is much smaller (relative bioavailability of 67% from mixed vegetables). Processing, such as mechanical homogenisation or heat treatment, has the potential to enhance the bioavailability of carotenoids from vegetables (from 18 to nearly 120%). The amount of dietary fat required to ensure carotenoid absorption is moderate (~3–5 g per meal), although it depends on the physicochemical characteristics of the carotenoids ingested, but the presence of fat is important. Unabsorbable, fat-soluble compounds reduce carotenoid absorption, and interaction among carotenoids may also result in a reduced carotenoid bioavailability.

Table 11: Estimation of the quantitative effects of various dietary factors on the bioavailability of carotenoids[a] (from van het Hof et al. 2000).

Dietary factor	*n*[b]	Carotenoid		
		β-Carotene	Lutein	Lycopene
Matrix type (carotenoids in oil = 1.0)				
Mixed vegetables	10–22	0.14 ± 0.011	0.67 ± 0.08	na[c]
Green leafy vegetables	56–62	0.04	na[c]	na[c]
Whole-leaf spinach	10–12	0.04	0.45	na[c]
Whole-leaf spinach	26–67	0.03 ± 0.5	na[c]	na[c]
Carrots	7–15	0.19	na[c]	na[c]
Carrots	5	0.19	na[c]	na[c]
Carrots	12–13	0.26	na[c]	na[c]
Broccoli	5	0.22	na[c]	na[c]
Broccoli	26–67	0.74 ± 0.64	na[c]	na[c]
Green peas	26–67	0.96 ± 0.71	na[c]	na[c]
Matrix disruption (undisrupted vegetables = 1.0)				
Chopped v. whole-leaf spinach	26	1.0	1.18	na[c]
Liquefied v. whole-leaf spinach	12	1.69	1.0	na[c]
Homogenized v. whole carrots	13	[1.7][d]	na[c]	na[c]
Homogenized v. whole carrots	7–10	5.9	na[c]	na[c]

Dietary factor	n[b]	Carotenoid		
		β-Carotene	Lutein	Lycopene
Tomato paste v. raw tomatoes	5	na[c]	na[c]	na[c]
Tomato paste v. raw tomatoes	9	na[c]	na[c]	1.2–1.5
Homogenized and heated v. raw carrots and spinach	8	3.1	na[c]	na[c]
Amount of dietary fat (high amount of fat = 1.0)				
0 g fat v. 5 g fat present in carotenoid-supplemented meal	22–26	0.48[f]	na[c]	na[c]
0 g fat v. 10 g fat present in carotenoid-supplemented meal	22–26	0.48[g]	na[c]	na[c]
5 g fat v. 10 g fat present in carotenoid-supplemented meal	22	1.0	na[c]	na[c]
3 g fat v. 18 g fat present in meal containing sweet potatoes	41–43	0.63[f]	na[c]	na[c]
3 g fat v. 36 g fat present in carotenoid-supplemented meal	15	1.0	0.43 ± 0.062[g]	na[c]
Indigestible fat-soluble compounds (regular dietary fat = 1.0)				
3 g/d sucrose polyester v. regular dietary fat with main meal	26–27	0.80 ± 0.03	na[c]	0.62 ± 0.05
12.4 g/d sucrose polyester v. regular dietary fat with main meal	21	0.66 ± 0.02	0.80 ± 0.04	0.48 ± 0.05
18 g/d sucrose polyester v. regular dietary fat at v.arious times during day	65–67	0.73	0.81	0.77
Dietary fibre (no dietary fibre = 1.0)				
12 g/d citrus pectin added to carotenoid-supplemented meal	7	0.42	na	na
Beet root fibre added to liquefied spinach	12	1.0	1.0	na

[a] Values are presented as means ± SEM or as mean. The factors were calculated from changes in plasma or serum concentrations of carotenoids, unless otherwise stated. The plasma or serum carotenoid response after the treatment stated was divided by the plasma or serum carotenoid response after the treatment, which was taken as a reference at 1.0 (identified between brackets for each dietary factor), and corrected if necessary for differences in carotenoid intake. In case no change was expected from the reference treatment (e.g. in case of indigestible v. regular fat), the factors were calculated as the percentage of change from baseline, corrected if necessary for the change in the control group. A factor <1.0 indicates that the bioavailability of carotenoids is reduced compared with the reference chosen; a factor >1.0 indicates an enhanced carotenoid bioavailability.
[b] Number of subjects per treatment.
[c] Not assessed.
[d] Value is not significantly different from 1.0 (α= 0.05).
[e] Calculated from area under the curve of the carotenoid response in triglyceride-rich lipoproteins.
[f] Calculated from changes in serum concentrations of retinol.
[g] Lutein was present as lutein esters.

There are few xanthophylls (e.g. lutein) in tomatoes but they are an important group of carotenoids. The xanthophylls, lutein and zeaxanthin, have specific distribution patterns in human tissue, especially in the retina of the eye (Zaripheh & Erdman 2002). The presence of these xanthophylls is thought to provide protection from macular degeneration. Like other carotenoids, environmental factors, food processing, food matrix, structural differences and the interaction among other food components all have an effect on their efficiency of uptake and absorption. From the limited human studies described in the literature, lutein appears to be more bioavailable from food sources than does β-carotene (Zaripheh & Erdman 2002). The disruption of the food matrix seems to improve β-carotene's bioavailability more than that of lutein. There is no evidence that a negative interaction between carotenoids occurs when foods are ingesting. However, interactions do occur between xanthophylls and carotenes when supplements are consumed. Several studies found that when they were consumed simultaneously, β-carotene reduced lutein bioavailability. With the broad consumption of lutein supplements from marigold flowers, some of which are high in lutein diesters, the question of lutein diester bioavailability arises. More dietary fat seems to be required for efficient absorption of lutein from lutein diester sources.

Despite these studies there are limited data on the bioavailability of carotenoids other than lycopene from tomatoes. Studies examining the bioavailability of lycopene have also demonstrated that β-carotene, and some other carotenoids, from tomatoes are bioavailable (Richelle et al. 2002; van het Hof et al. 2000), although these data are quite limited. Phytofluene has been shown to be better absorbed than lycopene from tomatoes (Richelle et al. 2002).

6.3 Phenolics

There have been various studies of the bioavailability of different phenolics (reviews by Rice-Evans et al. 2000; Ross & Kasum 2002; Scalbert & Williamson 2000). Phenolic acids account for about one-third of the total dietary phenols and flavonoids account for the remaining two-thirds (Scalbert & Williamson 2000). A total intake of polyphenolics of ~1 g/d was suggested over 25 years ago (Kühnau 1976). However, large uncertainties in the polyphenol intake and in the variations of intake remain. Comprehensive surveys on the content of some important polyphenol classes (e.g. anthocyanins, proanthocyanidins, phenolic acids) are still lacking. The intestinal absorption of polyphenols can be high, but differs markedly between the different groups (Table 12). Some flavonol glycosides are better absorbed than their aglycones, but very little is known about the influence of other structural parameters. However, the plasma concentration of any individual molecule rarely exceeds 1 μM after the consumption of 10–100 mg of a single compound. Measurement of the plasma antioxidant capacity suggests that more phenolic compounds are present, largely in the form of unknown metabolites, produced either in our tissues or by the colonic microflora. Further research is required in this area.

Table 12: Bioavailability in humans of polyphenols consumed alone or in foods[a] (taken from Scalbert & Williamson 2000).

Polyphenol	Source	Quantity of polyphenol ingested (mg)	Maximum concentration in plasma (μM)	Excretion in urine (%)
Phenolic acids				
Caffeic acid		1000		27
Flavonols				
Quercetin	Onion	68	0.74	1.39
Quercetin	Apple	98	0.30	0.44
Quercetin-4-O-rhamnoglucoside	Pure compound	202	0.30	0.35
Quercetin-4-O-glucoside	Pure compound	144	3.2	
Quercetin	Onion	139	1.34	0.8
Quercetin	Mixed black currant and apple juice, 1000 ml/d for 7 d	6.4		0.5
Catechins				
Epigallocatechin gallate	Green tea infusion, 1.2 g	88	0.33	nd[b]
Epigallocatechin		82	0.67	3.6
Epicatechin gallate		33	nd[b]	nd[b]
Epicatechin		32	0.27	6.2
Epigallocatechin gallate	Green tea infusion, 5 g	105	0.13–0.31	
Epigallocatechin gallate	Green tea infusion, 6 g		5.0	
Epigallocatechin gallate	Green tea extract	525	4.4	
Catechin	Red wine, 120 ml	34	0.072	
Catechin	Pure compound	500	2.0	0.45
Isoflavones				
Genistein	Soy milk	19	0.74	19.8
Daidzein		25	0.79	5.3
Genistein	Soy proteins, 60 g/d for 1 mo	20		9.2
Daidzein		25		2.5
Genistein	Soy proteins, 60 g/d for 28 d	80	0.50	
Daidzein		36	0.91	
Genistein	Soy proteins, 20 g/d for 9 d	23		8.7
Daidzein		13		26
Flavanones				
Naringin	Grapefruit juice, 120 m	43	<4	8.8
Naringin	Grapefruit and orange juice, 1250 ml each	689		6.8
Hesperidin		89		24.4
Naringin	Pure compounds	500		4.9
Hesperidin		500		3.0
Anthocyanins				
Anthocyanins	Red wine, 300 ml	218		1.0–6.7

[a] Polyphenols, principally in the form of conjugated metabolites, as sulfate esters or glucuronides, in plasma and urine, were hydrolysed by acid or enzymes before chromatrographic or colorimetric analysis.
[b] Not detected.

Only one study was found that looked specifically at the bioavailability of tomato phenolics. Naringenin from cooked tomato paste has been shown to be bioavailable in men (Bugianesi et al. 2002). Although rutin and chlorogenic acid were detected in the tomato paste used in this study they were not detected is plasma after tomato paste consumption. The levels of many of the phenolics in tomato may not be sufficiently high enough to be picked up in plasma in bioavailability studies using current methodology. Although there has only been one specific study on the bioavailability of phenolics from tomatoes, some of the compounds present have been shown to be bioavailable from other foods. Rutin has been shown to be bioavailable, although less so than some other quercetin glycosides or the aglycone (Erlund et al. 2001; Graefe et al. 2001). In one study examining quercetin and rutin, they were found in plasma as glucuronides and/or sulfates of quercetin and as unconjugated quercetin aglycone, but no unchanged rutin was detected (Erlund et al. 2000). Other studies on the bioavailability of phenolic acids have demonstrated that coumaric acid, from coffee and blackcurrant juice, was bioavailable (Nardini et al. 2002; Rechner et al. 2002). However, for coffee although chlorogenic acid was present in high amounts it was not detected in plasma (Nardini et al. 2002). It is possible that it is metabolised to other compounds, which may or may not have biological activity.

7 Tomato/lycopene consumption and major disease patterns

As discussed earlier, epidemiologic studies (also called observational or population studies) look at disease patterns to see if certain diseases are more common in some groups of people than others. By examining these data together with dietary information, patterns can be identified as to the influence of protective components from the diet. Table 13 shows the incidence of certain diseases in New Zealand populations compared to some other selected countries.

Not surprisingly, there is no official recommended daily intake for tomatoes or tomato products or their constituent compounds. More research is needed to identify the active compounds and establish the full health benefits derived from tomatoes. Researchers to date, who have largely been concerned with investigating the benefits of lycopene and have considered optimum intake levels, vary somewhat in what they consider to be necessary to have an efficacious effect. After considering results from the Health Professionals Follow-Up Study, Giovannucci suggests that two to four servings of tomato sauce per week (not ketchup) reduce the risk of prostate cancer by one-third to one-half (Giovannucci et al. 1995; Giovannucci 2003). Yeung and Rao in their book, ‘Unlock the power of lycopene’, recommend at least one serving of processed tomato daily. Other researchers mention a recommended intake of 35 mg of lycopene daily (Rao & Agarwal 2000), but this may be rather high. Roughly estimated, this amount could be obtained, for example, from two glasses of tomato juice (500 ml) or through a combination of tomatoes and tomato products (e.g. pasta sauce, fresh tomatoes).

Carotenoid intake has been estimated from food frequency questionnaires. In Great Britain the daily consumption of lycopene-rich food was equivalent to a lycopene intake of about 1.1 mg per day (Scott et al. 1996). In a study from the United States a daily intake of about 3.7 mg per day was reported (Forman et al. 1993). However, another study (Rao & Agarwal 1998) estimated it to be 25 mg/day, with processed tomato products accounting for 50% of the total intake (Table 14). This figure seems incredibly high and unlikely to be achieved by many people. Even Mediterranean diets may not achieve these levels. No such specific data have been reported for New Zealand and Australian populations.

Table 13: Prostate cancer incidence and mortality and mortalities from major cardiovascular diseases in some Mediterranean and non-Mediterranean countries.

Disease rates per 100 000	NZ	USA	Italy	Spain	Greece	UK
Prostate cancer cases (age standardised)[1]	139.1	104.3	24.9	24.2	20.2	40.2
Prostate cancer mortalities (age standardised)[1]	21.2	17.9	12.1	15.0	10.7	18.5
Diseases of circulatory system mortalities[2]	343.6	362.0	302.9	272.5	382.5	363.8
Ischaemic heart disease mortalities[2]	199.9	181.1	103.3	90.9	117.7	209.6
Acute myocardial infarction mortalities[2]	98.4	84.9	54.6	62.2	88.6	114.3
Cerebrovascular disease mortalities[2]	68.9	55.7	80.4	73.4	127.0	81.0

Sources of data:
1. Globocan 2000 estimates Figures age standardised according to Segi's world population.
2. Global Cardiovascular Infobase 1997 age standardised death rates are generated using the world standard population based on J. Waterhouse et al. (ed). Cancer incidence in five continents, Lyon, IARC, 1976 (Vol. 3, pl 456), as used by WHO.
Age-standardised data: An age-standardised rate (ASR) is a summary measure of a rate that a population would have if it had a standard age structure. Standardisation is necessary when comparing several populations that differ with respect to age because age has such a powerful influence on the risk of cancer. The most frequently used standard population is the World standard population. The calculated incidence or mortality rate is then called World Standardised incidence or mortality rate. It is also expressed per 100 000 (from Globocan).

Table 14: Estimates of daily intake of lycopene from tomatoes and tomato products, as determined from a food-frequency questionnaire (from Rao et al. 1998).

Product	Serving size	Lycopene intake (mg/d per subject)	% of total daily lycopene intake
Tomatoes	200 g	12.70	50.5
Tomato puree	60 ml	1.02	4.1
Tomato paste	30 ml	2.29	9.1
Tomato sauce	227 ml	1.52	6.0
Spaghetti sauce	125 ml	2.44	9.7
Pizza sauce	60 ml	0.66	2.6
Chilli sauce	30 ml	0.30	1.2
Tomato ketchup	15 ml	0.53	2.1
Barbecue sauce	30 ml	0.06	0.2
Tomato juice	250 ml	2.20	8.7
Tomato soup	227 ml	0.79	3.1
Clam cocktail	250 ml	0.50	2.0
Bloody Mary mix	156 ml	0.15	0.6
Total		25.16	

8 *Factors affecting phytochemical levels in tomatoes and tomato products*

8.1 *Lycopene and other carotenoids*

The levels of lycopene in tomatoes and tomato products vary considerably, as seen in Table 4 (Section 3.2). There is variation between variety (which may also be related to shapes, size and colour), degree of ripeness at harvest, method of production, growing conditions, and extent of processing. Unfortunately there are only a few studies relating particularly to New Zealand varieties and growing conditions.

8.1.1 *Cultivar*

A number of researchers have shown that significant differences in lycopene content occur between cultivars (Saini & Singh 1994; Hart & Scott 1995; Chen et al. 2000; Molyneux 2001; Toor & Savage 2005; Kerkhofs 2003), the latter three studies being New Zealand-based. Abushita et al. (2000) have examined the variation in carotenoid levels in tomato cultivars grown on a commercial scale (Table 14). As already discussed, since lycopene is related to the redness of the tomato, some cultivars, such as the yellow cultivars and ‘extended shelf life’ cultivars (with slow ripening characteristics, bred for the fresh tomato market), contain minimal amounts of lycopene. It has also been noted that cultivars with smaller fruits, such as the cherry tomatoes, appear to have higher concentrations of antioxidants than larger tomatoes (Leonardi et al. 2000; Raffo et al. 2002). Orlowski et al. (2001) noted that in addition to the high lycopene levels in the three cherry-type cultivars they studied, vitamin C content was also high. It has been hypothesised that this is due to the fact that they possess a larger surface area to weight ratio, which is important as lycopene reportedly concentrates in the pulp close to the skin of the fruit.

A wild relative of the domestic tomato, *Lycopersicon pimpernellifolium*, produces tiny, currant-like fruit that are said to contain 40 times more lycopene than regular tomatoes (Cox 2000) and is therefore a prime candidate for use in the breeding of new hybrids. Researchers have also isolated a crimson gene and found higher lycopene content in varieties carrying this gene than in those without it (Thompson et al. 2000). A new, conventionally bred tomato, Health Kick, is being advertised as possessing “50% more lycopene compared to common tomato varieties” (www.seminisgarden.com). A genetically modified cultivar, purportedly containing twice the lycopene level of conventional culitivars, was reported by Manzano (2001). Gomez et al. (2001) grew 15 different cultivars (standard red type) under the same conditions and fruit harvested at optimum ripeness had lycopene levels that varied from 5.04 to 13.46 mg/100 g FW.

Table 14: Carotenoid content of different tomato cultivars grown on a commercial scale (adapted from Abushita et al. 2000).

	Carotenoids (mg/100 g FW)					
Cultivar	Lutein	Lycopene epoxide	Lycopene	*cis*-Lycopene	β-Carotene	Total carotenoids
Amico	0.145	0.215	7.726	0.133	0.447	9.036
Casper	0.115	0.154	6.614	0.096	0.245	7.786
Gobe	0.143	0.116	5.918	0.127	0.402	7.150
Ispana	0.123	0.182	6.222	0.100	0.317	7.525
Pollux	0.348	0.148	5.140	0.097	0.210	6.799
?Soprano	0.429	0.361	8.646	0.107	0.321	11.026
Tenger	0.103	0.152	7.656	0.114	0.228	8.824
Uno	0.131	0.171	7.086	0.091	0.323	8.321
Zaphyre	0.303	0.173	6.950	0.113	0.375	8.907
Draco	0.076	0.208	6.868	0.090	0.291	8.191
Jovanna	0.138	0.282	11.606	0.082	0.339	13.205
K-541	0.118	0.256	9.954	0.092	0.283	11.248
Nivo	0.116	0.231	8.456	0.133	0.260	9.722
Simeone	0.361	0.200	9.879	0.103	0.296	11.882
Sixtina	0.332	0.249	10.510	0.111	0.318	12.521
Mean	0.199	0.207	7.949	0.106	0.310	9.476

8.1.2 *Growing conditions*

Using lycopene content quantified in studies of field-grown tomatoes (Abushita et al. 2000; Gomez et al. 2001;Takeola et al. 2001) and comparing data with those from studies of greenhouse-grown tomatoes, Leonardi et al. (2000) found tomatoes grown outdoors had a higher lycopene content than those grown indoors. This may of course be related to different cultivars. An old study found that β-carotene was lower in tomatoes grown under glass or plastic than in the open field. Similarly, lycopene was lowest in tomatoes grown under glass and highest in field-grown tomatoes (McCollum 1954). It is difficult to know which parameters caused these results, but they may include the level of intercepted light, and the high temperatures that occur under protected growth conditions (Dumas et al. 2003). In some cases tomatoes exposed to direct sunlight in the field may develop a poor colour because of exposure to too high temperatures. Temperatures above 35°C stop lycopene synthesis altogether, and temperatures below 12°C strongly inhibit this process. However, in tomatoes harvested for processing, lycopene levels have been shown to be enhanced by 5% at incubation temperatures of 30 and 34°C and by 33% at 37°C (Boothman et al. 1996). It has been postulated that high temperatures inhibit the accumulation of lycopene because they stimulate the conversion of lycopene to β-carotene. Best conditions appear to be sufficiently high temperatures. However, outdoor-grown tomatoes require good foliage cover to protect the fruit from direct exposure to the sun. It has been shown that at favourable temperatures (22-25ºC) the rates of synthesis of lycopene and β-carotene can be increased by illuminating tomato plants during the ripening of the fruit (Dumas et al. 2003).

Arias et al. (2000) found that tomatoes ripened on the vine had one-third higher lycopene than those ripened off the vine. In a study comparing tomatoes grown in organic media with those grown in soil, Lacatus et al. (1995) found lower dry matter and acidity, but increased sugar and lycopene contents in the former. Looking at antioxidative activity in general, Leonardi et al. (2000) found that plants under salt stress produced fruit with significantly higher carotenoid levels than those irrigated with lower salinity water. It was postulated that this was due to the concentration of the phloem sap, since high salinity restricts water supply to the fruit via the phloem with the result being a higher concentration of soluble solids and dry matter (including carotenoids). Another study on tomatoes irrigated with water of varying salinity showed an increase in lycopene levels only up to a certain point (about 0.25%NaCl w/v) and a decrease after that (De Pascale et al. 2001). One Japanese study found that in pink and red-type cultivars soil water deficit increased the amount of lycopene per fresh weight in the outer pericarp region of the tomato, and either increased or decreased vitamin C content depending on the cultivar (Matsuzoe et al. 1998). However, another study showed that fruit lycopene content decreased in response to moisture stress (Naphade 1993). Further studies of the effects of water availability are needed before firm conclusions can be drawn.

Mineral nutrition also has an impact on carotenoid levels. Highest fruit lycopene levels have been achieved with lowest nitrogen (N) levels (Aziz 1968). N fertilisers have generally been thought to increase carotene concentrations in plants but there are few data to confirm this. In one study tomatoes grown in pots did show an increase in fruit lycopene levels when the N supply was increased (Montagu & Goh 1990). For tomatoes to develop a good colour the N supply should be as low as possible without reducing the fruit yield (Dumas et al. 2003). In contrast, increasing phosphorus levels in tomatoes grown hydroponically (up to 100 mg/L) improved fruit colour and lycopene content (Saito & Kano 1970). Various studies have looked at the effect of potassium (K) on lycopene and other carotenoids and found it produced more evenly coloured fruit and higher lycopene levels (Trudel & Ozbun 1971; Winsor 1979). However, the levels used were very high and could not be achieved with modern agricultural practices (Dumas et al. 2003). In one study calcium was shown to significantly increase lycopene in tomatoes grown in pots, from 8.5 to 34 mg/100 g FW (Subbiah & Perumal 1990). However, lycopene was lowered in another (Paiva et al. 1998), although it has been suggested that this was due to a decrease in K absorption.

Some growth and development regulators (e.g. CPTA and/or ethepon) have also been shown to increase the carotenoid content of tomatoes (Dumas et al. 2003).

8.1.3 Degree of ripeness and postharvest storage

Since the conversion of chlorophyll to lycopene is part of the ripening process, it is not surprising that the highest levels of lycopene occur when the fruit is at its reddest and ripest. It is also important that the degree of maturity is determined if comparisons of lycopene content are made between cultivars. The increase in lycopene content during ripening for one cultivar is illustrated in Figure 11. It is interesting to note that lycopene content continues to increase markedly during a period of storage at 18°C. Similar patterns have been noted by other researchers with respect to other cultivars (Hayman 1999; Molyneux 2000). Various patterns of carotenoid accumulation have been reported. In a study in the open field, β-carotene increased steadily during ripening whereas lycopene showed a sharp increase at the 'breaker' stage (Cabibel & Ferry 1980). The lycopene content is regarded as a good index of maturation. In greenhouse-grown, vine-ripened tomatoes the lycopene and β-carotene concentrations showed a gradual, linear increase during the ripening process, whereas in postharvest-ripened fruit the lycopene and β-carotene levels followed an exponential trend (Giovanelli et al. 1999). The lycopene and β-carotene concentrations in postharvest-ripened tomatoes (12.5-13.0 and 1.2 mg/100 g FW respectively) were nearly twice as high as the vine-ripened tomatoes (7.5-8.0 and 0.5-0.7 mg/100 g FW respectively) that had the same colour index. Appropriate postharvest storage conditions can, therefore, increase the lycopene content of tomatoes (Dumas et al. 2003). Fruit bruising at the breaker stage can decrease carotenoids in the ripe fruit (Moretti et al. 1998).

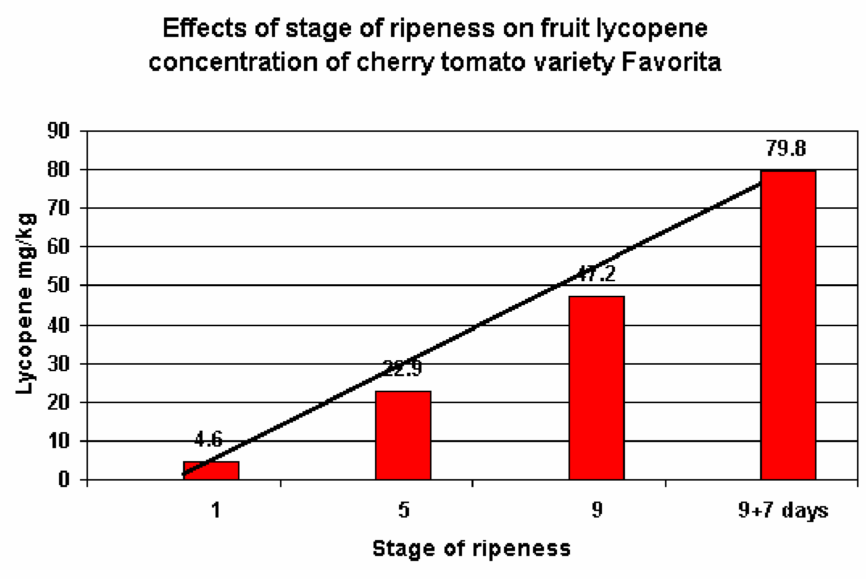


Figure 6: Changes in carotenoid levels during tomato fruit ripening (from www.britishtomatoes.co.uk). Stage of ripeness: 1 = first signs of colour change, sometimes referred to as "breaker" stage; 5 = half-ripe or orange; 9 = red; 9 + 7 days = colour stage 9 plus 7 days storage at room temperature (18°C).

8.1.4 Effects of cooking/processing

In the course of production, the availability of some nutrients may be enhanced, whilst quantities of others, such as the heat labile vitamin C, are lost. A number of factors affect the nutritional value of tomatoes, including storage conditions, method of processing, moisture, temperature and the presence of oxidants and lipids. Macrae et al. (1993) found that maximum ripening and colour development for tomatoes in storage occurred at between 20 and 24°C, with poor ripening at temperatures lower than 13°C.

The food matrix (i.e. the lipid and protein constituents of chromoplasts as well as the fibre contained within the tomato fruit) may contribute greatly to the stability of the all-*trans* form of lycopene in the fruit. This is supported by the observation that when tomatoes are heat processed only minor isomerisation is noted. Heat treatment improves the bioavailability of lycopene without significantly changing the *cis*-isomer composition of the heat-treated foods (Stahl & Sies 1992; Gärtner et al. 1997). Various types of dietary fibre have been shown to reduce the carotenoid bioavailability of some foods (Erdman et al. 1986).

The processing of tomatoes usually involves heat treatment and/or homogenisation. Tables 4 and 5 (see Section 3.2) and 15 give examples of lycopene concentration in some processed tomato products. These results reflect several different factors involved during processing.

Table 15: Change in the carotenoid content (mg/100 g DM) of tomato as a function of processing (adapted from Abushita et al. 2000).

Variety	Lutein	Lycopene epoxide	all-*trans*-Lycopene	*Cis*-Lycopene	all-*trans*-β-Carotene	*cis*-lycopene	Total carotenoids
Raw material	1.98	4.14	119.8	2.06	3.72	<0.10	143.0
Hot-break extract	1.85	3.70	122.0	2.55	3.85	0.39	131.9
Tomato paste	1.92	4.73	162.8	2.52	2.63	0.97	184.9

As already discussed in Section 6.1, processing appears to make lycopene more bioavailable (Stahl & Sies 1992; Gärtner et al. 1997). The health benefits resulting from isomerisation, however, are balanced to some extent by loss due to the same treatment that caused it. Table 24 gives the amount of lycopene lost from tomato juice over various temperatures and various heating times. It is evident that both temperature and the length of heating affect the extent of lycopene breakdown. It has also been reported that serious losses of lycopene can occur when the holding times at high temperatures are long (Shi & Le Maguer 2000). This process, however, was not observed by Nguyen & Schwarz (1999) who suggested that lycopene was relatively resistant to degradation, including by isomerisation, and Thompson et al. (2000) who found little difference in lycopene content between uncooked and samples cooked at 100°C, for 4, 8 and 16 minutes. Similarly Abushita et al. (2000) observed no change in lycopene concentration as fresh tomatoes were processed into paste.

Table 16: Loss rate in tomato juice during heating (from Shi & Le Maguer 2000).

	Lycopene loss (%)		
Heating temperature (°C)	Heating time 1 min	Heating time 3 min	Heating time 7 min
90	0.6	0.9	1.1
100	0.9	1.4	1.7
110	2.2	3.2	4.4
115	2.7	4.5	7.0
118	3.7	6.0	9.1
121	4.6	7.3	10.6
124	5.5	8.5	12.5
127	6.5	9.9	14.6
130	7.4	11.5	17.1

Shi & Le Maguer (2000) found that thermal processing in the forms of bleaching, retorting and freezing generally caused a loss of lycopene, due mainly to isomerisation and oxidation. However, once processed, frozen and heat sterilised foods exhibited excellent lycopene stability for the term of their normal shelf life. Takeoka et al. (2001) noted that the initial Brix level of the raw tomatoes appeared to influence the amount of lycopene that was lost during the processing of tomatoes into paste, but hypothesised that this could also have been the result of longer processing in order to obtain the desired Brix level. This study also found that overall antioxidant activity was greater with tomato paste than fresh tomatoes, but also found that in addition to the antioxidative effect of the lycopene present, there appeared to be significant antioxidant activity due to the polyphenols in the tomato.

There are varying reports on the presence of *cis*-isomers of lycopene. Nguyen & Schwartz (1998) showed only minor changes in their levels during a range of thermal treatments (Table 17). However, Schierle et al. (1996) did show some significant levels of *cis*-isomers in a range of tomato products (Table 18). The presence of other components or influence of factors may explain these effects rather than any thermal processing. Heat, light, acids and other factors have been reported to cause isomerisation (Schierle et al. 1996; Nguyen & Schwartz 1998; Shi et al. 1999). Swartz et al. (1999) have further investigated effects of thermal processing on isomerisation of lycopene and other tomato carotenoids. Upon thermal treatment β-carotene and lutein isomerise to a greater extent than δ-carotene, γ-carotene and lycopene. The presence of lipid was found not to influence the extent or likelihood of lycopene and other tomato carotenoids in the all-*trans* configuration to isomerise. Likewise the presence of different carotenoids did not influence the formation of lycopene *cis*-isomers.

Table 17: Lycopene isomers in various thermally processed tomato products (from Nguyen & Schwartz 1998).

Sample	Total lycopene (mg/100 g DW)	*Cis*-isomers (%)
Peeled tomato	149.89	5.37
Tomato juice (hot-break)	161.23	5.89
Tomato juice (retorted)	180.10	3.56
Tomato (whole, retorted)	183.49	3.67
Tomato paste (concentrated)	174.79	5.07
Tomato paste (retorted)	189.26	4.07
Tomato soup (retorted)	136.76	4.34
Tomato sauce (retorted)	73.33	5.13

Table 18: Lycopene isomers in commercial tomato products (data Schierle et al. 1996).

Sample	Total lycopene (mg/100 g FW)	All-*trans* (%)	5-*cis* (%)	9-*cis* (%)	13-*cis* (%)	Other *cis* (%)
Tomato paste (Tomatenmark, Panocchia, Italy)	52	96	4	<1	<1	<1
Tomato paste (Maracoli, Kraft, Germany	3.7	91	5	1	2	<1
Tomato ketchup (Hot Ketchup, Del Monte, Italy)	9.5	88	7	2	3	1
Tomato ketchup (Hot Ketchup, Heinz, USA)	3.0	77	11	5	7	1
Instant meal (Eier-Ravioli, Hero, Switzerland)	0.6	76	8	5	6	5
Sauce (Hamberger Relish, Heinz, The Netherlands)	3.0	93	5	<1	3	<1
Sauce (Sauce Bolognaise, Barilla, Italy)	9.2	67	14	14	5	8
Canned tomatoes (Chris, Roger Sud, Italy)	7.1	84	5	5	5	3

Dewanto et al. (2002) showed that thermal processing elevated total antioxidant activity and bioaccessible lycopene content in tomatoes and produced no significant changes in the total phenolics and total flavonoid content, although loss of vitamin was observed (Table 19).

Table 19: Percent changes in selected antioxidants and antioxidant activity in processed tomatoes compared to unprocessed fruit (from Dewanto et al. 2002).

	Processing time at 88°C		
	2 min	15 min	30 min
Vitamin C	-10.2	-15.5	-29.4
Lycopene	54.4	171.1	164.3
Total antioxidant activity	28.1	33.9	62.2

8.2 Phenolics

8.2.1 Raw tomatoes

Factors affecting the levels of phenolics in vegetables have been studied by numerous researchers. Mineral nutrition can have a major influence on phenolic accumulation, and a limited nitrogen supply is typically associated with higher levels of phenolics in the plant (Parr & Bolwell 2000). Other environmental factors that can influence phenolic metabolism include ambient temperature. Lower temperature increases some phenolics, in particular the anthocyanins (although these are not present in tomatoes). Although many stresses tend to increase the levels of phenolics, water deficit usually tends to impair accumulation. One of the major environmental controls on phenolic production is light, where both photoperiod and light intensity can have an effect.

There have been limited studies specifically looking at tomatoes and the factors affecting the levels of phenolics in the fruit. Various researchers have noted significant differences in phenolic levels between cultivars (Stewart at al. 2000; Martinez-Valverde et al. 2002). However, Senter et al. (1988) found that the levels did not vary significantly in the three cultivars they tested. Interestingly Minoggio et al. (2003) found that almost all the tomato lines they tested with low carotenoid content produced high levels of phenolics, and consequently had the strongest antioxidant activity.

The most comprehensive study of factors affecting levels of phenolics in tomato was conducted by Stewart at al. (2000). Their main findings were:

- fruit size: greater skin/volume ratio enhances flavonol content,
- country of origin: tomatoes from Spain and South Africa contained higher levels of flavonols than UK fruits. Spanish tomatoes are usually field-grown whereas those from the UK are usually glasshouse-grown and therefore exposed to lower UV levels,
- effect of season: there was some fluctuation, but not dramatic. However, it was only examined in Spain,
- effect of cultivar: significant differences were observed even when cultivars were grown under same conditions.

In another study with cherry tomatoes, plants grown in greenhouses with high light had approximately a twofold higher content of soluble phenolics than plants grown in low light (Wilkens et al. 1996). In all parts of the tomato the phenolics tend to increase from the green stage to the mid-ripe stage before decreasing to original levels at the ripe stage (Senter et al. 1988). In other cultivars the highest quantities of phenolic acids were present in the pulp at the earliest stages of development and decreased during ripening (Buta & Spaulding 1997). A similar pattern was observed for rutin in the skin. Variations in phenolic content during vine and postharvest ripening were also investigated by Giovanelli et al. (1999). The total phenolic content was higher in postharvest-ripened fruit than in vine-ripened fruit.

Attempts have been made to increase the antioxidant level of tomatoes by modifying the flavonoid biosynthetic pathway (Bovy et al. 2002; Verhoeyen et al. 2002). In one case up to a 78-fold increase in total fruit flavonols was achieved (Verhoeyen et al. 2002). It was also possible to produce flavonoids in the tomato fruit flesh, a tissue that normally produces little or no flavonoids (Bovy et al. 2002).

8.2.2 *Processing/cooking*

There appears to have been little study of the effects of processing on the phenolic content of tomatoes. The flavonol content of some processed tomato products is shown in Table 20. In contrast to tomato fruit, which contain almost exclusively conjugated quercetin, up to 30% of the quercetin in processed products is in the free form (Stewart et al. 2000). Hydrolysis of flavonol conjugates during cooking of tomatoes was not noted in an earlier study by this research group (Crozier et al. 1997). Thus, it was hypothesised that the accumulation of free quercetin in juices, puree and paste may have been a consequence of enzymatic hydrolysis of rutin and other quercetin conjugates during pasteurisation and processing procedures. The concentration of flavonols in some tomato products is likely to depend on the extraction of flavonols from the skin during initial processing, which often involves heating. Low levels of flavonols in canned compared to fresh fruit could be due to boiling, as cooking in this manner results in up to an 80% loss of flavonols (Crozier et al. 1997), presumably by leaching from the skins. One study was found reporting that, of the flavonoids, naringenin was the main one affected (a reduction in concentration) during processing of tomatoes into sauce (Re et al. 2002).

Table 20: The flavonol content (mg/100 g FW or for juice and soup mg/100 ml) of selected tomato-based food products (adapted from Stewart et al. 2000).

Tomato product	Brand	Free quercetin	Free kaempferol	Conjugated quercetin	Conjugated kaempferol	Total flavonol	Free flavonol %
Fresh tomatoes[a]	-	0.01	0.02	0.77	0.05	0.85	3.4
Tomato soup	Safeway	0.03	Nd	0.12	nd	0.15	19.6
Tomato juice	Del Monte	0.29	0.04	1.15	0.04	1.52	21.6
	Libby’s	0.35	0.04	1.27	0.03	1.69	22.9
Canned cherry tomatoes	Napolina	Nd	Nd	0.17	0.01	0.18	0
Canned plum tomatoes	Napolina	Nd	Nd	0.03	nd	0.04	0
Pasta sauce	Dolmio	0.12	Nd	0.79	0.01	0.92	12.6
Ketchup	Heinz	0.04	Nd	0.82	0.01	0.88	4.5
Puree	Casinop	0.38	0.06	3.25	0.02	3.71	11.9
	Masque D’or	0.54	Nd	1.09	0.03	1.66	32.5
	Safeway	0.95	Nd	6.14	0.13	7.22	13.2

[a] Average of a number of cultivars.

8.3 Vitamins

Changes in antioxidant vitamins are probably less important than carotenoids or phenolics. Vitamin E is only present in very low amounts and there is little information on factors affecting its level in tomatoes. Variations in the vitamin E content amounting to about one to threefold (from 0.1 to 0.32 mg/100 g FW for α-tocopherol and from 0.12 to 0.40 mg/100 g FW for total tocopherols) have been observed in various Hungarian cultivars (Abushita et al. 1997).

Vitamin C is present in reasonable levels in the raw fruit but it is significantly affected by processing and so is comparatively low in processed products. Some authors have stated that the variations in vitamin C content due to cultivar are fairly small in comparison with those resulting from growth conditions (Hamner et al. 1945). However, there are large variations within tomato species (from 8 up to 119 mg/100 g FW in some wild species) (Stevens & Rick 1986). Attempts to increase the vitamin C content of the cultivated tomato through traditional breeding have had little success. Variations ranging from 25 to 48 mg/100 g FW were observed for various cultivars of tomato grown in Hungary (Abushita et al. 1997).

Fruit ripening at relatively high temperatures, whether on or off the plant, along with relatively low light intensity levels probably leads to a decrease in the ascorbic acid content due to oxidation (Murneek et al. 1954). Under greenhouse conditions seasonal variations in the vitamin C content ranged from 7 to 23 mg/100 g FW at the mature-green stage and were directly correlated with temperature variations (Liptay et al. 1986). Light intensity prior to harvesting can also affect ascorbic acid content. Transfer of fruit from shade to sun results in increases in ascorbic acid content (Hamner et al. 1945). Greenhouse-grown tomatoes were usually found to have lower vitamin C levels than those grown outdoors, chiefly due to the lower light intensity and shorter day length (Murneek et al. 1954). A seasonal increase has been observed in the ascorbic acid content of field-grown fruit from early to late summer (Dumas et al. 2003).

Water shortage seems generally to increase the vitamin C content of the fruit, as well as the dry matter and soluble solid content (Dumas et al. 2003). Supplementary nitrogen, especially at high rates, tends to decrease the tomato vitamin C content, possibly due to the increased shading caused by the greater development of plant foliage (Dumas et al. 2003). Increasing phosphorus concentrations in hydroponics did not significantly affect vitamin C content (Saito & Kano 1970). As with lycopene, calcium application to tomatoes grown in pots resulted in a significant increase in vitamin C (Subbiah & Perumal 1990). It has been reported in several papers that the vitamin C content of tomatoes could increase with the supply of combined fertilisers (Dumas et al. 2003). Some plant growth regulators (e.g. alar, gibberelic acid, cycocel and phosphon) have also been shown to increase the vitamin C content of tomatoes (Dumas et al. 2003).

A French study showed that vitamin C was higher in tomatoes grown by conventional methods than those produced organically (Auclair et al. 1995). The vitamin C content of tomatoes picked green and allowed to ripen at 22-24.5°C increased from 11 to 26 mg/100 g FW (Murneek et al. 1954). Similar patterns have been observed in other studies (Venter 1977; Shi et al. 1999), but Abushita et al. (1997) reported an increase during initial reddening but then a decrease. The vitamin C content of fruit bruised at the breaker stage decreased at the ripe stage compared to undamaged fruit (Moretti et al. 1998). Variations in vitamin C content during vine and postharvest ripening were also investigated by Giovanelli et al. (1999). In postharvest-ripened fruit, ascorbic acid decreased and then returned to original levels, while in vine-ripened fruit it increased and then decreased to a similar or slightly lower level.

There are limited specific data on the loss of vitamin C in tomatoes during processing. One study by Abushita et al. (2000) did show loss of activity (Table 21). Dewanto et al. (2002) also showed that thermal processing resulted in a loss of vitamin C (Table 18).

Table 21: Change in ascorbic acid content of tomato as a function of processing (adapted from Abushita et al. 2000).

Processing steps	Ascorbic acid (mg/g dm)
Raw material	3.17
Hot-break extract	1.96
Tomato paste	1.45
Loss %	54.6%

8.4 Summary

Many of the studies of lycopene content in tomatoes and tomato products were carried out some time ago and many did not use commercially relevant cultivars. All experimental details are often not reported, which makes it difficult to compare results and may explain some of the contradictory findings. Some give different results for different antioxidants. For example, water storage during cropping may increase vitamin C level but reduce lycopene content. Direct sunlight may enhance accumulation of phenolics and vitamin C but foliage cover may help lycopene accumulation. Further research is required with commercially relevant processing cultivars to establish protocols for enhancing phytochemical content in tomatoes.

9 Promoting nutritional attributes

Dietary intakes of tomatoes and tomato products may be associated with decreased risk of various diseases, including cancers, especially prostate, and heart disease. The benefits have been attributed to the lycopene content, but it is probable other phytochemicals in tomatoes also contribute to these benefits. Lycopene is the main carotenoid present in tomatoes and unlike β-carotene, has no provitamin A activity. However, it is a powerful antioxidant and other modes of action may also be responsible for its health benefits (e.g. modulation of intercellular gap junction communication, hormonal and immune systems and metabolic pathways). In addition to lycopene, and other carotenoids (e.g. β-carotene, phytoene, phytofluene), tomatoes contain a range of other phytochemicals with potential health benefits, including phenolic acids (e.g. coumaric and chlorogenic acids), flavonoids (e.g. quercetin-3-rutinoside, naringenin) and antioxidant vitamins (vitamins C and E). Lycopene is readily absorbed from different food sources, distributes to different tissues in the human body and has been demonstrated to have antioxidant properties within the body. Serum levels of lycopene have been related to a reduced risk of several types of cancer. However, more research is still required to fully understand the health benefits of tomatoes/lycopene, the interactions between the phytochemicals in tomatoes, and establish clear dietary guidelines.

The more intense red the tomato is, the more lycopene it is likely to contain. Locally grown fruit, especially some of the more niche tomatoes (e.g. vine) appear to brighter in colour than the paler imported Australian varieties. Similarly, smaller tomatoes tend to have a higher lycopene content than larger cultivars. Storage can also affect lycopene levels and appropriate cooking methods appear to enhance the absorption of lycopene by the body.

Consuming the whole fruit, including the skins and seeds maximises the delivery of the potential health benefits of the tomato.

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Appendices

Appendix I Additional information of general interest

- The word ”tomato” comes from the Aztec, “tomatl”, which was used by the Spanish explorers who originally took the fruit back to Europe. In Italy, it was quickly adopted into local cuisine and was known as “pomo d’oro”, or golden apple, which suggests that the first tomatoes there were yellow. In France it was called “pomme d’amour” or love apple. This may have been a corruption of the Italian or may have reflected the belief that tomatoes had aphrodisiac powers. It was for the latter reason that tomatoes were forbidden to women in some cultures! The botanical name is *Lycopersicon esculentum* meaning “edible wolf peach”, which is derived from the German name for deadly nightshade, a relative of the tomato, which was believed to be used by witches to summon up werewolves.
- Although almost a staple in Western diets today, tomatoes were considered poisonous in some parts of Europe when early Spanish explorers brought them to the old world from their native South America. This belief was also held in North America, until, so the story goes, a champion for the tomato cause, Colonel Robert Gibbon Johnson, announced he would eat a bushel of tomatoes in front of the Boston courthouse. Apparently a 2000 strong crowd arrived, expecting to witness his demise, but to their amazement he lived and any remaining doubts about the tomato were dramatically and conclusively put to rest.
- Tomatoes are unusual amongst foods in that their consumption is not necessarily related to healthy eating choices. For example, whilst they may be part of a salad (healthy choice), they could also be consumed, as tomato sauce, along with fish and chips, French fries, pies or pizza (less healthy choices) or as a tomato-based sauce in a pasta meal (neither particularly healthy nor unhealthy). This makes it particularly interesting for researchers, as many potentially confounding issues are removed.
- In the USA, tomatoes contribute the second most dietary vitamin C, after citrus.
- “A world without tomatoes is like a string quartet without violins”. Laurie Colwyn, Home Cooking

Appendix II

Composition of various tomato products from the New Zealand Food Composition Database

- Tomato-based pasta sauce
- Tomato sauce
- Tomato puree
- Tomato paste, salted
- Tomatoes, flesh, skin and seeds, raw

SAUCE, PASTA,TOMATO-BASED, commercial, heated

Amount in 100 g edible portion	Units	Mean	Std Error	No.	Src.
PROXIMATES					
Water	g	85.35	-	1	z
Energy	kcal	50	-	-	c
Energy	kJ	205	-	-	c
Protein (Nitrogen x 5.8)	g	1.4	-	-	a
Total fat	g	0.7	-	-	a
Carbohydrate, available	g	9.4	-	-	a
Dietary fibre (Englyst, 1988)	g	0.6	-	-	b
Ash	g	1.4	-	-	a
NUTRIENT ELEMENTS					
Sodium	mg	470	-	-	a
Magnesium	mg	17	-	-	a
Phosphorus	mg	30	-	-	a
Sulphur	mg	-	-	-	-
Chloride	mg	830	-	-	b
Potassium	mg	360	-	-	a
Calcium	mg	24	-	-	a
Manganese	µg	0.10	-	-	b
Iron	mg	1.0	-	-	a
Copper	mg	0.16	-	-	b
Zinc	mg	0.25	0.08	10	z
Selenium	µg	T	-	-	g
VITAMINS					
Retinol	µg	1	-	-	a
Beta-carotene equivalents	µg	260	-	-	a
Total vitamin A equivalents	µg	44	-	-	a
Thiamin	mg	0.02	-	-	a
Riboflavin	mg	0.06	-	-	a
Niacin	mg	1.0	-	-	a

Potential niacin from tryptophan	mg	0.2	-	-	ac
Vitamin B6	mg	0.06	-	-	b
Pantothenate	mg	0	-	-	b
Biotin	µg	0	-	-	b
Folate, total	µg	10	-	-	b
Vitamin B12	µg	0	-	-	b
Vitamin C	mg	0	-	-	a
Vitamin D	µg	0	-	-	b
Alpha-tocopherol	mg	-	-	-	-
Vitamin E	mg	0	-	-	p
OTHER LIPIDS					
Cholesterol	mg	0	-	-	a

	g/100 g edible portion				mg/g Nitrogen			
AMINO ACIDS	Mean	Std Error	No.	Src.	Mean	Std Error	No.	Src.
Isoleucine	-	-	-	-	-	-	-	-
Leucine	-	-	-	-	-	-	-	-
Lysine	-	-	-	-	-	-	-	-
Methionine	-	-	-	-	-	-	-	-
Cystine	-	-	-	-	-	-	-	-
Phenylalanine	-	-	-	-	-	-	-	-
Tyrosine	-	-	-	-	-	-	-	-
Threonine	-	-	-	-	-	-	-	-
Tryptophan	-	-	-	-	-	-	-	-
Valine	-	-	-	-	-	-	-	-
Arginine	-	-	-	-	-	-	-	-
Histidine	-	-	-	-	-	-	-	-
Alanine	-	-	-	-	-	-	-	-
Aspartic acid	-	-	-	-	-	-	-	-
Glutamic acid	-	-	-	-	-	-	-	-
Glycine	-	-	-	-	-	-	-	-

Proline	-	-	-	-	-	-	-	-
Serine	-	-	-	-	-	-	-	-
Hydroxyproline	-	-	-	-	-	-	-	-

Common Measure 1 cup, 258 g

FOODINFO New Zealand Institute for Crop & Food Research
1.S

SAUCE, PASTA,TOMATO-BASED, commercial, heated

FATTY ACIDS	g/100 g edible portion Mean	Std Error	No.	Src.	g/100 g total fatty acids Mean	Std Error	No.	Src.
Total saturated fatty acids	0.1	-	-	a	-	-	-	-
Total monounsaturated fatty acids	0.2	-	-	a	-	-	-	-
Total polyunsaturated fatty acids	0.4	-	-	a	-	-	-	-

Additional information (in 100 g edible portion)	Units	Mean	Std Error	No.	Scr.
Alcohol	g	0	-	-	a
Cadmium	µg	1.39	0.21	10	z
Carbohydrate, available	g	9.4	-	-	a
Carbohydrate, total (by difference)	g	11	-	-	c
Density	kg/l	1.03	-	-	z
Dietary fibre	g	1.8	-	-	a
Dry matter	g	14.7	-	1	z
Fructose	g	3.7	-	-	ac
Glucose	g	3.8	-	-	ac
Insoluble non-starch polysaccharides	g	0	-	-	bc
Lactose	g	0	-	-	b
Lead	µg	0.63	0.08	8	zl
Maltose	g	0	-	-	b
Soluble non-starch polysaccharides	g	0.6	-	-	bc
Starch	g	1.9	-	-	a
Sucrose	g	T	-	-	b
Total available sugars	g	7.5	-	-	a
Total niacin equivalents	mg	1.2	-	-	ac
Total nitrogen	g	0.24	-	-	ac
Carbohydrate exchange		0.94	-	-	c

SAUCE, TOMATO

Composite of Cerebos,Watties `Homestyle' and King tomato sauce.

Amount in 100 g edible portion	Units Src.	Mean	Std Error	No.
PROXIMATES				
Water	g zc	69.54	-	-
Energy	kcal c	105	-	-
Energy	kJ c	432	-	-
Protein (Nitrogen x 5.8)	g z	1.07	-	1
Total fat	g z	0.10	-	1
Carbohydrate, available	g zc	24.87	-	-
Dietary fibre (Englyst, 1988)	g z	1.32	-	1
Ash	g z	2.36	-	1
NUTRIENT ELEMENTS				
Sodium	mg z	615.00	-	1
Magnesium	mg z	16.40	-	1
Phosphorus	mg z	23.78	-	1
Sulphur	mg z	18.86	-	1
Chloride	mg -	-	-	-
Potassium	mg z	397.70	-	1
Calcium	mg z	20.50	-	1
Manganese	µg z	151.70	-	1
Iron	mg z	1.35	-	1
Copper	mg z	0.11	-	1
Zinc	mg z	0.14	-	1
Selenium	µg z	3.28	-	1
VITAMINS				
Retinol	µg zr	15	-	-
Beta-carotene equivalents	µg zr	104.47	-	-
Total vitamin A equivalents	µg zr	32.41	-	-
Thiamin	mg z	0.02	-	1
Riboflavin	mg z	0.03	-	1

Niacin	mg	1.20	-	1	z
Potential niacin from tryptophan	mg	0.25	-	-	b
Vitamin B6	mg	0.13	-	-	zr
Pantothenate	mg	1.00	-	1	z
Biotin	µg	8	-	-	br
Folate, total	µg	11.65	-	-	zr
Vitamin B12	µg	0	-	-	b
Vitamin C	mg	7.85	-	1	z
Vitamin D	µg	0	-	-	b
Alpha-tocopherol	mg	-	-	-	-
Vitamin E	mg	5.52	-	-	br
OTHER LIPIDS					
Cholesterol	mg	0	-	-	p

	g/100 g edible portion				mg/g Nitrogen			
AMINO ACIDS	Mean	Std Error	No.	Src.	Mean	Std Error	No.	Src.
Isoleucine	-	-	-	-	-	-	-	-
Leucine	-	-	-	-	-	-	-	-
Lysine	-	-	-	-	-	-	-	-
Methionine	-	-	-	-	-	-	-	-
Cystine	-	-	-	-	-	-	-	-
Phenylalanine	-	-	-	-	-	-	-	-
Tyrosine	-	-	-	-	-	-	-	-
Threonine	-	-	-	-	-	-	-	-
Tryptophan	-	-	-	-	-	-	-	-
Valine	-	-	-	-	-	-	-	-
Arginine	-	-	-	-	-	-	-	-
Histidine	-	-	-	-	-	-	-	-
Alanine	-	-	-	-	-	-	-	-
Aspartic acid	-	-	-	-	-	-	-	-
Glutamic acid	-	-	-	-	-	-	-	-

Glycine	-	-	-	-	-	-	-	-
Proline	-	-	-	-	-	-	-	-
Serine	-	-	-	-	-	-	-	-
Hydroxyproline	-	-	-	-	-	-	-	-

Common Measure 1 tablespoon, 16.5 g

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3.S

SAUCE, TOMATO

Composite of Cerebos,Watties `Homestyle' and King tomato sauce.

FATTY ACIDS	g/100 g edible portion Mean	Std Error	No.	Src.	g/100 g total fatty acids Mean	Std Error	No.	Src.
Total saturated fatty acids	T	-	-	g	-	-	-	-
Total monounsaturated fatty acids	T	-	-	g	-	-	-	-
Total polyunsaturated fatty acids	T	-	-	g	-	-	-	-

Additional information (in 100 g edible portion)	Units	Mean	Std Error	No.	Scr.
Alcohol	g	0	-	-	p
Aluminium	µg	984.00	-	1	z
Arsenic	µg	0.57	-	1	z
Boron	µg	98.40	-	1	z
Cadmium	µg	1.60	-	1	z
Carbohydrate, available	g	24.87	-	-	zc
Carbohydrate, total (by difference)	g	27	-	-	c
Chromium	µg	3.57	-	1	z
Cobalt	µg	4.10	-	1	z
Density	kg/l	1.13	-	-	z
Disaccharides, total	g	12.70	-	1	z
Dry matter	g	30.46	-	-	zc
Fructose	g	6.10	-	1	z
Glucose	g	5.60	-	1	z
Insoluble non-starch polysaccharides	g	0.89	-	1	z
Iodide	µg	1	-	-	z
Lactose	g	T	-	1	z
Lead	µg	1.11	-	1	z
Lithium	µg	4.22	-	1	z
Maltose	g	T	-	1	z
Monosaccharides,total	g	11.70	-	1	z
Mercury	µg	T	-	1	z

Molybdenum .... z	µg	4.51	-	1
Nickel .... z	µg	17.22	-	1
Rubidium .... z	mg	0.41	-	1
Silicon .... z	µg	11480.00	-	1
Soluble non-starch polysaccharides.. z	g	0.42	-	1
Starch ....zc	g	0.47	-	-
Starch (monosacc).. z	g	0.52	-	1
Sucrose.. z	g	12.70	-	1
Tin .... z	µg	82.00	-	1
Total available sugars ....zc	g	24.4	-	-
Total dietary fibre (Prosky, 1984).. u	g	1.4	-	-
Total niacin equivalents.. bz	mg	1.45	-	-
Total nitrogen .... z	g	0.19	-	1
Vanadium .... z	µg	2.42	-	1
Carbohydrate exchange c		2.5	-	-

TOMATO PUREE

Amount in 100 g edible portion	Units	Src.	Mean	Std Error	No.
PROXIMATES					
Water	g	b	74.9	-	-
Energy	kcal	c	80	-	-
Energy	kJ	c	330	-	-
Protein (Nitrogen x 6.25)	g	b	5.0	-	-
Total fat	g	u	0.32	-	-
Carbohydrate, available	g	ab	14.2	-	-
Dietary fibre (Englyst, 1988)	g	b	2.50	-	-
Ash	g	u	2.53	-	-
NUTRIENT ELEMENTS					
Sodium	mg	b	240	-	-
Magnesium	mg	b	26	-	-
Phosphorus	mg	b	94	-	-
Sulphur	mg	x	14	-	-
Chloride	mg	b	550	-	-
Potassium	mg	b	1200	-	-
Calcium	mg	b	35	-	-
Manganese	μg	b	240	-	-
Iron	mg	b	1.4	-	-
Copper	mg	b	2.9	-	-
Zinc	mg	b	0.5	-	-
Selenium	μg	zr	0.87	-	-
VITAMINS					
Retinol	μg	p	0	-	-
Beta-carotene equivalents	μg	aug	634	-	-
Total vitamin A equivalents	μg	aug	106	-	-
Thiamin	mg	b	0.4	-	-
Riboflavin	mg	b	0.19	-	-
Niacin	mg	b	4.00	-	-

Potential niacin from tryptophan	mg	0.7	-	-	b
Vitamin B6	mg	0.11	-	-	b
Pantothenate	mg	1.0	-	-	b
Biotin	µg	6	-	-	b
Folate, total	µg	22	-	-	b
Vitamin B12	µg	0	-	-	b
Vitamin C	mg	38	-	-	bw
Vitamin D	µg	0	-	-	b
Alpha-tocopherol	mg	-	-	-	-
Vitamin E	mg	5.37	-	-	bw
OTHER LIPIDS					
Cholesterol	mg	0	-	-	p

	g/100 g edible portion				mg/g Nitrogen			
AMINO ACIDS	Mean	Std Error	No.	Src.	Mean	Std Error	No.	Src.
Isoleucine	0.099	-	-	b	124	-	-	b
Leucine	0.140	-	-	b	175	-	-	b
Lysine	0.149	-	-	b	186	-	-	b
Methionine	0.032	-	-	b	40	-	-	b
Cystine	0.032	-	-	b	40	-	-	b
Phenylalanine	0.090	-	-	b	113	-	-	b
Tyrosine	0.064	-	-	b	80	-	-	b
Threonine	0.115	-	-	b	144	-	-	b
Tryptophan	0.041	-	-	b	51	-	-	b
Valine	0.107	-	-	b	134	-	-	b
Arginine	0.107	-	-	b	134	-	-	b
Histidine	0.072	-	-	b	90	-	-	b
Alanine	0.124	-	-	b	155	-	-	b
Aspartic acid	0.578	-	-	b	722	-	-	b
Glutamic acid	-	-	-	-	-	-	-	-
Glycine	0.090	-	-	b	113	-	-	b

Proline.. ....b	0.080	-	-	b	100	-	-
Serine.. ....b	0.132	-	-	b	165	-	-
Hydroxyproline.. .... -	-	-	-	-	-	-	-

Common Measure 1 tablespoon, 16 g

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5.S

TOMATO PUREE

FATTY ACIDS	g/100 g edible portion Mean	Std Error	No.	Src.	g/100 g total fatty acids Mean	Std Error	No.	Src.
Total saturated fatty acids	0.045	-	-	u	20.0	-	-	u
Total monounsaturated fatty acids	0.047	-	-	u	21.1	-	-	u
Total polyunsaturated fatty acids	0.132	-	-	u	58.8	-	-	u

Additional information (in 100 g edible portion)	Units	Mean	Std Error	No.	Scr.
Alcohol	g	0	-	-	p
Carbohydrate, available	g	14.2	-	-	ab
Carbohydrate, total (by difference)	g	17.3	-	-	c
Density	kg/l	1.07	-	-	z
Dietary fibre	g	2.8	-	-	u
Dry matter	g	25.1	-	-	b
Fructose	g	7.6	-	-	b
Glucose	g	6.5	-	-	b
Insoluble non-starch polysaccharides	g	1.5	-	-	br
Lactose	g	0	-	-	a
Lactose (monosacc)	g	0	-	-	a
Maltose	g	0	-	-	a
Maltose (monosacc)	g	0	-	-	a
Soluble non-starch polysaccharides	g	1.0	-	-	br
Starch	g	0.1	-	-	b
Starch (monosacc)	g	0.1	-	-	b
Sucrose	g	T	-	-	b
Sucrose (monosacc)	g	T	-	-	b
Total available sugars	g	14.1	-	-	ab
Total available sugars (monosacc)	g	14.1	-	-	b
Total dietary fibre (Prosky, 1984)	g	1.9	-	-	a
Total niacin equivalents	mg	4.70	-	-	c
Total nitrogen	g	0.8	-	-	b

Carbohydrate exchange c	1.4	-	-

TOMATO PASTE, SALTED

Amount in 100 g edible portion	Units	Src.	Mean	Std Error	No.
PROXIMATES					
Water	g	a	76.5	-	-
Energy	kcal	c	67	-	-
Energy	kJ	c	276	-	-
Protein (Nitrogen x 5.8)	g	a	3.1	-	-
Total fat	g	a	0.3	-	-
Carbohydrate, available	g	br	12.9	-	-
Dietary fibre (Englyst, 1988)	g	b	2.8	-	-
Ash	g	u	2.67	-	-
NUTRIENT ELEMENTS					
Sodium	mg	a	630	-	-
Magnesium	mg	a	38	-	-
Phosphorus	mg	a	68	-	-
Sulphur	mg	-	-	-	-
Chloride	mg	br	490	-	-
Potassium	mg	a	960	-	-
Calcium	mg	a	28	-	-
Manganese	µg	br	T	-	-
Iron	mg	a	1.6	-	-
Copper	mg	br	0.53	-	-
Zinc	mg	a	0.4	-	-
Selenium	µg	br	T	-	-
VITAMINS					
Retinol	µg	a	0	-	-
Beta-carotene equivalents	µg	a	1320	-	-
Total vitamin A equivalents	µg	a	220	-	-
Thiamin	mg	a	0.12	-	-
Riboflavin	mg	a	0.08	-	-
Niacin	mg	a	2.8	-	-

Potential niacin from tryptophan .... br	mg	0.6	-	-
Vitamin B6 .... br	mg	0.44	-	-
Pantothenate .... br	mg	1	-	-
Biotin .... br	µg	6.1	-	-
Folate, total .... br	µg	54	-	-
Vitamin B12 .... br	µg	0	-	-
Vitamin C .... a	mg	15	-	-
Vitamin D .... br	µg	0	-	-
Alpha-tocopherol .... -	mg	-	-	-
Vitamin E .... br	mg	5.37	-	-
OTHER LIPIDS				
Cholesterol .... a	mg	0	-	-

AMINO ACIDS Src.	g/100 g edible portion Mean	Std Error	No.	Src.	mg/g Nitrogen Mean	Std Error	No.
Isoleucine .... -	-	-	-	-	-	-	-
Leucine .... -	-	-	-	-	-	-	-
Lysine .... -	-	-	-	-	-	-	-
Methionine .... -	-	-	-	-	-	-	-
Cystine .... -	-	-	-	-	-	-	-
Phenylalanine .... -	-	-	-	-	-	-	-
Tyrosine .... -	-	-	-	-	-	-	-
Threonine .... -	-	-	-	-	-	-	-
Tryptophan .... -	-	-	-	-	-	-	-
Valine .... -	-	-	-	-	-	-	-
Arginine .... -	-	-	-	-	-	-	-
Histidine .... -	-	-	-	-	-	-	-
Alanine .... -	-	-	-	-	-	-	-
Aspartic acid .... -	-	-	-	-	-	-	-
Glutamic acid .... -	-	-	-	-	-	-	-
Glycine .... -	-	-	-	-	-	-	-

Proline.. .... -	-	-	-	-	-	-	-
Serine.. .... -	-	-	-	-	-	-	-
Hydroxyproline.. .... -	-	-	-	-	-	-	-

Common Measure 1 cup, 277 g

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1.X

TOMATO PASTE, SALTED

FATTY ACIDS	g/100 g edible portion Mean	Std Error	No.	Src.	g/100 g total fatty acids Mean	Std Error	No.	Src.
Total saturated fatty acids	0	-	-	a	-	-	-	-
Total monounsaturated fatty acids	0	-	-	a	-	-	-	-
Total polyunsaturated fatty acids	0	-	-	a	-	-	-	-

Additional information (in 100 g edible portion)	Units	Mean	Std Error	No.	Scr.
Alcohol	g	0	-	-	a
Carbohydrate, available	g	12.9	-	-	br
Carbohydrate, total (by difference)	g	17.43	-	-	g
Density	kg/l	1.10	-	-	z
Dietary fibre	g	0	-	-	a
Dry matter	g	23.5	-	-	a
Fructose	g	6.6	-	-	br
Glucose	g	6	-	-	br
Insoluble non-starch polysaccharides	g	1.3	-	-	b
Lactose	g	0	-	-	br
Maltose	g	0	-	-	br
Soluble non-starch polysaccharides	g	1.5	-	-	bc
Starch	g	0.3	-	-	br
Sucrose	g	T	-	-	b
Total available sugars	g	12.6	-	-	br
Total niacin equivalents	mg	3.4	-	-	ab
Total nitrogen	g	0.53	-	-	ac
Carbohydrate exchange		1.3	-	-	c

TOMATOES, flesh, skin and seeds, raw

Lycopersicon esculentum

Amount in 100 g edible portion	Units	Src.	Mean	Std Error	No.
PROXIMATES					
Water	g	z	94.22	0.38	5
Energy	kcal	c	17	-	-
Energy	kJ	c	68	-	-
Protein (Nitrogen x 6.25)	g	z	0.89	-	1
Total fat	g	z	0.24	-	1
Carbohydrate, available	g	azc	2.7	-	-
Dietary fibre (Englyst, 1988)	g	z	1.21	-	1
Ash	g	z	0.59	-	1
NUTRIENT ELEMENTS					
Sodium	mg	z	3.74	-	1
Magnesium	mg	z	12.1	-	1
Phosphorus	mg	z	22.9	-	1
Sulphur	mg	z	10.9	-	1
Chloride	mg	z	48.3	-	1
Potassium	mg	z	265	-	1
Calcium	mg	z	10.9	-	1
Manganese	µg	z	56.8	9.0	3
Iron	mg	z	0.13	-	1
Copper	mg	z	0.049	0.024	3
Zinc	mg	z	0.09	-	2
Selenium	µg	z	0.110	-	1
VITAMINS					
Retinol	µg	p	0	-	-
Beta-carotene equivalents	µg	zc	549	-	1
Total vitamin A equivalents	µg	zc	92	-	1
Thiamin	mg	z	0.024	-	1
Riboflavin	mg	z	0.005	-	1
Niacin	mg	z	0.543	-	1

Nutrient	Unit	Mean	Std Error	No.	Src.
Potential niacin from tryptophan	mg	0.1	-	-	b
Vitamin B6	mg	0.009	-	1	z
Pantothenate	mg	0.229	-	-	u
Biotin	µg	1.3	-	-	b
Folate, total	µg	14	-	-	u
Vitamin B12	µg	0	-	-	p
Vitamin C	mg	23.7	-	1	z
Vitamin D	µg	0	-	-	p
Alpha-tocopherol	mg	0.760	-	1	z
Vitamin E	mg	0.77	-	-	zc
OTHER LIPIDS					
Cholesterol	mg	0	-	-	p

AMINO ACIDS	Src.	g/100 g edible portion Mean	Std Error	No.	Src.	mg/g Nitrogen Mean	Std Error	No.
Isoleucine	b	0.017	-	-	bz	120	-	-
Leucine	b	0.024	-	-	bz	170	-	-
Lysine	b	0.025	-	-	bz	180	-	-
Methionine	b	0.006	-	-	bz	40	-	-
Cystine	b	0.006	-	-	bz	40	-	-
Phenylalanine	b	0.015	-	-	bz	110	-	-
Tyrosine	b	0.011	-	-	bz	80	-	-
Threonine	b	0.020	-	-	bz	140	-	-
Tryptophan	b	0.007	-	-	bz	50	-	-
Valine	b	0.018	-	-	bz	130	-	-
Arginine	b	0.018	-	-	bz	130	-	-
Histidine	b	0.013	-	-	bz	90	-	-
Alanine	b	0.021	-	-	bz	150	-	-
Aspartic acid	b	0.101	-	-	bz	720	-	-
Glutamic acid	-	-	-	-	-	-	-	-
Glycine	b	0.015	-	-	bz	110	-	-

Proline... ....b	0.014	-	-	bz	100	-	-
Serine.. ....b	0.022	-	-	bz	160	-	-
Hydroxyproline.. .... -	-	-	-	-	-	-	-

Common Measure 1 tomato, 127 g
1 cup, chopped, 190 g

Edible Portion 100 % z

FOODINFO New Zealand Institute for Crop & Food Research

3.X

TOMATOES, flesh, skin and seeds, raw

Lycopersicon esculentum

FATTY ACIDS	g/100 g edible portion Mean	Std Error	No.	Src.	g/100 g total fatty acids Mean	Std Error	No.	Src.
Total saturated fatty acids	0.033	-	-	uz	19.6	-	-	u
Total monounsaturated fatty acids	0.036	-	-	uz	21.7	-	-	u
Total polyunsaturated fatty acids	0.099	-	-	uz	58.7	-	-	u

Additional information (in 100 g edible portion)	Units	Mean	Std Error	No.	Scr.
Alcohol	g	0	-	-	p
Alpha-carotene	µg	0	-	1	z
Available non-reducing sugars	g	0	-	1	z
Available reducing sugars	g	2.65	-	1	z
Beta-carotene	µg	549	-	1	z
Cadmium	µg	0.20	-	2	z
Carbohydrate, available	g	2.7	-	-	azc
Carbohydrate, total (by difference)	g	4.1	-	-	c
Chromium	µg	1.99	-	2	z
Density	kg/l	0.76	-	-	z
Dietary fibre	g	1.21	-	1	z
Dry matter	g	5.78	0.38	5	z
Fluoride	µg	8	-	-	zw
Fructose	g	1.38	-	-	zc
Gamma-tocopherol	mg	0.175	-	-	bz
Glucose	g	1.27	-	-	zc
Hemicellulose	g	0.09	-	1	z
Insoluble non-starch polysaccharides	g	0.67	-	1	z
Iodide	µg	1.5	-	-	z
Lactose	g	0	-	-	a
Lactose (monosacc)	g	0	-	-	p
Lead	µg	T	-	2	zl

Lignin.. z	g	0.35	-	1
Maltose .... a	g	0	-	-
Maltose (monosacc)... a	g	0	-	-
Neutral detergent fibre (Van Soest 1967)... z	g	0.93	-	1
Soluble non-starch polysaccharides.. z	g	0.55	-	1
Starch .... z	g	0.04	-	1
Starch (monosacc).. z	g	0.04	-	1
Sucrose...zc	g	0	-	-
Sucrose (monosacc)...zc	g	0	-	-
Total available sugars ....azc	g	2.7	-	-
Total available sugars (monosacc).. z	g	2.65	-	1
Total dietary fibre (Prosky, 1984)... a	g	1.2	-	1
Total niacin equivalents... c	mg	0.6	-	-
Total nitrogen .... z	g	0.14	-	1
Carbohydrate exchange c		0.27	-	-

4.X

Crop & Food Research Confidential Report No. 1473

Nutritional attributes of salad vegetables

L J Hedges & C E Lister

August 2005

A report prepared for
Vegfed

Copy 15 of 15

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

1.1 Background

This report provides information that may be incorporated into promotional and educational booklets for VegFed sector groups. We have gathered relevant literature, including medical research and scientific papers, and have provided information specific to New Zealand when it is available. This report focuses on the nutritional attributes of salad vegetables — lettuce, rocket, watercress, mesclun, cucumber, radish and celery. Factors that may influence the nutritional profile of these vegetables, such as agronomical issues, cooking or processing and storage, are covered. Some additional material of general interest has also been included.

Note: The amount of research on the vegetables covered in this report varies somewhat. This is reflected in the volume and depth of the detail in the various sections of the report so some sections may appear less substantial than others.

1.2 Lettuce

The common notion that lettuce is a nutritional desert does not do this vegetable justice, particularly the newer cultivars. These are often more strongly coloured than the traditional Iceberg-type cultivars, and the pigments that confer colour have a range of nutritional benefits. Most cultivars contain the pigments β-carotene, lutein and zeaxanthin, chlorophyll, with the red cultivars additionally containing anthocyanins. β-carotene is the major vitamin A precursor, so as well as contributing vitamin A activity, it also plays a role in preventing some cancers. Lutein and zeaxanthin are believed to maintain vision and eye health. Chlorophyll has been relatively little studied, but new nutritional roles for this photosynthetic compound, including anti-cancer activity, are being investigated. Red cultivars of lettuce also contain anthocyanins, which are of particular interest in relation to protecting against health problems associated with ageing. Other phytochemicals in lettuce include lignans, which have an oestrogenic effect, as well as the core nutrients of vitamin C, iron, folate and fibre.

Whilst it is true that lettuce is composed largely of water, this is an advantage in providing low calorific bulk, which is important in terms of satiety. It serves as a base for other salad ingredients as well as providing a range of sensory qualities. The fact that it is eaten so frequently means that its overall nutritional contribution may be quite high.

1.3 Rocket

Rocket contains similar core nutrients to those in lettuce and also shares many of the same phytochemicals (though not anthocyanins.) Besides its characteristic nutty flavour, what is distinctive about rocket is that it also provides glucosinolates. When the plant tissue is damaged, by cutting or chewing, these compounds are enzymatically converted to other compounds, including isothiocyanates. The latter protect against cancer through a number of mechanisms, particularly the induction of phase 2 enzymes and encouraging apoptosis. It is these compounds that impart the pungent mustardy taste. Although rocket is not alone in providing glucosinolates, it is eaten raw. Therefore, the enzyme that converts glucosinolates into isothiocyanates is not destroyed during cooking, ensuring that conversion to isothiocyanates is optimised.

1.4 Watercress

Watercress is a nutritional heavyweight, rich in both core nutrients and phytochemicals. Of particular interest is its range of glucosinolates, which, like in rocket, are converted into different isothiocyanates and similar compounds called indoles upon damage to the plant tissue. Phenethyl isothiocyanate (PEITC) and other watercress isothiocyanates were initially shown to protect against the major cancer-causing compounds in cigarette smoke. The mechanism by which this occurs is thought to be the induction of phase 2 enzymes, in concert with the inhibition of harmful phase 1 enzymes. More recently these compounds have been studied with respect to anti-inflammatory activity and the prevention of autoimmune diseases. Indole-3-carbinol, another glucosinolate-derived compound, has been found to be particularly promising in the prevention of hormone-related cancers. As with other glucosinolate-containing plants, such as rocket, the enzyme that catalyses the conversion of glucosinolates to other metabolites remains at optimum levels because watercress is generally eaten raw.

1.5 Mesclun

The mix of plants in a mesclun salad provides a range of phytochemicals in addition to visual, taste and textural appeal. Although the constituent plants used for a mix may differ, mesclun should provide good levels of core nutrients as well as phytochemicals. Mesclun will typically contain many major pigments – chlorophyll, carotenoids and anthocyanins – as well as glucosinolates and various phenolic compounds. How phytochemical and core nutrient levels differ between immature and adult plants appears to have been little studied.

1.6 Cucumber

The contribution of cucumber to the diet would appear to be more sensory than nutritional. It is relatively poor in terms of nutrient content, but is refreshing and provides interesting texture. Consuming the skin as well as the seeds maximises its nutritional benefits.

1.7 Radish

Radish has good levels of vitamin C, but is not especially rich in core nutrients. Its most important phytochemicals are glucosinolates, similar to those in rocket and watercress, and anthocyanins, which, like those in red lettuces, are thought to help prevent health problems associated with ageing.

1.8 Celery

Celery has some history and documented use as a herbal remedy, but to date there has been relatively little scientific interest in this vegetable. It is high in sodium and has reasonable levels of potassium, to which some researchers have attributed its purported ability to lower blood pressure, though other researchers believe this is due to another class of constituent compounds, phthalides. It is also one of a few plants to contain the flavonoid luteolin, which has not been extensively studied but may help prevent atherosclerosis.

2 *Lettuce* (Lactuca sativa *L.*)

2.1 Introduction

Lettuce has sometimes disparagingly been referred to as a 'nutritional desert'. While the most common of the lettuce varieties, Iceberg, is probably the least nutritious of this family, even it is not without nutritional value. Also, there has recently been an explosion of new cultivars in the marketplace with different colours, textures and forms. Not only do these add visual interest to a salad, they also significantly increase its phytochemical content and provide an excellent range of the important phytochemical groups. Whilst a vegetable comprising 96% water cannot be as nutritious as a denser product, it does make an important contribution both to the appeal of our food and our diets, especially given how frequently it is consumed.

Lettuces are an ancient food, featuring in Ancient Egyptian tomb drawings dating back to around 2500 BC. They have been documented throughout history, although they were probably rather different plants to the lettuces we know today. For example, it might be surprising to a consumer today that the Ancient Romans believed them to have soporific effects and consequently served them at the end of a meal. However, possibly because they tasted bitter, the sleep-inducing compounds have been bred out of modern forms.

The standard Iceberg-type lettuce is in fact a relative newcomer. It and cultivars bred from it are believed to originate from what at the time was a larger, firmer crisphead lettuce called Great Lakes in 1941. This cultivar was known as Iceberg because in pre-refrigeration days lettuces were transported packed in ice.

The term "lettuce" today includes a host of different cultivars and sometimes even non-lettuces such as endive. New Zealand lettuces can be divided into head lettuces such as Iceberg or Buttercrunch and leaf lettuces such as Romaine (Cos) or Lollo Rosso. In China a stem lettuce is the predominant form and in Egypt a cultivar is grown specifically for oil seed production. Since the lettuce belongs to the same family as sunflowers, perhaps this is not too surprising.

The recent trend for coloured cultivars is in fact a return to forms that existed centuries ago. Other trends include new textures and forms and the use of baby leaves. In the US 40% of production is now non Iceberg, with Romaine becoming increasingly popular. The widespread popularity of the Caesar salad may account in some part for this.

2.2 Composition

A host of variables can affect the composition of any item of fresh produce. Perhaps the most obvious of these is cultivar, but growing conditions, level of maturity and postharvest treatment are also important.

2.2.1 Core nutrients

Most kinds of lettuce are a good source of vitamin C, folate, fibre and pro vitamin A (in the form of β-carotene). Further detail from the New Zealand Food Composition Database is provided in Appendix I.

2.2.2 Other phytochemicals

Most cultivars provide the carotenoids β-carotene and lutein/zeaxanthin and assorted flavonoids. The latter include flavanols (mostly quercetin) and flavones (apigenin and luteolin), with the red cultivars in addition possessing anthocyanins. Although not a major dietary source, lettuces also contain lignans and, like all green plants, chlorophyll. This can vary from low levels in pale Iceberg to high levels in more strongly coloured cultivars, such as Cos. As already mentioned, although masked by other pigments, it is also present in the red-leafed cultivars.

2.3 Nutritional attributes

2.3.1 Health benefits of core nutrients

See Appendix II.

Fibre

Lettuce may lower cholesterol absorption. In an animal study, the inclusion of red oak leaf lettuce in the diet lowered cholesterol, the authors attributing this to the presence of fibre (Nicolle et al. 2004).

See also Appendix II.

2.3.2 Health benefits of phytochemicals in lettuce

Carotenoids

The carotenoids are a group of yellow-orange-red pigments present in a range of fruits and vegetables as well as in algae, fungi and bacteria. They cannot be synthesised in the body and are present solely as a result of ingestion, of material from other sources, either of the plant itself or of a product made from an animal that has consumed that plant source. The carotenoids that make egg yolks yellow are an example of this. Often the colours of the carotenoids present in plants are masked by chlorophyll, to the extent that some of the highest levels of carotenoids are found in dark green, leafy vegetables, such as kale and spinach.

Carotenoids are lipids and comprise a long chain hydrocarbon molecule with a series of central, conjugated double bonds. These conjugated (alternating) double bonds confer colour and are responsible for 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 partake 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 both the macula lutea of the eye and the skin against the same photoxidative damage (Sies & Stahl 2003).

There are two general classes of carotenoids, the carotenes, and their oxygenated derivatives, the xanthophylls. Structurally, the two groups are almost identical except that the xanthophylls have a terminal hydroxyl group. Their structure determines their properties and thus also their activities and physiological roles. The carotenes possess pro-vitamin A activity and are non-polar and hence in the body tend to be located on the periphery of cell membranes. Xanthophylls have no vitamin A capacity, and, being non 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).

Carotenes

Those carotenoids with at least one unsubstituted beta-ring and an unchanged side chain (e.g. β-carotene, α-carotene, cryptoxanthin, γ-carotene) may be converted to vitamin A in the body and are known as carotenes. Such carotenoids are referred to as having provitamin A activity. Many carotenoids are being considered as potential cancer prevention agents, although trial results are mixed.

Studies of β-carotene indicate that its antioxidant activities and health benefits only occur when it is derived from food and not supplements. β-carotene has been used as a so-called oral sun protectant due to its antioxidant properties, and its efficacy has been proven in studies (Stahl et al. 2000).

Xanthophylls

Another group of carotenoids, the xanthophylls (e.g. lutein and zeaxanthin), have specific distribution patterns in human tissue, especially in the retina of the eye (Zaripheh & Erdman 2002).

These carotenoids are thought to be important for normal eye function and play a role in the prevention of various eye diseases, including macular degeneration, glaucoma and cataracts (Head 1999, 2001).

Levels of these in some common foods are given in Table 1. Because of their similarity, the two compounds are often reported as a combined total, as is the case with information from the USDA carotenoid database used for Table 1. Whilst it is apparent that lettuce does not contain extraordinarily high levels of lutein + zeaxanthin in comparison with some other foods, it should be borne in mind that it is frequently consumed in many households and so is an important dietary source of these compounds.

Table 1: Lutein and zeaxanthin levels in selected foods (mcg per 100 g edible portion) (USDA 2003).

	Lutein + zeaxanthin
Lettuce, green leaf, raw	1730
Lettuce, Iceberg	352
Broccoli, cooked boiled drained, without salt	1517
Egg, raw	331
Corn, sweet, yellow, frozen, kernels cut off cob, drained, without salt	730
Corn, sweet, yellow, whole kernel, canned, drained solids	1029
Corn, sweet, yellow, raw	764
Kale, cooked	18346
Oranges, raw, all commercial varieties	129
Persimmons, Japanese, raw	834

Flavonoids and other phenolic compounds

There is huge structural diversity within the large group of antioxidant compounds known as phenolics. Several thousands of natural polyphenols have been identified in plants, many of them in plant foods (Shahidi & Naczk 1995), although only a more limited number are present at significant levels in most human diets. The chemical structure of polyphenols affects their biological properties, including their bioavailability, antioxidant activity, and specific interactions with cell receptors and enzymes. There has been little specific study of the role that lettuce flavonoids, and other phenolics, may play in human health. However, this group of compounds has received considerable attention in general, but particularly those compounds in red wine, tea, chocolate and onions.

Phenolic compounds, because of their structure, are very efficient scavengers of free radicals and are metal chelators (Shahidi et al. 1997). In addition to these antioxidant characteristics, other potential health-promoting bioactivities of the flavonoids 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 low density lipoprotein (LDL) (Frankel et al. 1993). Studies on the health benefits of the phenolic acids to date have largely focused on their antioxidant activity.

Anthocyanins are one of the various classes of flavonoids and are the pigments responsible for the red/blue/purple colours of some, though not all, fruits and vegetables. These pigments account for the reddish colours of the red cultivars of lettuce, the skins of red radishes and the purple of raddichio. They have strong antioxidant activity and in blueberries particularly have been studied for their contribution to protecting the brain against the effects of ageing. In addition, anthocyanins are believed to lower the risk of some cancers and help prevent cardiovascular disease by preventing inflammation and the oxidation of LDL cholesterol (Joseph et al. 2002).

Lignans

Lignans are plant compounds that are converted into mammalian oestrogens by gut bacteria. For this reason they are known as phytoestrogens or plant oestrogens. In the human body they have a weak oestrogenic effect and may help prevent hormone-related cancers, such as breast cancer (Joseph et al. 2002).

Chlorophyll

Relatively little is known about the health effects of chlorophyll, the primary photosynthetic pigment responsible for the green colour in plants and many algae. Some research suggests that it may be important in protecting against some forms of cancer, as, it is postulated, the chlorophyll binds to the mutant DNA and prevents it from proliferating. A very recent study suggests that chlorophyll has weak phase 2 enzyme inducer potency, and although its activity is relatively weak compared with some other phytochemicals (see Sections 3, 4 and 7), because of its concentration in many of the plants we eat, it may be responsible for some of the protective effects that have been observed with diets that are rich in green vegetables (Fahey et al. 2005).

2.4 Factors affecting nutritional attributes of lettuce

As mentioned earlier, a host of factors can potentially influence the nutrients and the levels of those nutrients present in any plant. This area of research is relatively new and as a result information is sparse.

2.4.1 Cultivar

Different cultivars can have both different levels of shared nutrients as well as some totally different phytochemicals, with colour/pigment differences perhaps the most obvious example. As a general rule, strongly coloured cultivars contain higher phytochemical levels than do less coloured ones (Wu et al. 2004). Red cultivars e.g. (Lollo Rosso, Red Oak, Oakleaf) also provide anthocyanins (Wu & Prior 2005), which are believed to contribute to their superior antioxidant activity, when compared to their green counterparts.

Tables 2 and 3 illustrate inter-cultivar variations for various core nutrients and phytochemicals. One striking difference is that in terms of core nutrients, Iceberg is generally well below those of the others listed, with Cos and Red Leaf sharing the highest levels for these nutrients between them. Cos is particularly outstanding in terms of vitamin C and folate, with Red Leaf possessing more β-carotene or pro vitamin A.

Table 2: Comparison of some nutrients in different varieties of lettuce (American data) USDA National Nutrient Database for Standard Reference, Release 17 (www.nal.usda.gov/fnic/foodcomp/index.html.

	Vit C (mg)	Vit E (mg)	Folate (µg)	Iron (mg)	B-carotene (µg)	Lutein & zeaxanthin (µg)
Butterhead	3.7	0.18	73	1.24	1987	1223
Cos/Romaine	24	0.13	136	0.97	3484	2312
Iceberg	2.8	0.18	29	0.41	299	277
Red Leaf	3.7	0.15	36	1.20	4495	1724

As is shown above, not only do core nutrients vary considerably according to the kind of lettuce (around 9 fold in terms of vitamin C), but so also do the carotenoid pigments, with a 15 fold difference for β-carotene. This is also true for other phytochemicals. Using the flavonoid class as an example (Table 3), it can be seen how these can vary even more, with a 690 fold difference between Iceberg and Lollo Rosso (DuPont et al. 2000).

Table 3: Flavonoids in eight varieties of lettuce (DuPont et al. 2000).

Cultivar	Total flavonoids (µg/g fresh weight)
Iceberg	0.3
Green Batavia	0.7
Cos Remus	9.6
Green Salad Bowl	19.9
Green Oak Leaf	32.9
Red Oak Leaf	76.2
Lollo Biondo	95.7
Lollo Rosso	207

In contrast to the above, however, and perhaps relating to differences in the other factors mentioned earlier that influence composition, an American study showed that Iceberg had higher phenolic content and similar antioxidant levels to that of Romaine (Kang & Saltveit 2002).

2.4.2 Growing conditions

Growing conditions can involve a large number of agronomic factors, any one of which could have an impact on the nutritional profile of the plant. These include soil type, hours of sunlight, irrigation, pest control, weather, growing location, cultivation methods and others.

Information in this area is far from comprehensive, although with growing interest in the health benefits of phytochemicals, research on ways of maximising levels may increase. The following two studies relating specifically to lettuce are evidence of interesting differences. In a comparison of young greenhouse and open-air grown plants of an Italian cultivar (Audran) it was found that all open-air grown samples had higher levels of polyphenol compounds than those grown in greenhouses (Romani et al. 2002). Similarly, field-grown curly lettuces had higher carotenoid levels than those grown hydroponically (Kimura & Rodriguez-Amaya 2003).

2.5 Promotional messages/tips

- Because of their high water content, lettuces are not as nutrient dense as some other vegetables, but this also means they are good ‘fillers’ for weight watchers and supply fibre. However, in providing bulk, they provide a low calorie base for a salad or sandwich filling as well as sensory attributes. Also, this ‘bulk’ provided by lettuce may have a further benefit of inducing satiety. Not only does the stomach feel fuller, but the act of chewing affects a hormone in the brain, histamine, which helps promote satiety (Sakata et al. 1997).
- The large assortment of lettuces currently available provide not only colour, texture and taste, but a variety of phytochemicals with their associated health benefits.
- Although lettuce is not nutrient dense, the frequency with which it is consumed means that the nutrients it contains make a sizeable overall contribution to dietary intake.
- Many of the phytochemicals in lettuces are carotenoids and are more bioavailable if consumed along with fats, e.g. good quality oil as in (non fat free) salad dressings.

3 *Rocket* (Eruca sativa *Mill. syn* Eruca vesicaria *L.)*

3.1 Introduction

Also known as arugula or roquette, rocket has a long history of medicinal use. Of all its attributes, its purported aphrodisiac qualities are one of the most frequently mentioned. These were described by Virgil as well as Dioscorides and Galen. Some herbalists of the time recommended that rocket be mixed with lettuce in salads to dilute this undesirable effect! This was also the reason why it was apparently forbidden in monasteries. Another of its virtues was in treating eye complaints, with both Pliny and the Bible reporting its efficacy (Nuez & Hernandez Bermejo 1994; Morales & Janick 2002; Barillari et al. 2005).

Today rocket is probably best known as an integral part of a mesclun mix, imparting a distinctive nutty flavour. It also often accompanies carpaccio.

3.2 Composition

Like all produce, composition is determined by a host of variables including cultivar, agronomy, level of maturity and postharvest treatment. Cultivar is a less important factor with respect to rocket, as different cultivars do not appear to be currently available in New Zealand.

3.2.1 Core nutrients

Rocket contains pro vitamin A (as β-carotene) vitamin C, folate, calcium and fibre. Further detail from the USDA National Nutrient Database 2005 is provided in Appendix I.

3.2.2 Other phytochemicals

Rocket also provides carotenoids (lutein, β-carotene), vitamin C, flavonoids and glucosinolates (glucoerucin) and fibre.

3.3 Nutritional attributes

3.3.1 Health benefits of core nutrients

See Appendix II.

3.3.2 Health benefits of phytochemicals

For general discussion of carotenoids, fibre, flavonoids see Section 2.3.2.

Glucosinolates

Rocket belongs to the Brassicaceae family, like broccoli, and like broccoli it contains glucosinolates, the compounds indirectly responsible for the characteristic pungent taste of this family. The range of these in rocket, however, is not the same as those in broccoli. Rocket has not enjoyed the scientific attention that broccoli has, perhaps because it is less well known but also perhaps because it has lower levels of the phase 2 enzyme-inducing activity for which broccoli is famous. Most study regarding glucosinolates has to do with a broccoli glucosinolate called glucoraphanin, which is converted to another kind of compound, an isothiocyanate called sulforaphane, when the plant tissue is damaged in some way – eaten by insects, cut by the chef's knife, or chewed by humans. Sulforaphane is best known for inducing phase 2 enzymes, such as quinone reductase, which detoxifies potential carcinogens, induces apoptosis (cell suicide) in cancer cells, and inhibits harmful phase 1 enzymes. The plant glucosinolates are converted to isothiocyanates by the enzyme myrosinase. However, because myrosinase is not heat stable it is destroyed by cooking and the conversion cannot take place. Although some conversion is carried out by bacteria in the gut, it is believed to be a much less efficient process. The pungent, mustardy taste is attributable to these isothiocyanates.

The main glucosinolate in rocket is glucoerucin, which the enzyme myrosinase converts to the isothiocyanate, erucin. An Italian study showed that erucin not only possesses indirect antioxidant activity (in inducing phase 2 enzymes, like sulforaphane), but that it additionally had direct antioxidant activity, decomposing hydroperoxides and hydrogen peroxide (which are often the catalysts that trigger the cancer cascade). Moreover, the by-product of this radical scavenging activity was sulforaphane itself, the most potent phase 2 enzyme inducer in the isothiocyanate family (Barillari et al. 2005). An advantage of rocket over broccoli is that it is most commonly eaten raw so the myrosinase remains at optimal levels. Although this study was carried out on rocket seeds and sprouts, the adult leaves also contain glucosinolates. Research results vary as to which glucosinates predominate; in one study it was glucoerucin (Nitz & Schnitzler 2002) while in another it was a new glucosinolate, 4-mercaptobutyl glucosinolate (Bennett et al. 2002).

3.4 *Factors affecting nutritional attributes*

No information relating specifically to factors that affect the nutritional attributes of rocket was available, apart from the fact that myrosinase is destroyed through heating.

3.5 *Promotional messages/tips*

- Rocket is nutrient dense, besides providing a distinctive taste.
- It contains glucosinolates and, because it is eaten raw, the enzymes required to convert glucosinolates to isothiocyanates remain intact. Erucin, a major isothiocyanate in rocket, may have good direct and indirect antioxidant activity as well as acting as a precursor to sulforaphane in certain conditions.
- The younger the leaves, the milder they will taste. If too pungent, older leaves can be chopped like herbs and sprinkled on the salad.

4 *Watercress* (Rorippa nasturtium aquaticum *(L.) Hayek syn* Nasturtium officinale *R. Br.*)

4.1 Introduction

Watercress was a much more valued part of the diet historically than it is today. The ancient Greeks believed it could instil courage, strength, character and even wit, the Romans that it would cure baldness, and the Victorians that it could get rid of hiccups and freckles!

Records show that there was large-scale cultivation of watercress in European countries from the eighteenth century. Although green watercress appears to be the only species currently cultivated, in England a brown watercress (*Nasturtium microphyllum*) was also popular during the 19th century (Palaniswamy & McAvoy 2001).

4.2 Composition

Composition varies according to a host of different factors, including cultivar, growing conditions, level of maturity and postharvest treatment.

4.2.1 Core nutrients

Watercress contains a large number of nutrients including pro vitamin A (from β-carotene), vitamin C, fibre, iron, potassium, calcium and some α-linolenic acid. Further detail from the New Zealand Food Composition Database is provided in Appendix I.

4.2.2 Phytochemicals

Watercress is well endowed with phytochemicals, including chlorophyll, lutein, β-carotene, and the glucosinoltes gluconasturtiin (which is converted to the isothiocyanate phenethyl isothiocyanate, or PEITC), glucoraphanin (which is converted to the isothiocyanate, sulforaphane), glucobrassican (which is converted to indole-3-carbinol or I-3-C , a compound similar to an isothiocyanate).

4.3 Nutritional attributes

4.3.1 Core nutrients

See Appendix II.

4.3.2 Other phytochemicals

- See Section 2.3.2 for general discussion of carotenoids (β-carotene, lutein), flavonoids and chlorophyll.
- See Section 3.3.2 for health effects of glucosinolates/isothiocyanates.

Phenethyl isothiocyanate

Besides providing an excellent range of phytochemicals and at reasonable levels, one of the distinctive features of watercress is its postulated ability to protect against cancer-causing nitrosamines in cigarette smoke. This was thought to be due to the presence of phenethyl isothiocyanate (PEITC) and was initially shown in a study using rats. A small human study of 11 smokers consuming watercress at each meal demonstrated that PEITC blocked the metabolic activation of one of the carcinogenic compounds in cigarette smoke, which was demonstrated through the excretion of detoxified metabolites (Hecht 1999; Rose et al. 2000).

A later study suggested, however, that contrary to expectations the observed induction of the phase 2 enzyme, quinine reductase (QR), was not associated with PEITC (which is rapidly lost to the atmosphere upon tissue disruption due to its volatility) or with a naturally occurring PEITC-glutathione conjugate, but instead with other watercress isothiocyanates (ITCs), 7-methylsulfinyheptyl and 8-methylsulfinyloctyl ITCs. While it was confirmed that PEITC does induce QR, 7-methylsulfinyheptyl and 8-methylsulfinyloctyl ITCs were more potent inducers. Thus, although watercress contains three times more phenethyl glucosinolate than methylsulfinylalkyl glucosinolates, ITCs derived from methylsulfinylalkyl glucosinolates may be more important phase 2 enzyme inducers than PEITC, having 10 to 25 fold greater potency. The authors concluded that watercress might have exceptionally good anticarcinogenic potential because it combined a potent inhibitor of phase 1 enzymes (PEITC) with at least three inducers of phase 2 enzymes (PEITC, 7-methylsulfinylheptyl ITC and 8-methylsulfinyloctyl ITC (Rose et al. 2000).

Other research has subsequently shown that watercress compounds may also prove beneficial in terms of other health problems. A recent study showed how PEITC and 8-methylsulphinyloctyl (MSO) isothiocyanates decreased levels of pro-inflammatory compounds that can cause chronic inflammation conditions, including auto immune diseases such as rheumatoid arthritis, multiple sclerosis, and Alzheimer's disease as well as cancer (Rose et al. 2005). The major metabolite of PEITC, phenethyl isothiocyananate N-acetylcysteine (PEITC-NAC), has also been shown to inhibit the growth and proliferation of xenografted human prostate cancer cells (Chiao 2004). Like with sulforaphane, it was postulated that this was achieved through cell cycle arrest and the induction of apoptosis. PEITC and sulforaphane were also shown to be effective in preventing the formation of colonic cancer cells (Chung 2000).

Indoles

Another important compound in watercress is an indole called glucobrassicin or indole-3-carbinol (I3C). An indole is similar to an isothiocyanate, and can similarly be formed through enzymatic conversion upon damage to the plant tissue. Indoles have been particularly investigated for their anti-oestrogenic effect; they block oestrogen receptors in the breast cells and thus assist in preventing oestrogen-sensitive breast cancers. They have also been found to induce apoptosis or cell suicide in tumour cells. Besides breast cancer, animal studies have shown I3C also assists in the prevention of endometrial and cervical cancers (Auborn et al. 2003) as well as prostate cancer (Nachshon-Kedmi et al. 2003).

4.4 Factors affecting nutritional attributes

Most research regarding watercress has concentrated upon the medicinal effects of some of the purified constituent compounds. There does not appear to be much information concerning the health benefits of the plant material itself, nor research into the effects of factors that may affect its nutritional content.

4.5 Promotional messages/tips

- Watercress is deserving of far more popularity than it actually enjoys. It is a nutritional heavyweight with plenty of carotenoids, good levels of lutein, plus the isothiocyanates and indoles of the brassicas and phenolics.
- Watercress is an exceptionally rich dietary source of PEITC as well as other glucosinolates that inhibit the detrimental phase 1 enzymes, which are responsible for activating many carcinogens, and induce phase 2 enzymes, which have been found to have potent anticarcinogenic activity.
- Because is it is often consumed raw, the enzyme myrosinase, which converts the glucosinolates to isothiocyanates, remains intact to do its job.
- Watercress adds crunch and spiciness to salads.
- It can be cooked (though some phytochemicals may be impaired) or consumed raw.
- Food safety has been an issue with wild watercress, which can be contaminated with *E. coli, Campylobacter*, lead and arsenic (from an ESR report, article in NZ Herald 08/08/05). Commercially grown produce is likely to be safer.

5 Mesclun

5.1 Introduction

The name 'mesclun' was originally a French term simply meaning mixture. It is used to refer to a mixture of young leaves used in a salad. This mixture provides variations of colour, taste, texture and a spread of nutrients. Assortments vary, but usually include different varieties of lettuce, rocket, and may contain some or all of the following: corn salad, red chard, raddicihio, tatsoi, curly endive baby spinach and leafy herbs.

5.2 Composition

Composition of a mesclun mix will vary according to the mix of the various plants included. As always, it will be affected by factors such as cultivar, growing conditions, maturity, storage, and postharvest treatment. Many of the lesser known plants have not yet been analysed, so comprehensive data are lacking. Data on lettuce are included in Section 2 and on rocket in Section 3. The known nutrients in the other various component plants are listed in Table 4.

The taxonomy and spelling of some of the newer Asian salad greens does not appear to be consistent in the published and web-based information available.

Table 4: Core nutrients and phytochemicals in some component plants of a mesclun mix.

Vegetable	Core nutrients	Phytochemical(s)
Bok choy / pak choy (*Brassica rapa chinensis*)	Vitamin A, vitamin C, calcium, iron, riboflavin, vitamin B6, magnesium, manganese, thiamine, niacin, folate, zinc	Glucosinolates, folate, lutein and zeaxanthin, β-carotene, chlorophyll
Chicory/curly endive/frisee (*Chicorium endivia* L.)	N/A	β-Carotene, folate, lutein, chlorophyll
Lamb's lettuce/ mache /corn salad (*Valeriana locusta*)	N/A	Chlorophyll
Mizuna (*Brassica campestris*)	N/A	Glucosinolates, folate, lutein and zeaxanthin, β-carotene, chlorophyll
Raddichio (red witloof) (*Chicorium intybus*)	N/A	Anthocyanins
Red chard (*Beta vulgaris* L.)	Vitamin A, vitamin C, calcium, iron, Vitamin E, vitamin K, riboflavin, magnesium, copper, manganese	Folate, lutein and zeaxanthin, β-carotene, betalains
Red mustard (*Brassica juncea* L.)	Vitamin A, vitamin C, calcium, iron, vitamin E, vitamin K, thiamine, riboflavin, vitamin B6, folate, magnesium, copper, manganese	Glucosinolates
Spinach (*Spinacea oleracea* L.)	Vitamin A, vitamin C, vitamin E, vitamin K, thiamin, riboflavin, vitamin B6, calcium, copper, iron, folate, potassium	Lutein and zeaxanthin, β-carotene, glutathione, alpha-lipoic acid, chlorophyll, oxalates
Tatsoi (*Brassica rapa*) var. *rosularis*	N/A	Glucosinolates, folate, lutein and zeaxanthin, β-carotene, chlorophyll

5.3 Nutritional attributes

5.3.1 Health benefits of core nutrients

See Appendix II.

5.3.2 Health benefits of other phytochemicals

The variation in a mesclun mix also provides for a range of phytonutrients; their high levels of vitamin A are indicative of β-carotene content (see Section 2) while anthocyanins (Section 2) and glucosinolates/isothiocyanates originate from members of the Brassica family that are present – tatsoi, mustard, chard – as well as rocket (Section 3).

To date there appears to be little specific information on the effect of leaf maturity on phytochemical levels in these plants. One study showed how baby leaves of endive and Boston lettuce contained lower levels of carotenoids than mature leaves, though this was not true for another of the samples investigated – New Zealand spinach, *Tetragonia expansa* (not silver beet) (de Azevedo-Meleiro & Rodriguez-Amaya 2005).

5.4 Factors affecting nutritional attributes

A study investigating the shelf life of baby leaf salad mixes found that mechanical stress, in the form of 100 paper strokes daily, promoted smaller leaf sizes and lessened leaf plasticity. This resulted in an estimated increase in shelf life of 33% in the assortment of baby Lollo Rosso, Cos and spinach leaves (Clarkson et al. 2003).

5.5 Promotional messages/tips

- Consuming a salad mix, such as mesclun, is an excellent and convenient way of obtaining a range of dietary phytochemicals in one dish.
- Like rocket, raw Brassica leaves are a potentially good way of obtaining the isothiocyanates from glucosinolate-rich foods because the enzyme myrosinase has not been destroyed by cooking.

6 *Cucumber* (Cucumis sativus *L.*)

6.1 Introduction

With a water content of around 96% (Athar et al. 2003), it is not surprising that cucumbers are cool and refreshing. Popular and ethnobotanical uses centre around its soothing effect upon the skin. Some home remedies recommend cucumber slices being applied topically to promote skin tone around the eyes, and there are various commercial preparations based upon cucumber extract in products such as skin lotions. Not surprisingly, in Chinese cuisine cucumber is considered a Yin or cooling food.

6.2 Composition

Composition varies according to a number of factors, including cultivar, growing conditions, level of maturity and postharvest treatment.

6.2.1 Core nutrients

Cucumber contains some vitamin C, pro vitamin A as β-carotene in the skins, fibre in skin and seeds, and potassium. Further detail from the New Zealand Food Composition Database is provided in Appendix I.

6.2.2 Phytochemicals

β-carotene, chlorophyll

6.3 Nutritional attributes

6.3.1 Health benefits of core nutrients

See Appendix II.

6.3.2 Health benefits of phytochemicals

Cucumber is not a nutrient-dense food. For example, in a comparison of 10 common vegetables, selected on the basis of per capita consumption, cucumber (cultivar unspecified), ranked at the bottom in terms of antioxidant activity, phenolic compound content and antiproliferative activity in relation to human liver cancer cells (Chu et al. 2002).

One compositional feature that makes cucumber interesting is that it is one of only a few foods to contain silicon. This is a less common mineral in the diet so levels are not quoted in the New Zealand Food Composition Database nor in that of the USDA. Dr Duke's database does confirm that cucumbers contain silica (Duke 2003), a fact alluded to in the popular literature. One source stated that silicon is important in connective tissue, such as skin, hair and nails (Atkinson 1982).

Fibre from skins and seeds (see Appendix II).

Chlorophyll (see Section 2.3.2).

6.4 Factors affecting nutritional attributes

No information on this topic has been found.

6.5 Promotional messages/tips

- Eating the skins and seeds maximises its health benefits. Alternating peeled and unpeeled strips of skin may make the concept more palatable.

- Crunchy cucumber adds texture, taste and body to a salad. Its coolness offsets other spicier tastes, as with raita accompanying curry dishes.
- Slices of cucumber can be added to a jug or glass of drinking water for a refreshing change.

7 *Radish* (Raphanus sativus *L.*)

7.1 *Introduction*

Although it grows underground, radish is really a swollen stem rather than a root. Radishes exist in a variety of shapes and sizes, as well as colour, ranging from red to white and even black.

7.2 *Composition*

Composition varies according to a host of different factors, including cultivar, growing conditions, level of maturity and postharvest treatment.

7.2.1 *Core nutrients:*

On a per weight basis radishes have high levels of vitamin C, more, for example than a fresh tomato (Athar et al. 2003). They also contain some fibre, potassium and folate, but like many salad vegetables are high in water so are not nutrient-dense. Further detail from the New Zealand Food Composition Database is provided in Appendix I.

7.2.2 *Phytochemicals*

The peppery taste of radishes is evidence of the presence of glucosinolates/isothiocyanates. Anthocyanins are present in red-skinned cultivars.

7.3 *Nutritional attributes*

7.3.1 *Health benefits of core nutrients*

See Appendix II.

7.3.2 *Health benefits of phytochemicals*

Radishes contain a variety of glucosinolates: glucoraphanin (Duke 2003), glucoraphenin, glucoerysolin and 4-methylthiobutanol (Schutze et al. 1999), glucoraphasatin (Scheuner et al. 2005). Many of these are also identified in seeds: glucoraphanin, glucoraphenin, 4-hydroxyglucobrassican and glucobrassican (West et al. 2004). Glucosinolates are also found in Brassicas such as broccoli and cabbage and their derivatives, isothiocyanates, have been found to have cancer protective properties (see Section 3.3). Cooking destroys the enzyme myrosinase, which converts the glucosinolates to isothiocyanates (see Section 3.3), so eating raw (as with radishes) is best. Sulforaphane, the isothiocyanate to which glucotaphanin is converted, is also being investigated with regard to treating *Helicobacter pylori* infection and blocking gastric tumour formation (Fahey et al. 2002).

Red cultivars contain anthocyanins in their skin (Stintzing & Carle 2004; Wu & Prior 2005). These compounds are believed to have a wide variety of benefits, including anti-inflammatory, anti-cancer, and cardiovascular protective (see Section 2.3.2), although most research has related to anthocyanins in fruit sources, such as berries.

7.4 Factors affecting nutritional attributes

A recent German study found that spraying the foliage of radish and broccoli plants with glutathione increased glucosinolates in broccoli heads but not in radishes (Scheuner et al. 2005).

7.5 Promotional messages/tips

- Radishes need not be just for decoration – radish glucosinolates are less studied than some others, but likely to have similar benefits to other members of the Brassica family.
- It also has the advantage of being consumed raw, so enzyme loss through heat treatment does not occur.
- The red skins contain anthocyanins, which have anti-inflammatory, anti-cancer, and cardiovascular protective properties.

8 *Celery* (Apium graveolens *L.*)

8.1 Introduction

Celery has a long history as a medicinal plant, but has only relatively recently been considered a food source and eaten as a vegetable. It was traditionally used as a diuretic, which is now attributed to its potassium and sodium content.

8.2 Composition

Composition varies according to a host of different factors, including cultivar, growing conditions, level of maturity and postharvest treatment.

8.2.1 Core nutrients

Celery contains some vitamin C, a small amount of vitamin A as β-carotene, sodium, potassium, calcium, and fibre. Further detail from the New Zealand Food Composition Database is provided in Appendix I.

8.2.2 Phytochemicals

Celery contains β-carotene, lutein/zeaxanthin and the flavones, luteolin and apigenin.

8.3 Nutritional attributes

8.3.1 Core nutrients

See Appendix II.

8.3.2 Phytochemicals

Most research to do with celery has investigated celery seed oil, probably due to its extensive use in ethnic remedies and herbal medicines combined with the fact that seeds often contain greater concentrations of bioactive compounds. In particular, the phthalides, 3-n-butylphthalide and sedanolide, have been identified, which are also believed to be responsible for the distinctive smell and taste of celery. This suggests they are also likely to be present in the stalks, though in lesser amounts.

In an animal experiment, 3-n-butylphthalide lowered blood pressure through its dilatory effect upon blood vessels. Previous animal experiments had also shown that a celery decoction decreased blood pressure in hypertensive dogs. This was similarly shown with a celery extract in rats (Tsi & Tan 1997).

One of the most commonly cited folk remedies using celery relates to treating inflammatory conditions such as gout and arthritis. Celery and celery seed supplements are often marketed as targeting these complaints. A Jordanian animal study investigating a number of traditional medicinal plants used to alleviate pain and inflammation described celery seed extract having both anti-inflammatory and analgesic effects (Atta & Alkofahi 1998). However, there appears to be little other scientific literature in this regard.

Celery, along with other vegetables such as capsicum and lettuce, contains a form of a compound called luteolin, a flavonoid that has been shown to have various beneficial health effects, such as antioxidant and anti-inflammatory activity. A Korean study showed how luteolin could inhibit the growth of vascular smooth muscle cells in the neointima, which would otherwise contribute towards the process of atherosclerosis and post angioplasty restinosis (Kim et al. 2005).

Apigenin, another flavonoid, has not been widely studied, but has been shown to have some anti-cancer and anti-inflammatory activity (Joseph et al. 2002; Smolinski & Pestka 2003).

In a comparison of 10 common vegetables, selected on the basis of per capita consumption, celery (cultivar unspecified) ranked around the middle in terms of antioxidant activity, towards the bottom for phenolic compound content and did not appear to have antiproliferative activity against human liver cancer cells (Chu et al. 2002).

8.4 Factors affecting nutritional attributes

No information was found in this area.

8.5 Promotional messages

- Celery is low calorie, refreshing and provides flavour as well as texture.
- It is one of the few sources of luteolin, a little studied compound as yet but one that may have cardiovascular benefits.

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Appendices

Appendix I Nutrients in selected vegetables/100 g fresh raw vegetable

	Water g	Energy kcal	Protein g	Total fat g	Available CHO g	Fibre (NSP) g	Sodium mg	Potassium mg	Ca mg	Iron mg	Zinc mg	Se mg	Total vit A equiv mg	Thiamin mg	Riboflavin mg	Total niacin equivmg	Vit B 6 mg	Folate mg	Vitamin C mg
Celery[1]	93	11	1	0.2	1.4	2	151	302	56	0.7	0.1	0.2	13	0.3	0.03	0.5	0.11	13	7.5
Cucumber[1]	96	10	0.6	0.1	1.7	0.6	13	139	23	0.3	0.2	0.1	6	0.04	0.04	0.3	0.04	16	7.9
Lettuce[1]	95	9	1.1	0.3	0.4	0.7	14	245	36	1	0.2	0.3	45	0.05	0.06	0.6	0.06	34	12
Lettuce,[1]* Hydroponic	95	18	1.9	0.3	1.8	0.6	13	280	61	1	0.2	T†	88	0.07	0.09	0.5	T†	55	T†
Radish[1]	94	19	1	0.5	2.6	1.3	56	229	42	1.8	0.4	0.3	2	0.04	0.02	0.3	0.1	23	23.9
Rocket[2] (arugula)	91.7	25	2.6	0.7	3.6	1.6	27	369	160	1.5	0.5	0.3	119	0.04	0.09	0.31	0.07	97	15
Spinach[1]	95	10	1.3	0.2	0.8	1	107	103	48	0.7	0.6	0.2	362	0.03	0.11	0.724	0.24	146	16
Watercress[1]	93	16	2.8	0.4	0.2	1.4	17	180	53	2.2	0.3	0.2	824	0.12	0.04	0.8	0.19	80	75

[1] Data taken from the Concise New Zealand Food Composition Tables (6th Ed).
[2] Data taken from the USDA National Nutrient Database for Standard Reference, Release 17.
* Composite of ‘Rocket’, ‘Red Lettuce’, ‘Lolla Bionda Lettuce’, ‘Butterhead Lettuce’, ‘Frillice Lettuce’ and ‘Lollo Rossa Lettuce’ cultivars.
† T - trace.

Appendix II Activities of vitamins and minerals and fibre

(Adapted from misc.medscape.com/pi/editorial/clinupdates/2004/3341/table.doc and http://www.bupa.co.uk/health_information/html/healthy_living/lifestyle/exercise/diet_exercise/vitamins.html).

Name	Major function
Vitamin A Retinol (animal origin) Carotenoids (plant origin, converted to retinol in the body) Note: Retinol Equivalents (RE) 1 RE = 1 mcg retinol or 6 mcg beta-carotene 1 IU = 0.3 mcg or 3.33 mcg = 1 mcg retinol = 1RE	Important for normal vision and eye health Involved in gene expression, embryonic development and growth and health of new cells Aids immune function May protect against epithelial cancers and atherosclerosis
Vitamin D (calciferol) Two main forms: cholecalciferol (animal origin) and ergocalciferol (plant origin) Cholecalciferol is formed by action of UV rays of sun on skin Note: 1 mcg calciferol = 40 IU vitamin D	Facilitates intestinal absorption of calcium and phosphorus and maintains serum concentrations Maintains bone health and strong teeth May be involved in cell differentiation and growth May be involved in immune function
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 includingt 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

Name	Major function
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 certain cancers Involved in hormone and neurotransmitter synthesis
Thiamin vitamin B_1 Aneurin	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells
Riboflavin vitamin B_2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein
Niacin vitamin B_3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown Reduces LDL cholesterol and increases HDL cholesterol
Vitamin B_6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis, haemoglobin synthesis. Involved in neuronal excitation Reduces blood homocysteine levels Prevents megaloblastic anemia
Vitamin B_{12} Cobalamin	Coenzyme in DNA synthesis with folate Synthesis and maintenance of myelin nerve sheaths Involved in the formation of red blood cells Reduces blood homocysteine levels Prevents pernicious anemia
Folate Generic term for large group of compounds including folic acid and Pterylpolyglut-amates	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

Name	Major function
Biotin	Important for normal growth and body function Involved in metabolism of food for energy Coenzyme in synthesis of fat, glycogen, and amino acids
Pantothenic acid	Coenzyme in fatty acid metabolism and synthesis of some hormones Maintenance and repair of cell tissues
Sodium	Major ion of extracellular fluid Role in water, pH, and electrolyte regulation Role in nerve impulse transmission and muscle contraction
Potassium	Major ion of intracellular fluid Maintains water, electrolyte and pH balances Role in cell membrane transfer and nerve impulse transmission
Chloride	Major ion of extracellular fluid Participates in acid production in the stomach as component of gastric hydrochloric acid Maintains pH balance Aids 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
Calcium	Structural component of bones and teeth Role in cellular processes, muscle contraction, blood clotting, enzyme activation, nerve function
Magnesium	Component of bones Role in cellular energy transfer Role in enzyme, nerve, heart functions, and protein synthesis
Iron	Component of haemoglobin and myoglobin in blood, needed for oxygen transport Role in cellular function and respiration
Iodine	Thyroid hormone production
Chromium	Assists in insulin system for use of blood glucose

Name	Major function
Cobalt	Component of vitamin B_{12}
Copper	Component of many enzymes Many functions – blood and bone formation, production of pigment melanin Aids in utilisation of iron stores Role in neurotransmitter synthesis
Fluoride	Helps prevent tooth decay
Manganese	Part of many essential enzymes Aids in brain function, bone structure, growth, urea synthesis, glucose and lipid metabolism
Molybdenum	Aids in enzymes activity and metabolism
Selenium	Important role in body’s antioxidant defence system as component of key enzymes May help prevent cancer and cardiovascular disease
Zinc	Major role in immune system Required for numerous enzymes involved in growth and repair Involved in sexual maturation Role in taste, smell functions
Fibre Fibre can be divided into insoluble and soluble fibre	Insoluble fibre: adds bulk to stool and thus helps to prevent bowel problems such as bowel cancer, irritable bowel syndrome and diverticulitis Soluble fibre: lowers cholesterol levels, helps manage blood glucose

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Health attributes of yellow/orange vegetables

L J Hedges & C E Lister

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New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

1.1 Background

This report is intended to provide information from which material can be identified for incorporation into one of a series of promotional and educational booklets for the various VegFed 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 yellow/orange vegetables: carrot, corn, capsicum, pumpkin, and melon. Beauregard kumara has also been briefly mentioned. Factors that may influence the nutritional profile of these vegetables, such as agronomical issues, storage, processing and cooking are discussed. Some additional material of general interest has also been included.

"Yellow/orange vegetables" may appear an arbitrary grouping for a product group, but there are good reasons for this on a phytochemical basis. The major phytochemicals in this group of vegetables are the orange/yellow pigments, known collectively as carotenoids. This group comprises structurally similar compounds, though even the minor structural differences between them can result in different biological activities and health effects. The predominant carotenoids covered in this report include β-carotene, α-carotene, lutein/zeaxanthin, and β-cryptoxanthin. Lycopene, the other major carotenoid, has already been extensively covered in the report, *Health attributes of tomatoes* (Hedges and Lister 2005).

The carotenes α- and β-carotene and β-cryptoxanthin, are described as having "provitamin A activity", as they can all be converted into vitamin A (retinol) by the body. How efficiently this is achieved varies between these compounds as a consequence of their different structures. In addition, they can also function as antioxidants, which are believed to provide protection against many chronic diseases, including cardiovascular disease and cancer, as well as other conditions associated with ageing. β-carotene is the most ubiquitous of this family and has been the most extensively studied.

Lutein and zeaxanthin are xanthophylls. Interest in them has focused on a possible role in protecting against eye problems, such as macular degeneration and cataracts. They also have antioxidant effects and research has widened to include their potential effects on chronic diseases.

Because they are lipophilic, carotenoids are best absorbed into the body when consumed in a meal where some sort of oil or fat is present. They are often more bioavailable in cooked foods, rather than raw, as heat breaks down the food matrix, and carotenoids are released from their previously bound states.

1.1.1 *Carrots*

Carrots are a particularly rich source of β-carotene. In addition they contain a much less common phytochemical, falcarinol, a relatively newly-researched compound, which is showing some promising early results in animal-based cancer prevention research.

1.1.2 *Corn*

The carotenoids lutein and zeaxanthin are the carotenoids of most interest in corn. Research examining these compounds has centred particularly upon eye health and the prevention of problems such as macular degeneration and cataracts. Corn also contains a phenolic compound, ferulic acid, which has been shown to have strong antioxidant activity. Yellow corn has more carotenoids than paler corn.

1.1.3 *Capsicum*

All capsicum have excellent levels of vitamin C. Ripe, red peppers, however, contain more than unripe or differently-coloured peppers as well as being best endowed in terms of β-carotene and lutein/zeaxanthin. This notwithstanding, the predominant carotenoid in red capsicums is capsanthin, though this has not yet received much research attention.

1.1.4 *Pumpkins*

There are several types of pumpkin (winter squash) all with differing levels of carotenoids. The more-orange cultivars contain largely carotenes, but the yellower varieties contain higher levels of lutein/zeaxanthin. They are also an excellent source of a lesser known carotenoid, β-cryptoxanthin, which also has been relatively little studied, but may be important for cardiovascular health. Compared with other similarly textured vegetables, pumpkins are relatively low in calories.

1.1.5 *Melons*

Cantaloupe and other orange melons derive their colour from β-carotene. Most studies have found the varieties with more highly coloured flesh to have better antioxidant activity in laboratory assays than their paler relatives, such as honeydew. Watermelon contains the pigment lycopene, which has been extensively studied in relation to tomatoes, with interest focusing on a possible protective role against prostate cancer.

1.1.6 *Orange kumara*

American sweet potato, which has an orange flesh, similar to the Beauregard kumara, has been found to have amongst the highest levels of β-carotene of any fruit or vegetable.

2 *Carrots* (Daucus carota)

2.1 *Introduction*

The humble carrot, almost a staple in many countries, has had a colourful history. The original carrots were believed to be purple and grew in the region that is now Afghanistan about 5000 years ago. These purple carrots were depicted in Ancient Egyptian temple drawings and, along with white varieties, were also known to the ancient Romans, who used them as much for medicinal purposes as culinary. There are also records of red and yellow carrots, but the orange carrot was not known until the 16th century, when it was deliberately developed by Dutch growers to honour of the House of Orange. Interestingly, the older colours are now appearing in new carrot cultivars, with the British retail chain Sainsbury's selling purple orange-centred carrots in 2002. Seed companies are also now offering a rainbow of multi-coloured carrot varieties.

Carrots belong to the Umbelliferae or Apiaceae family, so named because their flowers form umbrella-shaped clusters. This is an illustrious family, which also includes many other plants with aromatic and flavourful qualities, such as parsnips, parsley, dill, celery, coriander, cumin, caraway and anise. Many of these have also been used medicinally as treatments for a wide range of problems.

Carrots are well known for assisting night vision. During World War 2, in order to keep the newly invented radar a secret, it was rumoured that the air crews' night vision had been substantially bolstered by eating larger quantities of carrots.

2.2 *Composition*

A number of factors combine to determine the levels of both core nutrients and other phytochemicals in a food. These include not only the variety/cultivar of the plant, but also issues relating to the agronomy involved – soils, cultivation protocols (irrigation, pest control, use of fertiliser), degree of ripeness 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. This makes it difficult to be exact when comparing levels of these compounds.

These various factors may cause large differences in core nutrient levels, but even greater differences may occur in terms of phytochemicals.

Where data is available, the extent and effect of this variation will be discussed later in this section, under "Factors affecting health benefits".

2.3 Core nutrients

Carrots are an excellent source of vitamin A through the α- and β-carotene they contain (which the body converts into vitamin A). Moderate amounts of vitamin C, sodium, potassium and fibre are also present in carrots.

See Appendix 1 for full data from the New Zealand FOODFiles database.

2.4 Other phytochemicals

The major phytochemicals in carrots are the carotenoids α-carotene, β-carotene, β-cryptoxanthin, lutein, zeaxanthin and falcarinol, a polyacetylene compound. Whilst there are some phenolic compounds (Joseph et al. 2002), they appear to be present only at low levels (Vinson et al. 1998). Flavonoid data for carrots are unavailable on the USDA flavonoid database and are consequently judged to be of minimal importance.

2.4.1 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 human body and are present solely as a result of ingestion from other sources. either the plant source itself or a product from an animal that has consumed that plant source. Often the colours of the carotenoids present in plants are masked by chlorophyll, to the extent that some of the highest levels of carotenoids are found in dark green leafy vegetables, such as kale and spinach.

Carotenoids are lipids and consist of a long chain hydrocarbon molecule with a series of central, conjugated double bonds. (See Appendix III for structural diagrams of the major carotenoids in carrots.) These conjugated (alternating) double bonds not only confer colour, but are also responsible for the compounds' antioxidant properties. These compounds have been found to be 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 both the skin and the macula lutea of the eye against the same 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. They 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 latter, 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, the two compounds are often reported as a combined total.

Carotenoids are fat-soluble compounds and thus are best absorbed in the body if accompanied by some form of oil or fat in the meal. It has also been shown that chopping and cooking assists in releasing carotenoids from the food matrix which also increases their bioavailability.

The carotenoid content of some common yellow/orange fruits and vegetables is shown in Table 1. Interestingly, although cooking increases the carotenoid contents in carrots and corn, particularly for β-cryptoxanthin, and lutein and zeaxanthin, the reverse seems to be the case for pumpkin.

Table 1: Carotenoid content of assorted yellow/orange fruit and vegetables (mcg/100 g) from USDA National Nutrient Database for Standard Reference Release 18, 2005 (USDA 2005).

Food	β-carotene	α-carotene	β-cryptoxanthin	Lycopene	Lutein + zeaxanthin
Apricot	1094	19	104	0	89
Capsicum, red, raw	1624	20	490	308	51
Capsicum, yellow, raw	120	N/A	N/A	N/A	N/A
Carrot, raw	8285	3477	125	1	256
Carrot, boiled	8332	3776	202	0	687
Corn (sweet), raw	52	18	127	0	764
Corn (sweet) boiled	66	23	161	0	967
Melon (cantaloupe)	2020	16	1	0	26
Orange	87	7	116	0	129
Peach	162	0	67	0	91
Persimmon	253	0	1447	159	834
Pumpkin, raw	3100	515	2145	0	1500
Pumpkin, boiled	2096	348	1450	0	1014
Sweet potato, raw	8506	7	0	0	0
Sweet potato. boiled	9444	0	0	0	0

2.4.2 *Falcarinol and falcarindiol*

Carrots also contain compounds called polyacetylenes, of which falcarinol ((9Z)-heptadeca1,9-dien-4,6-diyn-3-ol) has been found to be among the most bioactive and therefore of particular importance in terms of health (Hansen et al. 2003; Zidorn et al. 2005). (See Appendix III for a structural diagram of this compound.) It is also present in other plants of the Apiaceae family including celery and parsnip, as well as in some medicinal herbs of the Araliaceae family, such as ginseng root, *Panax ginseng* (Hansen et al. 2003). For this reason it is also known as panaxynol. It has been postulated by some researchers that various health benefits associated with carrots and attributed to β-carotene, may in fact be due to falcarinol. Similarly, the health effects of ginseng may in part be attributable to this compound (Hansen et al. 2003). Interestingly, although this compound is associated most strongly with carrots, a study identifying and quantifying polyacetylenes in the Apiaceae family showed that both parsnips and celery had higher levels (Zidorn et al. 2005). However, it is likely that carrots are a major source of dietary falcarinol because they are consumed relatively often, and in large amounts.

Falcarinol is sensitive to both heat and light. In the plant it appears to be evenly distributed throughout the whole root.

A number of compounds including eugenin, terpenoids, water soluble phenolics and particularly an isocoumarin called 6-methoxymellein, were initially thought to cause the bitter taste of some carrots (Czepa & Hofmann 2004). However, a recent study identified another polyacetylene, falcarindiol, (Z)-heptadeca-1, 9-dien-4,6-diyn-3,8-diol), as the major contributor to the bitter taste in carrots.

The upper end of the phloem was deemed to be more bitter than the lower end (and contained higher concentrations of falcarindiol) and removing the peel, as well as green and dark parts, removed much of the bitter taste (Czepa & Hofmann 2004). Heat processing in this study did not affect the taste components of the compound.

2.5 Health benefits

2.5.1 Core nutrients

The roles of core nutrients are outlined in Table 4 in Appendix II.

2.6 Phytochemicals

2.6.1 Carotenoids

α- and β-carotene differ only very slightly in terms of structure. They are very commonly occurring carotenoids and are 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, α-carotene and β-cryptoxanthin each about 1/12.

Note: Although there is some controversy internationally regarding 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. Epidemiological studies have demonstrated that high intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing. Carotenoid-rich foods have also 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 also possess 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 4 studies, 5 studies found no association and 7 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, found that the risk of developing lung cancer actually increased in those taking supplements. However, no such effect has been found in studies where the β-carotene was consumed as part of a food as opposed to a supplement form, where the compound has been isolated and concentrated. Mixed results have also been reported from studies relating to prostate and colorectal cancer.

Similarly, there have been mixed results regarding the effect of dietary β-carotene on cardiovascular disease. 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 hypothesized that β-carotene, which itself is carried in LDL, might help prevent this oxidation, as a number of *in vitro* studies had shown it to be capable of scavenging potentially damaging radicals. However, whilst some research has shown higher plasma levels of carotenoids to be associated with better vascular health and lower cardiovascular disease risk, other studies have shown no effect (Higdon 2005 ; (Cooper et al. 1999). Further, some recent studies have produced contradictory results regarding the ability of β-carotene to stabilise LDL against oxidation (Cooper et al. 1999).

Carotemia is a condition arising from excessive intake of carotenoids in which high levels of β-carotene stored in the skin give it a yellowish appearance. The condition is harmless and disappears with lower consumption of carotenoid-rich foods.

α-carotene

α-carotene is less well-known and studied than β-carotene, but it has shown some promising results. Some studies have shown α-carotene to be even more effective than β-carotene at inhibiting cancer cells.

β-cryptoxanthin

This carotenoid is orange-yellow in colour and is found in various fruits and vegetables, including pumpkins. There are indications that it may play an important role in cardiac health.

Lutein and zeaxanthin

These two carotenoids are often grouped together as they have very similar structure and functions (see Appendix III for structure) and it is only relatively recently, with technology such as high performance liquid chromatography (HPLC), that it has been possible to differentiate between the two individual compounds. Lutein and zeaxanthin are essential for maintaining proper vision and may help to prevent macular degeneration and cataracts. They may also help reduce the risk of certain types of cancer. These pigments will be covered in greater detail in Section 3.

Falcarinol

Scientific research has only relatively recently focused on falcarinol. However, in the few studies undertaken to date it shows some promise in selected areas. As discussed earlier, whilst there are a number of polyacetylenes present in carrots, falcarinol has been shown to exhibit the most bioactivity, with pronounced cytotoxic effects against human tumor cells (Hansen et al. 2003; Brandt et al. 2004; Zidorn et al. 2005). At low concentrations, as would be available through normal dietary intake, falcarinol delayed or hindered the development of large, precancerous lesions and tumours in rats (Kobaek-Larsen et al. 2005). Together, these studies suggest that, besides the better-known carotenoids, falcarinol may contribute significantly to the health-promoting properties of carrots.

Falcarinol is a natural pesticide at high concentrations (Kobaek-Larsen et al. 2005) and polyacetylenes in general have potent antifungal and antibacterial properties (Zidorn et al. 2005). These attributes do not yet appear to have been investigated in terms of human health. Although falcarinol has been shown to be toxic at extremely high concentrations, to consume a fatal dose an estimated 400 kg carrots would have to be consumed over a short time frame (BBC News 2005). It is not unusual for plant constituents that have beneficial effects in normal quantities, to have detrimental effects in extremely high doses. The chemoprotective compound, sulphoraphane, found in broccoli is another such example. It would be almost humanly impossible to consume toxic quantities of these sorts of compounds as foods, or accidentally as part of a normal diet.

Phenolic compounds

The only flavonoid listed for carrots in the USDA flavonoid database is a small amount of quercetin. According to Joseph et al. (2002), carrots also contain apigenin and some phenolic acids, but Vinson et al. (1998) reported that carrots contained only low levels of phenolics.

2.7 Factors affecting health benefits

As explained in Section 2.2 above, a range of factors impact upon the composition of a food and thus the health benefits that it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

2.7.1 Cultivar

Differences in the levels of some or all of the major bioactive compounds have been demonstrated in different cultivars of carrots in a number of studies (Hansen et al. 2003; Czepa & Hofmann 2004; Kidmose et al. 2004). Variation also occurred in some of the compounds, but not the major bioactives, in relation to the size of the root (Kidmose et al. 2004).

2.7.2 Storage and processing

Kidmose et al (2004) found that the carotenoid content appeared to be stable in carrots that had been stored raw and refrigerated for 4 months and those that had been raw frozen at -24° C for 4 months. It was suggested that the 4-month time frame was possibly not long enough for the enzyme responsible for carotenoid degradation to show an effect. Nor was there any significant difference in carotenoid levels between raw-frozen and steam-blanched-then-frozen carrots. The authors postulated that this was because the steam blanching process was relatively short and mild and thus did not markedly degrade the carotenoids, although it did make them more extractable. (Pre-freezing blanching is a common industrial process that aims to prevent the development of an off-taste brought about by the release of fatty acids (Hansen et al. 2003)).

In contrast to carotenoid levels, Kidmose et al. (2004) found polyacetylene levels to be significantly higher in refrigerated carrots than in frozen carrots. The authors suggested that this was the result either of polyacetylene production or slower degradation of these compounds. In this study, steam blanching resulted in a 50% loss of falcarinol, but after 4 months frozen storage was nonetheless higher in carrots that had been blanched before freezing than in those that had been raw frozen. However, Hansen et al. (2003) measured a 35% falcarinol loss through blanching, and observed similar falcarinol losses in both frozen blanched carrots and raw frozen carrots. Interestingly, falcarinol content in refrigerated carrots was relatively stable for 1 month post-harvest, after which there was a steady decline.

2.7.3 Growing conditions

Carrots have been found to contain an antifreeze protein which has been shown to positively affect storage performance. It was found that carrots grown in temperatures of less than 6°C accumulated higher levels of this protein and subsequently had less electrolyte leakage from cells, slightly higher dry matter and less fungal infestation than carrots grown in warmer temperatures (Galindo et al. 2004). Kidmose et al. (2004) also found that variation also occurred between growing locations.

2.7.4 *Bioavailability*

The area of bioavailability broadly addresses the issue of how well a compound is absorbed so that it can be utilised by the body. It involves the degree and rate at which a substance is absorbed into a living system or is 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.

2.7.5 *Carotenoids*

The large difference between the number 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 (green, leafy vegetables)
- dissolved in oil droplets in chromoplasts, which are readily extracted during digestion (mango, papaya, pumpkin and sweetpotato) (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 (Borel 2003). 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 (Borel et al. 1996).

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 impacts upon 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 (Yeum & Russell 2002). The presence of soluble fibre, in the form of citrus pectin, has been shown to reduce the increase in β-carotene absorption following 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 (Yeum & Russell 2002).

High bioavailability

Formulated carotenoids in water-dispersible beadlets (natural or synthetic)

Carotenoids – oil form (natural or synthetic)

Fruits (peach, apricot, melon)

Tubers (sweetpotato, 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)

2.7.6 Falcarinol

Further work needs to be done regarding the bioavailability of falcarinol as well as its possible direct effect upon the cells and tissues present in the human gut. That it is likely to be bioavailable is supported by a rat study showing rapid absorption by a closely related compound, panaxytriol (Hansen et al. 2003).

2.7.7 Tips and quotes

- "Eating a carrot a day is like signing a life insurance policy" – Irena Chalmers in The Great Food Almanac.
- Carrots should be eaten both raw and cooked. Whilst some nutrients may be lost in the cooking process, others are made more bioavailable. Including some form of oil in the meal will assist in absorbing the carotenoids.
- Providing they are stored appropriately, carrots should continue to provide good levels of nutrients for a reasonable length of time.

3 *Sweetcorn* (Zea mays)

3.1 Introduction

Sweetcorn belongs to the grass family and is the same species as field or dent corn (*Zea mays*). However, field corn is grown primarily as animal fodder or for cooking oil, whereas sweetcorn is produced primarily for human consumption. Field corn was purportedly grown in North America before 200 BC (Schultheis 1994) but sweetcorn is relatively new, arising from a mutation believed to have taken place in the 19th century (Peet 2003). This mutation at the sugary locus causes the endosperm in the kernel to accumulate roughly two times more sugar than field corn. It also has a thinner pericarp, making it more tender (Peet 2003). Once harvested though, the sugars in the kernel convert rapidly to starch, leading to a floury taste.

A number of genes affect sweetness in corn (oregonstate.edu 2002). These are recessive mutants of the starchy gene found in field corn (*Su*) and their modifiers, and other genes. Normal sweetcorn has the recessive mutant of field corn (*su*). Modifiers and other genes include the sugary-extender gene (*se*) and the supersweet or shrunken gene (*sh2*). These make up three major genetic classes of importance in commercial production:

- Normal sugary (*su*) corn is the standard corn grown for processing and much of the fresh market.
- Sugary-enhanced (*se*) corn results in slightly increased sugar levels. Kernels are very tender with good "corn" flavour.
- Supersweet or extra sweet (*sh2*) corn produces kernels with two to three times the complex sugars of the standard corn varieties. The texture is crispy rather than creamy as with the standard and enhanced varieties. Fresh market shelf life is extended because of the slower conversion of sugars to starch after harvest. Seed kernels are smaller, lighter in weight and shrunken in appearance (giving the gene the name "shrunken").

The three genetic classes mentioned above are categorised into six major sugar-mutant types and these may be represented by yellow, white, or bi-colour varieties. Other categories exist, such as decoratively coloured, or "Indian", corn, but are not of commercial importance. Sweetcorn comes in variations of yellow and white and is sometimes bicoloured. There is no relationship between colour and sweetness, but, as will be discussed below, there is some correlation between colour and nutritional value.

3.1.1 Composition

See Section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under "Factors affecting health benefits".

3.1.2 Core nutrients

Sweetcorn contains many nutrients including vitamin C (ascorbic acid), folate, zinc, iron, thiamine, riboflavin, selenium and potassium along with fibre, starch and protein (Athar et al. 2004). Interestingly, corn has more protein than many vegetables (Joseph et al. 2002). There appear to be few data that indicate a distinction between sweet and supersweetcorn.

See Appendix I for full data from the New Zealand FOODFiles database.

3.1.3 Other phytochemicals

The most important phytochemicals identified to date in corn include the xanthophylls, lutein, zeaxanthin and cryptoxanthin, the carotenes α- and β-carotene, and phenolic compounds, primarily ferulic acid.

3.1.4 Carotenes

The main carotenes present in sweetcorn are β-carotene and α-carotene. (See Appendix III for structural diagrams of these compounds.) Corn also contains a variety of lesser known and less abundant carotenes including ζ-carotene, phytoene, phytofluene, α-zeacarotene and β-zeacarotene.

Xanthophylls (lutein and zeaxanthin)

Of the phytochemicals found in corn, those of most interest are lutein and zeaxanthin. (See Appendix III for structural diagrams of these compounds.) Esters of these compounds may also be present. Other xanthophylls present in sweetcorn include α-cryptoxanthin, β-cryptoxanthin, antheraxanthin, violaxanthin and neoxanthin. Some plants have a special biosynthetic capacity and produce carotenoids found almost exclusively in that genus or even species, although sometimes they have a slightly wider distribution. *Zea mays,* which contains zeinoxanthin, is one such species. Zeinoxanthin or α-cryptoxanthin, is the monohydroxy derivative of α-carotene. Other than in sweetcorn, it is only found in citrus, yellow peppers and squash (Gross 1991).

Levels of lutein and zeaxanthin in some common yellow/orange foods have been given in Table 1. Because of their similarity (and hence the difficulty in separating them by standard HPLC methods) the two compounds are often reported as a combined total, as is the case in the USDA carotenoid database used for Table 1. Corn does not contain extraordinarily high levels of lutein and zeaxanthin in comparison with some other foods, but it should be borne in mind that corn products are eaten with reasonable frequency in many households and this makes it an important dietary source of these compounds. It is interesting to note that boiled corn has higher levels of these compounds than raw corn.

In contrast to the combined lutein/zeaxanthin levels, which do not appear particularly high in corn, the level of zeaxanthin does appear to be higher than in most other fruit or vegetables.

3.1.5 Phenolic compounds

Phenolic compounds are a large group of secondary plant products that differ in chemical structure and reactivity. They are present in most, if not all, plants. The chemical structures range from quite simple compounds, like caffeic acid, to highly polymerised substances, like tannins. Their contribution to the pigmentation of plants is well recognised, although not all phenolics are coloured. There are numerous different groups of phenolics, but the most common phenolics found in foods generally belong to phenolic acids, flavonoids, lignans, stilbenes, coumarins and tannins (Harborne 1993). They are of interest primarily because of their radical scavenging and antioxidant activities, which are determined by their structure, particularly the number and configuration of H-donating hydroxyl groups (Soobrattee et al. 2005).

Vinson et al. (1998) reported that corn had a total phenolic content of 4.9 µmol/g FW (or 1.42 mg/g) and ranked fifth of 23 vegetables examined. In another study the total free phenolic content of raw sweetcorn was 250 µg/g, while the bound phenolic content was 470 µg/g (Dewanto et al. 2002).

Most of the phenolics in corn appear to be phenolic acids, predominantly ferulic acid, with smaller amounts of *p*-coumaric and syringic acids. In addition, isoquercitrin and quercetin 3-glucoside may be present (Harborne 1967).

Ferulic acid, 4-hydroxy-3-methoxy-cinnamic acid, is a phenolic compound present in many plants including rice, wheat, barley, oat, tomatoes, asparagus, peas and citrus fruits (Graf 1992). Its structure (see Appendix III), a phenolic nucleus with an extended conjugated side chain, confers significant antioxidant potential, enabling it to scavenge free radicals and suppress UV radiation-induced oxidative reactions.

In vegetables, most of the phenolics exist in free or soluble conjugate forms as glycosides (Vinson et al. 1998). In grains, however, phytochemicals exist in a combination of three forms: free, soluble conjugate, and insoluble bound forms, with a significant proportion in the latter form. A study examining the antioxidant activity of grains found that, of those studied, corn had the highest antioxidant activity and that bound phytochemicals were the major contributors to this activity (Adom & Liu 2002). About 74% of the phenolics were bound and about 87% of antioxidant activity came from bound compounds. Sosulski et al. (1982) also reported high levels of insoluble-bound phenolic acids in corn, constituting 69% of the total phenolic content. It is difficult to determine how relevant this is to sweetcorn because maturity has an impact upon phytochemical levels and sweetcorn is always eaten at an immature stage, in contrast to the mature grains examined in this study. Dewanto et al. (2002) researched the antioxidant activity of sweetcorn. They looked closely at the ferulic acid content and established that, in the raw state, by far the greatest amount was in a bound form. They also found that heat treatment released ferulic acid from the bound form to free ferulic acid and that antioxidant activity correspondingly increased.

3.2 Health benefits of sweetcorn

3.2.1 Core nutrients

The roles of core nutrients are outlined in Table 4 in Appendix II.

3.2.2 Other phytochemicals

The health benefits of α- and β-carotene have already been discussed in Section 2 above. The following sections focus primarily on the antioxidant benefits and health effects of lutein and zeaxanthin.

Antioxidant activity of sweetcorn

Several studies have examined the antioxidant activity of sweetcorn/maize, among other vegetables. Cao et al. (1996) gave corn an antioxidant score of 7.2 (based on ORAC scores with three different radicals), ranking it ninth of the 22 vegetables examined. On a fresh weight basis, corn ranked 13th in one study of 23 vegetables (Vinson et al. 1998). Halvorsen et al. (2002) reported an antioxidant activity of 0.19 mmol/100 g as measured by the FRAP assay; this value was relatively low compared to many other common vegetables (25th out of 32). The ORAC (oxygen radical absorbance capacity) of sweetcorn has been reported at 450 ORAC units, which is about the middle of the range for vegetables (Natural Food Hub 2003).

Carotenoids as antioxidants

Conjugated double bonds are highly effective in quenching singlet oxygen, and both lutein and zeaxanthin have the same high number of double bonds. However, zeaxanthin has an extra conjugated double bond. This conjugated double bond, compared with lutein’s allylic hydroxyl end group double bond, is potentially a more effective oxygen quencher (and hence, antioxidant).

Eye diseases

To determine the biological roles of a compound, scientists frequently consider its abundance and distribution in body tissues, as well as its variation in abundance across population groups. In a review of the roles of lutein and zeaxanthin in human health, Granado et al. (2003) noted that a number of studies had shown them to be selectively accumulated in different parts of the eye, where they were by far the most abundant of the major carotenoids present. Lutein and zeaxanthin are especially concentrated at the centre of the retina in the eye (the macula) and in fact are often referred to as macular pigments. These high concentrations in the eye, plus the presence of certain proteins specific to binding these compounds, has led to the suggestion that they may be important in protecting against age-related eye problems, particularly macular degeneration and the formation of cataracts. It has also been hypothesised that lutein and zeaxanthin could slow the progression of these diseases as well as the group of degenerative retinal diseases, retinitis pigmentosa.

Mares-Perlman et al. (2002) summarised a number of studies linking light exposure to eye diseases. Because these carotenoids absorb blue light, it was suggested that they protect the retina from photochemical damage that could occur from light at these wavelengths. Exposure to light has been found to increase the levels of free radicals in the lens and retina (Dayhaw-Barker 1986, cited in Mares-Perlmann et al. 2002) and exposure of the retina to light has been postulated as a cause of macular degeneration (Borges et al. 1990, cited in Mares-Perlmann et al. 2002).

Within the macula there is a distinct pattern in the distribution of these xanthophylls. Zeaxanthin is most concentrated in the inner macula, but lutein predominates further from the centre. This distribution suggests a possible function for lutein in protecting the rods that are concentrated in the peripheral retina, and for zeaxanthin in protecting the cones that are concentrated in the central retina (Granado et al. 2003; Mares-Perlman et al. 2002).

It has been shown that intake of these carotenoids increases their levels in macular tissue (Hammond et al. 1997; Landrum et al. 1997, cited in Mares-Perlman et al. 2002) and serum (Olmedilla et al. 2002), although variations in individual responses have been noted.

It appears plausible that lutein and zeaxanthin play a protective role in the eye, but there is a scarcity of data. This is partly because it is a relatively new field of research and partly because there is a difficulty in carrying out this research using cells or animals. Only primate eyes have a macula, and therefore the usual laboratory animals, such as rats, cannot be used. In one study, in which monkeys were fed diets lacking plant pigments, changes to the retina resembling the ocular degenerative changes in humans occured over several years (Malinow et al. 1980, cited in Mares-Perlman et al. 2002). Another study found an inverse relation between the level of zeaxanthin in quail retina (quails have a macula similar to that of primates) and light-induced retinal cell death (Dorey et al. 1997, cited in Mares-Perlman et al. 2002).

Some epidemiological evidence does suggest that lutein and zeaxanthin protect against macular degeneration and this is summarised below (from Sies & Stahl 2003 and Mares-Perlman et al. 2002). Lower risk of this disease has been found in conjunction with consumption of foods rich in lutein and zeaxanthin (Goldberg et al. 1988); higher overall levels of lutein and zeaxanthin in the diet (Mares-Perlman et al. 2002; Seddon et al. 1994); higher levels of lutein and zeaxanthin in the blood (Eye Disease Case-Control Study Group 1992); and higher levels of lutein and zeaxanthin in the retina (Bone et al. 2000; Beatty et al. 2001).

However, these relationships were not observed in other studies, or were only observed in subgroups of the study population (Granado et al. 2003; Mares-Perlman et al. 2002).

Mares-Perlman et al. (2002) describe findings with respect to the relationship between lutein and zeaxanthin and reducing cataract risk as “somewhat consistent”. Two studies showed a higher incidence of cataracts in those in the lowest quintile of lutein and zeaxanthin intake compared with the highest, and three prospective studies found that those in the highest quintiles had a 20–50% lower risk of experiencing cataract problems.

Cancer

Although concentrations are generally highest in ocular tissue, a number of studies have established the presence of lutein and zeaxanthin in serum and body tissues. The fact of their antioxidant activity has led to speculation that higher consumption of these chemicals will lead to higher levels in body tissues, and that this may lower the risk of chronic disease. It is possible that, along with other carotenoids with antioxidant activity, lutein, which is more widely dispersed in the body, may confer protection against diseases such as cancer and cardiovascular disease as well as positively affecting immune function.

One specific mechanism of cancer chemoprevention is the ability to induce detoxifying enzymes (Phase I and/or Phase II enzymes in liver and/or other organs (Talalay et al. 1995)). Interestingly, corn has shown Phase II enzyme-inducing activity (Wettasinghe et al. 2002). Few vegetables, apart from Brassicas, have this ability. Aqueous extracts of corn induced quinine reductase activity, an important Phase II enzyme, at rates of about 13-fold more than for kale.

Studies have shown that several carotenoids, both individually and in concert with others, can scavenge free radicals, be antimutagenic, prevent tumour development and assist immune function. Iannone et al. (1998) and Sujak et al. (1999) have shown that *in vitro*, lutein and β-carotene quench peroxyl radicals and exhibit antioxidant activity (cited in Mares-Perlman et al. 2002). It has also been found that carotenoids in combination appear to act synergistically, producing a greater effect than when acting alone. Stahl et al. (1998) found that lutein in combination with lycopene produced the greatest such effect. Synergistic effects such as these emphasise the advantages of foods, which contain a whole array of phytochemicals, over supplements, which contain a more limited number of components.

Two studies have considered the anticarcinogenic effects of lutein. It has been shown to counteract known mutagens, 1-nitropyrene and aflatoxin B1 (Gonzalez de Mejia et al. 1997) and in addition may stimulate certain protective genes (Park et al. 1998). Epidemiological research regarding the influence of these particular carotenoids on site specific cancers is relatively new and sparse. The most promising areas of research would appear to be in relation to skin cancer, in combination with other carotenoids (Slattery et al. 2000; Stahl et al. 2000) and breast cancer (Park et al. 1998; Sumantran et al. 2000; Freudenheim et al. 1996; Dorgan et al. 1998; Zhang et al. 1999; Toniolo et al. 2001, cited in Mares-Perlman et al. 2002). However, results are not clear, with some studies finding no associations and others reporting only inconsistent results. As is often the case in studies of fruit and vegetable compounds, it is uncertain whether the benefits are the result of the compounds themselves, or of some other component in the fruits and vegetables, whose role in human health is yet to be recognised.

Cardiovascular disease

As already discussed, a number of studies have established that lutein and other carotenoids have antioxidant properties. This has implications not only for cancer but also for the development of cardiovascular disease (CVD). Studies have found high serum levels of lutein and zeaxanthin to be associated with a reduced risk of coronary heart disease (Dwyer et al 2001; Irribaren et al. 1997). Additionally, the consumption of green leafy vegetables (which also contain lutein and zeaxanthin) was associated with a reduced incidence of stroke in the Nurse's Health and Health Professionals Follow-up study (Joshipura et al. 1999).

Immune function

There is a possibility that these xanthophylls may have immune-enhancing properties. One study showed an enhanced immune effect in cats, but there have been no human or epidemiological studies to investigate this further (Kim et al. 2000, cited in Mares-Perlman et al. 2002).

3.3 *Factors affecting health benefits*

As discussed in Section 2.2 above, a range of factors impact upon the composition of a food and thus the health benefits it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

In addition, as mentioned earlier, in many databases all xanthophylls are combined to give only a total xanthophyll content. This should be borne in mind when comparing data.

3.3.1 *Variety/cultivar*

Hundreds of varieties of sweetcorn exist and information regarding the relative quantities of phytochemicals in each variety is very limited. One study by Lee et al. (1981) examining the provitamin A activity of several cultivars of sweetcorn, illustrates how nutrient levels may vary between cultivars (Table 2).

Table 2: Major provitamin A carotenoids (μg/100 g) in four cultivars of sweetcorn (adapted from Lee et al. 1981).

Carotenoid	Jubilee	Iosweet	70-2499	Stylpak
Hydrocarbon	89.0	41.4	45.0	45.6
Monohydroxy	98.5	92.7	101.6	89.5
Polyhydroxy	58.5	19.6	35.0	51.5
α-carotene	24.6	5.0	8.4	8.1
β-carotene	9.8	5.3	14.0	8.4
β-zeacarotene	15.7	16.8	14.5	17.0
γ-carotene	15.1	8.9	7.5	10.6
Zeinoxanthin	79.2	66.0	77.2	68.9
β-cryptoxanthin	18.9	18.3	15.1	18.4

A major study by Kurilich & Juvic (1999) included 44 genotypes chosen for a number of variables (each homozygous for one of four different endosperm carbohydrate mutations). Amongst these variables was that of kernel pigmentation – there is a recognised association between colour and carotenoid concentration. Of the genotypes selected on the basis of colour, it was established that the dark yellow kernels had the greatest total carotenoid content, followed by light yellow, orange and pale yellow. Those identified as having higher levels of carotenoids were largely, though not exclusively, *sh2* or supersweet lines. Interestingly, some of the lowest levels also belonged to this line.

Agronomic effects

Depending on location and variety, corn matures at around 18-24 days after pollination (Kurilich & Kuvik 1999). It is recommended that harvesting is carried out in the early morning or at night, as at this time the corn is cool and less additional cooling is needed to reduce the temperature to the optimal storage temperature of around 0°C (and relative humidity of around 95%). Rapid cooling to this temperature and maintaining it through transportation and appropriate storage is important in preserving sweetness and texture. It is also recommended that the cobs are closely trimmed, as the kernels lose moisture if long flags and shanks remain (Peet 2003).

Provitamin A carotenoids in raw corn from different geographical areas ranged from 0.6 to 2.1 μg/g FW and were higher in autumn varieties than in spring varieties (Klein & Perry 1982).

In a 3-year trial of organically and conventionally grown sweetcorn, no difference was found in the vitamin C or E content of kernels grown using either method in any year (Warman & Havard 1998). There were, however, some significant differences from year to year, with the same trends for both organically and conventionally grown crops.

Maturity

When carotenoid levels were tested at 18, 21, 24 and 27 days after pollination, Kurilich and Juvic (1999) found that the concentration of some, but not all, depended on the state of maturity. Their results indicated that β-cryptoxanthin and lutein levels tended to increase with age, but that there was no consistent change in zeaxanthin, α-carotene or β-carotene levels. There were substantial increases in γ-tocopherol as kernels matured (Kurilich & Juvik 1999).

Warman & Harvard (1998) examined the effect of harvest date on vitamin C content for a single cultivar (Sunnyvee). A large difference in ascorbic acid content of the kernels was observed from one week to the next (varying from 55 to 300 mg/kg FW).

3.4 Bioavailability

3.4.1 Carotenoids

A discussion of the general bioavailability of carotenoid compounds has already been covered in Section 2.4.2.

3.4.2 Phenolic compounds

There have been a few studies on the bioavailability of hydroxycinnamates, such as ferulic acid, although not specifically in sweetcorn. In general, results suggest that ferulic acid is more bioavailable than most other individual dietary flavonoids and phenolics so far studied (Bourne et al. 2000).

Ferulic acid is widely present in cereals. However, the cereal matrix appears to severely limit its bioavailability, at least for wheat (Adam et al. 2002). The inherently low bioavailability of ferulic acid in cereals probably reflects ferulic acid's association with the fibre fraction through cross-linking with arabinoxylans and lignins. Zhao et al. (2003) found the form of ferulic acid in the plant/diet affected its absorptivity, its absorption site, and its fate in the gastrointestinal tract. They also determined that microbial degradation in the gut may play an important role in bioavailability and the amount of microbial degradation depended on the form of ferulic acid. How ferulic acid bioavailability may be affected in fresh sweetcorn, especially once it has been cooked, remains to be seen. Since Dewanto et al. (2002) found that heat treatment reduced the amount of the bound form of ferulic acid and that antioxidant activity correspondingly increased, it is possible that bioavailability may also be enhanced by processing. This is similar to the situation with lycopene in tomatoes.

3.4.3 Tips and trivia

- Lutein and zeaxanthin are the most important compounds in corn in terms of potential health benefits. Although lutein is present in greater amounts, it is a ubiquitous compound, occurring in many fruits and vegetables and in reasonable amounts. Zeaxanthin, in contrast, is present in far fewer food sources and usually in much smaller amounts.

- Dietary sunglasses? Lutein and zeaxanthin appear to have unique functions in the macular luteum of the eye, where they may confer protection against oxidative damage from light. It is possible that they may also protect against other chronic diseases. Is corn an ear that helps you see?
- The average ear of corn has 800 kernels.

4 *Capsicum* (Capsicum annuum)

4.1 *Introduction*

Capsicums belong to the Solanaceae family, which also includes potatoes, tomatoes, petunias and deadly nightshade. Although there are about 26 species of this ”pepper”, most of these are wild, with cultivated varieties belonging to one of the five major groups:

- *Capsicum annuum*, including the Bell and Jalapeno varieties, a mild and sweet form, from which paprika is produced,
- *C. frutescans* including the Tabasco variety,
- *C. chinense*, including the Habanero variety,
- *C. baccatum*, including the Aji varieties
- C*. pubescans* including the Manzano variety.

In New Zealand, the most common of these are *C. annuum* and *C. frutescens*, although the diversification of culinary tastes and interest from gardeners has led to the availability of other varieties for niche uses both for food and as ornamental plants. However*, C. annuum* is the primary focus in this group for this report, as it is by far the most commonly grown commercially.

As the name suggests, *C. annuum* is an annual plant, grown in temperate regions and used mostly as a vegetable. The latter four varieties are grown in hotter regions as perennials – but can be grown in New Zealand where they tend to be cultivated as annuals – and are used more as spices. Capsicum fruit come in an assortment of colours, including red, orange, yellow and purplish black, and can be a multitude of shapes and sizes. In terms of taste, the plants originating from hotter regions seem to produce fruit with a hotter taste. It is also sometimes said that the smaller and thinner the pepper, the hotter it is.

It is generally believed that the greatest “heat” is in the seeds, though some sources state that it is contained in the “placenta” of the fruit, the tissue that attaches the seeds to the pod (Anon 2005). Although the degree of pungency in the fruit is sometimes erroneously linked to colour, “heat” in fact depends largely on the level of capsaicin, a phenolic substance (trans-8-methyl-N-vanillyl-6-nonemamide) not associated with colour. The pharma-cological and toxicological properties of this substance have been investigated in a number of experimental and clinical investigations (Suhr 2002). Naturally, since levels of this compound determine pungency, the *C. annuum* cultivars have lower concentrations than do fruits of *C. frutescens*, but do contain a similar compound.

Most popular information regarding the health effects of capsicum relate to hot or chilli peppers, with uses ranging from aiding digestion and circulation to alleviating pain, reducing flatulence and treating dropsy (Chevallier 1996). It has also been postulated that capsicums may be beneficial for cardiac health by preventing platelet aggregation (Wang et al., cited in Suhr 2002).

4.2 Composition

See Section 2.2 for a fuller explanation regarding factors that impact upon the composition of a food and thus the health benefits it may deliver.

A number of differently coloured capsicums are now available and this means that they contain different phytochemicals in the form of these pigments. Like other fruit, capsicums change colour as they ripen. Whether they end up red, yellow, orange or black, they all start off green.

4.2.1 Core nutrients

Capsicums are an exceptional source of vitamin C, with much more than the traditional vitamin C source, oranges. The ripe fruit also contain significantly more than unripe (170 mg vs 100 mg per 100 g fresh) (Athar et al. 2003).

See Appendix I for detailed data (including information on different cultivars) from the New Zealand database FOODfiles.

4.2.2 Other phytochemicals

The major phytochemicals present in capsicums include α-carotene, β-carotene, β-cryptoxanthin, lutein and zeaxanthin, lycopene, capsanthin, chlorophyll (green capsicum), capsaicin (hot varieties only), small amounts of the flavonoids quercetin and luteolin (USDA 2005, Marin et al. 2004) and other phenolic compounds known collectively as hydroxycinnamic acid derivatives (Marin et al. 2004). “Bell peppers” (maturity and cultivar unknown) posses only moderate levels of phenolic compounds according to Vinson et al. (1998).

4.3 Health benefits

4.3.1 Core nutrients

The roles of core nutrients are outlined in Table 4 in Appendix II.

4.3.2 *Other phytochemicals*

Carotenoids

Information regarding the phytochemical composition of yellow and orange capsicum cultivars is sparse. A study of β-carotene and total carotenoid content in an assortment of differently coloured capsicum fruit showed, surprisingly, that the two yellow cultivars contained not only very low levels of β-carotene, but also low levels of total carotenoids. The two orange varieties contained higher levels, but both were well below the average of those in red cultivars (Wall et al. 2001). The major carotenoids in yellow capsicums are β-carotene and lutein/zeaxanthin (Lee et al. 2005). These compounds are also present in red capsicum, and at generally much higher levels (Wall et al. 2001). The health benefits of these are discussed in general terms in Section 2.3.

As mentioned above, although they too contain α- and β-carotene, in fully mature red, ripe capsicum, capsanthin is the major carotenoid. Because this is a relatively uncommon compound and is relatively specific to capsicum species, there has been little research concerned specifically with capsanthin. However, a Japanese study investigating capsanthin isolated from paprika powder showed strong anti-tumour activity in an *in vitro* and *in vivo* mouse study (Maoka et al. 2001).

Capsaicin

The pharmacological and toxicological properties of capsaicin, the compound responsible for the heat of chilli-type peppers, have been investigated in a few experimental and clinical investigations (Suhr, 2002). Naturally, since levels of this compound determine pungency, *C. annuum* cultivars have lower concentrations than do fruits of *C. frutescens.* Instead *C. annuum* cultivars have a capsiate hydroderivative compound which shares some of capsaicin's biological activities (Sancho et al. 2002). Much research has focused on the use of capsaicin to treat pain and inflammation, and there is at least one pharmaceutical preparation for this purpose.

Polyphenols

Many phenolics display antioxidant activity and thus may help reduce the risk of heart disease and certain types of cancer, but they may also have other health benefits. Capsicums contain the flavonoids quercetin and luteolin. Quercetin is the most widely studied as it is the predominant flavonoid found in foods (Cook & Samman 1996). It is most abundant in onions, kale, tea, apple skin, berries, broccoli, and lettuce.

Quercetin is a very strong antioxidant but it has also been found to reduce inflammation and inhibit the growth of certain cancer cells, as well as causing malignant cells to self-destruct, through a process called apoptosis (Joseph et al. 2002). Quercetin is also hypothesised to be effective in preventing atherosclerosis and thrombosis by protecting low density lipoproteins (LDL) against oxidation, as well as by lowering the cytotoxicity of oxidised LDL and platelet aggregation (Manach et al. 1998).

Chorophyll

Relatively little is known about the health effects of chlorophyll, the primary photosynthetic pigment and responsible for the green colour in plants and many algae. Some research suggests that it may be important in protecting against some forms of cancer, as, it is postulated, the chlorophyll binds to the mutant DNA and prevents it proliferating. A recent study suggests that chlorophyll has weak Phase II enzyme inducer potency, and although its activity is relatively weak compared with some other phytochemicals, because of its concentration in many of the plants we eat it may be responsible for some of the protective effects that have been observed with diets that are rich in green vegetables (Fahey et al. 2005).

4.4 *Factors affecting health benefits*

As discussed in Section 2.2, a range of factors impact upon the composition of a food and thus the health benefits it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

4.4.1 *Cultivar*

Several studies have shown phytochemical levels to vary considerably between cultivars. Lee et al. (2005) investigated differences in β-carotene, lutein, zeaxanthin, quercetin and luteolin content and found colour-related variations as well as differences between the *C. annuum* and *C. chinense* samples. Howard et al. (1994) found that provitamin A activity ranged from 27.3 to 501.9 retinol equivalents (RE/100g) and that vitamin C ranged from 76.1 to 243.1 mg/100g in assorted mature cultivars. Wall et al. (2001), Russo & Howard (2002) and Lee et al. (2005) all reported a wide variation for both β-carotene and total carotenoid levels. The latter study also looked at levels of the other major carotenoids in capsicum and found a similarly wide range.

4.4.2 *Growing conditions*

A study comparing individual carotenoids found significantly higher levels in glasshouse-grown capsicums than in those grown in the field (Russo & Howard 2002). Wall et al. (2001) also observed substantial differences in β-carotene and total carotenoid levels in the same cultivars grown in the same location over two successive seasons. It was postulated that this was the result of different climatic conditions. Whilst temperatures were similar during the growth period of both seasons, they averaged 3°C cooler in the two months prior to harvest when the fruit were ripening and accumulating pigment, and this resulted in lower levels of carotenoids. Lee et al. (2005) also reported variations between two different growing locations.

4.4.3 *Maturity*

The maturity of capsicums has been shown to strongly influence phytochemical concentrations. Howard et al. (1994) found that both vitamin C and provitamin A activity increased with maturity in all cultivars. Phenolic compounds such as flavonoids and hydroxycinnamic acid derivatives were generally at much higher concentrations in immature and unripe peppers than in mature red peppers, which had higher concentrations of vitamin C and carotenoids. Marin et al. (2004) found four times the total carotenoid levels in mature red peppers than in immature green fruit, with xanthophyll and capsanthin the predominant carotenoids. Mature red peppers also had the highest levels of provitamin A activity and the highest concentrations of β-carotene and β-cryptoxanthin (Marin et al. 2004). This study also found that phenolic compounds were contained largely in the peel. A study investigating β-carotene and total carotenoid content in a variety of capsicum species and cultivars, showed, perhaps surprisingly, that red cultivars not only had higher levels of total carotenoids than the yellow and orange cultivars tested, but also tended to have higher levels of β-carotene (Wall et al. 2001).

4.4.4 *Bioavailability*

The general bioavailability of carotenoids has been covered in Section 2.4.2. Section 3.4.2 discusses the bioavailability of hydroxycinnamic acid and ferulic acid.

Quercetin bioavailability has been shown to be affected by the food matrix, though it is also thought to be influenced by the particular sugars that are attached to the quercetin molecule (Hollman et al. 1997b). Originally, the absorption of flavonols from the diet was considered to be negligible due to the fact that they were bound to sugars (glycosides) present in plants. It was thought that only aglycones were absorbed. However, this view has since been discounted with various studies showing greater, and faster, absorption of quercetin glucoside than aglycones or quercetin rutinoside (rutin) (Hollman et al. 1995; Hollman & Katan 1997; Hollman & Katan 1999). Additionally, absorption was better from some food sources than from others. For example, Hollman et al. (1997a) found that in humans quercetin compounds from onions (quercetin glucosides) were better absorbed than those from apples (quercetin glucosides and galactosides) or from pure rutin (quercetin rutinoside). In a rat trial, the quercetin aglycone was absorbed more quickly than rutin (Manach et al. 1997).

Even though flavonoid glycosides have less free radical quenching ability than aglycones *in vitro*, it appears that the presence of glycosides (in particular, glucosides) enables their hydrolysation to aglycone and subsequent absorption, thus rendering them more bioavailable.

4.4.5 Tips and trivia

- Capsicums have some of the highest levels of vitamin C of all vegetables.
- Cooking will reduce the amount of vitamin C, but will increase the bioavailibility of carotenoids.
- Red peppers generally have much higher levels of both vitamin C and carotenoids than immature or yellow or orange types. Immature green peppers have higher levels of flavonoids.

5 *Pumpkin (*Cucurbita *spp)*

5.1 Introduction

A pumpkin or a squash? Pumpkins belong to the squash family Cucurbitaceae which also includes cucumber, gourd, and melons. The vegetables that are generally considered “pumpkins” in New Zealand are hard skinned, hard fleshed mature fruit, generally harvested in autumn. In the United States and some other countries these are known as “winter squash”, in contrast to the likes of zucchini, scaloppini and marrow, which are termed “summer squash”. The term “pumpkin” seems to be used in those parts of the world solely for the types of squash that are carved to make Jack O’ Lanterns at Halloween. These are fibrous, have a large seed cavity and are not used for eating.

It is ironic that although squash originated in the Americas, in the area between Guatemala and Mexico, in the US they are only rarely consumed as a food. It is estimated that only 1% of the annual crop is used as a food. By far the vast majority is grown for decorative purposes, including the making of Jack O’ Lanterns. The British also make little use of this vegetable, eating it mostly in the form of pumpkin pie or as an extender in products such as jams. In New Zealand pumpkins are available year round and are eaten in an assortment of dishes, forming an integral part of our diet. Despite this, the majority of the crop is exported, mostly to Japan. Kabucha (meaning “sweet mama”), a kind of buttercup squash, is one of the favourite varieties in Japan.

5.2 Composition

See Section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under “Factors affecting health benefits”.

5.2.1 Core nutrients

Pumpkins are an excellent source of vitamin A, containing high levels of provitamin A, the carotenoids α- and β-carotene, as well as β-cryptoxanthin. Some vitamin C, potassium and fibre are also present in pumpkins. See

Appendix I for detailed data (including information on different cultivars) from the New Zealand database FOODfiles,

Perhaps surprisingly, pumpkin is relatively low in calories. Although pumpkins contain more energy than carrots, they contain fewer calories than other vegetables with similar cooking uses and textures. It is also versatile, being used in both sweet and savoury dishes.

Table 3: Energy content of selected vegetables (per 100 g raw, fresh sample) (Athar et al. 2004)

Vegetable	Energy (kcal)
Carrot	18
Corn	115
Kumara	108
Parsnip	54
Potatoes	72
Pumpkin	31

5.2.2 Other phytochemicals

Pumpkins contain excellent levels of both α- and β-carotene (see Section 2), and lutein and zeaxanthin (see Section 3). In addition, they are one of the richest sources of β-cryptoxanthin, a phytochemical more commonly found in fruits. (Dragovic-Uzelac et al. 2005) found the major phenolic compound in pumpkin was chlorogenic acid, though neither Joseph (2002) nor Pratt & Matthews (2004) mention it.

5.3 Health benefits

There have been few studies examining the health benefits of these vegetables. This is not because they are nutritionally worthless, but rather, reflects the fact that for some reason they are not particularly popular in the USA or Europe.

The health benefits of the major phytochemicals present in pumpkins have already been covered in Sections 2 and 3.

Chlorogenic acid has been found to have some antioxidant/radical quenching activity. In particular it is believed to help combat the effects of carcinogenic nitrosamines, such as those in some processed meats and cigarette smoke (Joseph et al. 2002).

5.3.1 Factors affecting health benefits

As discussed in Section 2.2 a range of factors impact upon the composition of a food and thus the health benefits it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

5.3.2 *Cultivar*

(Murkovic et al. 2002) found considerable variation in phytochemical levels between cultivars when they analysed a range of produce in the Austrian market. They found that high carotene levels were present in the more orange-coloured fruit but that high levels of lutein/zeaxanthin and lower levels of the carotenes were present in fruit of a bright yellow colour. For 100 g of fresh product, β-carotene levels ranged from 0.6 to 7.4 mg; α-carotene from undetectable to 7.5 mg; and lutein/zeaxanthin from undetectable to 17 mg. Generally β-carotene was the most abundant carotenoid, though in the *Cucurbita maxima* types, which are commonly grown in New Zealand and include the cultivars kumi kumi, Whangaparoa crown and triamble, lutein was the major carotenoid.

5.3.3 *Bioavailability*

Bioavailability has already been discussed in Sections 2.4.2 and 3.4.2. It would be expected that cooking would increase the bioavailability of pumpkin carotenoids as it does with carrots, since the food matrix is similar.

5.4 *Tips and trivia*

- The brighter and stronger the colour of the flesh, the more carotenoids the pumpkin will contain.
- Pumpkin is surprisingly low in calories and thus a good alternative for more starchy, energy dense vegetables such as potatoes and kumara.
- It can be used in both savoury and sweet dishes.
- The name “squash” is derived from the Native American word, askutasquash.
- Q: What is pumpkin pi? A: What you get if you divide the circumference of a pumpkin by its diameter.

6 *Cantaloupe and other melons:* Cucumis melo *(melon);* Citrullus lanatus *(watermelon)*

6.1 Introduction

Like pumpkins, melons belong to the Cucurbitaceae family and include cantaloupe, also known as rockmelon or muskmelon. They are a multi-coloured family, with flesh that can be red, orange, green or white, and vary in size and shape from huge to small and from round to cylindrical. Some, including cantaloupe and pumpkin, contain their seeds in an internal cavity, whilst others, such as watermelon and cucumbers, have their seeds dispersed throughout the flesh. The focus in this report will be on orange-fleshed types.

6.2 Composition

See Section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under “Factors affecting health benefits”.

Melons contain large amounts of water, which accounts for their refreshing taste and their low energy content. More comprehensive detail from New Zealand data on assorted varieties is contained in Appendix I.

6.2.1 Core nutrients

Despite their high water content, melons have high levels of vitamin C and moderate amounts of potassium. Orange varieties also contain β-carotene which is converted to vitamin A in the body.

6.2.2 Other phytochemicals

Carotenoids

As its orange flesh would indicate, cantaloupe contains good amounts of β-carotene, its major phytochemical (see Table 1). Watermelon, with its red flesh, contains a different carotenoid pigment, lycopene.

Phenolics

Vinson et al. (2001) found cantaloupe, honeydew and watermelon all contained phenolic compounds, although they did not specify which ones. Honeydew and cantaloupe were at the lower end of the range, whereas watermelon was in the moderate to high range. Another study, which included only honeydew, found it to have the lowest antioxidant capacity of the 14 popular fruits investigated (Chun et al. 2005). Similarly, Pellegrini et al.

(2003) and Wu et al. (2004) found all three types to have amongst the lowest antioxidant activity levels of a larger selection of popular fruits. These results are somewhat perplexing, given that both cantaloupe and watermelon contain reasonable levels of β-carotene and lycopene respectively, both of which have demonstrated antioxidant activity in other studies.

Note: Lycopene is the same pigment that makes tomatoes red and has been of considerable interest to researchers in terms of preventing a number of cancers – in particular, prostate cancer. Because it has strong antioxidant activity it is also thought to aid in the prevention of heart disease, as well as other conditions such as diabetes and eye disease. It also appears to have good bioavailability. For example, Edwards et al. (2003) found the bioavailability of lycopene from red watermelon juice was similar to that found in tomato juice. In a study of Chinese men, Jian et al. (2005) found that the risk of prostate cancer declined with increasing intake of both cooked tomatoes and watermelon.

As explained in Section 2.4.2 carotenoids from a raw source are generally less bioavailable than those from a cooked source. However, this was not borne out in the study above, where lycopene was well absorbed from both (raw) watermelon juice and (processed/heated) tomato juice (Edwards et al. 2003). This may be because the soft texture of its food matrix does not hinder absorption.

The health benefits of lycopene are covered in considerable detail in Hedges and Lister (2005).

6.3 Factors affecting health benefits

As discussed in Section 2.2, a range of factors impact upon the composition of a food and thus the health benefits it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

6.3.1 Variety/cultivar

The different flesh-colours of these fruits indicate different kinds of pigment phytochemicals, with some varieties, such as honeydew, appearing to lack any such pigments. This might explain their low antioxidant activity rating. Beyond this, no specific data has been found in this area.

6.3.2 Bioavailability

β-carotene is the major phytochemical present in cantaloupe and its bioavailability is covered in Section 2.4.2.

6.3.3 Tips and trivia

- "Success to me is having ten honeydew melons, and eating only the top half of each one." Barbra Streisand.
- "Watermelon – it's a good fruit. You eat, you drink, you wash your face." Enrico Caruso.

- “The true Southern watermelon is a boon apart, and not to be mentioned with commoner things. It is chief of this world's luxuries, king by the grace of God over all the fruits of the earth. When one has tasted it, he knows what the angels eat. It was not a Southern watermelon that Eve took; we know it because she repented.” Mark Twain (1835-1910).

7 *Orange-fleshed kumara (*Ipomea batatas *cv. Beauregard)*

Kumaras will be covered in detail in a future report focusing on root vegetables, but it is appropriate to make mention of orange-fleshed kumara here. No information specific to Beauregard kumara has been found. However, this cultivar is an American variety and consequently is likely to be similar to data on the American database for sweet potato. The data contained in Table 1 show how sweet potato has the highest β-carotene content of all the vegetables, though few other carotenoids. Although it is unknown how the samples evaluated for the USDA compare with the New Zealand-grown Beauregard cultivar, it is likely that Beauregard kumara also has high levels of β-carotene, with some also in the skin. It is likely that the health benefits ascribed to β-carotene in Section 1 would be relevant to this vegetable cultivar.

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Appendices

Appendix I

Nutritional information on assorted yellow/orange vegetables (per 100 g edible portion) from FOODFiles 2004

X31~Carrot,flesh,raw~CARROT~~~Flesh~Raw~~~~Daucus~carota~~		
Water	g	90.1
Energy	kcal	18
Protein	g	0.6
Total fat	g	0.2
Carbohydrate, available	g	3.49
Dietary fibre (Englyst, 1988)	g	3.2
Ash	g	0.8
Sodium	mg	27
Phosphorus	mg	26
Potassium	mg	340
Calcium	mg	30
Iron	mg	0.2
Beta-carotene equivalents	µg	6160
Total vitamin A equivalents	µg	1030
Thiamin	mg	0.034
Riboflavin	mg	0.013
Niacin	mg	0.55
Vitamin C	mg	7
Cholesterol	mg	0
Total saturated fatty acids	g	0.044
Total monounsaturated fatty acids	g	0.012
Total polyunsaturated fatty acids	g	0.113
Dry matter	g	9.93
Total nitrogen	g	0.09
Glucose	g	0.9
Fructose	g	0.8
Sucrose	g	1.55
Lactose	g	T
Maltose	g	T
Total available sugars	g	3.25
Starch	g	0.24
Alcohol	g	0
Total niacin equivalents	mg	0.65
Soluble non-starch polysaccharides	g	1.6

Insoluble non-starch polysaccharides	g	1.6
Energy	kJ	75
Magnesium	mg	10
Manganese	µg	160
Copper	mg	0.04
Zinc	mg	0.18
Selenium	µg	0.3
Retinol	µg	0
Potential niacin from tryptophan	mg	0.1
Vitamin B6	mg	0.012
Folate, total	µg	12
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.84

T = trace

X272~Capsicum,Red,raw~CAPSICUM~RED~~~Raw~~~~~~~		
Water	g	91.1
Energy	kcal	35
Protein	g	1.7
Total fat	g	0.2
Carbohydrate, available	g	6.7
Dietary fibre (Englyst, 1988)	g	1.6
Ash	g	0.3
Sodium	mg	1
Phosphorus	mg	34
Potassium	mg	180
Calcium	mg	2
Iron	mg	0.3
Beta-carotene equivalents	µg	1470
Total vitamin A equivalents	µg	245
Thiamin	mg	0.04
Riboflavin	mg	0.05
Niacin	mg	1
Vitamin C	mg	170
Cholesterol	mg	0
Total saturated fatty acids	g	0
Total monounsaturated fatty acids	g	0
Total polyunsaturated fatty acids	g	0
Dry matter	g	8.9
Total nitrogen	g	0.29
Glucose	g	2.5
Fructose	g	3.6
Sucrose	g	T
Lactose	g	0
Maltose	g	0
Total available sugars	g	6.1
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	1.2
Soluble non-starch polysaccharides	g	1.3
Insoluble non-starch polysaccharides	g	0.3
Energy	kJ	146
Magnesium	mg	2

Manganese	µg	T
Copper	mg	0.01
Zinc	mg	0.4
Selenium	µg	T
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.36
Folate, total	µg	21
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.8

T = trace

X44~Corn,Sweet,kernels,raw~CORN~SWEET~On cob~Kernel~Raw~~~~Zea~mays~~		
Water	g	68
Energy	kcal	115
Protein	g	3.8
Total fat	g	2.21
Carbohydrate, available	g	19.9
Dietary fibre (Englyst, 1988)	g	2
Ash	g	0.7
Sodium	mg	6
Phosphorus	mg	76
Potassium	mg	249
Calcium	mg	3.68
Iron	mg	0.24
Beta-carotene equivalents	µg	176
Total vitamin A equivalents	µg	29
Thiamin	mg	0.04
Riboflavin	mg	0.074
Niacin	mg	0.9
Vitamin C	mg	11.1
Cholesterol	mg	0
Total saturated fatty acids	g	0.3
Total monounsaturated fatty acids	g	0.54
Total polyunsaturated fatty acids	g	0.91
Dry matter	g	32.1

Total nitrogen	g	0.61
Glucose	g	0.9
Fructose	g	0.2
Sucrose	g	0.4
Lactose	g	0
Maltose	g	0
Total available sugars	g	1.5
Starch	g	18.4
Alcohol	g	0
Total niacin equivalents	mg	1.3
Soluble non-starch polysaccharides	g	0.1
Insoluble non-starch polysaccharides	g	1.9
Energy	kJ	475
Magnesium	mg	22
Manganese	µg	185
Copper	mg	0.07
Zinc	mg	1.09
Selenium	µg	0.256
Retinol	µg	0
Potential niacin from tryptophan	mg	0.405
Vitamin B6	mg	0.05
Folate, total	µg	48
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.2

T = trace

X111~Pumpkin,combined cultivars,flesh,raw~PUMPKIN~~Combined cultivars~Flesh~Raw~~~~Cucurbita~maxima~crown~		
Water	g	89.5
Energy	kcal	31
Protein	g	0.97
Total fat	g	0.26
Carbohydrate, available	g	6.2
Dietary fibre (Englyst, 1988)	g	2.7
Ash	g	0.69
Sodium	mg	2.01
Phosphorus	mg	22.7
Potassium	mg	315
Calcium	mg	20.7
Iron	mg	0.31
Beta-carotene equivalents	µg	3530
Total vitamin A equivalents	µg	589
Thiamin	mg	0.029
Riboflavin	mg	0.004
Niacin	mg	0.203
Vitamin C	mg	18.1
Cholesterol	mg	0
Total saturated fatty acids	g	0.157
Total monounsaturated fatty acids	g	0.039
Total polyunsaturated fatty acids	g	0.015
Dry matter	g	10.5
Total nitrogen	g	0.16
Glucose	g	1.48
Fructose	g	1.22
Sucrose	g	1.44
Lactose	g	0
Maltose	g	0
Total available sugars	g	4.1
Starch	g	2.03
Alcohol	g	0
Total niacin equivalents	mg	0.4
Soluble non-starch polysaccharides	g	1.03
Insoluble non-starch polysaccharides	g	1.67
Energy	kJ	128

Magnesium	mg	12.8
Manganese	µg	63.3
Copper	mg	0.066
Zinc	mg	0.15
Selenium	µg	0.198
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.064
Folate, total	µg	13
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.06

T = trace

X108~Pumpkin,Kumi Kumi,flesh,raw~PUMPKIN~KUMI KUMI~~Flesh~Raw~~~~Cucurbita~maxima~~		
Water	g	92.5
Energy	kcal	19
Protein	g	0.74
Total fat	g	0.19
Carbohydrate, available	g	3.7
Dietary fibre (Englyst, 1988)	g	1.94
Ash	g	0.59
Sodium	mg	1.25
Phosphorus	mg	23.8
Potassium	mg	256
Calcium	mg	18.8
Iron	mg	0.34
Beta-carotene equivalents	µg	494
Total vitamin A equivalents	µg	82
Thiamin	mg	0.028
Riboflavin	mg	0.003
Niacin	mg	0.167
Vitamin C	mg	21.3
Cholesterol	mg	0
Total saturated fatty acids	g	0.113
Total monounsaturated fatty acids	g	0.028
Total polyunsaturated fatty acids	g	0.011
Dry matter	g	7.53

Total nitrogen	g	0.12
Glucose	g	0.99
Fructose	g	0.82
Sucrose	g	0.58
Lactose	g	0
Maltose	g	0
Total available sugars	g	2.4
Starch	g	1.32
Alcohol	g	0
Total niacin equivalents	mg	0.4
Soluble non-starch polysaccharides	g	0.74
Insoluble non-starch polysaccharides	g	1.2
Energy	kJ	81
Magnesium	mg	13.6
Manganese	µg	87.2
Copper	mg	0.052
Zinc	mg	0.19
Selenium	µg	0.2
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.016
Folate, total	µg	13
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.06

T = trace

X109~Pumpkin,Triamble,flesh,raw~PUMPKIN~TRIAMBLE~~Flesh ~Raw~~~~Cucurbita~maxima~~		
Water	g	87
Energy	kcal	42
Protein	g	1.13
Total fat	g	0.4
Carbohydrate, available	g	8.5
Dietary fibre (Englyst, 1988)	g	3.36
Ash	g	0.74
Sodium	mg	1.43
Phosphorus	mg	21
Potassium	mg	359

Calcium	mg	18.9
Iron	mg	0.3
Beta-carotene equivalents	µg	6180
Total vitamin A equivalents	µg	1030
Thiamin	mg	0.029
Riboflavin	mg	0.005
Niacin	mg	0.268
Vitamin C	mg	14.2
Cholesterol	mg	0
Total saturated fatty acids	g	0.239
Total monounsaturated fatty acids	g	0.06
Total polyunsaturated fatty acids	g	0.023
Dry matter	g	13.1
Total nitrogen	g	0.18
Glucose	g	1.97
Fructose	g	1.63
Sucrose	g	2.11
Lactose	g	0
Maltose	g	0
Total available sugars	g	5.7
Starch	g	2.77
Alcohol	g	0
Total niacin equivalents	mg	0.5
Soluble non-starch polysaccharides	g	1.28
Insoluble non-starch polysaccharides	g	2.07
Energy	kJ	174
Magnesium	mg	11.4
Manganese	µg	50.1
Copper	mg	0.059
Zinc	mg	0.22
Selenium	µg	0.2
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.122
Folate, total	µg	13
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.06

T = trace

X192~Squash,Buttercup,flesh,raw~SQUASH~BUTTERCUP~~ Flesh~Raw~~~~~~~		
Water	g	83.7
Energy	kcal	52
Protein	g	1.39
Total fat	g	0.22
Carbohydrate, available	g	11.2
Dietary fibre (Englyst, 1988)	g	1.03
Ash	g	0.81
Sodium	mg	0.79
Phosphorus	mg	31
Potassium	mg	471
Calcium	mg	17.9
Iron	mg	0.66
Beta-carotene equivalents	µg	3180
Total vitamin A equivalents	µg	530
Thiamin	mg	0.079
Riboflavin	mg	0.005
Niacin	mg	0.411
Vitamin C	mg	25.5
Cholesterol	mg	0
Total saturated fatty acids	g	0.051
Total monounsaturated fatty acids	g	0.019
Total polyunsaturated fatty acids	g	0.105
Dry matter	g	16.3
Total nitrogen	g	0.22
Glucose	g	2.44
Fructose	g	2.35
Sucrose	g	T
Lactose	g	0
Maltose	g	0
Total available sugars	g	4.8
Starch	g	6.35
Alcohol	g	0
Total niacin equivalents	mg	0.7
Soluble non-starch polysaccharides	g	0.36
Insoluble non-starch polysaccharides	g	0.67

Energy	kJ	215
Magnesium	mg	9.5
Manganese	µg	40
Copper	mg	0.058
Zinc	mg	0.2
Selenium	µg	T
Retinol	µg	0
Potential niacin from tryptophan	mg	0.3
Vitamin B6	mg	0.099
Folate, total	µg	50
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.83

T = trace

X119~Squash,Butternut,flesh,raw~SQUASH~BUTTERNUT~~ Flesh~Raw~~~~Cucurbita~maxima~~		
Water		
Energy	g	86.4
Protein	kcal	44
Total fat	g	1.34
Carbohydrate, available	g	0.12
Dietary fibre (Englyst, 1988)	g	9.5
Ash	g	1.6
Sodium	g	0.77
Phosphorus	mg	1.5
Potassium	mg	23.3
Calcium	mg	342
Iron	mg	20.2
Beta-carotene equivalents	mg	0.35
Total vitamin A equivalents	µg	3470
Thiamin	µg	579
Riboflavin	mg	0.076
Niacin	mg	0.004
Vitamin C	mg	0.409
Cholesterol	mg	20
Total saturated fatty acids	mg	0
Total monounsaturated fatty acids	g	0.029

Total polyunsaturated fatty acids	g	0.011
Dry matter	g	0.06
Total nitrogen	g	13.6
Glucose	g	0.22
Fructose	g	2.1
Sucrose	g	2
Lactose	g	0.2
Maltose	g	0
Total available sugars	g	0
Starch	g	4.3
Alcohol	g	5.21
Total niacin equivalents	g	0
Soluble non-starch polysaccharides	mg	0.7
Insoluble non-starch polysaccharides	g	0.7
Energy	g	0.9
Magnesium	kJ	184
Manganese	mg	16.1
Copper	µg	63.5
Zinc	mg	0.053
Selenium	mg	0.17
Retinol	µg	0.544
Potential niacin from tryptophan	µg	0
Vitamin B6	mg	0.3
Folate, total	mg	0.088
Vitamin B12	µg	22
Vitamin D	µg	0
Vitamin E	µg	0

T = trace

L104~Melon,Cantaloupe,flesh,fresh~MELON~CANTALOUPE~~ Flesh~Fresh~~~~Cucumis~melo~cantaloupensis~		
Water	g	93.6
Energy	kcal	26
Protein	g	1
Total fat	g	0.1
Carbohydrate, available	g	5.2
Dietary fibre (Englyst, 1988)	g	0.81
Ash	g	0.7
Sodium	mg	14
Phosphorus	mg	30
Potassium	mg	320
Calcium	mg	19
Iron	mg	0.3
Beta-carotene equivalents	µg	951
Total vitamin A equivalents	µg	159
Thiamin	mg	0.05
Riboflavin	mg	0.03
Niacin	mg	0.5
Vitamin C	mg	25
Cholesterol	mg	0
Total saturated fatty acids	g	T
Total monounsaturated fatty acids	g	T
Total polyunsaturated fatty acids	g	T
Dry matter	g	6.4
Total nitrogen	g	0.16
Glucose	g	1.4
Fructose	g	2.5
Sucrose	g	1.3
Lactose	g	0
Maltose	g	0
Total available sugars	g	5.2
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	0.5
Soluble non-starch polysaccharides	g	0.24
Insoluble non-starch polysaccharides	g	0.57
Energy	kJ	106

Magnesium	mg	12
Manganese	µg	30
Copper	mg	0.04
Zinc	mg	0.1
Selenium	µg	0.1
Retinol	µg	0
Potential niacin from tryptophan	mg	T
Vitamin B6	mg	0.07
Folate, total	µg	30
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.1

T = trace

Appendix II

Table 4: Activities of vitamins and minerals (Adapted from misc.medscape.com/pi/editorial/clinupdates/2004/3341/table.doc) and www.bupa.co.uk/health_information/html/healthy_living/lifestyle/exercise/diet_exercise/vitamins.html)

Name	Major Function
Vitamin A Retinol (animal origin) Carotenoids (plant origin, converted to retinol in the body) Note: Retinol Equivalents (RE) 1 RE =1 mcg retinol or 6 mcg beta-carotene 1IU = 0.3 mcg or 3.33 mcg = 1 mcg retinol = 1RE	Important for normal vision and eye health Involved in gene expression, embryonic development and growth and health of new cells Aids immune function May protect against epithelial cancers and atherosclerosis
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 includingt 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
Vitamin C Ascorbic acid	Neccesary for healthy connective tissues – tendons, ligaments, cartilage, wound healing and healthy teeth Assists in iron absorption A protective antioxidant – may protect against certain cancers Involved in hormone and neurotransmitter synthesis
Thiamin vitamin B_1 Aneurin	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells

Name	Major Function
Riboflavin vitamin B_2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein
Niacin vitamin B_3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown Reduces LDL cholesterol and increases HDL cholesterol
Vitamin B_6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis, haemoglobin synthesis. Involved in neuronal excitation Reduces blood homocysteine levels Prevents megaloblastic anemia
Vitamin B_{12} Cobalamin	Coenzyme in DNA synthesis with folate. Synthesis and manitenance of myelin nerve sheaths Involved in the formation of red blood cells Reduces blood homocysteine levels Prevents pernicious anemia
Folate Generic term for large group of compounds including folic acid and Pterylpolyglut-amates	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

Biotin	Important for normal growth and body function Involved in metabolism of food for energy Coenzyme in synthesis of fat, glycogen, and amino acids
Pantothenic acid	Coenzyme in fatty acid metabolism and synthesis of some hormones Maintenance and repair of cell tissues
Sodium	Major ion of extracellular fluid Role in water, pH, and electrolyte regulation Role in nerve impulse transmission and muscle contraction
Potassium	Major ion of intracellular fluid Maintains water, electrolyte and pH balances Role in cell membrane transfer and nerve impulse transmission
Chloride	Major ion of extracellular fluid Participates in acid production in the stomach as component of gastric hydrochloric acid Maintains pH balance Aids 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 constuent of many essential compounds in body and processes
Calcium	Structural component of bones and teeth Role in cellular processes, muscle contraction, blood clotting, enzyme activation, nerve function
Magnesium	Component of bones Role in cellular energy transfer Role in enzyme, nerve, heart functions, and protein synthesis
Iron	Component of haemoglobin and myoglobin in blood, needed for oxygen transport Role in cellular function and respiration

Iodine	Thyroid hormone production
Chromium	Assists in insulin system for use of blood glucose
Cobalt	Component of vitamin B_{12}
Copper	Component of many enzymes Many functions – blood and bone formation, production of pigment melanin Aids in utilisation of iron stores Role in neurotransmitters synthesis
Fluoride	Helps prevent tooth decay
Manganese	Part of many essential enzymes Aids in brain function, bone structure, growth, urea synthesis, glucose and lipid metabolism
Molybdenum	Aids in enzyme activity and metabolism
Selenium	Important role in body's antioxidant defense system as component of key enzymes May help prevent cancer and cardiovascular disease
Zinc	Major role in immune system Required for numerous enzymes involved in growth and repair Involved in sexual maturation Role in taste, smell functions

Note: This table is compiled and adapted from: Groff JL, Gropper SS. *Advanced nutrition and human metabolism*. 3rd ed. Belmont, CA: Wadsworth/Thomson Learning 1999.; Wardlaw GM. *Perspectives in Nutrition*. 4th ed. Boston, Mass: WCB/McGraw Hill, 1999; and *Dietary Reference Intakes: Vitamins* Available at: www.nap.edu.

Appendix III

Chemical structures of major phytochemicals in yellow/orange vegetables

Figure 2: β-carotene.

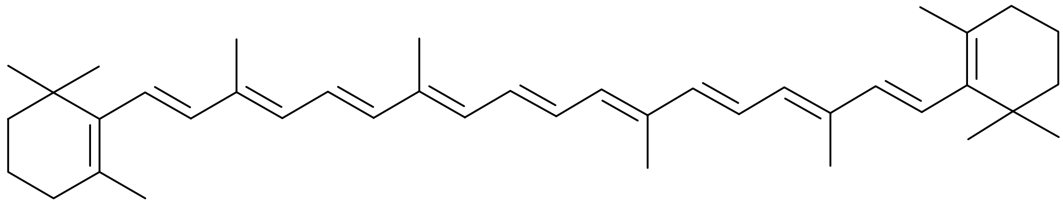


Figure 3: α-carotene.

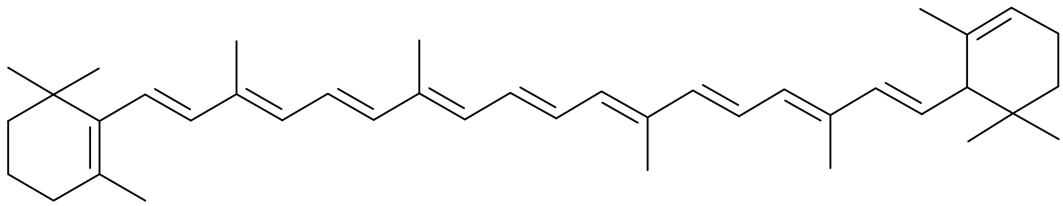


Figure: β-cryptoxanthin.

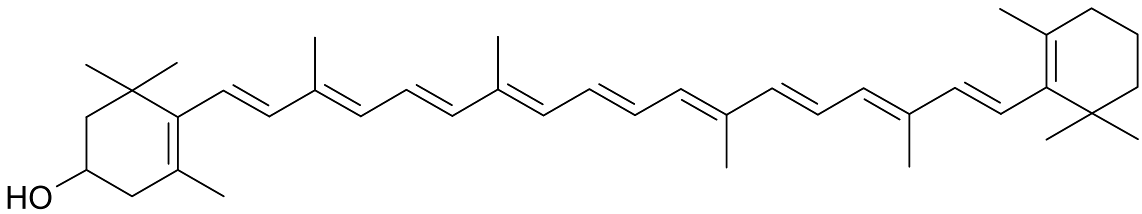


Figure 5: Lutein.

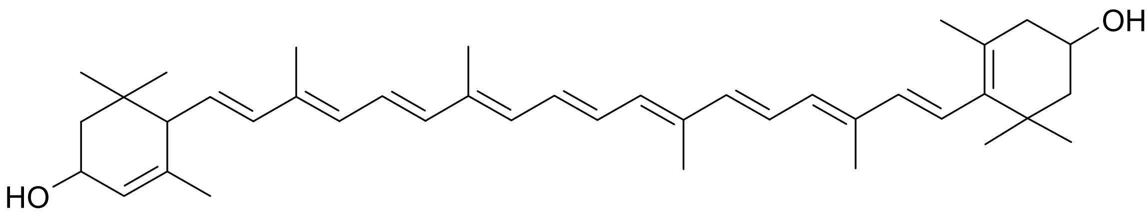


Figure 6: Zeaxanthin.

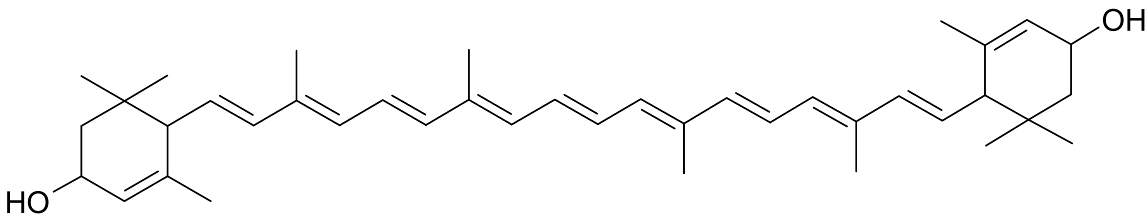


Figure 7: Falcarinol.

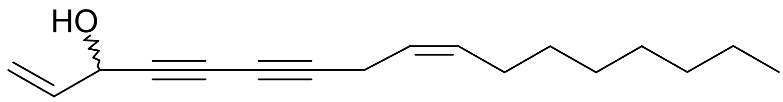


Figure 8: Ferulic acid.

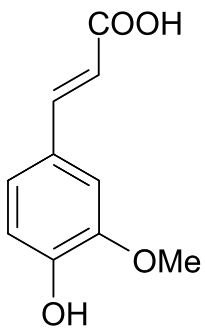


Figure 9: Quercetin.

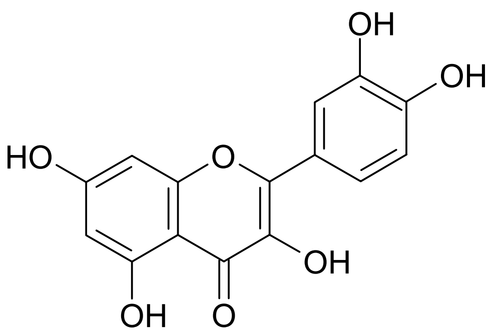
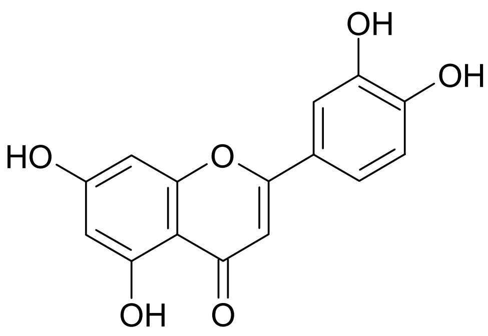


Figure 10: Luteolin.



Crop & Food Research Confidential Report No. 1569

Health attributes of roots and tubers

L J Hedges & C E Lister

March 2006

A report prepared for
Horticulture New Zealand

Copy 1 of 15

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

1.1 Background

This report is intended to provide information from which material can be identified for incorporation into one of a series of promotional and educational booklets for the various VegFed 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 root vegetables and tubers: carrot, kumara, parsnip, taro and yam. The depth of information available varies considerably; it is very sparse for the lesser known vegetables such as taro and yams. Factors that may influence the nutritional profile of these vegetables, such as agronomical issues, cooking or processing and storage are covered. Some additional material of general interest has also been included.

The vegetables in this group are nutritionally diverse. The range of colours, from the orange of carrots and Beauregard kumara to the reddish purple skins of Owairaka Red kumara and the white of parsnip and taro flesh, is suggestive of some of the phytochemical groups that are present – carotenoids, particularly β-carotene in the yellow/orange vegetables, and anthocyanins or betalains in the red/purple groups. White vegetables lack antioxidant pigments, but may contain other kinds of bioactives.

The carotenes, α- and β-carotene and β-cryptoxanthin, are described as having "pro-vitamin A activity", as the body can convert them into vitamin A (retinol). Structural differences between these compounds affect the efficiency with which they are converted to retinol. Besides this, however, they can also function as antioxidants. In general, antioxidants are believed to provide protection against many chronic diseases, such as cardiovascular disease and cancer, as well as other conditions associated with ageing. β-carotene is the most ubiquitous of this family and has been the most extensively studied.

Anthocyanins and betalains are also antioxidants. Anthocyanins – particularly those in fruit – have been relatively well studied, but the health benefits of betalains are less well researched. Much research attention has focused on the effect of anthocyanins on brain function, but these compounds are also believed to lower the risk of some cancers and help prevent cardiovascular disease.

1.2 *Carrots*

Carrots are a particularly rich source of β-carotene. In addition, they contain a much less common phytochemical, falcarinol, a relatively newly researched compound, which is showing some promising early results in animal studies with respect to cancer prevention.

1.3 *Kumara*

Simple phenolic acids in kumara are believed to be responsible for some of the antioxidant activity shown in many sweet potato cultivars. Owairaka Red also contains anthocyanins in the skins, and the orange-fleshed varieties such as Beauregard have very high levels of β-carotene.

1.4 *Beetroot*

A number of studies have ranked beetroot among the 10 most potent vegetables in terms of antioxidant activity. The major phytochemicals in beetroot are betalains, compounds similar to anthocyanins, that have not been extensively studied.

1.5 *Parsnips*

Parsnips lack antioxidant pigments but do contain a newly researched photochemical, falcarinol. Particular interest has focused on the ability of falcarinol to inhibit the growth of some human cancer cells.

1.6 *Taro*

Taro also lacks antioxidant pigments, but one study showed a boiled taro extract to have very high antioxidant activity. The compound(s) responsible for this were not identified. Taro also contains an antinutritive compound, calcium oxalate crystals, which cause irritation if handled or eaten raw or undercooked, but which are broken down with long cooking. Oxalates also compromise calcium levels in the body and may lead to the formation of kidney stones.

1.7 *Yams*

Yellow yams contain carotenoids and the red skinned cultivars also contain anthocyanins. They, too, contain oxalates, but these are water soluble and their levels are generally reduced if boiled.

2 *Carrots* (Daucus carota)

2.1 *Introduction*

The humble carrot, almost a staple in many countries, has had a colourful history. The original carrots were believed to be purple and grew in the region that is now Afghanistan about 5000 years ago. These purple carrots were depicted in Ancient Egyptian temple drawings and, along with white varieties, were also known to the ancient Romans, who used them as much for medicinal purposes as culinary. There are also records of red and yellow carrots, and the orange carrot was not known until the 16th century, when it was deliberately developed by Dutch growers to honour of the House of Orange. Interestingly, the older colours are now appearing in new carrot cultivars, with the British retail chain Sainsbury's selling purple orange-centred carrots in 2002. Seed companies are also now offering a rainbow of multi-coloured carrot varieties.

Carrots belong to the Umbelliferae or Apiaceae family, so named because their flowers form umbrella-shaped clusters. This is an illustrious family, which also includes many other plants with aromatic and flavourful qualities, such as parsnips, parsley, dill, celery, coriander, cumin, caraway and anise. Many of these have also been used medicinally as treatments for a wide range of problems.

Carrots are well known for assisting night vision. During World War 2, in order to keep the newly invented radar a secret, it was put about that the air crews' night vision had been substantially bolstered by eating larger quantities of carrots.

2.2 *Composition*

A number of factors combine to determine the levels of both core nutrients and other phytochemicals in a food. These include not only the variety/cultivar of the plant, but also issues relating to the agronomy involved – soils, cultivation protocols (irrigation, pest control, use of fertiliser), degree of ripeness 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. This makes it difficult to be exact when comparing levels of these compounds.

These various factors may cause large differences in core nutrient levels, but even greater differences may occur in terms of phytochemicals.

Where data are available, the extent and effect of this variation will be discussed later in this section, under "Factors affecting health benefits".

2.2.1 *Core nutrients*

Carrots are an excellent source of vitamin A through the α- and β-carotene they contain (which the body converts into vitamin A). Moderate amounts of vitamin C, sodium, potassium and fibre are also present in carrots.

See Appendix 1 for full data from the New Zealand FOODFiles database.

2.2.2 *Other phytochemicals*

The major phytochemicals in carrots are the carotenoids α-carotene, β-carotene, β-cryptoxanthin, lutein, zeaxanthin and falcarinol, a polyacetylene compound. Whilst there are some phenolic compounds (Joseph et al. 2002), they appear to be present only at low levels (Vinson et al. 1998). Flavonoid data for carrots are unavailable on the USDA flavonoid database and are consequently judged to be of minimal importance.

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 the 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 highest levels of carotenoids are found in dark green leafy vegetables such as kale and spinach.

Carotenoids are lipids and consist of a long-chain hydrocarbon molecule with a series of central, conjugated double bonds. (See Appendix III for structural diagrams of the major carotenoids in carrots.) These conjugated (alternating) double bonds not only confer colour, but also cause the compounds' antioxidant properties. These compounds have been found to be 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 both the skin and the macula lutea of the eye against the same 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. They 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, levels of the two compounds are often reported as a combined total.

Carotenoids are fat-soluble compounds and thus are best absorbed in the body if accompanied by some form of oil or fat in the meal. It has also been shown that chopping and cooking assists in releasing carotenoids from the food matrix and this also increases their bioavailability.

The carotenoid content of some common yellow/orange fruits and vegetables is shown in Table 1. Interestingly, although cooking increases the carotenoid contents in carrots and corn, particularly for β-cryptoxanthin, lutein and zeaxanthin, the reverse seems to be the case for pumpkin. This is contrary to what would normally be expected.

Table 1: Carotenoid content of assorted yellow/orange fruit and vegetables (mcg/100g) from USDA National Nutrient Database for Standard Reference Release 18, 2005 (Service 2005).

Food	β-carotene	α-carotene	β-cryptoxanthin	Lycopene	Lutein + zeaxanthin
Apricot	1094	19	104	0	89
Capsicum, red, raw	1624	20	490	308	51
Capsicum, yellow, raw	120	N/A	N/A	N/A	N/A
Carrot, raw	8285	3477	125	1	256
Carrot, boiled	8332	3776	202	0	687
Corn (sweet), raw	52	18	127	0	764
Corn (sweet), boiled	66	23	161	0	967
Melon (cantaloupe)	2020	16	1	0	26
Orange	87	7	116	0	129
Peach	162	0	67	0	91
Persimmon	253	0	1447	159	834
Pumpkin, raw	3100	515	2145	0	1500
Pumpkin, boiled	2096	348	1450	0	1014
Sweet potato, raw	8506	7	0	0	0
Sweet potato, boiled	9444	0	0	0	0

Falcarinol and falcarindiol

Carrots also contain compounds called polyacetylenes, of which falcarinol ((9Z)-heptadeca1,9-dien-4,6-diyn-3-ol) has been found to be among the most bioactive and therefore of particular importance in terms of health (Hansen et al. 2003; Zidorn et al. 2005). (See Appendix III for a structural diagram of this compound.) It is also present in other plants of the Apiaceae family including celery and parsnip, as well as in some medicinal herbs of the Araliaceae family, such as ginseng root, *Panax ginseng* (Hansen et al. 2003). For this reason it is also known as panaxynol. It has been postulated by some researchers that various health benefits associated with carrots and attributed to β-carotene, may in fact be due to falcarinol. Similarly, the health effects of ginseng may in part be attributable to this compound (Hansen et al. 2003). Interestingly, although this compound is associated most strongly with carrots, a study identifying and quantifying polyacetylenes in the Apiaceae family showed that both parsnips and celery had higher levels. However, it is likely that carrots are a major source of dietary falcarinol because they are consumed relatively often, and in large amounts.

Falcarinol is sensitive to both heat and light. In the plant it appears to be evenly distributed throughout the whole root.

A number of compounds, including eugenin, terpenoids, water-soluble phenolics and particularly an isocoumarin called 6-methoxymellein, were initially thought to cause the bitter taste of some carrots (Czepa & Hofmann 2004). However, a recent study identified another polyacetylene, falcarindiol, ((Z)-heptadeca-1, 9-dien-4,6-diyn-3,8-diol), as the major contributor to the bitter taste in carrots. The upper end of the phloem was deemed to be more bitter than the lower end (and contained higher concentrations of falcarindiol) and removing the peel, as well as green and dark parts, removed much of the bitter taste (Czepa & Hofmann 2004). Heat processing in this study did not affect the taste components of the compound.

2.3 Health benefits

2.3.1 Core nutrients

The roles of core nutrients are outlined in Table 4, Appendix II.

2.3.2 Phytochemicals

Carotenoids

α- and β-carotene differ only very slightly in terms of structure. They are very common carotenoids, and are 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, α-carotene and β-cryptoxanthin each about 1/12.

Note: Although there is some controversy internationally regarding 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. Epidemiological studies have demonstrated that high intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing. Carotenoid-rich foods have also 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 also possess 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, found that the risk of developing lung cancer actually increased in those taking supplements. However, no such effect has been found in studies where the β-carotene was consumed as part of a food as opposed to a supplement form, where the compound has been isolated and concentrated. Mixed results have also been reported from studies relating to prostate and colorectal cancer.

There have also been mixed results regarding the effect of dietary β-carotene on cardiovascular disease. 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 a number of *in vitro* studies had shown it to be capable of scavenging potentially damaging radicals. However, whilst some research has shown that higher plasma levels of carotenoids are associated with better vascular health and lower cardiovascular disease risk, other studies have shown no effect (Higdon 2005; Cooper et al. 1999). Further, some recent studies have produced contradictory results regarding the ability of β-carotene to stabilise LDL against oxidation (Cooper et al. 1999).

Carotemia is a condition arising from excessive intake of carotenoids in which high levels of β-carotene stored in the skin give it a yellowish appearance. The condition is harmless and disappears with lower consumption of carotenoid-rich foods.

α-carotene

α-carotene is less well-known and studied than β-carotene, but some studies have shown α-carotene to be even more effective than β-carotene at inhibiting cancer cells.

β-cryptoxanthin

This carotenoid is orange-yellow in colour and is found in various fruits and vegetables, including pumpkins. There are indications that it may play an important role in cardiac health.

Lutein & zeaxanthin

These two carotenoids are often grouped together as they have very similar structure and functions (see Appendix III for structure) and it is only relatively recently, with technology such as high performance liquid chromatography (HPLC), that it has been possible to differentiate between the two individual compounds. Lutein and zeaxanthin are essential for maintaining proper vision and may help to prevent macular degeneration and cataracts. They may also help reduce the risk of certain types of cancer. These pigments will be covered in greater detail in section 3.

Falcarinol

Scientific research has only relatively recently focused on falcarinol. However, in the few studies undertaken to date it shows some promise in selected areas. As discussed earlier, whilst there are a number of polyacetylenes present in carrots, falcarinol has the most bioactivity, with pronounced cytotoxic effects against human tumor cells (Hansen et al. 2003; Brandt et al. 2004; Zidorn et al. 2005). At low concentrations, as would be available through normal dietary intake, falcarinol delayed or hindered the development of large, precancerous lesions and tumours in rats (Kobaek-Larsen et al. 2005). Together, these studies suggest that, besides the better-known carotenoids, falcarinol may contribute significantly to the health-promoting properties of carrots.

Falcarinol is a natural pesticide at high concentrations (Kobaek-Larsen et al. 2005) and polyacetylenes in general have potent antifungal and antibacterial properties (Zidorn et al. 2005). These attributes do not yet appear to have been investigated in terms of human health. Although falcarinol has been shown to be toxic at extremely high concentrations, to ingest a fatal dose an estimated 400 kg carrots would have to be consumed over a short period (BBC News 2005). It is not unusual for plant constituents that have beneficial effects in normal quantities to have detrimental effects in extremely high doses. The chemoprotective compound sulphoraphane, found in broccoli. is another such example. It would be almost impossible to consume toxic quantities of these sorts of compounds as foods, or accidentally as part of a normal diet.

Phenolic compounds

The only flavonoid listed for carrots in the USDA flavonoid database is a small amount of quercetin. According to Joseph et al. (2002), carrots also contain apigenin and some phenolic acids, but Vinson et al. (1998) reported that carrots contained only low levels of phenolics.

2.4 Factors affecting health benefits

As explained in section 2.2 above, a range of factors affect the composition of a food and thus the health benefits that it may deliver. Where information is available, this section deals with those factors as well as the issue of bioavailability.

2.4.1 Cultivar

Differences in the levels of some or all of the major bioactive compounds have been demonstrated in different cultivars of carrots in a number of studies (Hansen et al. 2003; Czepa & Hofmann 2004; Kidmose et al. 2004). Variation also occurred in some of the compounds, but not the major bioactives, in relation to the size of the root (Kidmose et al. 2004).

2.4.2 Storage and processing

Kidmose et al. (2004) found that the carotenoid content appeared to be stable in carrots that had been stored raw and refrigerated for 4 months and those that had been raw frozen at -24^{o}C for 4 months. It was suggested that the 4-month time frame was possibly not long enough for the enzyme responsible for carotenoid degradation to show an effect. Nor was there any significant difference in carotenoid levels between raw-frozen and steam-blanched-then-frozen carrots. The authors postulated that this was because the steam blanching process was relatively short and mild and thus did not markedly degrade the carotenoids, although it did make them more extractable. (Pre-freezing blanching is a common industrial process that aims to prevent the development of an off-taste brought about by the release of fatty acids (Hansen et al. 2003)).

In contrast to carotenoid levels, Kidmose et al. (2004) found polyacetylene levels to be significantly higher in refrigerated carrots than in frozen carrots. The authors suggested that this was the result either of polyacetylene production or slower degradation of these compounds. In that study, steam blanching resulted in a 50% loss of falcarinol, but after 4 months frozen storage levels of falcarinol were nonetheless higher in carrots that had been blanched before freezing than in those that had been raw frozen. However, Hansen et al. (2003) found blanching reduced falcarinol levels by 35%, and observed similar falcarinol losses in both frozen blanched carrots and raw frozen carrots. Interestingly, falcarinol content in refrigerated carrots was relatively stable for 1 month post-harvest, after which there was a steady decline.

2.4.3 Growing conditions

Carrots contain an antifreeze protein which improves storage performance. Carrots grown in temperatures of less than 6°C accumulate higher levels of this protein and subsequently show less electrolyte leakage from cells, slightly higher dry matter and less fungal infestation than carrots grown in warmer temperatures (Galindo et al. 2004). Kidmose et al. (2004) also found that variation occurred between growing locations.

2.4.4 Bioavailability

Bioavailability broadly addresses the issue of how well a compound is absorbed so that it can be utilised by the body. It involves the degree and rate at which a substance is absorbed into a living system or is 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.

Carotenoids

The large difference in the number 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 (green, leafy vegetables);

- dissolved in oil droplets in chromoplasts, which are readily extracted during digestion (mango, papaya, pumpkin and sweetpotato) (West & Castenmiller 1998); and
- 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 (Borel 2003). 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 (Borel et al. 1996).

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 impacts upon 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 following 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).

Falcarinol

Further work needs to be done regarding the bioavailability of falcarinol, as well as its possible direct effect upon the cells and tissues present in the human gut. That it is likely to be bioavailable is supported by a rat study showing rapid absorption of a closely related compound, panaxytriol (Hansen et al. 2003).

2.5 Quotes and trivia

- "Eating a carrot a day is like signing a life insurance policy" – Irena Chalmers in *The Great Food Almanac*.
- Carrots should be eaten both raw and cooked. Whilst some nutrients may be lost in the cooking process, others are made more bioavailable. Including some form of oil in the meal will assist in absorbing the carotenoids.
- Providing they are stored appropriately, carrots should continue to provide good levels of nutrients for a reasonable length of time.

3 *Kumara* (Ipomea batatas *(L.) Lam)*

3.1 *Introduction*

Ironically, the sweet potato family, which includes kumara, is a dietary staple in some underdeveloped countries, yet in more developed countries it is virtually ignored. Annual consumption ranges from very low in Australia, Canada and Europe (less than 2 kg/per person) to over 100 kg/per person in parts of Africa and Oceania. The fact that sweet potatoes rank 7th in terms of production, after wheat, rice, maize, potato, barley, and cassava, attests not only to widespread popularity, but to the fact that it is a mainstay in many of the world's most populous nations. Yet it is an adaptable, easily grown plant – providing the climate is warm – and some varieties are extremely valuable nutritionally. So far, this potential has been underexploited, with pale, less nutritious varieties being popular in poorer countries, and general neglect in wealthier countries. However, times are changing. An aid programme sponsored by the Gates Foundation is seeking to introduce a strongly coloured orange-fleshed variety with high levels of provitamin A and β-carotene into undernourished East Africa, in an attempt to combat the high incidence of child blindness due to vitamin A deficiency there. At the other end of the spectrum, the advent of functional foods, particularly in countries such as Japan, has led to new interest in this vegetable and particularly in new purple cultivars.

Grown in 111 countries, it is believed that there are over 400 varieties of this adaptable vegetable and it comes in a variety of shapes, sizes and colours (CIP 2006). Despite the large number of varieties, only three are commercially available in New Zealand – Owairaka Red (red skinned with cream-coloured flesh), Toka Toka Gold (brown/orange skin with pale yellow flesh) and Beauregard (orange skinned and fleshed). Recently a breeding programme has seen the advent of purple cultivars, particularly in Japan, but also in New Zealand on an experimental basis. Much recent research relates to these new purple varieties.

3.2 *Composition*

See Section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under "Factors affecting health benefits".

3.2.1 *Core nutrients*

Kumaras provide vitamin C, iron, potassium and calcium. A Japanese study showed the latter to be highest in the cortex of the vegetable (Yoshimoto 1998). The skin also contains fibre. Orange-fleshed kumara, such as the cultivar Beauregard, are a particularly rich source of vitamin A (from β-carotene). This is not so for paler-fleshed varieties, however.

See Appendix I for full data from the New Zealand FOODFiles database for Owairaka Red. Unfortunately, data on other cultivars are not available.

3.2.2 *Other phytochemicals*

Various phenolic compounds are present in kumaras, with the simple phenolic acids being the most widespread. Varieties with red or purple skins or flesh also contain anthocyanins and those with orange and yellow pigmentation contain β-carotene, which besides being a precursor to vitamin A, also has antioxidant activity. One source mentioned the presence of the flavonoid, quercetin, though this was not discussed in any of the papers reviewed for this report. In addition to the antioxidant phenolic compounds, a Taiwanese study showed that a storage protein also exhibited antioxidant activity.

In addition to these antioxidative qualities, an acidic glycoprotein in sweet potato was identified as the compound responsible for an observed improvement in insulin sensitivity in diabetic patients.

β-carotene

According to the New Zealand Food Composition Database the cultivar Owairaka Red contains only low levels of β-carotene, only slightly more than is found in potatoes. However, those with strongly coloured flesh, such as Beauregard, contain high levels of β-carotene. The USDA database gives much higher levels of β-carotene for sweet potatoes, reflecting stronger colouration in the varieties consumed there (USDA 2006). Besides its pro-vitamin A activity, β-carotene is an effective antioxidant and may confer protection against many chronic diseases. See section 2.2.2.

Phenolic compounds

There is a huge diversity in terms of the structure of phenolics and this makes them different from other antioxidants. Several thousand natural polyphenols have been identified in plants, many of them in plant foods (Shahidi & Naczk 1995), although only a more limited number are at significant levels in most human diets. The chemical structure of polyphenols affects their biological properties: bioavailability, antioxidant activity, specific interactions with cell receptors and enzymes and other properties. (For structures of the major phenolics in kumaras see Appendix III). There has been some study of the role that kumara phenolics may play in human health, but this has mostly concerned anthocyanins in sweet potatoes with purple flesh and skins, though this research also identifies simple phenolic acids as contributing towards antioxidant activity. These appear to occur mostly in the skins of most varieties, regardless of flesh colour.

Anthocyanins are one of the various classes of flavonoids and are the pigments responsible for the red/blue/purple colours of some, though not all, fruits and vegetables. These pigments account for the reddish colours of the skin of Owairaka Red and both the skin and flesh of experimental purple varieties.

Phenolic acids

Sweet potatoes contain the hydroxycinnamic acids (HCA), caffeic and chlorogenic acid (Joseph et al. 2002; Philpott et al. 2003). These are simple phenolic acids that are widely distributed in the cell walls of plants and consequently are significant components of the human diet. They have been studied largely in relation to antioxidant activity though these have been largely *in vitro* studies and further work regarding *in vivo* effects in humans is needed before health benefits can be claimed (Kroon 1999). A New Zealand study showed that, in the Toka Toka Gold variety, the skin had greater antioxidant activity than the flesh, and this was attributed to the presence of phenolic acids (Philpott et al. 2003). Yoshimoto et al. (1999) similarly found that the outer portion of non-purple cultivars contained phenolic compounds at levels several times higher than the inner portion. Rabah et al. (2004) also observed strong radical scavenging effects in a baked sweet potato extract from the yellow-fleshed cultivar Koganesengan, which was associated with a high level of total phenolic compounds. Foley et al. (1999) demonstrated the antioxidant activity of six common HCAs, including caffeic and chlorogenic acids, in quenching the highly reactive radical, singlet oxygen.

Anthocyanins

The traditional New Zealand kumara, Owairaka Red, has skin which contains anthocyanins, though for these to be nutritionally valuable they must of course be ingested, and generally kumaras are peeled before cooking. Here in New Zealand and overseas, particularly in Japan, there is considerable research into purple fleshed cultivars, some of which contain high levels of anthocyanins (Yoshimoto et al. 1999; Philpott et al. 2003; Andersen et al. 2005). Interestingly, these vegetable anthocyanins are different from those in berries and other red/purple fruit, where anthocyanins are more commonly found. It is possible that they will have different properties and health effects. For example, a diacylated anthocyanin from a purple-fleshed cultivar had antihyperglycaemic effects in a recent animal study (Matsui et al. 2002).

Flavonoids

Although Joseph et al. (2002) listed quercetin as a component in sweet potatoes, the levels at which it was purportedly present were not given. Nor has this been mentioned by other researchers, which would suggest that levels are insignificant.

Coumarins

According to Cambie et al. (2003), sweet potatoes have also been found to contain antioxidants called coumarins, which have anti-coagulation properties and thus help prevent cardiovascular disease. In addition they may inhibit HIV replication.

Antioxidant storage proteins

A Taiwanese study has shown that the major storage proteins in two sweet potato cultivars (colours unknown) showed *in vitro* antioxidant activity (Hou et al. 2001; Hou et al. 2005). They are known to be trypsin inhibitors, compounds which in the plant protect against insect attack by preventing the digestion of protein. A group of proteins known as sporamins was identified as accounting for around 80% of total root protein and may have some anti-cancer properties (Cambie 2003).

Antidiabetic acidic glycoprotein

An extract from a white-skinned sweet potato improved insulin sensitivity in a study of diabetic patients (Ludvik et al. 2003).

3.3 Health benefits

3.3.1 Core nutrients

The roles of core nutrients are outlined in Table 4, Appendix II.

3.3.2 Phytochemicals

For the health benefits of β-carotene, see section 2.3.2.

Phenolic compounds

A study by Rabah et al. (2004) showed a number of anti-cancer effects of a baked extract of a yellow-fleshed Japanese variety, Koganesengan. These included cytotoxicity against human cancer cells, suppressed TPA (12-O-tetradecanoyl-phorbol-13-acetate) -induced transformation in mouse skin, induced apoptosis in human leukaemia cells, and free radical scavenging activity *in vitro*. It was further shown that high levels of phenolic compounds in baked sweet potato extracts correlated with antioxidant activity. The authors hypothesised that these anti-cancer activities might also prevent other chronic diseases such as atherosclerosis, Alzheimer's and Parkinson's disease and arthritis. This study, however, did not identify the individual active compounds, but did demonstrate that the components were not affected by heat treatment/cooking.

Yoshimoto et al. (1999) cite Japanese studies which demonstrate various health benefits of sweet potatoes, including antioxidant activity and a reduction of liver injury from carbon tetrachloride in rats and humans. In their study, antimutagenic components were found in the outer portions (skin) of all coloured sweet potatoes, but were particularly strong in a newer purple cultivar, Ayamurasaki. In Ayamurasaki this appeared to be related to the high concentration of anthocyanins, which was present in both skins and flesh. In the non-purple forms, however, anitmutagenic components were present only in the skins and were attributed to the presence of other phenolic compounds.

Information on the additional phytochemicals present in Owairaka Red and Toka Toka Gold does not appear to be available. It is hard to verify which cultivars were used in the USDA database, but it is reasonable to assume that Beauregard-type cultivars comprised at least part of the samples analysed.

Anthocyanins

Anthocyanins have strong antioxidant activity and, in blueberries particularly, research has focused on their ability to protect the brain against the effects of ageing. In addition, they are believed to lower the risk of some cancers and help prevent cardiovascular disease by preventing inflammation and the oxidation of LDL cholesterol (Joseph et al. 2002; Philpott et al. 2004)

As mentioned earlier, Owairaka Red contains anthocyanins in the skin, but not the flesh. However with the growth of interest in functional foods, there has been much interest in purple varieties containing anthocyanins. Breeding programmes are currently taking place in New Zealand and also in Japan. Research here has shown high levels of antioxidant activity and anthocyanins in purple kumaras, attributed both to the presence of anthocyanins and hydroxycinnamic acids (Philpott et al. 2003; Philpott et al. 2004). Similarly, the authors of an Australian study attributed the observed antimutagenic and antiproliferative effects of a purple cultivar to be related to both anthocyanins, particularly the cyanidin-type pigments and simple phenolic acids (Konczak-Islam et al. 2003).

3.4 Factors affecting health benefits

3.4.1 Cultivar

As already discussed, the many differences in terms of cultivar colour influence which phytochemicals are present.

3.4.2 Cooking

Since kumara is usually cooked before eating, Philpott et al. (2003) studied the effects of various cooking methods upon antioxidant activity in the skin and flesh fractions of Toka Toka Gold and a new purple variety. Antioxidant activity in the flesh of Toka Toka Gold was low and did not alter significantly when baked, boiled or microwaved. However, the antioxidative activity of the skins was much higher and decreased significantly when both baked and boiled, but not when microwaved. Similarly the antioxidant activity in the flesh of the purple cultivar, which was higher than that of Toka Toka Gold, did not alter significantly with cooking, but that of the skins decreased with baking and boiling and actually increased with microwaving.

3.4.3 Bioavailability

Carotenoids

The bioavailability of carotenoids, including β-carotene has been discussed in section 2.4.4.

Phenolic compounds

There have been few studies on the bioavailability of hydroxycinnamic acids, and none specifically examining those in sweet potato. However, in two studies reviewing the bioavailability of dietary polyphenols, phenolic acids appeared to be 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.

3.5 Quotes and trivia

- The Bill & Melinda Gates Foundation has made a US$6 million grant to introduce a nutritionally improved, staple-food orange-fleshed sweet potato into the diets of the undernourished in East Africa (CIP 2006). It is hoped that this will address vitamin A deficiency, the major cause of blindness for many children in poorer countries. Although sweet potato is a dietary mainstay in many such nations, the common variety is pale skinned with white flesh, and delivers negligible amounts of β-carotene.
- In the densely populated, infertile plains of eastern Africa, sweet potato is called *cilera abana*, "protector of the children", alluding to its importance in sustaining the population in times of famine.
- American recipes may refer to "yam", which is actually an orange-fleshed sweet potato variety, like Beauregard. True yams are an entirely different vegetable, but the term was coined in the 1950s when the orange-fleshed variety was introduced, in order to differentiate it from the paler cream-coloured variety that predominated in the market at that time.
- The Japanese have been at the forefront of much sweet potato research, driven by increasing interest in health and functional foods as a way to improved health. In Japan, sweet potatoes are used for a variety of purposes – in bread and noodles, as an ingredient in an alcoholic drink, and as colourants for the food and cosmetic industries.
- Baking produces a sweeter cooked product than microwaving. This is because the longer time required to bake the potato means more conversion of starch to the sugar, maltose (S. Lewthwaite, pers. comm.).
- Said Aristotle unto Plato

  "Have another sweet potato?"

  Said Plato unto Aristotle,

  "Thank you, I prefer the bottle."

  Owen Wister (1860-1938) American novelist

4 *Beetroot* (Beta vulgaris)

4.1 Introduction

Beetroot is an unusual vegetable in many ways. Firstly, it is one of the few vegetables that are consumed pickled more frequently than in other forms. Secondly, its vibrant colour is conferred by pigments that occur in no other common vegetable. Thirdly, all parts of this vegetable can be eaten, although nowadays particular cultivars have been developed for their roots and others for their stems and foliage.

There are four main types of beet: red or garden beet (beetroot), Swiss chard (eaten for its leaves, e.g. silver beet), sugar beet (grown for its sugar content) and fodder beet, such as mangelwurzel (stock feed). Beetroot is the focus of this report; silver beet will be covered in a subsequent report.

The red beet that we know as beetroot is relatively modern, dating back to the 17th century. However beets can be white, golden or multicoloured. Beets lose their colour readily when cut as their colour pigments are contained in cell vacuoles, which are empty spaces in the cells and thus are easily ruptured if the cell is damaged.

Interestingly, diverse uses for this vegetable have not evolved. In New Zealand beetroot is commonly consumed pickled with summer salads or incorporated into sandwiches or hamburgers. More recently beetroot has been roasted along with other root and starchy vegetables.

4.2 Composition

Given its kinship with sugar beet, it is not surprising that beetroot is one of the sweetest vegetables, containing more sugar than carrots or sweet corn. Interestingly, one of the few vegetables that surpasses it for sweetness is the parsnip.

See section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under “Factors affecting health benefits”.

4.2.1 Core nutrients

The major nutrients in beetroot are folate and potassium, though it also provides some vitamin C and iron.

See Appendix I for full data from the New Zealand FOODFiles database.

4.2.2 Other phytochemicals

Betalains

As mentioned earlier, beetroot are almost unique amongst vegetables in containing a group of red pigments called betalains. Although visually similar to anthocyanins, these compounds are mutually exclusive, never occurring together in the same plant. It has been assumed that they perform similar functions within the plant, attracting pollinators and seed dispersers as well as having physiological roles. Thus they may protect the plant against oxidative damage, and act as transport vehicles for monosaccharides, and as osmotic regulators. Pigments can also be the result of stress in the plant, such as caused by drought or low temperatures or wounding. For underground plant components, colouration is thought to be associated with increased pathogen and viral resistance (Stintzing & Carle 2004).

These compounds comprise betacyanins, which are red to violet in colour, and betaxanthins, which are yellow. The major betalain in beetroot is a betacyanin called betanin (Kanner et al. 2001), a betanidin 5-*0*-*β*-glucoside which contains a phenolic and a cyclic amine group (Kanner et al. 2001) (see structure in Appendix III). However, they also contain some betaxanthins, at levels which vary according on the cultivar (Cai et al. 2005).

Betalains are water soluble and are generally located in cell vacuoles (Stintzing & Carle 2004).

4.3 Health benefits

4.3.1 Core nutrients

The roles of core nutrients are outlined in Table 4 in Appendix II.

4.3.2 Phytochemicals

Because they are relatively rare, and beetroot are not a particularly popular food, there has been little research either on beetroots themselves or on their betalains.

Most research on beetroot and betalains has focused on antioxidant activity. According to a recent review, findings from various studies ranked beetroot among the 10 most potent vegetables in terms of antioxidant capacity, with other studies agreeing that betalains were at least in part responsible for this (Stintzing & Carle 2004). A study investigating the radical scavenging capacity of different betalains found that structural features were related to antioxidant potential (Cai et al. 2005). In betaxanthins, radical scavenging increased with increasing numbers of hydroxyl and imino residues and in betacyanins, acylation increased antioxidant potential, while glycosylation reduced activity. Also 6-*0*-glycosylated structures had stronger antioxidant activity than did 5-*0*-glycosylated betacyanins.

An early animal study showed that beetroot had a significant inhibitory effect upon skin and lung cancer in mice (Kapadia et al. 1996, cited in Stintzing & Carle 2004). It has been postulated that antioxidant activity may be responsible for preventing many chronic diseases, including cancer, and this has been the focus of most subsequent studies. Kanner et al. (2001) undertook one of the earliest studies investigating antioxidant capacity and mechanism, and physiological activity of the major beet betalains, betanin and betanidin. Both betanin and betanidin inhibited lipid peroxidation of membranes and performed better than known antioxidants, catechin and α-tocopherol. It was proposed that this resulted from interaction with peroxyl and alkoxyl radicals. Both betacyanins were also found to act as very effective antioxidants in a model using linoleate peroxidised by metmyoglobin, and measured by four different parameters of oxidation; accumulation of conjugated dienes, oxidative products, heme decomposition and pigment decolouration. Interestingly, although both betanin and betanidin inhibited lipid peroxidation and heme decomposition at similarly low concentrations, differing effects upon pigment decolouration suggested differing mechanisms of protection. This study also demonstrated the bioavailability of these betalains, though the study population was small (n=4).

Antioxidant activity in terms of radical scavenging was also the focus of a very recent study, which investigated the behaviour and stability of betalains at differing pH levels, bile salt concentrations and in an *in vitro* gastrointestinal tract model (Pavlov et al. 2005). It was shown that these compounds were stable under pH3 and at bile salts concentrations of up to

4%. In the simulated gastrointestinal tract, radical scavenging activity decreased, though this was at a level similar to that of the widely used synthetic antioxidant, butylated hydroxytoluene (BHT).

Rey et al. (2005) further investigated the latter concept, using an assortment of natural plant extracts to reduce lipid peroxidation in cooked pork patties. Extracts from beetroot peel were shown to have inhibitory effects similar to the well known natural antioxidant, quercetin.

Radical scavenging can be regarded as direct antioxidant activity, but there are also food compounds which act as indirect antioxidants. These include so-called Phase 2 enzyme inducers. Broccoli and a derivative of one of its constituent compounds, sulforaphane, is famous as a chemoprotective agent for this reason. Phase 2 enzymes have been found to detoxify potential carcinogens, induce apoptosis (cell suicide) in cancer cells, and inhibit harmful Phase 1 enzymes. Both direct and indirect antioxidant activity in differently coloured beets, including a highly pigmented red cultivar, was the focus of part of the research conducted by Wettasinghe et al. (2002). Overall, they found that the highly pigmented sample performed best in both aqueous and ethanol extracts when assessed by a raft of different antioxidant assays. The red and highly pigmented red cultivars also showed higher quinine reductase (a Phase 2 enzyme) inducing capacity than did the white and orange cultivars, leading to the hypothesis that betalains may also be responsible for this beneficial property. This was in contrast, however, to an early study by Prochaska et al. (1992) (cited in Wettasinghe et al. 2002), where beetroot were rated among the least effective phase 2 enzyme inducers. Wettasinghe et al. (2002) suggested, however, that this could be explained by the use of acetonitrile as an extractant.

4.4 Factors affecting health benefits

4.4.1 Bioavailability

As mentioned above, in their small study Kanner et al. (2001) also investigated the bioavailability of beet betalains in four volunteers ingesting beetroot juice. Although absorption was low, it was similar to that of flavonoids and the authors postulated that, like flavonoids, betalains may act at low concentrations and very specifically. Furthermore, since 99% of these compounds remained in the gut area, it was thought possible that they might exert a localised effect, preventing oxidative stress that could otherwise lead to many of the chronic diseases. As cationised antioxidants, their affinity for membranes could heighten their effectiveness.

Tesoriere et al. (2004) investigated the bioavailability of betalains from cactus pear pulp. The major betalains in cactus pear juice are betanin and indicaxanthin. This study was also small (n=8), and demonstrated the bioavailability of betalains through their identification in urine and plasma, including their incorporation into low density lipoprotein (LDL). Consistent with findings from other studies showing protection of lipids from oxidation, LDL isolated after ingestion of the fruit pulp showed more resistance to oxidative injury than did pre-ingestion LDL.

4.5 Processing

Processing generally results in some nutritive losses, but several studies, such as those on tomatoes and carotenoids, have shown increased nutritive value after heat processing or cooking. Despite losses of vitamin C, folate and colour, Jiratanan & Liu (2004) found that the antioxidant activity of processed beetroot remained virtually unchanged and that the phenolic content slightly increased.

4.6 Quotes and trivia

- In an acid environment the colour pigments are more stable than at a higher pH. This is why pickled beetroot has such good colour. At an alkaline pH the colour dissipates to a brownish purple.
- Sugar beet has been bred to have up to 15-20% sucrose and weigh 1-2 kg. They are white in colour.
- In a condition known as beeturia, between 10 and 14% of people cannot break down beetroot betalains and these are subsequently excreted, turning urine pink (Stintzing & Carle 2004).

5 *Parsnips* (Pasinaca sativa)

5.1 Introduction

Given that parsnips are hardly a common vegetable these days, it is hard to believe that they were once the staple that potatoes are now. Until Columbus brought back potatoes to Europe, parsnips were a major source of starch, besides providing sweetness in the diet. In fact parsnips are amongst the sweetest of vegetables and were used as a sweetener before the sugar beet industry in the 19th century (Innvista.com, 2006). The juices were evaporated and the residue used as honey – much as we would use golden syrup today.

It is popularly thought that the best parsnips come from locations where winters are cold, and in fact there is some basis for this belief. Cold temperatures encourage the conversion of starches to sugars, though these days this can also be achieved through storing the parsnips at near freezing temperatures for some time.

Commercially available parsnips in New Zealand tend to be roughly carrot shaped, but can in fact also be bulbous or wedge-shaped. Their flesh is generally off white, but can be pale yellow.

5.2 Composition

Containing little in the way of pigmentation, it is obvious that parsnips do not contain the phytochemicals associated with colour. And, as they are a less popular vegetable, they have received relatively little research attention.

See section 2.2 regarding the large number of possible factors that can influence composition. Where data are available, the extent and effect of this variation will be discussed later in this section, under “Factors affecting health benefits”.

5.2.1 *Core nutrients*

Parsnips are a good source of fibre and potassium and also contribute some folate, calcium, iron, magnesium.

Interestingly, parsnips are one of the sweetest vegetables, though not as sweet as many fruits.

Table 2: Sugar content of various vegetables (Athar et al. 2003).

Vegetable	Total available sugars
Onions	8
Parsnips	8.9
Sweetcorn	1.5
Carrots	3.25
Beetroot	5.9

See Appendix I for full data from the New Zealand FOODFiles database.

5.2.2 *Other phytochemicals*

As mentioned earlier, although falcarinol is mostly associated with carrots, other vegetables, particularly parsnips, may in fact contain higher levels of this compound according to one recent study.

*Table 3: Falcarinol content in different vegetables of the Apiaceae family (*adapted from Zidorn et al. 2005).

Vegetable	Falcarinol (mg/g freeze dried plant material)
Celery 1	0.23
Celery 2	1.62
Carrot	0.29
Fennel	0.04
Parsnip	1.60
Parsley	not detectable

See section 2.2.2, Falcarinol, for further detail.

A Hungarian study showed that parsnips also contained a high level of the flavonoid kaempferol (Lombaert et al. 2001). However, none was listed for parsnips in the USDA flavonoid database (USDA 2003).

5.3 Health benefits

5.3.1 Core nutrients

The roles of core nutrients are outlined in Table 4, Appendix II.

5.3.2 Phytochemicals

To date, falcarinol appears to be the only phytochemical in parsnips to have received reasonable scientific study. This has already been covered under falcarinol in section 2.3.2.

5.4 Factors affecting health benefits

5.4.1 Bioavailability

See section 2.4.4 regarding the bioavailability of falcarinol.

5.5 Quotes and trivia

- "Fine words butter no parsnips" (English proverb)
- Buttered parsnips were commonly eaten with salt fish during Lent (Grieve 1931).
- According to Pliny, the emperor Tiberius had such a fondness for parsnips that he had them especially brought to Rome from the banks of the Rhine, where they were most successfully cultivated.

6 *Taro* (Colocasia esculenta)

6.1 Introduction

The taro plant is a member of the calla lily family and is technically a corm. It is a dietary staple in the Pacific Islands, where the leaves as well as the tubers are utilised. It is also used in Asian and Caribbean cuisine. Taro is thought to be a very old crop, originating in India and is thought to have been cultivated for over 10 000 years, longer than wheat or barley. It was mentioned by ancient Roman and Greek historians and was an important crop in the Mediterranean long before potatoes.

Taro contains calcium oxalates in the form of needle-shaped crystals. This causes irritation and a burning sensation if the vegetable is handled or eaten raw. Consequently the use of gloves is sometimes suggested when preparing taro and long cooking is necessary to destroy these compounds.

6.2 Composition

There is not a lot known about taro because it has not been extensively studied. The presence of anthocyanins has been recorded by some researchers (Cambie & Ash 1994), though it is highly unlikely that they are present in New Zealand taro given their colour.

6.3 Core nutrients

Taro roots are a major source of starch and consequently are one of the highest vegetable sources of energy. They are a very good source of fibre and also contain potassium, a little vitamin C and some zinc, thiamin and folate.

See Appendix 1 for full data from the New Zealand FOODFiles database.

6.3.1 Other phytochemicals

Whilst varieties of coloured-fleshed taro do exist, that sold in New Zealand generally has a whitish-grey flesh and therefore contains little in the way of antioxidant pigmentation.

As mentioned above, taro also contain the irritant calcium oxalate, which prevents their being consumed raw or lightly cooked, but which is broken down if the taro is well cooked.

6.4 Health benefits

The roles of core nutrients are outlined in Table 4, Appendix II.

A South African study of traditional foods showed that a boiled extract of taro, or “indumbe” as it is colloquially known, had very high antioxidant activity according to an assay measuring lipid peroxidation (Lindsey et al. 2002).

Poi, a cooked fermented paste made from taro, was the subject of research which examined its effect upon gut flora and potential use as a probiotic. However, the study found that it had no effect upon gastrointestinal bacterial counts, though the authors concluded with the observation that “sour poi” (3-4 days old) might have a greater effect than “fresh poi” which was only 1-2 days old (Brown et al. 2005).

A study of the glycaemic index (GI) of commonly eaten Caribbean foods established that taro, or “dasheen” as it is known locally, had a relatively high glycaemic index of around 76. Crushing the material after boiling and prior to consumption did not appear to have any effect (Ramdath et al. 2004).

6.5 Quotes and trivia

- Taro has been called the “potato of the humid tropics”.

7 *Yams* (Oxalis tuberosa)

7.1 Introduction

Like potato, the yam, or oca as it is also known, originates from South America. Interestingly, this vegetable does not appear to have been widely adopted and according to a National Research Council (1989) report cited in Flores et al. (2002), besides its native habitat, is only cultivated in New Zealand, Australia and Mexico.

7.2 Composition

According to Flores et al. (2002), besides being a prolific and adaptable plant, oca compare favourably with potatoes in terms of nutrition. New Zealand data however, suggest that yams are only moderately nutritious. Major food components include some vitamin A, vitamin B6 and fibre, and small amounts of riboflavin, thiamine and potassium.

See Appendix 1 for full data from the New Zealand FOODFiles database.

The almost fluorescent colours of yams, which are now available as both red and yellow cultivars, show the presence of carotenoids (yellow colours; see Section 2.2.2) and anthocyanins (red skins and specks within the flesh). The Concise New Zealand Food Composition Tables (2003) show that whilst carotenoids levels are not high, they contain more than some other yellow vegetables such as corn.

Yams also contain oxalates, the compounds that are partially responsible for the slightly tangy taste of yams. Oxalates are produced by the plant for protection against insect attack, but in humans can interfere with the absorption of calcium and promote the formation of kidney stones. However, unlike other oxalate-containing plants such as rhubarb and spinach, yams are unusual in containing only the soluble form of oxalate. Boiling or steaming are the cooking methods most recommended for minimising oxalate levels; baking appeared to increase oxalate content (Albihn & Savage 2001).

7.3 Health benefits

The roles of core nutrients are outlined in Table 4, Appendix II.

See section 2.2.2 for more on carotenoids and 3.2.2 for anthocyanins.

Very little research has taken place regarding taro, and specific information on its nutritional benefits for humans has not been found.

7.4 Quotes and trivia

- Historic accounts suggest that oca was a major Andean staple prior to Columbus, second only to potato.
- The crop requires minimal production inputs, grows on marginal soil and can flourish at high altitudes. A single oca plant can produce up to 4 kg of crop.

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Appendices

Appendix I Nutritional information on assorted root vegetables (per 100 g edible portion) from FOODFiles 2004

X308~Yam,flesh,raw,South Island		
Water	g	88.8
Energy	kcal	39
Protein	g	1.25
Total fat	g	0.14
Carbohydrate, available	g	8.25
Dietary fibre (Englyst, 1988)	g	2.25
Ash	g	0.65
Sodium	mg	2.6
Phosphorus	mg	29
Potassium	mg	270
Calcium	mg	5.4
Iron	mg	T
Beta-carotene equivalents	µg	525
Total vitamin A equivalents	µg	87.5
Thiamin	mg	0.07
Riboflavin	mg	0.07
Niacin	mg	0.48
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	0.1
Total monounsaturated fatty acids	g	0.006
Total polyunsaturated fatty acids	g	0.1
Dry matter	g	11.2
Total nitrogen	g	0.2
Glucose	g	0.75
Fructose	g	0.75
Sucrose	g	1.8
Lactose	g	T
Maltose	g	T
Total available sugars	g	3.3
Starch	g	4.95
Alcohol	g	0
Total niacin equivalents	mg	0.78
Soluble non-starch polysaccharides	g	1.09
Insoluble non-starch polysaccharides	g	1.17
Energy	kJ	162
Magnesium	mg	12
Manganese	µg	80
Copper	mg	0.07
Zinc	mg	0.17
Selenium	µg	T
Retinol	µg	0
Potential niacin from tryptophan	mg	0.3
Vitamin B6	mg	0.26
Folate, total	µg	15.5
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	T

T = trace

X49~ Kumara Owairaka Red flesh		
Water	g	71.6
Energy	kcal	108
Protein	g	1.25
Total fat	g	0.21
Carbohydrate, available	g	25.3
Dietary fibre (Englyst, 1988)	g	2.56
Ash	g	1.07
Sodium	mg	28
Phosphorus	mg	44
Potassium	mg	506
Calcium	mg	16
Iron	mg	0.53
Beta-carotene equivalents	µg	118
Total vitamin A equivalents	µg	20
Thiamin	mg	0.1
Riboflavin	mg	0.07
Niacin	mg	2.2
Vitamin C	mg	32.3
Cholesterol	mg	0
Total saturated fatty acids	g	0.069
Total monounsaturated fatty acids	g	0.012
Total polyunsaturated fatty acids	g	0.09
Dry matter	g	28.4
Total nitrogen	g	0.2
Glucose	g	0.55
Fructose	g	0.52
Sucrose	g	2.79
Lactose	g	0
Maltose	g	0
Total available sugars	g	3.9
Starch	g	21.4
Alcohol	g	0
Total niacin equivalents	mg	2.5
Soluble non-starch polysaccharides	g	1.47
Insoluble non-starch polysaccharides	g	1.09
Energy	kJ	446
Magnesium	mg	21
Manganese	µg	753
Copper	mg	0.11
Zinc	mg	0.21
Selenium	µg	0.122
Retinol	µg	0
Potential niacin from tryptophan	mg	0.3
Vitamin B6	mg	0.11
Folate, total	µg	15
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	4.6

T = trace

X18~ Beetroot,flesh,raw ~Beta vulgaris		
Water	g	87.1
Energy	kcal	30
Protein	g	1.3
Total fat	g	0.12
Carbohydrate, available	g	5.9
Dietary fibre (Englyst, 1988)	g	1.9
Ash	g	0.9
Sodium	mg	84
Phosphorus	mg	32
Potassium	mg	300
Calcium	mg	25
Iron	mg	0.4
Beta-carotene equivalents	µg	15
Total vitamin A equivalents	µg	3
Thiamin	mg	0.03
Riboflavin	mg	0.05
Niacin	mg	0.1
Vitamin C	mg	6
Cholesterol	mg	0
Total saturated fatty acids	g	0.021
Total monounsaturated fatty acids	g	0.026
Total polyunsaturated fatty acids	g	0.049
Dry matter	g	12.9
Total nitrogen	g	0.21
Glucose	g	0.2
Fructose	g	T
Sucrose	g	5.7
Lactose	g	0
Maltose	g	0
Total available sugars	g	5.9
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	0.3
Soluble non-starch polysaccharides	g	0.9
Insoluble non-starch polysaccharides	g	0.9
Energy	kJ	124
Magnesium	mg	15
Manganese	µg	358
Copper	mg	0.07
Zinc	mg	0.4
Selenium	µg	0.27
Retinol	µg	0
Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.05
Folate, total	µg	90
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.05

T = trace

X70~parsnip, flesh, raw~ Pastinaca sativa		
Water	g	81.9
Energy	kcal	54
Protein	g	1.75
Total fat	g	0.2
Carbohydrate, available	g	11.3
Dietary fibre (Englyst, 1988)	g	4
Ash	g	1
Sodium	mg	17.6
Phosphorus	mg	71.6
Potassium	mg	353
Calcium	mg	57
Iron	mg	0.62
Beta-carotene equivalents	µg	33
Total vitamin A equivalents	µg	5.5
Thiamin	mg	0.104
Riboflavin	mg	0.083
Niacin	mg	1.04
Vitamin C	mg	15.6
Cholesterol	mg	0
Total saturated fatty acids	g	0.038
Total monounsaturated fatty acids	g	0.086
Total polyunsaturated fatty acids	g	0.036
Dry matter	g	18.2
Total nitrogen	g	0.28
Glucose	g	1.5
Fructose	g	1.5
Sucrose	g	5.9
Lactose	g	0
Maltose	g	0
Total available sugars	g	8.9
Starch	g	2.35
Alcohol	g	0
Total niacin equivalents	mg	1.4
Soluble non-starch polysaccharides	g	2.3
Insoluble non-starch polysaccharides	g	1.7
Energy	kJ	223
Magnesium	mg	22.8
Manganese	µg	261
Copper	mg	0.797
Zinc	mg	0.44
Selenium	µg	0.236
Retinol	µg	0
Potential niacin from tryptophan	mg	0.4
Vitamin B6	mg	0.104
Folate, total	µg	69.5
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	1.04

T = trace

X161~Taro,combined cultivars,corms,raw~Colocasia esculenta		
Water	g	68.1
Energy	kcal	114
Protein	g	1.34
Total fat	g	0.11
Carbohydrate, available	g	26.8
Dietary fibre (Englyst, 1988)	g	2.5
Ash	g	1.91
Sodium	mg	4.2
Phosphorus	mg	61.5
Potassium	mg	489
Calcium	mg	20.3
Iron	mg	0.44
Beta-carotene equivalents	µg	36
Total vitamin A equivalents	µg	6
Thiamin	mg	0.028
Riboflavin	mg	0.029
Niacin	mg	0.78
Vitamin C	mg	14.3
Cholesterol	mg	0
Total saturated fatty acids	g	0.026
Total monounsaturated fatty acids	g	0.01
Total polyunsaturated fatty acids	g	0.052
Dry matter	g	31.9
Total nitrogen	g	0.21
Glucose	g	0.04
Fructose	g	0.06
Sucrose	g	0.56
Lactose	g	0
Maltose	g	0.06
Total available sugars	g	0.7
Starch	g	26.1
Alcohol	g	0
Total niacin equivalents	mg	1.04
Soluble non-starch polysaccharides	g	1.4
Insoluble non-starch polysaccharides	g	1
Energy	kJ	469
Magnesium	mg	71
Manganese	µg	255
Copper	mg	0.195
Zinc	mg	2.06
Selenium	µg	0.2
Retinol	µg	0
Potential niacin from tryptophan	mg	0.26
Vitamin B6	mg	0.08
Folate, total	µg	22.2
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	3

T = trace

X308~Yam,flesh,raw,South Island		
Water	g	88.8
Energy	kcal	39
Protein	g	1.25
Total fat	g	0.14
Carbohydrate, available	g	8.25
Dietary fibre (Englyst, 1988)	g	2.25
Ash	g	0.65
Sodium	mg	2.6
Phosphorus	mg	29
Potassium	mg	270
Calcium	mg	5.4
Iron	mg	T
Beta-carotene equivalents	µg	525
Total vitamin A equivalents	µg	87.5
Thiamin	mg	0.07
Riboflavin	mg	0.07
Niacin	mg	0.48
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	0.1
Total monounsaturated fatty acids	g	0.006
Total polyunsaturated fatty acids	g	0.1
Dry matter	g	11.2
Total nitrogen	g	0.2
Glucose	g	0.75
Fructose	g	0.75
Sucrose	g	1.8
Lactose	g	T
Maltose	g	T
Total available sugars	g	3.3
Starch	g	4.95
Alcohol	g	0
Total niacin equivalents	mg	0.78
Soluble non-starch polysaccharides	g	1.09
Insoluble non-starch polysaccharides	g	1.17
Energy	kJ	162
Magnesium	mg	12
Manganese	µg	80
Copper	mg	0.07
Zinc	mg	0.17
Selenium	µg	T
Retinol	µg	0
Potential niacin from tryptophan	mg	0.3
Vitamin B6	mg	0.26
Folate, total	µg	15.5
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	T

T = trace

Appendix II Activities of Vitamins and Minerals

(Adapted from misc.medscape.com/pi/editorial/clinupdates/2004/3341/table.doc) and http://www.bupa.co.uk/health_information/html/healthy_living/lifestyle/exercise/diet_exercise/vitamins.html)

Name	Major function
Vitamin A Retinol (animal origin) Carotenoids (plant origin, converted to retinol in the body) Note: Retinol Equivalents (RE) 1 RE =1 mcg retinol or 6 mcg beta-carotene 1IU = 0.3 mcg or 3.33 mcg = 1 mcg retinol = 1RE	Important for normal vision and eye health Involved in gene expression, embryonic development and growth and health of new cells Aids immune function May protect against epithelial cancers and atherosclerosis
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
Vitamin C Ascorbic acid	Neccesary for healthy connective tissues – tendons, ligaments, cartilage, wound healing and healthy teeth Assists in iron absorption A protective antioxidant – may protect against certain cancers Involved in hormone and neurotransmitter synthesis
Thiamin vitamin B_1 Aneurin	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells
Riboflavin vitamin B_2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein

Name	Major function
Niacin vitamin B_3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown Reduces LDL cholesterol and increases HDL cholesterol
Vitamin B_6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis, haemoglobin synthesis. Involved in neuronal excitation Reduces blood homocysteine levels Prevents megaloblastic anemia
Vitamin B_{12} Cobalamin	Coenzyme in DNA synthesis with folate. Synthesis and maintenance of myelin nerve sheaths Involved in the formation of red blood cells Reduces blood homocysteine levels Prevents pernicious anemia
Folate Generic term for large group of compounds including folic acid and pterylpolyglut-amates	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
Biotin	Important for normal growth and body function Involved in metabolism of food for energy Coenzyme in synthesis of fat, glycogen, and amino acids
Pantothenic acid	Coenzyme in fatty acid metabolism and synthesis of some hormones Maintenance and repair of cell tissues
Sodium	Major ion of extracellular fluid Role in water, pH, and electrolyte regulation Role in nerve impulse transmission and muscle contraction

Name	Major function
Potassium	Major ion of intracellular fluid Maintains water, electrolyte and pH balances Role in cell membrane transfer and nerve impulse transmission
Chloride	Major ion of extracellular fluid Participates in acid production in the stomach as component of gastric hydrochloric acid Maintains pH balance Aids 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 constuent of many essential compounds in body and processes
Calcium	Structural component of bones and teeth Role in cellular processes, muscle contraction, blood clotting, enzyme activation, nerve function
Magnesium	Component of bones Role in cellular energy transfer Role in enzyme, nerve, heart functions, and protein synthesis
Iron	Component of haemoglobin and myoglobin in blood, needed for oxygen transport Role in cellular function and respiration
Iodine	Thyroid hormone production
Chromium	Assists in insulin system for use of blood glucose

Name	Major function
Cobalt	Component of vitamin B_{12}
Copper	Component of many enzymes Many functions – blood and bone formation, production of pigment melanin Aids in utilisation of iron stores Role in neurotransmitters synthesis
Fluoride	Helps prevent tooth decay
Manganese	Part of many essential enzymes Aids in brain function, bone structure, growth, urea synthesis, glucose and lipid metabolism
Molybdenum	Aids in enzyme activity and metabolism
Selenium	Important role in body's antioxidant defense system as component of key enzymes May help prevent cancer and cardiovascular disease
Zinc	Major role in immune system Required for numerous enzymes involved in growth and repair Involved in sexual maturation Role in taste, smell functions

Note: This table is compiled and adapted from: Groff JL, Gropper SS. Advanced nutrition and human metabolism. 3rd ed. Belmont, CA: Wadsworth/Thomson Learning 1999.; Wardlaw GM. Perspectives in Nutrition. 4th ed. Boston, Mass: WCB/McGraw Hill, 1999; and Dietary Reference Intakes: Vitamins Available at: www.nap.edu.

Appendix III Chemical structures

Chemical structures of major phytochemicals in root vegetables and tubers

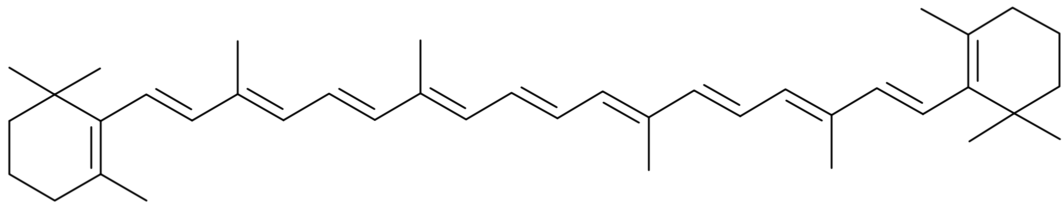

Figure 1: β-carotene

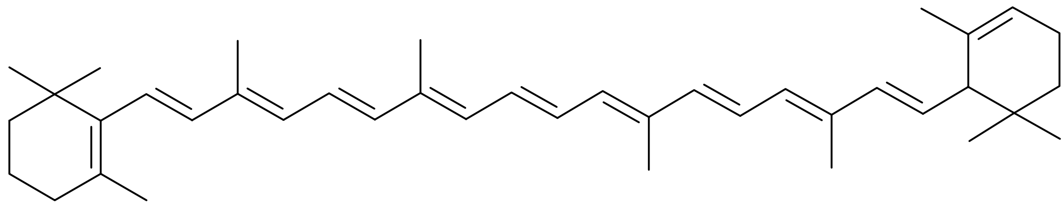

Figure 2: α-carotene

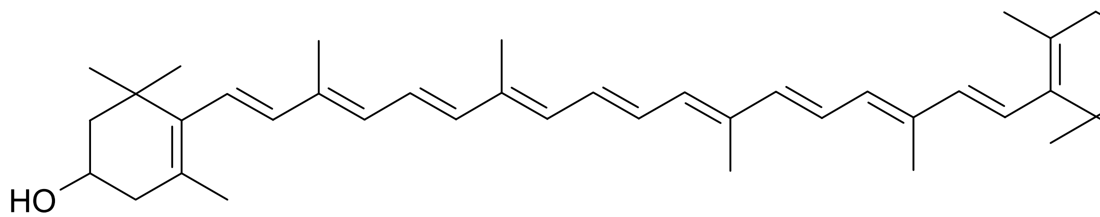

Figure 3: β-cryptoxanthin

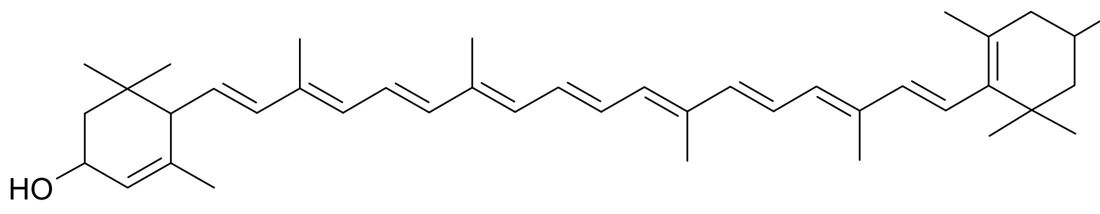

Figure 4: Lutein

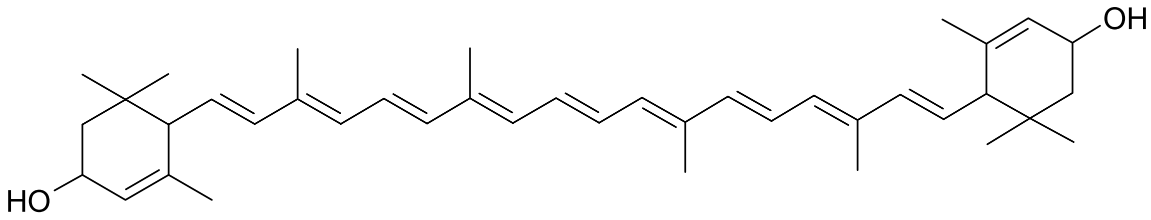

Figure 5: Zeaxanthin

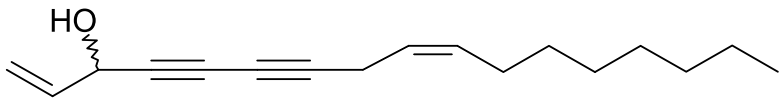

Figure 6: Falcarinol

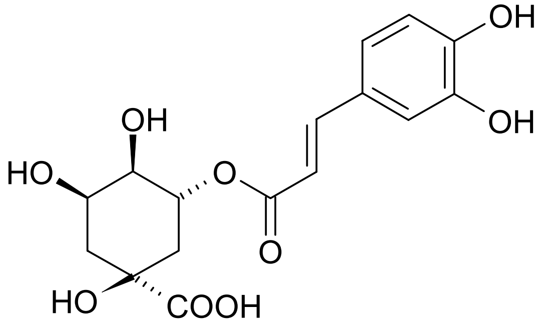

Figure 7: Chlorogenic acid

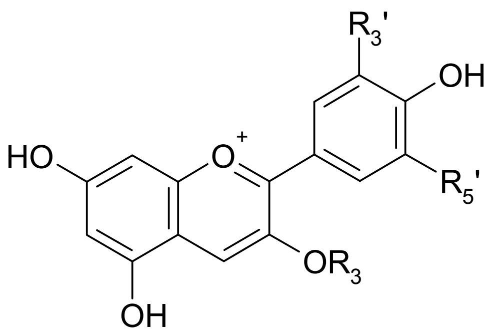

Figure 8: Basic anthocyanin

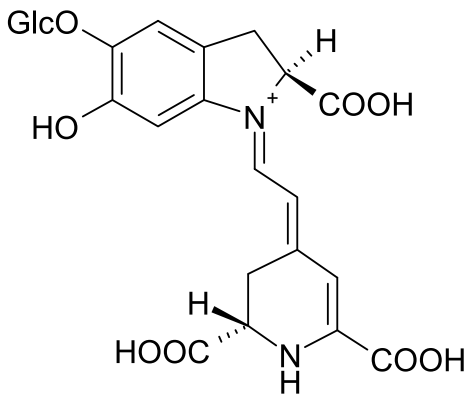

Figure 9: Betanin

Crop & Food Research Confidential Report No. 1618

Nutritional attributes of* Brassica *vegetables

L J Hedges & C E Lister

May 2006

A report prepared for
Horticulture New Zealand

Copy 16 of 16

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

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

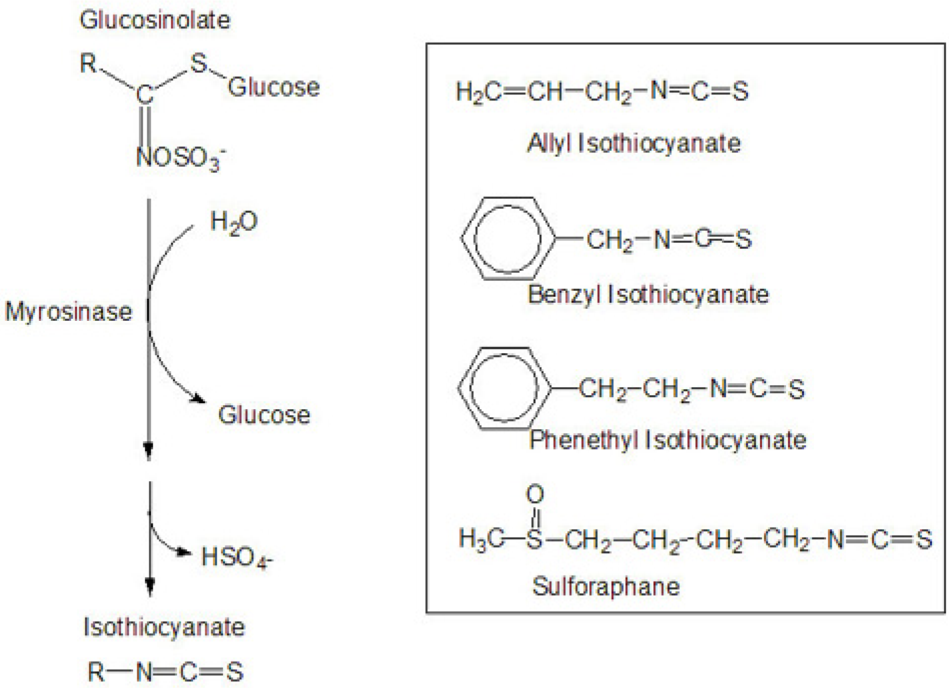

Figure 1: Myrosinase-catalysed glucosinolate hydrolysis and chemical structures of selected isothiocyanates (Higdon 2005).

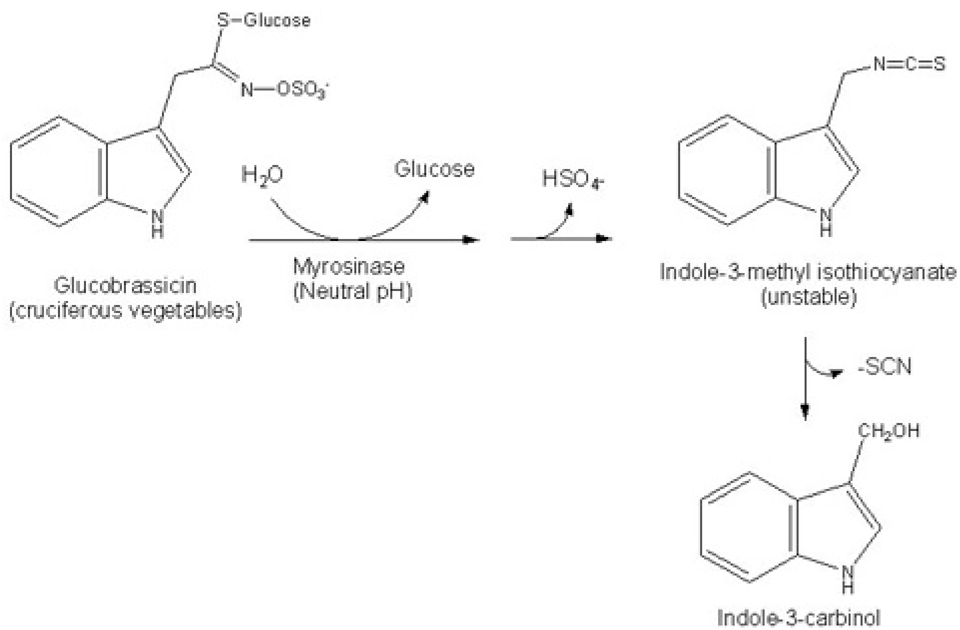

Figure 2: Formation of indole-3-carbinol (Higdon 2005).

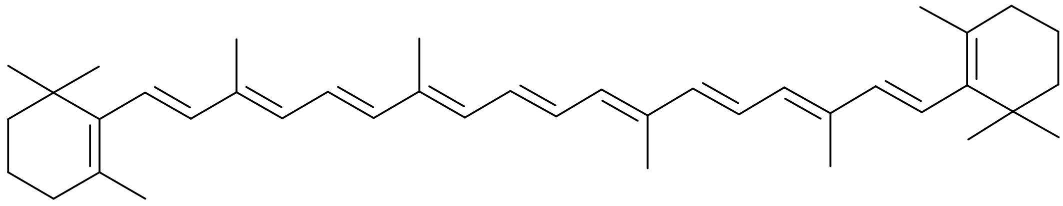

Figure 3: β-carotene.

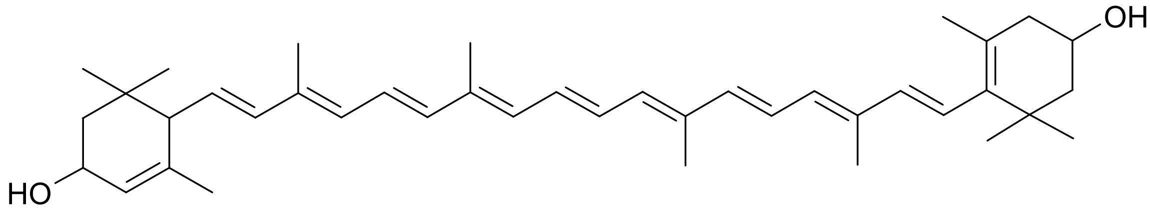

Figure 4: Lutein.

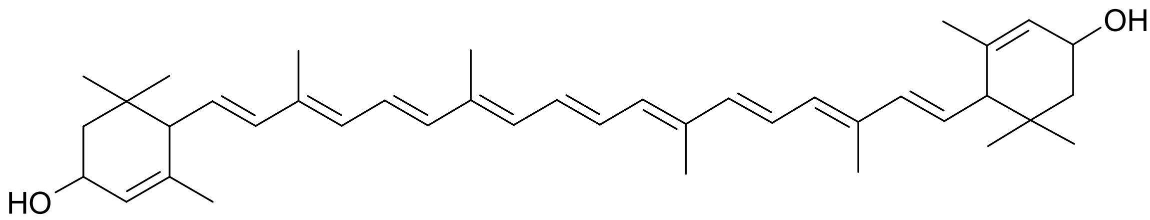

Figure 5: Zeaxanthin.

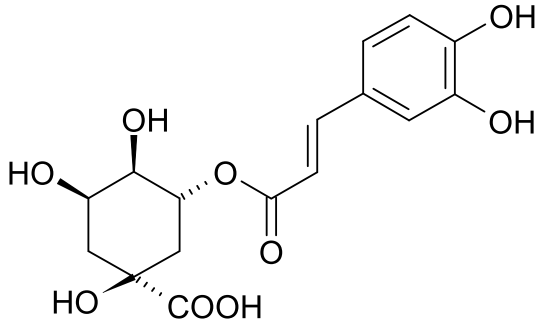

Figure 6: Chlorogenic acid.

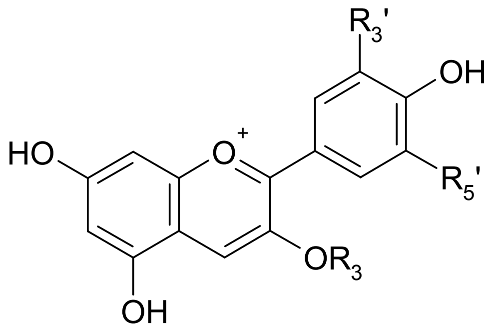

Figure 7: Basic anthocyanin.

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		

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The nutritional attributes of legumes

L J Hedges & C E Lister

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A report prepared for
Horticulture New Zealand

Copy 15 of 15

New Zealand Institute for Crop and Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

1.1 Introduction

There is little information on the health benefits of the fresh legumes that are the subject of this report; most research relates to their mature, dried seeds and to other legume species, particularly soy. So the applicability and relevance of findings from these studies to the vegetables described in this report are difficult to determine.

Pulses are known to contain antinutritional components, which may affect absorption of some macro and micronutrients. While this can be a problem if diets are heavily reliant on these vegetables, there is nothing in the literature to suggest that they constitute major health threats to well nourished populations, such as consumers in New Zealand. This may be either because they are only present at low levels or they are destroyed by cooking.

1.2 Peas

Peas are a particularly useful all-round food, containing good amounts of vitamin $B_{1,}$ (thiamin), as well as vitamins C, B_6 B_3 and $B_{2,}$ folate, provitamin A carotenoids, and iron and zinc. In addition they are one of the best vegetable sources of protein. In terms of phytochemicals, they are well endowed with the antioxidant carotenoids, lutein and zeaxanthin, which are thought to be especially important for protecting against eye problems, such as macular degeneration. They also contain isoflavones, which have oestrogenic effects and thus protect against some hormone-related cancers, but these are present at much lower levels than in soy, on which most of the study in this area has been focused. Both soluble and insoluble fibre are present in peas too. Insoluble fibre, or roughage, is believed to be important in maintaining bowel health. Soluble fibre is also thought to help with bowel health, particularly in protecting against bowel cancer, but, in addition, appears to benefit the cardiovascular system by lowering cholesterol and blood pressure. Because it swells in the gut, soluble fibre also delays stomach emptying. This has a positive effect upon glycaemic response, which is important for diabetes management as well as weight control, as it gives a feeling of satiety. Saponins are also present in peas and are thought to be beneficial, particularly by reducing cholesterol.

1.3 Edible pod peas

Snow peas contain excellent levels of vitamin C and good levels of pro vitamin A (in the form of β-carotene and α-carotene). They also supply useful amounts of thiamin, vitamin $B_{6,}$ iron, folate and both soluble and insoluble fibre. They are also low in calories and provide important sensory benefits, such as crunchiness and sweetness. There is little information on the phytochemicals in edible pod peas, though their high levels of vitamin C should provide antioxidant activity.

1.4 Beans

The major nutrients in green beans are folate, vitamins A (through β-carotene) and C, with thiamin, niacin, calcium, zinc and iron present at low levels. They also contain some fibre and are low in calories. There is little phytochemical information on beans, possibly because they do not show strong antioxidant activity. They consistently rate toward the lower end of the scale in comparisons with the antioxidant activity of other vegetables. Nonetheless, like edible pod peas, with which they have much in common, they have special sensory attributes and good nutrient density since their calorie content is not high.

1.5 Broad beans

Broad beans contain very good amounts of vitamin C and folate, good amounts of niacin, and small but useful levels of zinc and iron. Like peas, they are also an excellent vegetable source of protein and are also a very good source of both soluble and insoluble fibre.

They are also very interesting for their phytochemical content. They are one of the richest sources of catechins – the flavonoids made famous through their presence in tea, and chocolate. Many of the health benefits of catechin-rich foods, such as protecting against chronic diseases, including cardiovascular disease and cancer, are thought to be attributable to their antioxidant activity. *In vitro* studies have shown catechins to inhibit LDL oxidation and platelet aggregation, reduce inflammation and improve vascular endothelial function.

Broad beans also contain the medicinal compound L-dopa, used in treating Parkinson's disease. They can also cause potentially fatal haemolytic anaemia in certain ethnic groups with a genetic condition known as favism.

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 legumes – peas (green peas and edible pod peas such as snow peas and sugar snap), and beans (green and yellow), plus broad beans.

The amount of information available varies considerably; and in some areas where no specific information exists, research on related legumes may be cited. 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.

3 *Peas (*Pisum sativum*)*

3.1 *Introduction*

This report focuses on green or garden peas and edible pod varieties rather than peas that are grown to a fully mature stage and then dried (seed or field peas). However, information specifically relating to garden peas is relatively thin and sometimes the type of pea is not identified. Because most research is related to seed or field peas, reference to these types is sometimes made. However, it should be borne in mind that the composition of these types is likely to differ somewhat from green peas since they are grown for quite different purposes, such as for use as a pulse (like chickpeas), for flour, as a protein source, or for animal feed. Reasons for their differences are numerous, but, most obviously, different cultivars are involved, they are harvested at different stages of maturity, and different agronomic practices are employed.

Peas and beans both belong to the Fabaceae or Leguminosae family, along with plants as diverse as alfalfa and gorse. A feature that these plants have in common is that their “fruit” is a pod that opens along a seam. These seeds, especially when dried, are called “pulses”.

Cultivated for centuries for their dried seeds, peas do not appear to have been eaten young and fresh in European civilizations until popularised by the French king, Louis XIV in the 17th century. However, it is thought that the Chinese were the first to consume both the seeds and the pods.

Because of their relatively short season, fresh peas are not as frequently consumed as vegetables that are available all year round. Also, because frozen peas are a good alternative, retaining many nutrients, excellent taste and attractive appearance, there is less incentive for them to be grown in glasshouses out of season, or imported. The edible pod peas (snow peas (also known as mange tout) and sugar snap peas) are now available year-round and, in particular, contribute to stir fry dishes, though usually in small quantities.

3.2 *Composition*

A number of factors combine to determine the levels of both core nutrients and other phytochemicals in a food. These include not only the variety/cultivar of the plant, but also issues relating to the agronomy involved – soils, cultivation protocols (irrigation, pest control, use of fertiliser), degree of ripeness 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 various factors may cause large differences in core nutrient levels, but even greater differences may occur in their phytochemical levels.

Where data is available, the extent and effect of this variation will be discussed later in this section, under Section 3.5, “Factors affecting health benefits”.

3.3 Core nutrients

Peas are not celebrity vegetables, the focus of scientific research and media attention like broccoli and tomatoes. They are, however, a particularly useful all-round food, containing excellent amounts of vitamin C, thiamin (vitamin B_1) and folate, as well as vitamins B_6 B_3 and $B_{2,}$ provitamin A carotenoids, and a range of minerals, notably iron and copper. They also include phosphorus, potassium, zinc and magnesium. In addition, they are one of the best vegetable sources of protein. Figure 1 shows the contributions of these major nutrients towards the Recommended Dietary Intake (RDI) – or Adequate Intake (AI) – if an RDI is not available. Note: RDIs and AIs are generally higher for males than females and thus the same amount gives a smaller percentage for males than females. Sometimes they are the same for both sexes, as in the case of vitamin C. In the case of iron, however, women of childbearing age (judged to be 19-50 years) require higher intakes, and this figure has been used to calculate the contribution toward the RDI for iron for women, depicted in this graph and others subsequently.

See Appendix I for full data from the New Zealand FOODFiles database.

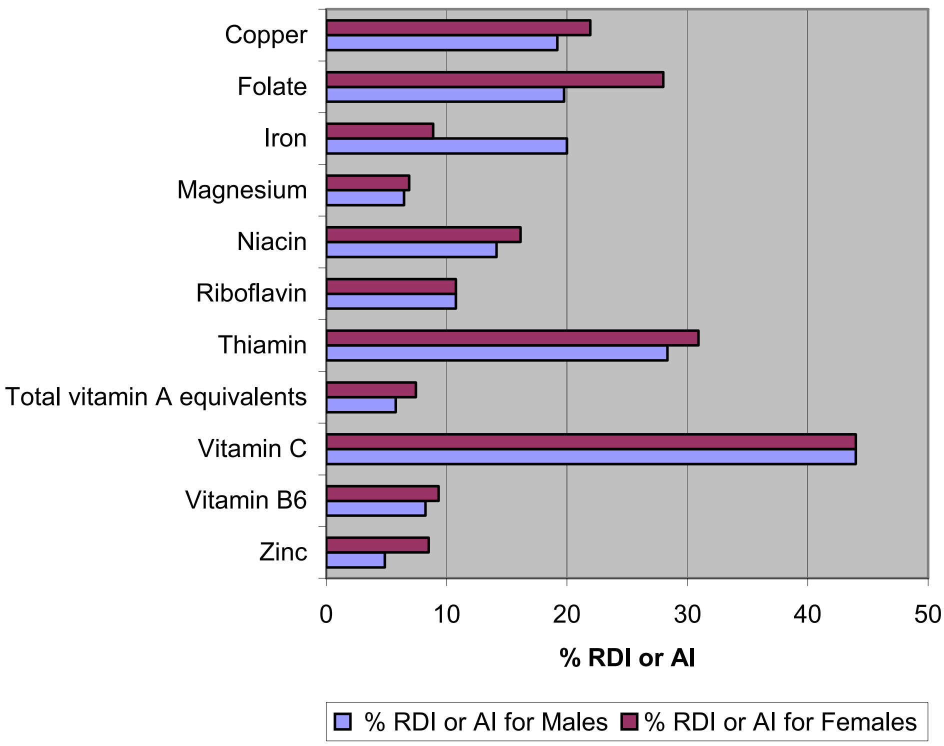

Figure 1: Contributions to RDI or AI by the major micronutrients in green peas adapted from Athar (2004) and NHMRC (2006).

3.4 Other phytochemicals

Although there has not been a great deal of research specifically on peas, some information is available on general databases and in studies comparing their composition or antioxidant activity.

The major phytochemicals in peas are the carotenoids, including lutein and zeaxanthin and β-carotene, chlorophyll, phenolic compounds, including some flavonoids as well as phenolic acids. Fibre should also be mentioned here, as it can have physiological effects similar to that of some phytochemicals. Saponins can have both positive and negative health effects and are also present in peas. Legumes also often contain other anti-nutritive compounds, such as trypsin inhibitors, phytates and α-galactosides (Vidal-Valverde et al. 2003), but these do not appear to be an issue with green peas, probably because they are harvested before completely mature when maximum concentrations are reached, and/or because they are destroyed during cooking.

3.4.1 Carotenoids

Epidemiological studies have demonstrated that high intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing. Some of the benefits of fruit and vegetable consumption have been attributed to their constituent compounds, including a class of phytochemicals called carotenoids. The most important carotenoids in peas are the xanthophylls, lutein and zeaxanthin, but they also contain the carotenes, α- and β-carotene.

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. 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 legumes.) These conjugated (alternating) double bonds confer colour and the compound's antioxidant properties. 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, whereas lycopene and the xanthophylls, lutein and zeaxanthin, have no vitamin A capacity. Because of their similarity, amounts of the latter 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 fruit and vegetables is shown in Table 1. Whilst peas contain respectable levels of the carotenes, they are present at much lower levels than in other highly vegetables, such as carrots and spinach. It is interesting to note that boiled frozen peas rate much more highly in terms of β-carotene than raw peas. It is likely that this results from freezing and boiling processes as these break down cell structure, releasing compounds that were previously bound to other components. Levels of lutein and zeaxanthin are amongst the highest in these carotenoid-rich fruit and vegetables, however. Whilst significantly lower than in spinach, levels in peas are several fold higher than in most other legumes.

Table 1: Carotenoid content of assorted fruit and vegetables (mcg/100 g) from USDA National Nutrient Database for Standard Reference Release 18, 2005 (USDA 2005) 2006.*

Food	β-carotene	α-carotene	Lutein + zeaxanthin
Apricot	1094	19	89
Beans,* green, raw	376	69	640
Beans, yellow, boiled*	49	0	709
Broad beans	32	0	0
Broccoli, raw	361	25	1403
Capsicum, red, raw	1624	20	51
Carrot, raw	8285	3477	256
Corn (sweet), raw	52	18	764
Corn (sweet) boiled	66	23	967
Orange	87	7	129
Peas (raw)*	449	21	2447
Peas (edible pod)*	630	44	740
Peas (frozen, boiled)*	1250	20	2400
persimmon	253	0	834
Pumpkin, raw	3100	515	1500
Spinach, raw	5626	0	12198

3.4.2 Phenolics

Phenolics are a group of over 4000 compounds occurring widely in the plant kingdom. Of these, there are two classes of compounds with particular dietary relevance — the flavonoids and phenolic acids. In the plant they serve a variety of purposes, including protecting 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.

Structurally phenolics all contain at least one phenol ring and at least one hydroxyl group, which is important as these are partially responsible for their antioxidant activity. (See Appendix II for structural diagrams of some of the phenolics in peas and beans.) They are water-soluble, which affects some of their functional properties.

Synthesised in response to light, phenolic compounds are often most concentrated in the skins of fruit and vegetables. This was demonstrated in a Spanish study of “dark peas” (Duenas et al. 2006) where the highest concentrations of glycosides of the flavonoids, quercetin, luteolin and apigenin were present in the seed coat, though they were also present in the cotyledon (body of the pea). Most of the phenolic acids (largely hydoxybenzoic compounds) were present in the cotyledon. There were also small amounts of catechins, which occurred in both parts of the seed. However, levels differed considerably according to cultivar. It is important to note though that in this study a number of factors were not reported, including the pea type (green/seed or field) and their level of maturity at harvest. Thus the relevance of these findings to green peas is not clear. A Polish study found proanthocyanidins (condensed tannins) in the seed coats of white and coloured varieties of peas to be a major source of antioxidant activity, along with phenolic acids (Troszynska et al. 2002). However, again the level of maturity and type of pea were not reported. None of the flavonoids routinely quantified by the USDA appear to have been detected in raw, green peas according to its flavonoid database, though quercetin was identified in both frozen and canned peas at 0.15 mg/100 g edible portion and 0.11 mg/100 g edible portion respectively (USDA 2003). Quercetin was also the major flavonoid identified by Ewald et al. (1999) in a study on the effects of processing. In a comparison of phenolic compounds in a range of commonly consumed foods in the United States (Table 2), frozen peas were found to contain moderately good levels of phenolics (Wu et al. 2004), though they were towards the bottom in the large group of Asian vegetables studied by Kaur and Kapoor (2002).

Table 2: Total phenolics in some commonly consumed vegetables in the US (Wu et al. 2004).

	Total phenolics expressed as milligrams gallic acid equivalents per gram (mg GAE/g) in raw form, unless stated otherwise
Beans	0.92
Broccoli	3.37
Cabbage	2.03
Carrots	1.25
Corn	2.11
Lettuce (iceberg)	0.50
Onions	0.91
Peas (frozen)	1.87
Peppers (green)	2.71
Potatoes (red)	1.38
Spinach	2.17
Tomatoes	0.80

Isoflavones

Isoflavones are a sub-group of the flavonoid class of compounds, and are present in a number legumes. They have been of particular interest recently because of postulated oestrogenic activity and a potential role in protecting against hormone-related cancers and assisting with other hormone-related complaints, such as menopausal symptoms. Because of this, along with other compounds with similar effects, they are also known as phytoestrogens. Soy is particularly rich in isoflavones, specifically genistein and daidzein and has been the most intensively studied. Peas have been found to contain either none or only minimal amounts of these compounds (Nakamura et al. 2001; Boker et al. 2002). There is no entry under fresh or frozen peas for the isoflavones quantified in the USDA database for isoflavones, although a value is given for dried, split, mature peas (USDA 1999). Despite the low content relative to soy products cited in Boker et al. (2002), these authors maintained that for their population group of post menopausal Dutch women, peas and beans were the main source of almost all isoflavones in the diet, though acknowledging that general phytoestrogen intake was low in this population.

Table 3: Estimated isoflavone intake in different population groups.

Isoflavone intake (mg/day)	Population group	Author
0.88	White Dutch women	Keinen et al. (2002)
0.76	American white women	Kleijn et al (2002)
2.9	Whites, Latino-Americans, African-Americans	Horn-Ross et al (2000) cited in Keinen et al. (2002)
39.26	Chinese women in Shanghai	Chen et al (1999)

3.4.3 Fibre

Peas are also a good source of both soluble and insoluble fibre (Garcia-Domingo et al. 1997; Li et al. 2002). Investigating the “indigestible fraction” in frozen and canned peas, Garcia-Domingo et al. (1997) found that it comprised mainly non-starch polysaccharides followed by resistant starch and resistant protein. Lignin and oligosaccharides were present, but only at very low levels. Because fibre compounds can cause flatulence, it is possible that, to some extent, they have deliberately been bred out of these vegetables when intended for human consumption.

In simplified terms, dietary fibre is the edible part of a food that cannot be broken down by human digestive enzymes. It is often divided into soluble and insoluble fibre. Insoluble fibre cannot be dissolved in water, but can attract water. It is what is popularly called roughage and present in whole grain cereals and baked beans. Soluble fibre does dissolve in water and is often associated with oat bran, but fruits and vegetables, including legumes are also good sources. According to the New Zealand Food Composition Database, FoodFiles, vegetable peas contain good amounts of the fibre components, soluble and insoluble non-starch polysaccharides, both in comparison with other legumes and other vegetables (Table 4).

Table 4: Soluble and insoluble non-starch polysaccharides in legumes and assorted common vegetables (Athar et al. 2004).

	Soluble non-starch polysaccharides	Insoluble non-starch polysaccharides
Beans, green raw	0.9	1.3
Beans, butter raw	0.6	0.8
Broad beans	1.4	5.1
Broccoli	1.5	2.2
Cabbage	0.7	1.2
Carrot	1.6	1.6
Lettuce	0.4	0.4
Peas	1.2	3.1
Potato (Rua) raw	0.9	0.6
Snow peas	1.0	1.3
Sweet potato	1.2	1.5
Tomatoes	0.6	0.7

A wider concept of dietary fibre also includes resistant starch as it is not digested by enzymes in the intestine but fermented in the bowel (Garcia-Domingo et al. 1997). Like many legumes, peas contain resistant starch that is locked within cells walls and thus inaccessible to digestive enzymes. It was present in the raw peas studied by de Almeida Costa et al. (2006) and also in cooked peas, though at reduced levels. The type of pea were used in this study was not reported, but it is likely that they were seed rather than green peas.

3.4.4 Chlorophyll

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

3.4.5 Saponins

Saponins are a diverse group of biologically active glycosides, widely distributed in the plant kingdom (Curl et al. 1985). Structurally they comprise a carbohydrate portion attached to an aglycone base, which is either a steroid or triterpene (Sparg et al. 2004). Named for their ability to form stable, soap-like solutions with water, they possess both useful and deleterious bioactive qualities. Although not apparent in green peas, saponins can create a bitter or astringent taste.

A number of different saponins have been isolated in peas. Soyasoponin I appears to be predominant (Curl et al. 1985; Daveby et al. 1997; Murakami et al. 2001). The saponin content of green peas is listed in Savage & Deo (1989) at 2.5 g/kg, though it is unclear what type of pea this refers to or their stage of maturity. Soyasaponin 1 ranged from 0.82 to 2.5 g/kg in different varieties of Swedish field peas (Daveby et al. 1997).

Saponins are heat-sensitive and water-soluble (Shi et al. 2004), so short cooking with minimal water would enable maximum retention of these compounds.

3.4.6 *Anti-nutritional factors*

Although peas contain a number of compounds that can have detrimental effects upon the nutritive value of peas, such as trypsin inhibitors, oxalates, and haemagglutinins (Savage & Deo 1989), there does not appear to be any evidence that the consumption of peas causes health problems in humans. Anti-nutritional factors are of most importance in relation to animal feeds, where the diet is largely unvaried. Also, in human food, they appear to be present at relatively low levels and cooking appears to reduce or destroy the majority of these compounds (Savage & Deo 1989).

3.5 *Health benefits*

3.5.1 *Core nutrients*

If dried legumes are excluded, peas are one of the best plant sources of protein. Although they do not contain the complete range of essential amino acids in the necessary proportions for this vegetable to be classed as ideal protein, if combined with other grain foods or cereals, the range of amino acids is complemented, compensating for this deficiency. They also contain complex carbohydrates, which are important for sustained release of energy, providing satiety and thus assisting in weight control, and managing glucose response. Peas are also one of the best sources of vitamin B_1 or thiamin, which is a co-enzyme for many critical bodily functions relating to energy metabolism. It is also necessary for nerve transmission and muscle function.

The major functions of the various micronutrients are summarised in Appendix I.

3.5.2 *Carotenoids*

Lutein and zeaxanthin

Carotenoids are probably best known for their antioxidant activity, but those predominant in peas, lutein and zeaxanthin have been most researched in relation to eye diseases. To determine the biological roles of a compound, scientists frequently consider its abundance and distribution in body tissues, as well as its variation in abundance across population groups. In a review of the roles of lutein and zeaxanthin in human health, Granado et al. (2003) noted that a number of studies had shown these compounds to be selectively accumulated in different parts of the eye, where they were by far the most abundant of the major carotenoids present. Lutein and zeaxanthin are especially concentrated at the centre of the retina in the eye (the macula) and in fact are often referred to as macular pigments. These high concentrations in the eye, plus the presence of certain proteins specific to binding these compounds, has led to the suggestion that they may be important in protecting against age-related eye problems, particularly macular degeneration and the formation of cataracts. It has also been hypothesised that lutein and zeaxanthin could slow the progression of these diseases as well as the group of degenerative retinal diseases, retinitis pigmentosa.

Mares-Perlman et al. (2002) summarised a number of studies linking light exposure to eye diseases. Because these carotenoids absorb blue light, it was suggested that they protect the retina from photochemical damage that could occur from light at these wavelengths. Exposure to light has been found to increase the levels of free radicals in the lens and retina (Dayhaw-Barker 1986, cited in Mares-Perlmann et al. 2002) and exposure of the retina to light has been postulated as a cause of macular degeneration (Borges et al. 1990, cited in Mares-Perlmann et al. 2002).

Within the macula there is a distinct pattern in the distribution of these xanthophylls. Zeaxanthin is most concentrated in the inner macula, but lutein predominates further from the centre. This distribution suggests a possible function for lutein in protecting the rods that are concentrated in the peripheral retina, and for zeaxanthin in protecting the cones that are concentrated in the central retina (Granado et al. 2003; Mares-Perlman et al. 2002).

It has been shown that intake of these carotenoids increases their levels in macular tissue (Hammond et al. 1997; Landrum et al. 1997, cited in Mares-Perlman et al. 2002) and serum (Olmedilla et al. 2002), although variations in individual responses have been noted.

It appears plausible that lutein and zeaxanthin play a protective role in the eye, but there is a scarcity of data. This is partly because it is a relatively new field of research and partly because it is difficult to carry out this research using cells or animals. Only primate eyes have a macula, and therefore the usual laboratory animals, such as rats, cannot be used. In one study, in which monkeys were fed diets lacking plant pigments, changes to the retina resembling the ocular degenerative changes in humans occurred over several years (Malinow et al. 1980, cited in Mares-Perlman et al. 2002). Another study, found an inverse relation between the level of zeaxanthin in quail retina (quails have a macula similar to that of primates) and light-induced retinal cell death (Dorey et al. 1997, cited in Mares-Perlman et al. 2002).

Some epidemiologic evidence does suggest that lutein and zeaxanthin protect against macular degeneration and this is summarised below (from Sies & Stahl 2003 and Mares-Perlman et al. 2002). Lower risk for this disease has been found in conjunction with consumption of foods rich in lutein and zeaxanthin (Goldberg et al. 1988); higher overall levels of lutein and zeaxanthin in the diet (Mares-Perlman et al. 2002; Seddon et al. 1994); higher levels of lutein and zeaxanthin in the blood (Eye Disease Case-Control Study Group 1992); and higher levels of lutein and zeaxanthin in the retina (Bone et al. 2000; Beatty et al. 2001).

However, these relationships were not observed in other studies, or were only observed in subgroups of the study population (Granado et al. 2003; Mares- Perlman et al. 2002).

Mares-Perlman et al. (2002) describe findings with respect to the relationship between lutein and zeaxanthin and reducing cataract risk as “somewhat consistent”. Two studies showed a higher incidence of cataracts in those in the lowest quintile of lutein and zeaxanthin intake compared with the highest, and three prospective studies found that those in the highest quintiles had a 20–50% lower risk of experiencing cataract problems.

Although concentrations are generally highest in ocular tissue, a number of studies have established the presence of lutein and zeaxanthin in serum and body tissues. The fact of their antioxidant activity has led to speculation that higher consumption of these chemicals will lead to higher levels in body tissues, and that this may lower the risk of chronic disease. It is possible that, along with other carotenoids with antioxidant activity, lutein, which is more widely dispersed in the body, may protect against diseases such as cancer and cardiovascular disease as well as positively affecting immune function.

α- and β-carotene

α- and β-carotene differ only very slightly in terms of structure. They are very commonly occurring carotenoids and are 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, α-carotene and β-cryptoxanthin each about 1/12.

Note: Although there is some controversy internationally regarding the carotenoid/retinol conversion rate, the rates above are used in New Zealand and Australia in accordance with the FAO/WHO decision (National Health and Medical Research Council of Australia and New Zealand Ministry of Health 2004).

β-carotene has been the focus of most research. Epidemiological studies have demonstrated that high intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing. Carotenoid-rich foods have also 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 also possess properties consistent with anti-cancer activity, e.g. they may play an important role in the cell communication that leads to the demise of pre-cancerous cells. However, results have been somewhat inconsistent (Cooper et al. 1999). Mixed results have also been reported from studies relating to prostate and colorectal cancer.

Similarly, there have been mixed results regarding the effect of dietary β-carotene on cardiovascular disease. 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 a number of *in vitro* studies had shown it to be capable of scavenging potentially damaging radicals. However, whilst some research has shown higher plasma levels of carotenoids to be associated with better vascular health and lower cardiovascular disease risk, other studies have shown no effect (Higdon 2005; Cooper et al. 1999). Further, some recent studies have produced contradictory results regarding the ability of β-carotene to stabilise LDL against oxidation (Cooper et al. 1999). None of these studies have specifically investigated the effect of consuming green peas.

3.5.3 Phenolics

Phenolic compounds are primarily of interest with regards to human health 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.

Flavonols

The predominant flavonoid in peas is quercetin, which is present as a glycoside (with an attached sugar molecule). Like most flavonoids, it is believed to have a number of cancer-fighting properties. It has been shown to inhibit the growth of malignant cells, encourage apoptosis (self-destruction) of cancerous cells, and interfere with proliferative activities of certain cancer cells. Quercetin's antioxidant activity is also believed to be responsible for some of the observed cardio protective qualities of onions, which are well endowed with this compound (Joseph et al. 2002).

Isoflavones

Compared with soy and soy products, peas contain only low levels of isoflavones (Kleijn et al. 2001; Boker et al. 2002), and it is thus unclear how applicable research focusing on soy and isoflavones are to the health attributes of peas. Nonetheless, peas together with beans were found to contribute most isoflavones to the diets of groups of both Dutch and US women (Kleijn et al. 2001; Boker et al. 2002) and this warrants mention in this report. It is likely that the situation would be similar in New Zealand. The 1997 National Nutrition Survey found that 73% of males and 64% of females consumed peas at least once a week C Russell et al. 1999).

Isoflavones belong to a group of compounds known collectively as phytoestrogens. They are structurally similar to the human hormone, oestrogen, and have been shown to have weak oestrogenic activity. They were initially of interest because it was observed in epidemiological studies that Asian women who had a high intake of isoflavones through traditional soy foods, appeared to have lower incidences of hormone-related health problems, such as breast cancer and menopausal symptoms. Because of their structural similarity to oestrogen, genistein and daidzein, the main isoflavones in peas as well as in soy, are able to bind to oestrogen receptors. This activity is thought to be responsible for their part in reducing the risk for hormone-related cancers, since the proliferation of these kinds of cancer cells is oestrogen dependent (Higdon 2005; Steer 2006).

Soy isoflavones have also been studied in relation to reducing cholesterol and antioxidant effects in preventing LDL cholesterol oxidation. Antioxidant activity is thought to be responsible for other observed anti-carcinogenic effects too, including the inhibition of free radical reactions, cell mutation, cell proliferation and angiogenesis (Steer 2006).

3.5.4 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 potential carcinogens, such as aflatoxin and heterocyclic amines to prevent their absorption (Joseph et al. 2002). A recent study found that chlorophyll had phase 2 enzyme-inducing potential and, although its activity was relatively weak, its high concentration in so many edible plants may be responsible for some of the protective effects observed in diets rich in green vegetables (Fahey et al. 2005). An *in vitro* study in which chlorophyll was extracted from spinach demonstrated anti-inflammatory activity as well as anti-proliferative effects against breast, colon, stomach, central nervous system and lung cancer cell lines (Reddy et al. 2005).

3.5.5 Fibre

Insoluble fibre

For many years, the term “fibre” referred only to what is now known as insoluble fibre, or, colloquially, roughage. Although it is insoluble in water, it has water-attracting properties, which help assist stool bulking and reduce the transit time through the gut. It is thus important in preventing constipation and conditions such as diverticulitis and bowel cancer.

Soluble fibre

Soluble fibre is not as readily identifiable as fibre as is insoluble fibre. It includes compounds like gums, pectins, inulin and the oligosaccharides (compounds containing 3-10 sugar molecules) that are present in many legumes. Although not strictly speaking fibre, resistant starch is often considered alongside soluble fibre as it behaves similarly and has similar physiological effects. Also present in peas, it is starch that is sequestered in cell walls and therefore is not available to digestive enzymes and can occur naturally, or be caused through processing, or cooling and reheating. Because these compounds cannot be digested, they pass to the colon where they are fermented by colonic bacteria. During the fermentation process, short chain fatty acids (SCFA) are produced together with gases. The latter are responsible for the flatulence that frequently arises from consumption of foods containing these compounds. SCFAs are thought to have several beneficial effects, including providing energy for colonic mucosa, protection against various diseases of the colon, including cancer, and lowering colonic pH, so preventing the transformation of primary bile acids to co-carcinogenic secondary bile acids. A number of laboratory studies have shown that peas give rise to a high proportion of the SCFA, butyric acid, which is thought to be particularly beneficial (Garcia-Domingo et al. 1997; Ekvall et al. 2006). Garcia-Domingo et al. (1997) suggest that this is due to the high levels of resistant starch in peas. Some soluble fibre, particularly that which is viscous also inhibits cholesterol absorption and reduces blood glucose response (Ekvall et al. 2006).

The viscous kinds of fibre, such as pectins, some gums, mucilages and β-glucans, form gels in water and it is this property that explains why some fibres slow stomach emptying, delay absorption of some nutrients and reduce cholesterol. Although there have been several trials using dried legumes, which have shown beneficial effects upon cholesterol (Anderson & Major 2002), little published material relates specifically to green peas. In addition to fibre, several of the other compounds present in legumes may also assist in this hypocholesterolaemic effect, including, in order of importance, vegetable protein, oligosaccharides, isoflavones, phospholipids and fatty acids and saponins (Anderson & Major 2002). Besides lowering cholesterol, consumption of pulses may also reduce risk for cardiovascular disease through lowering blood pressure, as well as beneficially affecting glycaemia and reducing the risk of diabetes and obesity (Anderson & Major 2002).

3.5.6 Saponins

Saponins are believed to have a beneficial effect on human health particularly in terms of lowering cholesterol (Cheeke 1996 cited in Daveby et al. 1998). It is thought that saponins cause the adsorption of bile acids on to dietary fibre in the intestine, which is then excreted in the faeces. To compensate for this loss, serum cholesterol is converted by the liver into bile acids, thus lowering levels of cholesterol in the blood (Savage & Deo 1989). They are also believed to protect against cancer, by breaking down the cholesterol-rich membranes of cancer cells. Because saponins are not well absorbed into the blood stream, they are thought to be most useful in exerting a localised effect in the intestinal tract, such as combating colon cancer (Joseph et al. 2002). Some members of the saponin family have also been shown to have anti-fungal, antibacterial and anti-inflammatory activity (Sparg et al. 2004).

Although some saponins have also been shown to have anti-nutritive effects, including haemolytic and cytotoxic activity, there appears to be no evidence of harmful effects of pea saponins in humans (Sparg et al. 2004).

3.5.7 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 phytochemicals 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 its own antioxidants and has other defence mechanisms, it is thought that antioxidants from the diet also have an important role.

The major antioxidants in peas 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. Unfortunately, however, peas have been relatively little studied and there is a shortage of data in this area. In one study comparing antioxidant activity in 21 commonly consumed vegetables, (frozen) peas ranked moderately low at 6 micromoles Trolox equivalents/gram with values for other vegetables ranging from around 1 to 94 micromoles Trolox equivalents/gram (excluding dried legumes) (Wu et al. 2004). In this study it appeared that hydrophilic compounds, probably mostly phenolics, were responsible for the majority of this activity. In another study, peas were ranked lowest of 13 vegetables according to two different antioxidant assays, FRAP and ORAC (Ou et al. 2002). Similarly, and also using the FRAP assay, Halvorsen et al. (2002) measured antioxidant activity in peas and found that it was amongst the lowest in the large range of vegetables and pulses in the study.

3.6 *Factors affecting health benefits*

As already mentioned, a number of variables combine to affect how consumption of a particular food will affect human health. Major factors include how well nutrients are absorbed and used by the body, agronomic issues and the effects of processing.

3.6.1 *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.

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.

The carotenes appear to be absorbed differently from the xanthophylls on account of their differing polarities. Lutein appears to be better absorbed than β-carotene (van het Hof et al. 1999; Zaripheh & Erdman 2002) and absorption takes place in different locations within the gut (Goni et al. 2006).

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. The type of fat present, including fatty acid length, and the presence of protein also influences absorption (West & Castenmiller 1998).

Insoluble and soluble dietary fibre are also thought to have a negative effect on β-carotene bioavailability (Hammond et al. 1997; Rock & Swendseid 1992, cited in West & Castenmiller 1998).

Phenolics

There have been few studies on the bioavailability of hydroxycinnamic acids, and not specifically those in peas or beans. However, in two studies reviewing the bioavailability of dietary polyphenols, phenolic acids were among the best absorbed (Scalbert et al. 2002; Karakaya 2004).

Although there have been a number of studies regarding soy isoflavones, there do not appear to be any regarding isoflavones in peas. Soy isoflavones appear to be well absorbed in the gastrointestinal tract and achieve peak concentrations within a few hours of consumption (de Pascual-Teresa et al. 2006). In general it appears that for humans genistein and daidzein aglycones are more bioavailable than their conjugated forms and genistein is more bioavailable than daidzein (Lin & Lai 2006). It has also been found, however, that there are population differences in the way in which isoflavones are metabolised, which affects their bioactivity. An example of this is the metabolising of daidzein to equol, which has higher oestrogenic activity than daidzein itself, but only occurs in 33% of people in Western populations (Higdon 2005).

Saponins

Saponins do not appear to be well absorbed and consequently their effects take place largely in the gastro-intestinal tract (Joseph et al. 2002).

3.6.2 *Agronomic factors*

A number of studies have shown large differences between pea cultivars in terms of their constituent compounds (Savage & Deo 1989; Troszynska & Ciska 2002; Troszynska et al. 2002; Vidal-Valverde et al. 2003; Duenas et al. 2006).

3.6.3 *Level of maturity*

Numerous studies document changes in the constituent compounds of plants during different stages of growth, but there appear to be few specifically on peas. Daveby et al. (1997) observed a considerable decrease in soyasaponin I, the major saponin in peas, during maturation, though their level in vegetable peas, harvested at a fully developed but immature stage, is unknown.

3.6.4 *Processing*

Processing, such as cooking, freezing or pureeing, can have both positive and negative effects upon the nutrients present in foods. For example, whilst cooking decreases levels of heat labile compounds like vitamin C and folate and saponins, it can increase the bioavailability of carotenoids and destroy anti-nutritional factors. The small amount (0.15 mg/100 g) of quercetin measured in blanched peas by Ewald et al. (1999) was little affected by further processing by cooking, frying or warm holding. The effect of blanching on the quercetin content of raw peas was not measured in this study. The evidence of soy isoflavones in a variety of processed foods would suggest that processing does not substantially compromise these compounds.

3.7 *Quotes and trivia*

- "Petits pois [peas] are like children – you have to understand them" James de Coquet (French author) writing in Le Figaro.
- Peas and beans belong to a family known popularly as legumes. The word "legume" is derived from the French légume, which means vegetable, probably testament to their importance as staples in earlier times. Legumes all have fruit pods that usually open on both sides. Peanuts are actually legumes, along with beans, alfalfa and gorse.
- Peas have a place in the history of science as the plants with which Gregor Mendel deduced the laws of genetic inheritance.
- In Chinese traditional medicine peas were prescribed for diuretic, anti-inflammatory and stomachic purposes (Murakami et al. 2001).

4 Snow peas, sugar snap peas

Although these terms are sometimes used interchangeably, this is erroneous and they are in fact a little different. Snow peas are flat wide pods with only miniature immature seeds. Their pods lack the “parchment” present in regular green peas and have strings on one or both sides of the pods. Snap peas have larger, often very sweet seeds, their pods similarly do not contain ”parchment” and they have no strings (Goulden pers. comm. 2006).

Snow peas contain excellent levels of vitamin C and good levels of pro vitamin A (in the from of β-carotene and α-carotene). They also supply useful amounts of thiamin, vitamin $B_{6,}$ iron, folate and both soluble and insoluble fibre. Because they are also low in calories, they are considered reasonably nutrient dense. In addition they provide important sensory benefits, such as crunchiness and sweetness to dishes in which they are used.

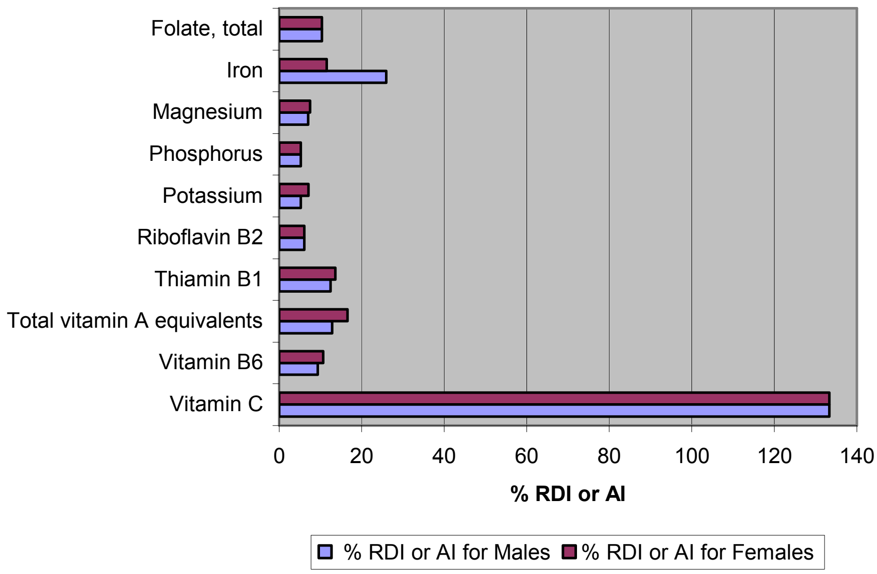

Figure 2: Contributions to RDI or AI by the major micronutrients in snow peas adapted from Athar et al. (2004) and NHMRC (2006).

There is little information on the phytochemicals in edible pod peas, though the high levels of vitamin C in this vegetable should provide antioxidant activity. An Indian study that investigated the antioxidant activity and phenolic content of “pea pods”, placed them in a medium antioxidant activity group, but with fairly low levels of phenolics (Kaur & Kapoor 2002). An early study of dietary fibre in South-east Asian vegetables found snow peas to be one of the richest sources of dietary fibre (Candlish et al. 1987), though this is at odds with data from the New Zealand FOODFiles database. There are various reasons for this, including differences in cultivar, growing conditions and analytical methods.

5 *Beans (*Phaseolus vulgaris*)*

5.1 *Introduction*

Beans can roughly be sorted into three groups:

- edible pod beans – green beans, string beans, snap beans, butter beans, scarlet runners,
- seed beans – those grown primarily for use as mature, dry beans, such as kidney beans, black beans, and
- fresh semi-mature seed beans – broad beans that are eaten fresh rather than dried (though they can also be dried and often are in Middle Eastern and some Mediterranean countries).

They all belong to the same family, though can be different genera and/or different cultivars. Equally they are obviously harvested at different stages of maturity. Seed beans are not covered in this report and broad beans are dealt with in a separate section.

Both seed beans and pod beans are generally referred to as “common beans”. It is believed that these originated in South America, possibly Peru, and over time spread throughout South and Central America. Along with maize and squash they were known as the “Three Sisters”, the three staple foods that sustained early Native American populations. Like many other vegetables, they were introduced to Europe by Spanish explorers on their return from the Americas in around the 16^{th} century.

Note: There is potential confusion regarding the term “butter beans”. In New Zealand this terms refers to beans of the same genus as the common green beans, and differ only in that they are yellow. In other countries the term is an alternative name for lima beans, where the seed can be used either dry or fresh in the same way as broad beans. The yellow “green” beans are usually known as “yellow” or “wax” beans overseas.

5.2 *Composition*

Green beans are not nutritional stars, but because they are eaten with reasonable frequency it is likely that their nutrients make a fair contribution to the diet. According to the 1997 National Nutrition Survey they were consumed by 46-48% of the population at least once a week (Russell et al. 1999).

5.2.1 *Core nutrients*

The major nutrients in green beans are folate, vitamins A (through β-carotene) and C, with thiamin, niacin, calcium, zinc and iron present at low levels. They also contain some fibre and are low in calories. See Appendix I for more data.

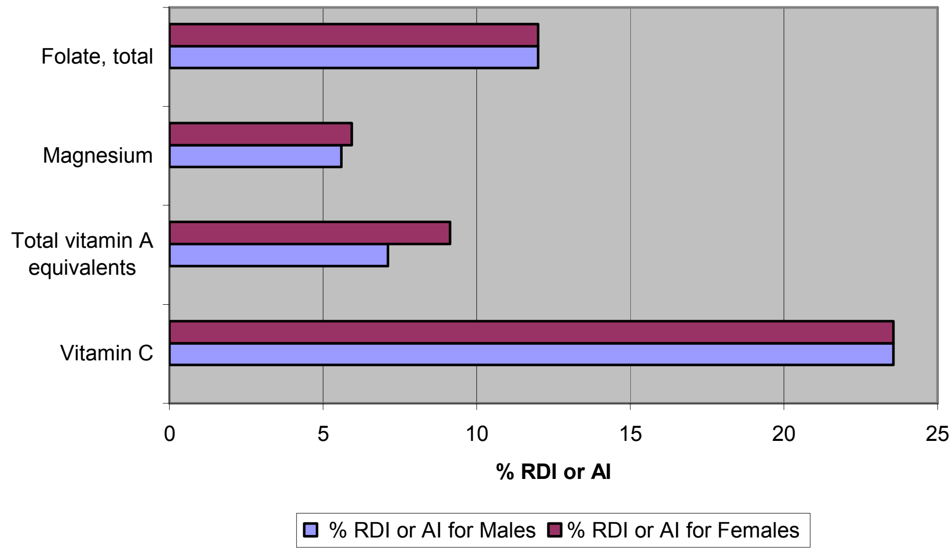

Figure 3: Contributions to RDI or AI by the major micronutrients in green beans adapted from Athar et al. (2004) and NHMRC (2006).

5.2.2 Other phytochemicals

There is very little information on phytochemicals in green beans. They do however, contain some β- and α-carotene, and good amounts of lutein and zeaxanthin (see Table 1). Raw green beans also contain chlorophyll and reasonable amounts of the flavonoids quercetin and kaempferol at 2.73 mg/100 g and 0.41 mg/100 g respectively (USDA 2003). Yellow beans contain slightly higher levels of both (3.03 mg/100 g and 0.42 mg/100 g) (USDA 2003).

5.3 Health benefits

No studies investigating bioactives or health benefits specifically of green beans have been found. However, the information covered in Section 2.5 relating to the phytochemicals above should also be relevant to beans.

5.3.1 Antioxidant activity

In a number of studies comparing antioxidant activity and/or phenolic content by assorted assays, beans rank in the low to average range (Cao et al. 1996; Vinson et al. 1998; Pellegrini et al. 2003; Chun et al. 2005; Zhou & Yu 2006).

5.4 Factors affecting health benefits

Apart from the differences between cultivars of green and yellow beans documented in Table 1 and Appendix I, nothing relating specifically to green beans has been found. The same general issues regarding bioavailability that applied to peas will also apply to these kinds of beans, and processing is likely to affect the nutrients common to both peas and beans similarly.

5.5 Tips and trivia

- A bean feast, which now means a party or social gathering was originally a dinner party put on by an employer for his employees.

6 *Broad beans (*Vicia fava*)*

6.1 Introduction

A different genus from "common beans", which originate from South America, broad beans are an ancient food source, native to North Africa and south-west Asia. In most Western countries they are usually consumed fresh (or frozen) when the seeds are developed though not fully mature, but in Middle Eastern, Mediterranean and Asian cuisine, the fully mature, dried seeds are usually used. For example, falafel is traditionally made from a small-seeded variety of broad bean. The term fava bean is often used in Mediterranean cuisine and also sometimes in the US. Although both the immature pod and seeds can be eaten, this report deals only with the (immature) seeds, as this is the stage at which they are commonly sold and consumed in New Zealand.

Broad beans have a number of little known, but important idiosyncrasies. They are one of the richest sources of the flavonoids made famous through their presence in tea, and chocolate, they contain the medicinal compound L-dopa, used in treating Parkinson's disease, and they can also cause potentially fatal haemolytic anaemia in certain ethnic groups with a genetic condition known as favism.

6.2 Composition

6.2.1 Core nutrients

Not surprisingly, given that they are both seeds, nutritionally broad beans have more in common with peas, than with green beans. They contain good amounts of many B vitamins, as well as folate, small amounts of provitamin A carotenoids, zinc and iron and are also an excellent vegetable source of protein. Like peas, they are also a very good source of both soluble and insoluble fibre. See Appendix I for full data.

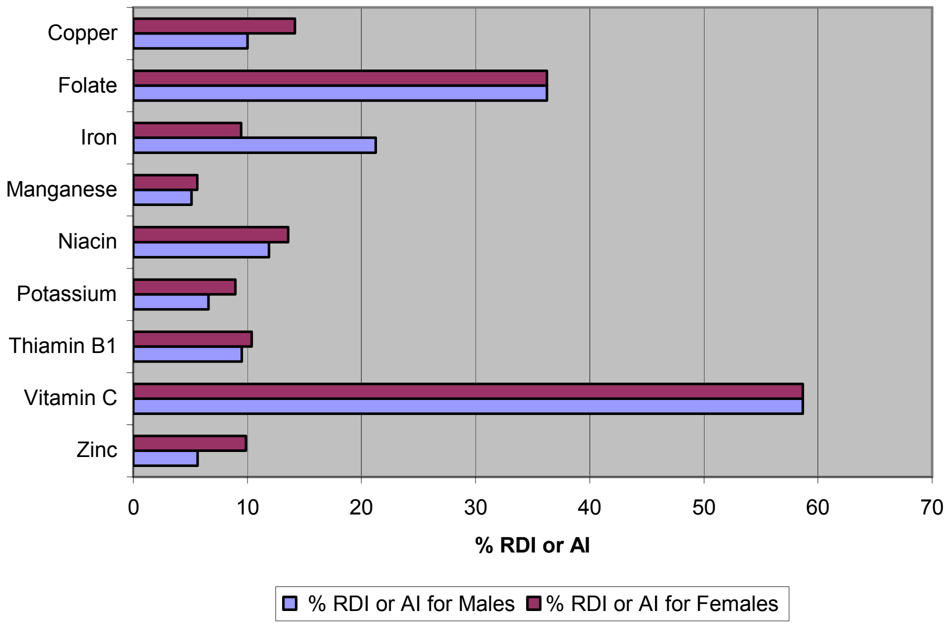

Figure 4: Contributions to RDI or AI by the major micronutrients in frozen uncooked broad beans, adapted from Athar et al. (2004) and NHMRC (2006).

6.2.2 *Other phytochemicals*

Broad beans contain only very small amounts of carotenoids (USDA, 2005; Athar et al. 2004), with a little β-carotene and, unlike peas, no lutein or zeaxanthin (see Table 1). However, they do contain a number of phenolic compounds, including the flavonols, quercetin and myricetin, and additionally are an excellent source of other flavonoids known as catechins, flavanols or flavan-3-ols (USDA 2003).

Catechins

According to a study by Auger et al. (2004), broad beans contain the highest levels of catechins by far of all the selected fruits, vegetables and other foods analysed, which included grapes, apples and chocolate, foods often referred to as having high levels of catechins (Table 5).

Table 5: Catechin levels in fruits, vegetables and other products adapted from Auger et al. (2004).

Food	Catechin content (mg/100 g fresh weight solids, mg/100 mL liquids)
Broad beans	184
Chocolate	7
Pinto beans	7
Lentils	3
Plums	49
Apples	10-43
Berries	5-20
Cherries	13
Tea	25-43
Red wine	56

Although such high catechin levels are not mirrored in USDA data (total catechins content ~ 50 mg/100 g), in comparison with other foodstuffs, the levels reported in broad beans are still among the highest listed. The levels of individual broad bean catechins from the USDA Flavonoid Database are shown in Table 6, with epicatechin the most prevalent. The greatest concentrations of these catechins were found by Borowska et al. (2003) to occur in the seed coat. The chemical structures of catechin and epicatechin are given in Appendix III.

Table 6: Individual catechins identified in immature raw broad bean seeds, mg/100 g fresh weight (USDA 2003).

(-)-Epicatechin	22.51
(-)-Epigallocatechin	14.03
(+)-Catechin	12.83

Isoflavones

A Japanese study showed that the major isoflavonoids in a sample of Chinese broad beans was of a lesser known and studied compound, biochanin A (Nakamura et al. 2001). USDA data on raw, mature seeds lists a small amount of daidzein (0.03 mg/100 g edible portion) and no genistein and for fried broad beans, no daidzein, but 1.29 mg/100 g edible portion of genistein (USDA 1999). Although these amounts are higher than for most other beans listed in this database, levels are minuscule compared with soy whose values for total isoflavonoids in raw beans range from 59.75 to 144.99 mg/100 g edible portion, depending on the country of origin.

Levodopa

Broad beans also contain a chemical called levodopa or L-dopa, which is used medicinally in the treatment of Parkinson's disease. Although it is present in the whole plant, young pods and beans contain more L-dopa than mature dried beans. It has been estimated that around 85 grams of fresh green fava beans may contain between 50 and 100 mg of levodopa (Holden 2001).

Fibre and resistant starch

The New Zealand food composition database, FoodFiles, lists frozen uncooked broad beans as having 6.5 g of fibre per 100 g, comprising 1.4 g soluble non starch polysaccharides and 5.1 g insoluble non starch polysaccharides (Athar et al. 2004). In a Polish study of fully mature seeds it was observed that the broad bean cultivars studied were good sources of resistant starch as well as dietary fibre. Around half of the latter was concentrated in the seed coat. Soluble dietary fibre ranged from 11.81 to 15.89% of total fibre (Giczewska & Borowska 2003).

6.3 Health benefits

The health benefits of some of the nutrients in broad beans have already been covered earlier. See Section 2.5.5 for fibre and Section 2.5.3 for flavonols.

6.3.1 Catechins

Catechins are present in both wines and tea, and it is thought that these compounds may be partly responsible for some of the health benefits attributed to these beverages. Recently there has also been a surge of scientific interest in cocoa and cocoa products such as chocolate, whose major catechins, like those in broad beans, are epicatechin and catechin. Whilst there does not appear to have been any research relating specifically to broad beans, the general findings regarding catechins are likely to be of some relevance.

Many of the health benefits of catechin-rich foods are thought to be attributable to their antioxidant activity, which is conferred by their structures, including the hydroxylation of a flavan ring structure, particularly the 3,4 dihydroxylation of the B-ring, the oligomer chain length and stereochemical features of the molecule (Keen et al. 2005). Their antioxidant activity includes radical scavenging and metal chelating properties. This is believed to be important in protecting against several chronic diseases, including cardiovascular disease and cancer.

In vitro studies have shown catechins to inhibit LDL oxidation as well as platelet aggregation, reduce inflammation and improve vascular endothelial function through the activation of nitric oxide synthesis (Auger et al. 2004; Hollenberg et al. 2004; Keen et al. 2005; Williamson & Manach 2005). In a review of human intervention studies, Williamson & Manarch concluded that catechins increased plasma antioxidant activity, decreased plasma lipid peroxide and malondialdehyde concentrations, and increased the resistance of LDL to oxidation. These authors also concluded that catechins appeared to have the deleterious effect of decreasing non-heme iron absorption.

6.4 Factors affecting health benefits

6.4.1 Bioavailability

The bioavailability of carotenoids and some phenolic compounds has already been covered in Section 2.6.1. Whilst not as well absorbed as isoflavones, catechins are better absorbed than most of the other phenolics, though this differs markedly between the catechins themselves. However, a number of studies have shown measurable levels of catechins (particularly epicatechin) in plasma after consumption of chocolate or cocoa, the major catechins being the same as those in broad beans (Manach et al. 2005).

6.4.2 Agronomy

Borowska et al. (2003) found the major difference between the bioactive components in small- and large-seeded broad bean varieties was in terms of phenolic compounds, which were nearly twice as high in large seeds as in small seeds, though there were also differences in antinutritional components (phytates and trypsin and amylase inhibitors). There were also differences in concentrations in all components studied between the cotyledon and the seed coat, which also varied according to variety. Similarly Giczewska & Borowska (2003) found varietal differences in terms of starch and fibre content.

6.4.3 Processing

See Section 2.6.5 for general effects of processing, which apply to most legumes. Data from the USDA (Table 7) suggest that cooking reduces catechin levels. There is very little information available on the effect of heat on broad bean catechins, though it is known that tea catechins are epimerised by heat, so it is possible that although losses of the original compounds were observed with cooking, the resulting epimers were not identified and quantified. Kobayashi et al. (2005) showed that both native tea catechins and heat-epimerised tea catechins were equally effective in lowering cholesterol in an animal study.

Table 7: Catechin levels in raw and boiled broad beans (UDSA 2003).

	(-)-Epicatechin	(-)-Epigallocatechin	(+)-Catechin
Broad beans, immature seeds, raw	22.51	14.03	12.83
Broad beans, immature seeds, cooked, boiled	7.82	4.65	8.16

6.5 Tips and trivia

- Broad beans were part of the diet in many ancient cultures, though not in Ancient Egypt. Priests there forbade the eating of these, believing they each contained the soul of a dead man.
- Some ethnic groups, including some Mediterranean peoples (usually males), lack the gene that codes for the enzyme glucose-6-phoshate dehydrogenase (G6PD). Compounds present in the beans or the pollen of the flowers are metabolised into compounds, which, without G6PD, attack red blood cells causing anaemia, which in severe cases can be fatal. This condition is known as favism, after the broad bean.
- Voting in Ancient Rome took place with broad beans. White beans counted for and black beans against. This is possibly the origin of the term “bean counter”.

7 Overall summary

- Peas and broad beans are excellent all-round vegetables. They contain a wide range of micronutrients and are one of the best vegetable sources of protein.
- The insoluble fibre contained in peas and beans is thought to be particularly important for bowel health, including protecting against bowel cancer. Peas and broad beans also contain soluble fibre and resistant starch, which may also protect against bowel cancer through other mechanisms and have additional health benefits such as preventing other gastro-intestinal problems, cardiovascular disease, diabetes and obesity.
- Peas contain very high levels of the antioxidant carotenoids, lutein and zeaxanthin, which are thought to protect against eye diseases, particularly macular degeneration.
- Broad beans contain very high levels of catechins – the same antioxidants more commonly associated with chocolate, red wine and tea.
- Peas and broad beans also contain isoflavonoids, which have weak oestrogenic effects. Although these phytoestrogens are only present at low levels, it is likely that peas and broad beans are major sources in Western diets. Whilst there is evidence that high levels of isoflavones from soy in the diets of Oriental women may protect against some hormone-related conditions, the health implications of pea and broad bean isoflavones in the diets of Western women is unclear.
- Peas and broad beans both contain saponins, which are thought to lower cholesterol as well as have anti-inflammatory, anti-bacterial and anti-fungal properties.
- Although the edible pod vegetables are less nutrient dense than the seed types, they also have particular dietary benefits. For example, besides

their distinctive sensory attributes, snow peas contain very high levels of vitamin C and beans are an excellent low calorie vegetable.

- Although legumes can contain anti-nutritional compounds, there is no evidence that they pose a threat to the majority of the population.

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Appendices

Appendix I Data from FOODFiles

		Peas,Green,raw
Water	g	77.1
Energy	kcal	62
Protein	g	5.08
Total fat	g	0.5
Carbohydrate, available	g	9.3
Dietary fibre (Englyst, 1988)	g	4.2
Ash	g	0.78
Sodium	mg	5
Phosphorus	mg	72
Potassium	mg	155
Calcium	mg	22
Iron	mg	1.6
Beta-carotene equivalents	µg	311
Total vitamin A equivalents	µg	52
Thiamin	mg	0.34
Riboflavin	mg	0.14
Niacin	mg	2.26
Vitamin C	mg	20
Cholesterol	mg	0
Total saturated fatty acids	g	0.187
Total monounsaturated fatty acids	g	0.158
Total polyunsaturated fatty acids	g	0.056
Dry matter	g	22.9
Total nitrogen	g	0.81
Glucose	g	0.3
Fructose	g	0.4
Sucrose	g	5.1
Lactose	g	0
Maltose	g	0
Total available sugars	g	5.8
Starch	g	3.52
Alcohol	g	0
Total niacin equivalents	mg	3.07
Soluble non-starch polysaccharides	g	1.2
Insoluble non-starch polysaccharides	g	3.1
Energy	kJ	257
Magnesium	mg	22
Manganese	µg	260
Copper	mg	0.336
Zinc	mg	0.68
Selenium	µg	0.286
Retinol	µg	0
Potential niacin from tryptophan	mg	0.813
Vitamin B6	mg	0.14

Folate, total	µg	78
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.64

T=trace

		Peas,Snow,peapod,raw
Water	g	88.9
Energy	kcal	29
Protein	g	2.8
Total fat	g	0.2
Carbohydrate, available	g	4.09
Dietary fibre (Englyst, 1988)	g	2.3
Ash	g	0.56
Sodium	mg	4
Phosphorus	mg	53
Potassium	mg	200
Calcium	mg	43
Iron	mg	2.08
Beta-carotene equivalents	µg	695
Total vitamin A equivalents	µg	116
Thiamin	mg	0.15
Riboflavin	mg	0.08
Niacin	mg	0.6
Vitamin C	mg	60
Cholesterol	mg	0
Total saturated fatty acids	g	0.039
Total monounsaturated fatty acids	g	0.021
Total polyunsaturated fatty acids	g	0.089
Dry matter	g	11.1
Total nitrogen	g	0.48
Glucose	g	2.6
Fructose	g	0.3
Sucrose	g	0.47
Lactose	g	0
Maltose	g	0
Total available sugars	g	3.37
Starch	g	0.72
Alcohol	g	0
Total niacin equivalents	mg	1.12
Soluble non-starch polysaccharides	g	1
Insoluble non-starch polysaccharides	g	1.3
Energy	kJ	122
Magnesium	mg	24
Manganese	µg	244
Copper	mg	0.079
Zinc	mg	0.27
Selenium	µg	T
Retinol	µg	0
Potential niacin from tryptophan	mg	0.6

Vitamin B6	mg	0.16
Folate, total	µg	41.7
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.39

T=trace

		Beans,Green,raw
Water	g	90.7
Energy	kcal	18
Protein	g	1.22
Total fat	g	0.2
Carbohydrate, available	g	2.8
Dietary fibre (Englyst, 1988)	g	2.2
Ash	g	0.48
Sodium	mg	3
Phosphorus	mg	27
Potassium	mg	159
Calcium	mg	48
Iron	mg	0.33
Beta-carotene equivalents	µg	382
Total vitamin A equivalents	µg	64
Thiamin	mg	0.037
Riboflavin	mg	0.028
Niacin	mg	0.5
Vitamin C	mg	10.6
Cholesterol	mg	0
Total saturated fatty acids	g	0.046
Total monounsaturated fatty acids	g	0.009
Total polyunsaturated fatty acids	g	0.105
Dry matter	g	9.35
Total nitrogen	g	0.2
Glucose	g	1.4
Fructose	g	0.3
Sucrose	g	0.3
Lactose	g	0
Maltose	g	0
Total available sugars	g	2
Starch	g	0.79
Alcohol	g	0
Total niacin equivalents	mg	0.7
Soluble non-starch polysaccharides	g	0.9
Insoluble non-starch polysaccharides	g	1.3
Energy	kJ	74
Magnesium	mg	19
Manganese	µg	202
Copper	mg	0.059
Zinc	mg	0.13
Selenium	µg	0.16
Retinol	µg	0

Potential niacin from tryptophan	mg	0.2
Vitamin B6	mg	0.032
Folate, total	µg	48
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.11

T=trace

		Beans,Butter,raw
Water	g	91.6
Energy	kcal	19
Protein	g	2.3
Total fat	g	0.2
Carbohydrate, available	g	2.1
Dietary fibre (Englyst, 1988)	g	1.5
Ash	g	0.5
Sodium	mg	3
Phosphorus	mg	27
Potassium	mg	230
Calcium	mg	16
Iron	mg	0.4
Beta-carotene equivalents	µg	90
Total vitamin A equivalents	µg	15
Thiamin	mg	0.06
Riboflavin	mg	0.09
Niacin	mg	1
Vitamin C	mg	15
Cholesterol	mg	0
Total saturated fatty acids	g	0.046
Total monounsaturated fatty acids	g	0.009
Total polyunsaturated fatty acids	g	0.105
Dry matter	g	8.4
Total nitrogen	g	0.37
Glucose	g	0.4
Fructose	g	1
Sucrose	g	0.4
Lactose	g	0
Maltose	g	0
Total available sugars	g	1.8
Starch	g	0.3
Alcohol	g	0
Total niacin equivalents	mg	1.4
Soluble non-starch polysaccharides	g	0.6
Insoluble non-starch polysaccharides	g	0.8
Energy	kJ	81
Magnesium	mg	22
Manganese	µg	202
Copper	mg	0.06
Zinc	mg	1.5
Selenium	µg	0.16

Retinol	µg	0
Potential niacin from tryptophan	mg	0.4
Vitamin B6	mg	0.03
Folate, total	µg	48
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.11

T=trace

		Beans,Broad,frozen, uncooked
Water	g	78.8
Energy	kcal	58
Protein	g	5.29
Total fat	g	0.3
Carbohydrate, available	g	8.6
Dietary fibre (Englyst, 1988)	g	6.5
Ash	g	0.81
Sodium	mg	6.4
Phosphorus	mg	96
Potassium	mg	250
Calcium	mg	29
Iron	mg	1.7
Beta-carotene equivalents	µg	195
Total vitamin A equivalents	µg	33
Thiamin	mg	0.114
Riboflavin	mg	0.036
Niacin	mg	1.9
Vitamin C	mg	26.4
Cholesterol	mg	0
Total saturated fatty acids	g	0.052
Total monounsaturated fatty acids	g	0.061
Total polyunsaturated fatty acids	g	0.127
Dry matter	g	21.3
Total nitrogen	g	0.85
Glucose	g	0.7
Fructose	g	0.3
Sucrose	g	1.4
Lactose	g	0
Maltose	g	0
Total available sugars	g	2.4
Starch	g	6.22
Alcohol	g	0
Total niacin equivalents	mg	2.8
Soluble non-starch polysaccharides	g	1.4
Insoluble non-starch polysaccharides	g	5.1
Energy	kJ	242
Magnesium	mg	25
Manganese	µg	280
Copper	mg	0.17
Zinc	mg	0.79

Selenium	µg	0.11
Retinol	µg	0
Potential niacin from tryptophan	mg	0.9
Vitamin B6	mg	0.04
Folate, total	µg	145
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.11

T=trace

Appendix II Table of major functions of main micronutrients contained in legumes

Main micronutrients in legumes and their physiological functions, adapted from Medscape (2004) and 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 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
Thiamin vitamin B1	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells
Riboflavin vitamin B2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein
Niacin vitamin B3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown Reduces LDL cholesterol and increases HDL cholesterol
Vitamin B6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis, haemoglobin synthesis. Involved in neuronal excitation Reduces blood homocysteine levels Prevents megaloblastic anemia

Name	Major function
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 B12 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
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
Zinc	Major role in immune system Required for numerous enzymes involved in growth and repair Involved in, sexual maturation Role in taste, smell functions

Appendix III Chemical structures of major phytochemicals in legumes

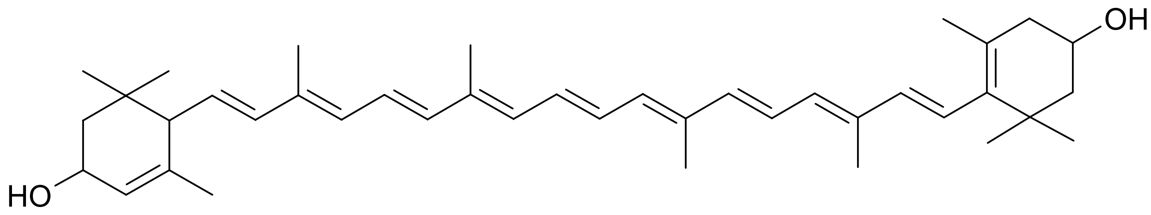

Figure 1: Lutein

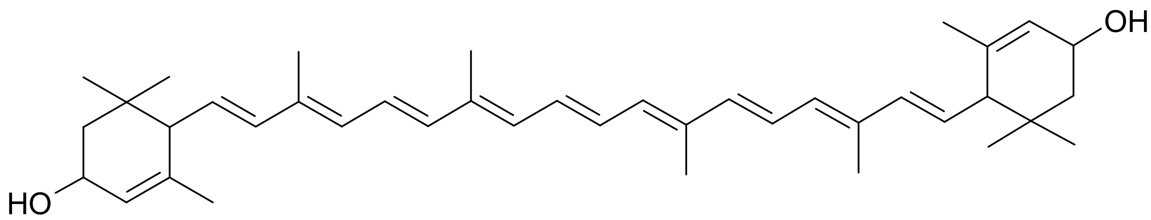

Figure 2: Zeaxanthin

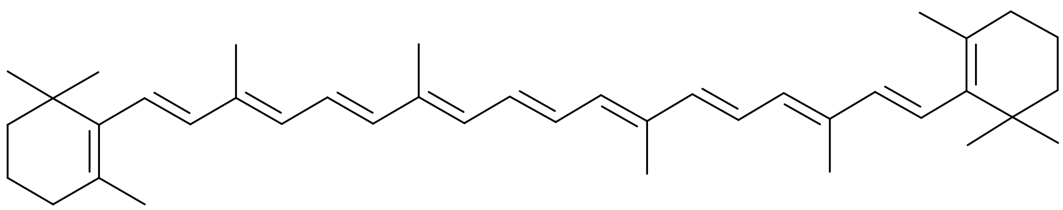

Figure 3: β-carotene

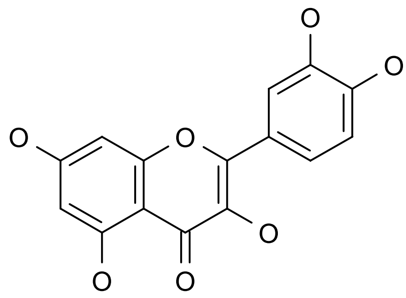

Figure 4: Quercetin

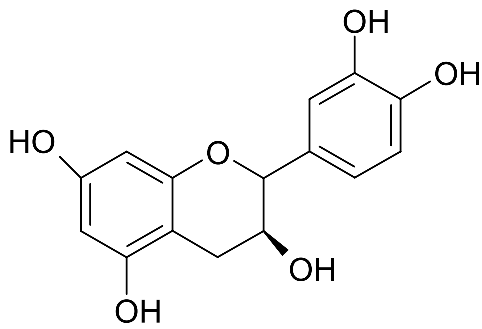

Figure 5: Catechin

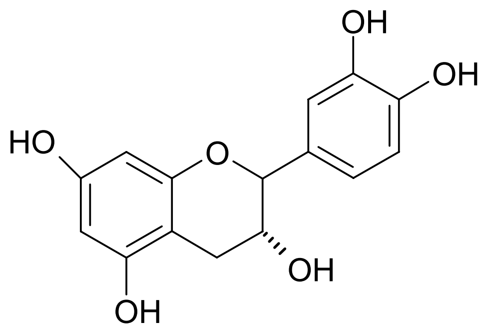

Figure 6: Epicatechin

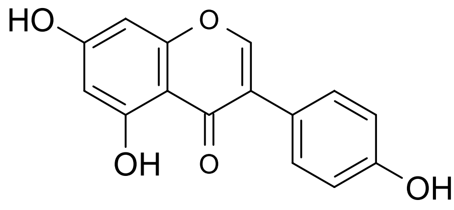

Figure 7: Genistein

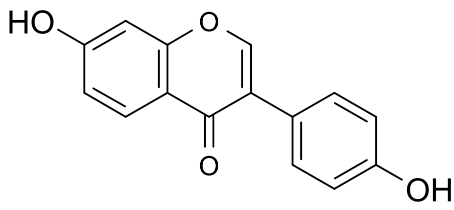

Figure 8: Daidzein

Crop & Food Research Confidential Report No. 1795

Nutritional attributes of legumes (2) Sprouted beans and seeds

L J Hedges & C E Lister

December 2006

A report prepared for
Horticulture New Zealand

Copy 15 of 15

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

Once considered hippie or “new age” food, sprouted seeds have become relatively mainstream over the last decade. They are widely available in supermarkets, and the range has widened to include many different legumes as well as brassica and onion species. Rather than being largely garnishes, they are now frequently an integral component of salads and sandwiches. However, despite this increase in popularity, there has been little nutritional research and information about many sprouted foods is minimal.

1.1 Germination

The germination process has been used for centuries in many Asian cuisines. It has the beneficial effect of reducing anti-nutritional factors and increasing the bioavailability of both macro and micronutrients, such as protein and some minerals. Sprouting also affects phytochemical levels, depending on the sprouting process, seed type and temperature.

1.2 Microbial contamination

Although pathogen contamination, particularly with *E. coli* and *Salmonella* spp., was a serious issue worldwide for the industry in the 1980s and early 1990s, considerable research and industry effort has reduced the occurrence of such incidents. This has been largely due to treatments for contaminated seeds, the major cause of the problem, along with scrupulous hygiene during production processes.

1.3 Sprouted legumes

Information on individual sprouted legumes is somewhat patchy, with only isolated pieces of information rather than complete overviews. According to the information available, the major nutrients in most sprouted legumes are the B vitamins and some minerals. Most information is available on sprouted soy beans, which appear to be one of the most nutritious of this group, with around double the levels of nutrients compared with other sprouted legumes. However, this is partially explained by the fact that they also contain a much higher dry matter content than many of the other sprouts.

1.4 Sprouted brassicas

There are a number of papers specifically focusing on broccoli sprouts relating to the broccoli-associated isothiocyanate, sulforaphane. There is also considerable information about sulforaphane itself, as well as other isothiocyanates and glucosinolates. Broccoli sprouts, particularly a commercially available patented product that was used in many of the studies, can have extremely high levels of the sulforaphane glucosinolate, glucoraphanin, in levels several times higher than in the mature heads. However, it should be borne in mind that the average serving size of broccoli sprouts is considerably less than of broccoli florets.

1.5 Conclusions

It is likely that these products provide a good range of both core nutrients and phytochemicals, but until more information is available, this conclusion is not definitive. It is to be hoped that they receive more research attention, as they have the potential to satisfy many of the needs of tomorrow's consumer, being fresh, minimally processed, convenient and healthy.

2 Background

Note: This report is intended to be viewed as an adjunct to the report "The nutritional attributes of legumes". Unfortunately there is a dearth of research in the area of sprouted beans and seeds and it has not been possible to find information on all commercially available sprouts.

Sprouted beans and seeds have progressed from being dismissed as the domain of health food fanatics or hippie food to being regarded as healthy, convenient and tasty. The rise in popularity of certain ethnic cuisines, such as Thai and Chinese, has also helped raise awareness and acceptance of these foods and led consumers to consider them as more than just garnishes to a salad. Their presence in supermarkets means that they are also readily available and new technologies and production processes have meant fewer incidences of pathogenic contamination, which has periodically given these foods a bad reputation.

2.1 Germination and sprouting

The effects of germination depend both upon the nature of the plant and on the environmental conditions, although the general process is common to most plants. Germination is a period of intense metabolic activity in the plant. Following the uptake of water by the seed, metabolic processes oxidise oils and carbohydrates stored within the seed and break down storage proteins to provide the energy and amino acids necessary for normal physiological processes and for growth (Zielinski 2002; Urbano et al. 2006). Germination has also been documented as an effective means of removing some of the antinutritional factors present in the seeds, such as trypsin inhibitors, phytates and raffinose oligosaccharides. Some antinutritive components may be leached during soaking and others may be mobilised in the germinating seed into secondary metabolites. For example, trypsin inhibitors that impede the digestion of protein are reduced and phytic acid, which forms insoluble complexes with some minerals in seeds, is hydrolysed, allowing minerals to be more available for absorption.

Another obvious change is the accumulation of moisture, with sprouts having considerably higher water content than their seeds. For example, mung bean sprouts contain 93.2% water, whereas the raw seeds contain only 11% (Athar et al. 2004).

2.2 Microbial contamination

In the past there have been a number of incidences of various forms of microbial contamination of sprouted products, especially from *E. coli* and *Salmonella* spp. The consensus appears to be that contamination occurs primarily through the seed, although production and handling practices may also be involved. With sprouts there is particular potential for the growth of pathogenic bacteria because the conditions that are most favourable to the sprouting process are also favourable to the growth of many pathogens. In addition, sprouts are often hard to wash adequately without compromising organoleptic qualities and are frequently consumed raw.

There has been considerable research investigating methods of ensuring a pathogen-free product and this, coupled with greater industry awareness, should mean that high standards of food safety in today's products are possible. Such was the concern regarding this problem that in 1997 the National Advisory Committee on Microbiological Criteria for Foods was asked to review the current literature on sprout-associated outbreaks, identify the organisms and production practices of greatest public health concern, prioritise research needs, and provide recommendations on intervention and prevention strategies (1999; NACMCF 1999). The findings of this study, together with much subsequent research, appear to have considerably improved the food safety aspects of these foodstuffs.

3 Sprouted legumes

The major nutrients in sprouted legumes are the B vitamins, particularly thiamine. They also provide small amounts of a range of minerals. Some, such as alfalfa and pea shoots, have a high water content and thus have only low concentrations of the nutrients they supply, but are also low in calories. However, sprouted beans, such as soy and adzuki beans, contain more dry matter and higher levels of nutrients but more calories. Being young, most sprouts are sweet and tender and provide interesting textures, being crunchy rather than fibrous like older plants.

Without their hard seed coats, these young plants are potentially vulnerable, and so have evolved defence mechanisms through protective phytochemicals. Levels of these appear to fluctuate and they may change form during the germination process, such as from glycosylated compounds to aglycones or vice versa.

3.1 *Adzuki beans (*Vigna angularis*)*

New Zealand data on adzuki bean sprouts are not available, but it is likely that adzuki beans will have a roughly similar nutrient profile to other sprouted beans in this report (see Appendix I).

One of the few studies involving adzuki sprouts related to levels of bioactive compounds over a 4-day period of germination/sprouting. High levels of phenolic compounds, including flavonoids, were measured in the seed, and are attributed to their strongly coloured maroon seed coats. These mainly contain proanthocyanins, according to two early studies (Ariga et al. (1988) and Ariga & Hamaon (1990), cited in Lin & Lai (2006)). Lin & Lai (2006) also observed the extremely high *in vitro* radical scavenging activity of these procyanindins.

Lin & Lai (2006) found that over short-term germination (1 day), levels of total phenolics and flavonoids decreased, which was attributed to loss of pigments in the seed coats. This was confirmed visually with staining of the coloured cheesecloth in the container in which the seeds were soaked. After 4 days of germination total phenolics increased again, although total flavonoids decreased. Antioxidant activity, measured according to reducing power, initially declined and then increased to around the same level as present in the seed. Radical scavenging ability progressively increased over the germination process (Table 1). (See Section 3.5 of the report "Nutritional attributes of legumes", which describes the health benefits of phenolic compounds and the importance of antioxidant activity.) Of the four sprouted legumes investigated (soy, black soy, mung and adzuki), the adzuki sprouts had the highest levels of total flavonoids and moderately high levels of total phenolics. Reducing power for both seeds and germinated forms of adzuki beans was around the highest of the four species, although radical scavenging, as measured by the DPPH assay, was towards the lowest.

Table 1: DPPH scavenging ability of mature and germinated seeds of one adzuki bean cultivar (Lin & Lai 2006).

Seed	1-day germinated	4-day germinated
0.4 EC_{50} (mg/ml)	0.6 EC_{50} (mg/ml)	2.5 EC_{50} (mg/ml)

3.2 *Alfalfa sprouts (*Medicago sativa*)*

The main core nutrients in alfalfa sprouts are the B vitamins, particularly thiamin (Figure 1). Further detail is provided in Appendix I and the major functions of the various micronutrients are summarised in Appendix II.

One of the few *in vivo* studies using sprouts involved a 3-day germinated mix of equal quantities of alfalfa, broccoli, radish and clover sprouts (Gill et al. 2004). Volunteers were fed 113 g of a commercially available sprout mix daily for 14 days, after which a range of parameters were measured, including DNA damage in lymphocytes, the activity of three detoxifying enzymes, antioxidant status, plasma antioxidants, blood lipids and plasma levels of lutein and lycopene. There was no significant effect upon detoxifying enzymes, nor were plasma antioxidant levels altered. However, there was a significant antigenotoxic effect against H_2O_2-induced DNA damage in peripheral blood lymphocytes of the volunteers. The authors concluded that these results supported the theory that cruciferous vegetable consumption reduces the risk of cancer by protecting DNA from damage. A parallel *in vitro* study showed that colorectal cells preincubated for 24 hours with the sprout extract were better able to resist H_2O_2 damage to DNA (Gill et al. 2004).

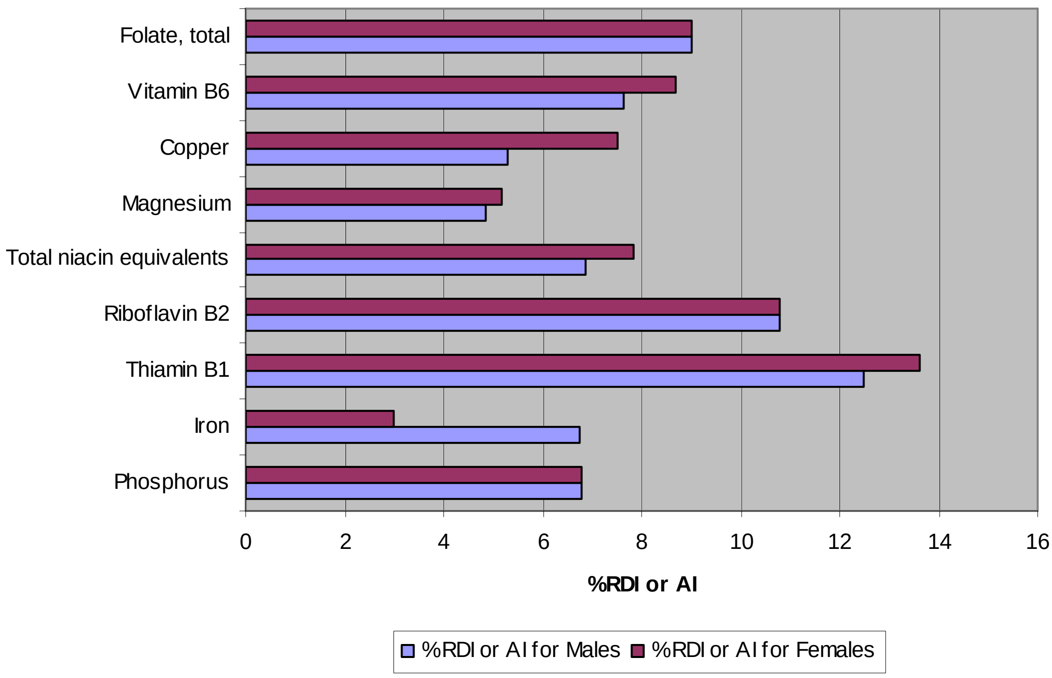

Figure 1: Contributions to RDI (recommended daily intake) or AI (adequate intake) by the major micronutrients in 100 g alfalfa sprouts, adapted from Athar et al. (2004) and NHMRC (2006).

Alfalfa sprouts are sweet and crunchy, but relatively bland. They are consequently often mixed with other sprouts, such as onion, which have more pungent flavours and different bioactive components. Onions contain flavonoids, fructans and organosulfur compounds. These bioactives have been found to have many beneficial health effects, including reducing the risk of thrombosis, protecting against cancer and cardiovascular disease, and having anti-bacterial activity. Interestingly, there is very little difference between levels of the main core nutrients in the pure alfalfa mix as opposed to the alfalfa/onion mix, except that the mix has a greater amount of thiamin (Figure 2).

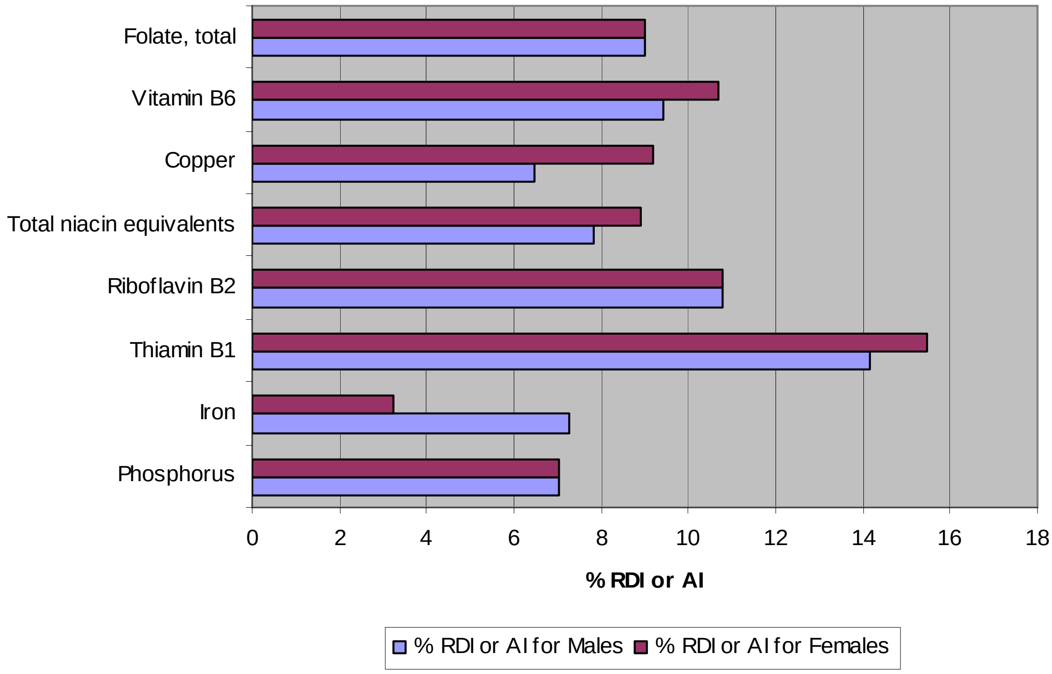

Figure 2: Contributions to RDI (recommended daily intake) or AI (adequate intake) by the major micronutrients in 100 g of alfalfa and onion sprouts, adapted from Athar et al. (2004) and NHMRC (2006).

3.3 *Lentil sprouts (*Lens culinaris*)*

New Zealand data on lentil sprouts are not available, but it is likely that their nutritional profile would be similar to that of other legume sprouts.

Vidal-Valverde (2003) showed a dramatic decrease in antinutritional factors, including trypsin inhibitors and phytates, over the course of 6 days' germination. However, the amount of tannins and catechins in both varieties studied increased. (The latter are well known antioxidant compounds, more commonly associated with chocolate and tea.) After 6 days, catechin levels were measured at 1.0 and 1.2 mg/g (dry weight) for the two varieties. Converting to fresh weight values on the basis of USDA data (USDA 2005), this equates to 36.26 and 43.51 mg/100 g. These levels are similar to those reported in tea and red wine. (See Sections 6.2 and 6.3 of the "Health attributes of legumes" report for further detail on catechins and their health benefits.) Ziielinski (2002) showed that germinated lentil seeds were more effective than germinated soy seeds when their peroxyl-trapping capacity was compared and that this fluctuated over the course of the 7-day germination period.

3.4 *Mung beans (*Vigna radiata *syn* Phaseolus aureus*)*

As with others in this group, the major core nutrients in mung bean sprouts are the B vitamins (Figure 3).

Mung bean sprouts had moderate levels of phenolic compounds when compared with soy and adzuki beans and sprouts and similar levels of flavonoids and reducing power to sprouted soy (Lin & Lai 2006). See Section 3.5.3 of the 'Health attributes of legumes" report for a discussion of phenolic compounds and their benefits.

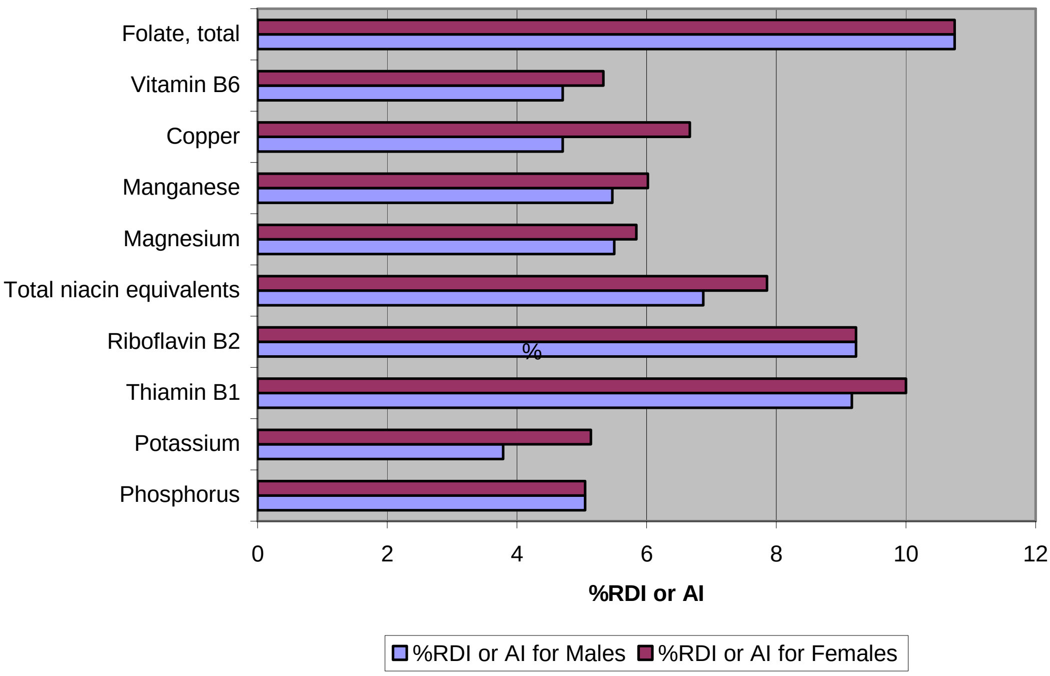

Figure 3: Contributions to RDI (recommended daily intake) or AI (adequate intake) by the major micronutrients in 100 g of mung bean sprouts, adapted from Athar et al. (2004) and NHMRC (2006).

3.5 *Pea sprouts (*Pisum sativum*)*

The major core nutrients in pea sprouts are again the B vitamins (Figure 4). Further detail is provided in Appendix I and the major functions of the various micronutrients are summarised in Appendix II.

One of the few studies found on pea sprouts involved looking at the effect of germination on levels and bioavailability of certain minerals. Although soaking prior to germination caused the leaching of zinc and magnesium, in this animal study the improved bioavailability after germination more than compensated for such losses (Urbano et al. 2006). This study also found that the optimum time for sprouting was 4 days and that whether sprouting took place in the dark or light made no difference to the levels of these minerals or their bioavailability.

A very recent *in vitro* study showed that a phenolic extract from 5- and 8-day old pea sprouts exhibited dose dependent anti-*Helicobacter pylori* activity (Ho et al. 2006). Phenolic content was also measured and found to fluctuate between 0.35

and 0.75 mg/g (fresh weight) and to be highest on days 1 and 5. However, these levels would be considered low in comparison with other vegetables (Wu et al. 2004b), being around the same as those in iceberg lettuce.

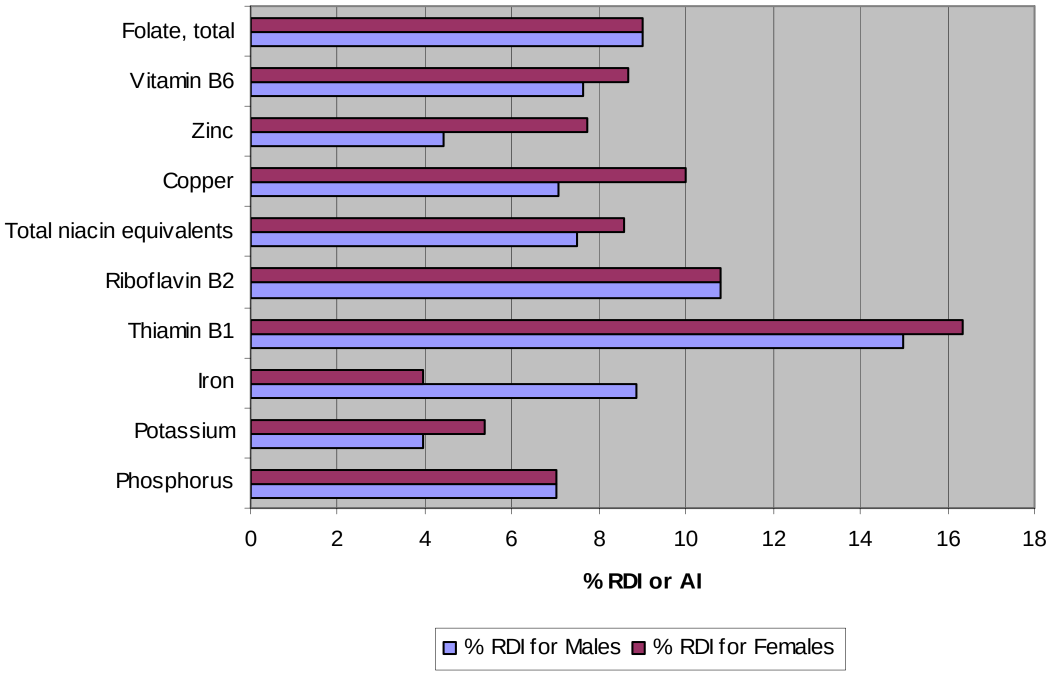

Figure 4: Contributions to RDI (recommended daily intake) or AI (adequate intake) by the major micronutrients in 100 g of snow pea shoots, adapted from Athar et al. (2004) and NHMRC (2006).

3.6 *Soy bean shoots (*Glycine max*)*

In comparison with other sprouted legumes, soy bean sprouts appear to be nutritionally superior. However, it should be borne in mind that they are also a far denser product, with a water content of only 69.1 g/100 g fresh weight, than mung bean sprouts which have a water content of 93.2 g/100 g fresh weight. It is not surprising therefore that their energy content is 141 kcal as opposed to 23 kcal for mung bean sprouts. Unlike many other legume sprouts they also contain reasonable amounts of vitamin C.

Soy beans have received significant attention because of their isoflavone content, and it is these same phytochemicals that have mostly interested researchers with respect to the sprouts. The major isoflavones in sprouts according to Zhu et al. (2005) are genistein, followed by daidzein. They are predominantly present as aglycones (Nakamura et al. 2001), which is important as they reportedly have higher antioxidant activity and are absorbed faster and in higher amounts than when in their carbohydrate-bound forms (McCue & Shelly 2004). Plaza et al. (2003) observed a 2.8 fold increase in genistein and a 3.7 fold increase in daidzein from the dry beans to the sprouts. Genistein and daidzein were highest just after soaking, and high levels of free phenolics and antioxidant activity in dark-germinated sprouts were reported in a genetically modified glyphosate-resistant cultivar (McCue & Shelly 2004). (See Sections 3.4.2 and 3.5.3 of the “Nutritional attributes of legumes” report for further detail on the nature of these compounds and their health effects.)

As with other sprouted legumes, germination brought about decreased levels of trypsin inhibitors and flatulence-causing oligosaccharides as well as increases in vitamin C and riboflavin, according to Zhu et al. (2005). Plaza et al. (2003) also observed increases in vitamin C of 4-20 times the original level, reaching a maximum after 4-5 days.

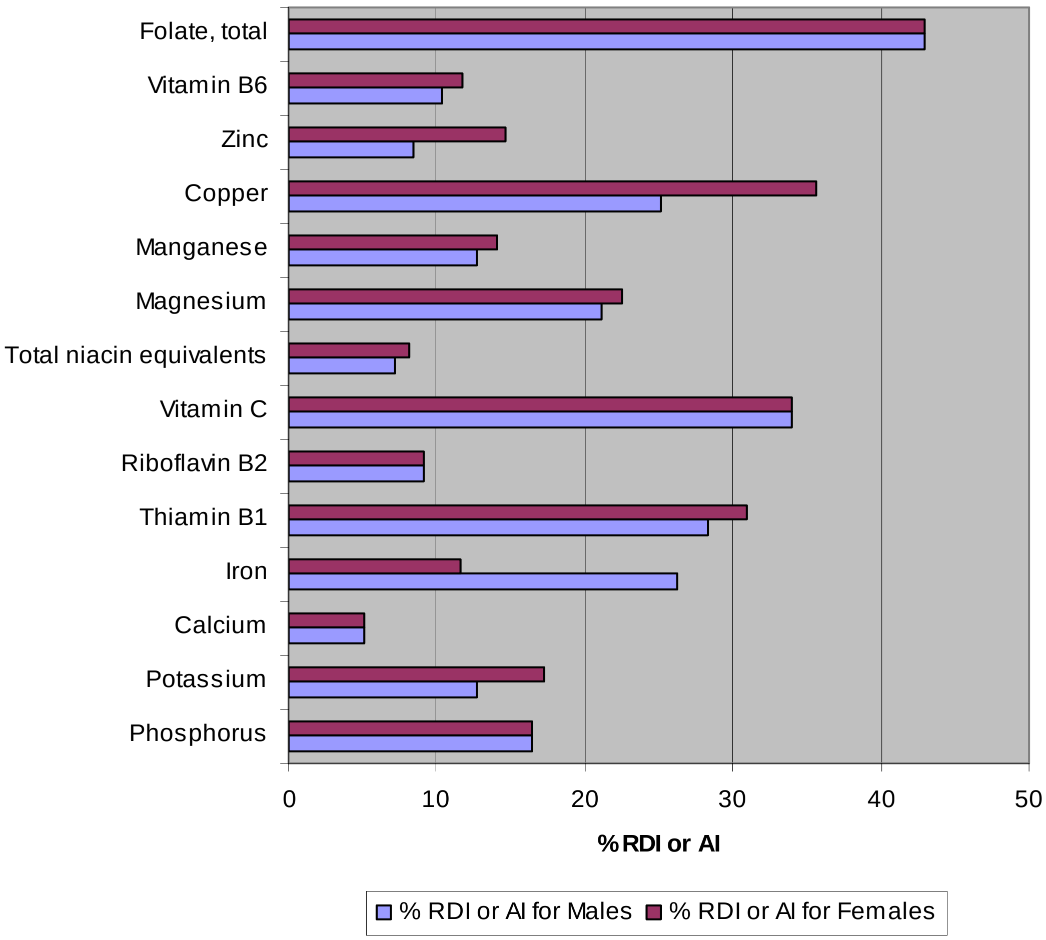

Figure 5: Contributions to RDI (recommended daily intake) or AI (adequate intake) by the major micronutrients in soy bean sprouts, adapted from Athar et al. (2004) and NHMRC (2006).

4 Sprouted brassica vegetables

4.1 *Broccoli sprouts (*Brassica oleracea*)*

There appear to be only a few studies relating specifically to the health effects of broccoli sprouts, but there is a large and growing body of research regarding sulforaphane, the compound most famously associated with the ability of broccoli to protect against cancer. The initial focus was on its anti-cancer properties, with studies across a range of different cancers, including the bladder, breast, liver, lung, prostate and skin. Research has recently included other health problems such as hypertension, cardiovascular disease, joint health, Alzheimer's disease, stomach health and eye health.

An early review of epidemiological studies in relation to *Brassica* vegetable consumption 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 7 cohort studies, the authors concluded that high brassica vegetable consumption was most strongly associated with a decreased risk of lung, stomach, colon and rectal cancer and least consistent for cancers of the prostate, ovaries and endometrium. However, the authors noted that various factors are believed to lead to inconsistent results in epidemiological studies, including trial design, with retrospective case-control studies being the 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. For further information on this area see the earlier report, "Nutritional attributes of brassica vegetables".

Most of the considerable research that has taken place has used purified sulforaphane, rather than broccoli or broccoli sprouts. Of those using broccoli sprouts, a number have used a specially produced high-sulforaphane content cultivar, which may or may not be nutritionally equivalent to other commercially available products.

An early research project identified that 3-day-old sprouts of certain brassica species contained 10-100 times the level of glucoraphanin, the parent glucosinolate of sulforaphane, compared to the corresponding mature plants (Fahey et al. 1997). However, it should be borne in mind that sprouts are consumed in much smaller quantities (average serving size 5 g, 1 cup ~35 g) than the mature heads (average serving size 100 g).

Studies relating specifically to broccoli sprouts include:

- broccoli sprout extracts were extremely effective in reducing the incidence of mammary tumours in rats that had been treated with a known mammary cancer-inducing compound (Fahey et al. 1997);
- a large placebo-controlled blind human clinical trial of 100 participants and 100 controls found that consuming a liquid broccoli extract over two weeks resulted in lower levels of biomarkers of DNA damage. Tests of the subjects'

urine also showed that carcinogens present in the diet were being detoxified and removed from the body (Kensler et al. 2005);

- a small Japanese pilot study found that subjects who ate at least 3.5 oz (~100 g) of broccoli sprouts daily over the course of a week reduced their LDL (bad) cholesterol, whilst increasing their HDL (good) cholesterol and improving biomarkers of oxidative stress (Murashima et al. 2004). However, as stated earlier, given that 1 cup of broccoli sprouts weighs about 35 g, this would involve eating nearly 3 cups daily, which many people would not find possible;
- an intake of high glucosinolate broccoli sprouts lowered blood pressure, decreased oxidative stress, and inflammation in the kidneys and cardiovascular system in an animal study using spontaneously hypertensive rats (Wu et al. 2004a).

The Brassica Protection Products LLC website www.brassica.com provides extensive information regarding broccoli sprouts, broccoli, and sulforaphane research as well as general information.

5 *Conclusions*

It is to be hoped that as the popularity of these foods grows, so too will research interest in them. Satisfying growing consumer demand for nutritious, convenient and minimally processed foods, they are low calorie, but from the (incomplete) information available, seem to be relatively nutrient dense. Although information is scanty, it does appear that now microbial contamination is currently rare, they could provide a useful contribution to the diet. It is highly likely that these will prove to be useful additional sources of many nutrients, but more information on both the core nutrients of lesser-known sprouts and the range of bioactives within these species is necessary.

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Appendices

Appendix I Data from FOODFiles

		Sprouts, Alfalfa, raw
Water	g	92.3
Energy	kcal	21
Protein	g	3.7
Total fat	g	0.7
Carbohydrate, available	g	T
Dietary fibre (Englyst, 1988)	g	0.97
Ash	g	0.33
Sodium	mg	6.1
Phosphorus	mg	67.8
Potassium	mg	83.2
Calcium	mg	12.5
Iron	mg	0.54
Beta-carotene equivalents	µg	96
Total vitamin A equivalents	µg	16
Thiamin	mg	0.15
Riboflavin	mg	0.14
Niacin	mg	0.5
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	0.069
Total monounsaturated fatty acids	g	0.056
Total polyunsaturated fatty acids	g	0.409
Dry matter	g	7.71
Total nitrogen	g	0.64
Glucose	g	T
Fructose	g	T
Sucrose	g	T
Lactose	g	T
Maltose	g	T
Total available sugars	g	T
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	1.1
Soluble non-starch polysaccharides	g	0.39
Insoluble non-starch polysaccharides	g	0.58
Energy	kJ	88
Magnesium	mg	16.5
Manganese	µg	165
Copper	mg	0.09
Zinc	mg	0.03
Selenium	µg	2.3
Retinol	µg	T
Potential niacin from tryptophan	mg	0.6
Vitamin B6	mg	0.13
Folate, total	µg	36

		Sprouts, Alfalfa, raw
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0
T=trace		

		Sprouts, Alfalfa and Onion, raw
Water	g	92.3
Energy	kcal	20
Protein	g	4.01
Total fat	g	0.44
Carbohydrate, available	g	T
Dietary fibre (Englyst, 1988)	g	1.01
Ash	g	0.33
Sodium	mg	6.75
Phosphorus	mg	70.4
Potassium	mg	92.2
Calcium	mg	13.4
Iron	mg	0.58
Beta-carotene equivalents	µg	96
Total vitamin A equivalents	µg	16
Thiamin	mg	0.17
Riboflavin	mg	0.14
Niacin	mg	0.65
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	T
Total monounsaturated fatty acids	g	T
Total polyunsaturated fatty acids	g	T
Dry matter	g	7.66
Total nitrogen	g	0.69
Glucose	g	T
Fructose	g	T
Sucrose	g	T
Lactose	g	T
Maltose	g	T
Total available sugars	g	T
Starch	g	0
Alcohol	g	0
Total niacin equivalents	mg	1.25
Soluble non-starch polysaccharides	g	0.32
Insoluble non-starch polysaccharides	g	0.68
Energy	kJ	84
Magnesium	mg	15.7
Manganese	µg	174
Copper	mg	0.11
Zinc	mg	0.38

		Sprouts, Alfalfa and Onion, raw
Selenium	µg	2.51
Retinol	µg	T
Potential niacin from tryptophan	mg	0.6
Vitamin B6	mg	0.16
Folate, total	µg	36
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0
T=trace		

		Beans, Mung, sprouts, raw
Water	g	93.2
Energy	kcal	23
Protein	g	2.88
Total fat	g	0.77
Carbohydrate, available	g	1.1
Dietary fibre (Englyst, 1988)	g	0.89
Ash	g	0.41
Sodium	mg	2.98
Phosphorus	mg	50.5
Potassium	mg	144
Calcium	mg	18.6
Iron	mg	0.4
Beta-carotene equivalents	µg	13
Total vitamin A equivalents	µg	2
Thiamin	mg	0.11
Riboflavin	mg	0.12
Niacin	mg	0.6
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	0.223
Total monounsaturated fatty acids	g	0.107
Total polyunsaturated fatty acids	g	0.282
Dry matter	g	6.79
Total nitrogen	g	0.46
Glucose	g	T
Fructose	g	0.5
Sucrose	g	T
Lactose	g	T
Maltose	g	T
Total available sugars	g	0.5
Starch	g	0.6
Alcohol	g	0
Total niacin equivalents	mg	1.1
Soluble non-starch polysaccharides	g	0.39
Insoluble non-starch polysaccharides	g	0.5

		Beans, Mung, sprouts, raw
Energy	kJ	95
Magnesium	mg	18.7
Manganese	µg	301
Copper	mg	0.08
Zinc	mg	0.33
Selenium	µg	1.36
Retinol	µg	T
Potential niacin from tryptophan	mg	0.5
Vitamin B6	mg	0.08
Folate, total	µg	43
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.06

T=trace

		Shoots, Snow Pea
Water	g	93.3
Energy	kcal	18
Protein	g	3.99
Total fat	g	0.23
Carbohydrate, available	g	T
Dietary fibre (Englyst, 1988)	g	0.8
Ash	g	0.42
Sodium	mg	0.99
Phosphorus	mg	70.3
Potassium	mg	150
Calcium	mg	6.66
Iron	mg	0.71
Beta-carotene equivalents	µg	16
Total vitamin A equivalents	µg	2.7
Thiamin	mg	0.18
Riboflavin	mg	0.14
Niacin	mg	0.6
Vitamin C	mg	T
Cholesterol	mg	0
Total saturated fatty acids	g	T
Total monounsaturated fatty acids	g	T
Total polyunsaturated fatty acids	g	T
Dry matter	g	6.72
Total nitrogen	g	0.69
Glucose	g	T
Fructose	g	T
Sucrose	g	T
Lactose	g	T
Maltose	g	T
Total available sugars	g	T
Starch	g	0

		Shoots, Snow Pea
Alcohol	g	0
Total niacin equivalents	mg	1.2
Soluble non-starch polysaccharides	g	0.29
Insoluble non-starch polysaccharides	g	0.51
Energy	kJ	75
Magnesium	mg	15
Manganese	µg	236
Copper	mg	0.12
Zinc	mg	0.62
Selenium	µg	0.18
Retinol	µg	T
Potential niacin from tryptophan	mg	0.6
Vitamin B6	mg	0.13
Folate, total	µg	36
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0

T=trace

		Soybean, sprouts, raw
Water	g	69.1
Energy	kcal	141
Protein	g	13.1
Total fat	g	6.7
Carbohydrate, available	g	7
Dietary fibre (Englyst, 1988)	g	2.5
Ash	g	1.59
Sodium	mg	14
Phosphorus	mg	164
Potassium	mg	484
Calcium	mg	67
Iron	mg	2.1
Beta-carotene equivalents	µg	6
Total vitamin A equivalents	µg	1
Thiamin	mg	0.34
Riboflavin	mg	0.118
Niacin	mg	1.15
Vitamin C	mg	15.3
Cholesterol	mg	0
Total saturated fatty acids	g	0.929
Total monounsaturated fatty acids	g	1.52
Total polyunsaturated fatty acids	g	3.78
Dry matter	g	31
Total nitrogen	g	2.26
Glucose	g	0.5
Fructose	g	0.5

		Soybean, sprouts, raw
Sucrose	g	1
Lactose	g	0
Maltose	g	0
Total available sugars	g	2
Starch	g	5
Alcohol	g	0
Total niacin equivalents	mg	1.15
Soluble non-starch polysaccharides	g	1.2
Insoluble non-starch polysaccharides	g	1.3
Energy	kJ	587
Magnesium	mg	72
Manganese	µg	702
Copper	mg	0.427
Zinc	mg	1.17
Selenium	µg	2
Retinol	µg	0
Potential niacin from tryptophan	mg	T
Vitamin B6	mg	0.176
Folate, total	µg	172
Vitamin B12	µg	0
Vitamin D	µg	0
Vitamin E	mg	0.06

T=trace

Appendix ll Table of major functions of main micronutrients contained in sprouted seeds and beans

Activities of Vitamins and Minerals and Fibre (adapted from

misc.medscape.com/pi/editorial/ clinupdates/2004/3341/table.doc and

www.bupa.co.uk/health_information/html/healthy_living/lifestyle/exercise/diet_exercise/vitamins.html)

Name	Major function
Vitamin A Retinol (animal origin) Carotenoids (plant origin, converted to retinol in the body) Note: Retinol Equivalents (RE) 1 RE =1 mcg retinol or 6 mcg beta-carotene 1 IU = 0.3 mcg or 3.33 mcg = 1 mcg retinol = 1 RE	Important for normal vision and eye health. Involved in gene expression, embryonic development and growth and health of new cells. Aids immune function. May protect against epithelial cancers and atherosclerosis.
Vitamin D (calciferol) Two main forms cholecalciferol (animal origin) and ergocalciferol (plant origin) Cholecalciferol is formed by action of UV rays of sun on skin Note: 1 mcg calciferol = 40 IU vitamin D	Facilitates intestinal absorption of calcium and phosphorous and maintains serum concentrations. Maintains bone health and strong teeth. May be involved in cell differentiation and growth. May be involved in immune function.
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.

Name	Major function
	Involved in energy metabolism, especially carbohydrates. May also be involved in calcium metabolism.
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 certain cancers. Involved in hormone and neurotransmitter synthesis.
Thiamin vitamin B_1 Aneurin	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids. Needed for nerve transmission. Involved in formation of blood cells.
Riboflavin vitamin B_2	Important for skin and eye health. Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein.
Niacin vitamin B_3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown. Reduces LDL cholesterol and increases HDL cholesterol.
Vitamin B_6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis and haemoglobin synthesis. Involved in neuronal excitation. Reduces blood homocysteine levels. Prevents megaloblastic anaemia.
Vitamin B_{12} Cobalamin	Coenzyme in DNA synthesis with folate. Synthesis and maintenance of myelin nerve sheaths. Involved in the formation of red blood cells.

Name	Major function
	Reduces blood homocysteine levels. Prevents pernicious anemia.
Folate Generic term for large group of compounds including folic acid and pterylpolyglut-amates	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.
Biotin	Important for normal growth and body function. Involved in metabolism of food for energy. Coenzyme in synthesis of fat, glycogen, and amino acids.
Pantothenic acid	Coenzyme in fatty acid metabolism and synthesis of some hormones. Maintenance and repair of cell tissues.
Sodium	Major ion of extracellular fluid. Role in water, pH and electrolyte regulation. Role in nerve impulse transmission and muscle contraction.
Potassium	Major ion of intracellular fluid. Maintains water, electrolyte and pH balances. Role in cell membrane transfer and nerve impulse transmission.
Chloride	Major ion of extracellular fluid. Participates in acid production in the stomach as component of gastric hydrochloric acid. Maintains pH balance. Aids nerve impulse transmission.
Phosphorus	Structural component of bone, teeth, cell membranes, phospholipids, nucleic acids, nucleotide enzymes and cellular energy metabolism.

Name	Major function
	pH regulation. Major ion of intracellular fluid and constituent of many essential compounds in body and processes.
Calcium	Structural component of bones and teeth. Role in cellular processes, muscle contraction, blood clotting, enzyme activation and nerve function.
Magnesium	Component of bones. Role in cellular energy transfer. Role in enzyme, nerve, heart functions, and protein synthesis.
Iron	Component of haemoglobin and myoglobin in blood, and needed for oxygen transport. Role in cellular function and respiration.
Iodine	Thyroid hormone production.
Chromium	Assists in insulin system for regulation of blood glucose.
Cobalt	Component of vitamin B_{12}.
Copper	Component of many enzymes. Many functions – blood and bone formation, and production of pigment melanin. Aids in utilization of iron stores. Role in neurotransmitters synthesis.
Fluoride	Helps prevent tooth decay.
Manganese	Part of many essential enzymes. Aids in brain function, bone structure, growth, urea synthesis, glucose and lipid metabolism.
Molybdenum	Aids in enzyme activity and metabolism.
Selenium	Important role in body's antioxidant defence system as component of key enzymes. May help prevent cancer and cardiovascular disease.
Zinc	Major role in immune system.

Name	Major function
	Required for numerous enzymes involved in growth and repair. Involved in sexual maturation. Role in taste and smell functions.
Fibre Fibre can be divided into insoluble and soluble fibre	Insoluble fibre: Adds bulk to stool and thus helps to prevent bowel problems, such as bowel cancer, irritable bowel syndrome and diverticulitis. Soluble fibre: Lowers cholesterol levels. Helps manage blood glucose.

Crop & Food Research Confidential Report No. 1814

The nutritional attributes of* Allium *species

L J Hedges & C E Lister

January 2007

A report prepared for
Horticulture New Zealand

Copy 15 of 15

New Zealand Institute for Crop & Food Research Limited
Private Bag 4704, Christchurch, New Zealand

Contents

1 Executive summary

1.1 Introduction

Onions are one of the world's most widely cultivated vegetables, with their culinary and medicinal uses spanning history and the globe. Equally varied are their health benefits, for they contain a range of phytochemicals with an array of biological effects, including antioxidant activity. There is evidence that they play an important role in protecting against major chronic diseases as well as health problems associated with ageing. Their antimicrobial activity, long recognised in folk remedies, has also now been scientifically validated.

1.2 Onions

Onions are not a particularly rich source of core nutrients, with vitamin C being the most important. However, the frequency in which they are eaten makes their nutrients a valuable contribution to the diet. It is their phytochemical compounds that are of most interest nutritionally. The major groups of these are:

- the flavonoids: quercetin glycosides and, in red varieties, anthocyanins;
- fructans;
- sulfur-containing compounds, including the cepaenes and thiosulfinates;
- saponins.

Each of the groups exhibits at least one of the following beneficial health effects:

- reduction in risk of thrombosis (blood clotting);
- anti-carcinogenic effects;
- anti-bacterial effects;
- reduction in risk of atherosclerosis/coronary heart disease.

Many of the health benefits have been attributed to their antioxidant activity.

In New Zealand spring onions tend to be simply young onion plants,. Of particular nutritional interest is their very high levels of vitamin C. Spring onions appear to contain similar compounds to mature bulbs, although it is likely that these are present at different levels. In addition they contain carotenoids and chlorophyll, both of which have antioxidant activity.

1.3 Garlic

Although on a per weight basis garlic is a rich source of a number of nutrients, since only low quantities are consumed, it is not a major source of these in the diet. Main core nutrients include high levels of vitamins C and B_6. In terms of phytochemicals, garlic contains the same classes of compounds as onions, although individual compounds may differ slightly in structure. For example, onions contain high levels of the flavonol, quercetin, whereas the main flavonol in garlic is myricetin.

The organosulfur compounds in garlic, which differ from those in onions, have received most research attention, particularly those derived from allicin. However, the other bioactives present in garlic are also likely to contribute to the observed health effects, probably with synergistic interactions. The major health issues that garlic is thought to protect against include cardiovascular disease, cancer and other age-related problems such as loss of brain function. In addition, garlic has strong antimicrobial activity against a wide range of organisms. As with onions, antioxidant activity is thought to be an important factor behind observed health benefits.

1.4 Leeks

Leeks have high levels of vitamin C and also folate. There is relatively little information on these vegetables, but they appear to contain good levels of carotenoids and phenolic compounds, both of which have antioxidant activity. Like others in this family, they have been shown to have anti-blood clotting properties.

1.5 Shallots

Shallots have similarly been little studied. The meagre information available suggests that they contain similar compounds to other family members and that they likewise have good antioxidant activity.

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 *Allium* genus – onions, garlic, leeks, spring onions and shallots. The depth of information available varies considerably; it is sparser for leeks, spring onions and shallots. 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.

3 *Onions* (Allium cepa)

All species within the *Allium* genus tend to contain the same compounds but at different levels, as apparent in Figures 1, 2, 4, 5 and 6. However, it should also be borne in mind that smaller quantities of some species are consumed, particularly garlic, and thus although they may appear more nutrient dense, in reality they actually make a smaller dietary contribution.

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). There can also be other issues, such as the form in which the food was analysed (raw, fresh, canned, boiled, frozen) and the analytical techniques used as well as variations between the laboratories doing the analysis. These factors can lead to apparently inconsistent results. They may also lead to large differences in core nutrient levels and even greater differences in terms of phytochemicals.

3.1 *Composition*

3.1.1 *Core nutrients*

Besides being low in energy at around 30 calories per serving (75 g), onions provide vitamin C, folate, niacin and potassium (Figure 1). In addition they provide fibre and abundant flavour. More detail on their macro and micronutrient content is included in Appendix I and the health effects of these in Appendix II.

Spring onions (also known as scallions, green onions and sometimes erroneously as shallots) in New Zealand are just immature onion plants, rather than special cultivars as they are in some other parts of the world. Their major core nutrient is their large amount of vitamin C (Figure 2), although it can be seen that they also contain a greater variety and higher levels of some nutrients than mature onions.

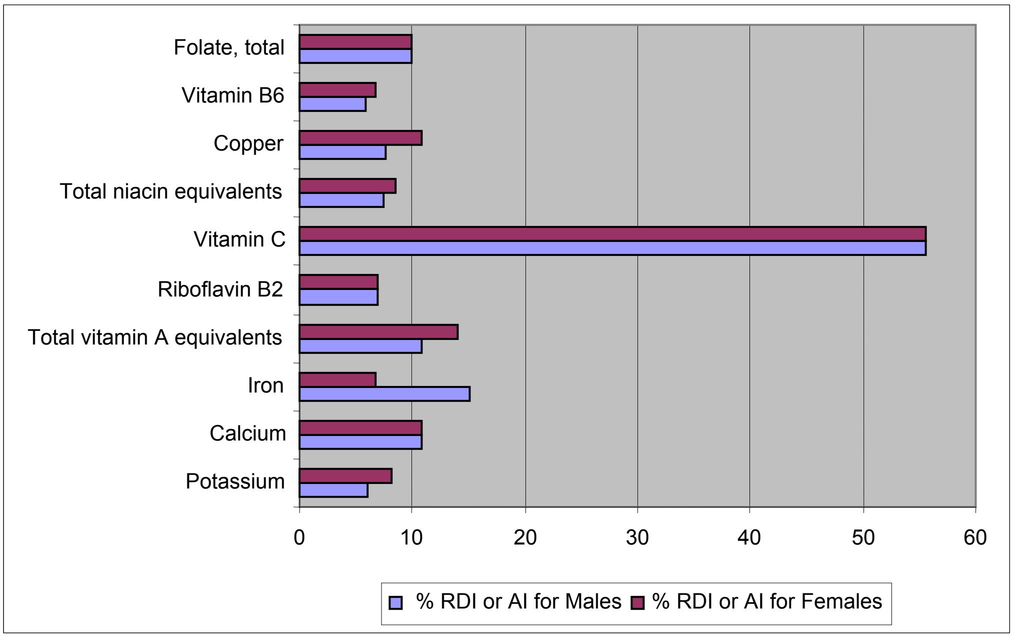

Figure 2: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw spring onions (flesh of bulb), adapted from Athar et al. (2004) and NHMRC (2006).

3.1.2 *Phytochemicals*

Biologically active plant chemicals, other than traditional nutrients, that have a beneficial effect on human health have been termed 'phytochemicals' (Hasler 1998). There are four major groups of compounds found within onions that have health benefits when consumed by humans. These groups are:

1. the flavonoids, including those that provide the yellow and red pigmentation in onions,
2. the fructans, which are an energy store for plants,
3. sulfur-containing compounds, including the cepaenes that are used in plant defence when stressed and
4. saponins, which are present in the plant to protect against potential pathogens.

Flavonoids

Two main groups of flavonoids are found in onions:

1. Flavonols that are responsible for the yellow flesh and brown skins of many varieties. Quercetin and kaempferol, the major flavonoids in onions, belong to this subclass. The degree of hydroxylation distinguishes them from one another.

2. Anthocyanins, which impart a red/purple colour to some varieties.

Flavonoids are present in both the bulbs and leaves of onions and in spring onions. The flavonoids found in onion include quercetin, isorhamnetin and kaempferol derivatives in varying proportions (Bilyk et al. 1984). There are at least eight quercetin glucosides, the 4'-glucoside, the 7,4'-diglucoside, the 3-4'-diglucoside, the 3-glucoside, the 7-glucoside, the 3,7-diglucoside, the 3-rutinoside (rutin), the 3-rhamnoside (quercitrin), the 7,4'-, and 3-glucosides of kaempferol, plus isorhamnetin 4'-glucoside. However, the predominant compounds are quercetin 4'-glucoside and quercetin 3-4'-diglucoside. There are differences in flavonol composition and levels depending on variety (discussed further in Section 3.3).

A number of anthocyanins have been detected in onions, with early studies showing the presence of predominantly cyanidin 3-glucoside, with lesser amounts of cyanidin 3-laminaribioside and other minor unidentified cyanidin, peonidin and pelargonidin glycosides. Terahara et al. (1994) determined the anthocyanins in the Japanese cultivar Kurenai and found it contained cyanidin 3-glucoside, cyanidin 3-laminaribioside and their 6"-malonyl derivatives. Fossen et al. (1996) reported four major and six minor anthocyanins in the cultivars Red Baron, Tropea and Comred (grown in Norway) including the 3-malonylglucoside, 3-dimalonylglucoside and 3,5-diglucoside derivatives of cyanidin, peonidin 3,5-diglucosides and two 3-glycosylated derivatives of pelargonidin. In red onion cultivars grown in Canada and the USA (Mambo, Red Jumbo, Red Bone and Red Granex), the main anthocyanins were cyanidin 3-glucoside, cyanidin 3-laminaribioside, cyanidin 3-(6"-malonylglucoside) and cyanidin 3-(6"-malonyllaminaribioside) (Donner et al. 1997). Minor anthocyanins were shown to be cyanidin3 (3"-malonylglucoside), peonidin 3-glucoside, peonidin 3-malonylglucoside and cyanidin 3-dimalonyllaminaribioside. These differences in anthocyanin composition between studies/locations are probably due to a genetic basis (i.e. cultivar differences).

The flavonoids discussed above are potent antioxidants and have a wide array of biochemical functions. They are involved in immune function, gene expression, capillary and cerebral blood flow, liver function, enzyme activity, platelet aggregation, and collagen, phospholipid, cholesterol and histamine metabolism. The beneficial health effects associated with these compounds, such as reduced risk of coronary heart disease and different types of cancer, are thought to be primarily from antioxidative activity, including metal ion chelation and inhibition of lipid peroxidation (Formica & Regelson 1995). Research studies have shown quercetin to:

- decrease cancer tumour initiation,
- promote healing of stomach ulcers and
- inhibit the proliferation of cultured ovarian, breast and colon cancer cells.

More detailed research on the health benefits is discussed in Section 3.1.2.

Fructans

Fructans (including oligofructans or fructooligosaccharides (FOS)) are polymers based on fructose. They are indigestible ingredients that are fermented in the body and help maintain the health of the gut and colon (Gibson 1998). Onion bulbs may contain a high concentration (35-40% dry weight) of fructans, which constitute a major portion of the water-soluble carbohydrates and have been associated with storage life of bulbs. Onions are composed of 2.8% FOS (wet weight) compared with 1.0% FOS in garlic, 0.7% in rye and 0.3% in bananas.

A number of health benefits result from ingestion of fructans. These include proliferation of bifidobacteria and reduction of detrimental bacteria in the colon, reduction of toxic metabolites and detrimental enzymes, prevention of constipation, protection of liver function, reduction of serum cholesterol, reduction of blood pressure and anticancer effects.

Sulfur compounds

The third main group of phytochemicals in onions is the organosulfur compounds, such as cepaenes and thiosulfinates (Dorsch & Wagner 1991; Goldman et al. 1996). These compounds are formed when an onion is cut and the cell walls are disrupted (Figure 2). Allinase enzymes produce sulfenic acids via S-alk(en)yl cysteine sulfoxides (ACSOs), which rearrange to various compounds such as thiosulfinates, cepaenes and onion lachrymatory factor (Block et al. 1997; Lancaster et al. 1998).

Research studies have shown organosulfur compounds to:

- reduce symptoms associated with diabetes mellitus,
- inhibit platelet aggregation (involved in thrombosis) and
- prevent inflammatory processes associated with asthma.

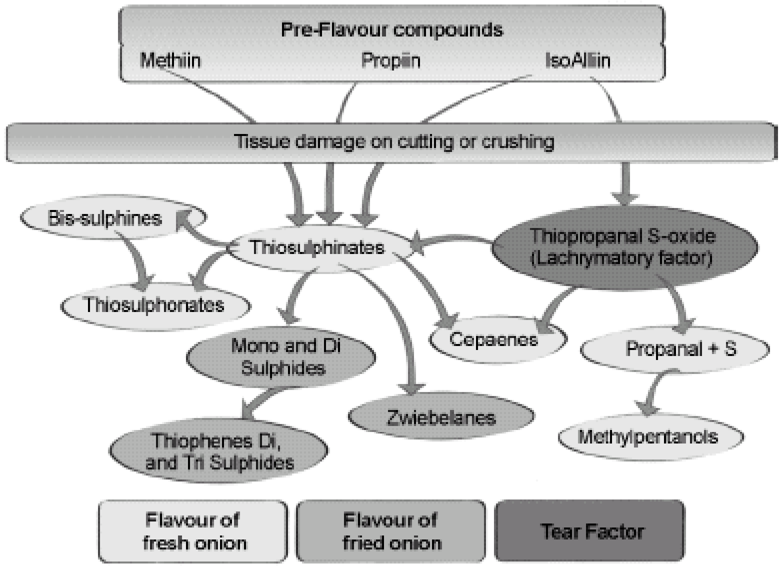

Figure 3: Generation of the major flavour groups in onions (from Griffiths et al. 2002).

Saponins

The fourth group, saponins, are a diverse group of biologically active glycosides, widely distributed in the plant kingdom (Curl et al. 1985). They are divided into two main groups, triterpenoids and steroid saponins (Amagase 2006). Structurally they comprise a carbohydrate portion attached to the triterpenoid or steroid aglycone base. Named for their ability to form stable, soap-like solutions with water, they possess both beneficial and deleterious bioactive qualities. They are often bitter–tasting. A number of different saponins have been identified in *Allium* species, with processing giving rise to different saponins again (Corea et al. 2005; Amagase 2006; Lanzotti 2006).

Saponins are believed to have a beneficial effect on human health particularly in terms of lowering cholesterol (Lutomski 1983; Price et al. 1987). It is thought that saponins cause the adsorption of bile acids onto dietary fibre in the intestine, which is then excreted in the faeces. To compensate for this loss, serum cholesterol is converted by the liver into bile acids, thus lowering levels of cholesterol in the blood (Savage & Deo 2001). They are also believed to protect against cancer by breaking down the cholesterol-rich membranes of cancer cells. Because saponins are not well absorbed into the blood stream, they are believed to be most useful in exerting a localised effect in the intestinal tract, such as combating colon cancer (Joseph et al. 2002). Some members of the saponin family have also been shown to have anti-inflammatory, anti-fungal, anti-yeast, anti-parasitic, antibacterial, anti-microbial and anti-viral activity (Sparg et al. 2004).

Although some saponins have also been shown to have antinutritive effects, including haemolytic and cytotoxic activity (Sparg et al. 2004), there appears to be no evidence of harmful effects of *Alllium* saponins in humans.

Carotenoids (spring onions only)

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. 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. These conjugated (alternating) double bonds confer colour and the compound's antioxidant properties. 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 body can convert α-carotene, β-carotene and β-cryptoxanthin into retinol (vitamin A), whereas lycopene and the xanthophylls, lutein and zeaxanthin, have no vitamin A capacity. Because of their structural similarity they are difficult to separate for analytical purposes and, amounts of the latter two compounds are often reported as a combined total.

The carotenoid content of some common fruit and vegetables is shown in Table 1. Whilst spring onions contain moderate levels of the carotenoids, they are present at much lower levels than in other highly coloured vegetables, such as carrots and spinach.

Table 1: Carotenoid content of assorted fruit and vegetables (µcg/100 g), from USDA National Nutrient Database for Standard Reference Release 18, 2005 (USDA 2005, 2006).

Food	β-carotene	Lutein + zeaxanthin
Apricot	1094	89
Beans,* green, raw	376	640
Broccoli, raw	361	1403
Capsicum, red, raw	1624	51
Carrot, raw	8285	256
Corn (sweet), raw	52	764
Leeks, raw	1000	1900
Onions, raw	1	4
Peas (raw)*	449	2447
Peas (edible pod)*	630	740
Persimmon	253	834
Pumpkin, raw	3100	1500
Spinach, raw	5626	12198
Spring onions	598	1137

* 2006 data.

Carotenoids are probably best known for their antioxidant activity, but those predominant in spring onions, lutein and zeaxanthin, have been most researched in relation to eye diseases. Mares-Perlman et al. (2002) summarised a number of studies linking light exposure to eye diseases. Because these carotenoids absorb blue light, it was suggested that they protect the retina from photochemical damage that could occur from light at these wavelengths. Exposure to light has been found to increase the levels of free radicals in the lens and retina (Dayhaw-Barker 1986, cited in Mares-Perlmann et al. 2002) and exposure of the retina to light has been postulated as a cause of macular degeneration (Borges et al. 1990, cited in Mares-Perlmann et al. 2002).

Chlorophyll (spring onions only)

The green colour of their leaves is evidence of the chlorophyll present in spring onions. 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.

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 potential carcinogens, such as aflatoxin and heterocyclic amines to prevent their absorption (Joseph et al. 2002). A recent study found that chlorophyll had phase 2 enzyme-inducing potential and, although its activity was relatively weak, its high concentration in so many edible plants may be responsible for some of the protective effects observed in diets rich in green vegetables (Fahey et al. 2005). An *in vitro* study found that chlorophyll extracted from spinach exhibited anti-inflammatory activity as well as anti-proliferative effects against breast, colon, stomach, CNS and lung cancer cell lines (Reddy et al. 2005).

3.2 *Health benefits*

The use of *Allium* species for medicinal purposes dates back at least 3500 years with mention of them in the ancient Egyptian papyrus *Codex Ebers,* which documents their therapeutic uses (along with those of other food and ornamental plants (Rivlin 2001). It is said that slaves working on the pyramids were fed onions and garlic to increase their strength and stamina, and these foods were fed to fortify athletes in ancient Greece before the Olympic Games (Rivlin 2001; National Onion Association). Numerous health benefits have been attributed to the onion, including prevention of cancer and cardiovascular disorders (Joseph et al. 2002; Galeone et al. 2006). Scientific studies have shown a positive relationship between vegetable intake and risk for these common diseases. This has led many researchers to test whether the proposed medicinal attributes of onions are valid. Some of these studies have shown that including onion in the diet:

- was associated with a reduced risk of stomach cancer in humans,
- was associated with a decreased risk of brain cancer in humans,
- inhibited platelet-mediated thrombosis (a process leading to heart attacks and strokes),
- reduced levels of cholesterol, triglycerides and thromboxanes (substances involved in the development of cardiovascular disease) in the blood and
- was associated with a reduction in symptoms of osteoporosis.

The major groups of compounds found within onions, described above, all have various health benefits when consumed by humans. Each of the groups exhibits at least one of the following beneficial health effects:

- cardio-protective effects,
- anti-cancer effects,
- gut health effects,
- antimicrobial activity (including anti-bacterial, anti-viral, anti-fungal, anti-yeast effects),
- circulatory benefits,
- boosting of immune-system and
- eye health

3.2.1 *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. This is often attributed to a high intake of phytochemicals with antioxidant activity, as this is thought to be the mechanism underpinning many of these protective effects.

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 left 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 its own antioxidants and has other defence mechanisms, it is thought that antioxidants from the diet also have an important role.

Flavonoids, ubiquitous in the plant kingdom, have been widely studied for their antioxidative effects (Rice-Evans et al. 1995; Hertog & Katan 1998) Onions are known to contain anthocyanins and the flavonols quercetin and kaempferol (Bilyk et al. 1984; Rhodes & Price 1996) and both have antioxidant activity. The antioxidative effects of consumption of onions have been associated with a reduced risk of neurodegenerative disorders (Shutenko et al. 1999), many forms of cancer (Hertog & Katan 1998; Kawaii et al. 1999), cataract formation (Sanderson et al. 1999), ulcer development (Suzuki et al. 1998), and prevention of vascular and heart disease by inhibition of lipid peroxidation and lowering of low density lipoprotein (LDL) cholesterol levels (Frémont et al. 1998; Aviram et al. 1999; Kaneko & Baba 1999). Data from a range of *in vitro* testing methods suggest onions have moderate levels of antioxidant activity compared with other vegetables (Halvorsen et al. 2002; Pellegrini et al. 2003; Wu et al. 2004). In spring onions, the carotenoids also contribute antioxidant activity.

3.2.2 *Anti-thrombotic activities*

Substances that can inhibit platelet aggregation (antiplatelet activity (AP)) reduce the risk of blood clotting and heart disease. Platelet aggregation is a complex process and substances can affect aggregation by inhibiting at least one of the enzymes involved.

Sulfides of onions have been shown to reduce platelet aggregation (Ali et al. 2000; Bayer et al. 1989) and AP has been shown to be partially determined by the concentration of organosulfur compounds (Mayeux et al. 1988). Different sulfur-containing compounds affect different enzymes and when combined the compounds have a cumulative effect. The organosulfur compounds found in whole onions have little AP, but upon cutting, sulfides are generated by enzymes that exhibit AP. This has been demonstrated by comparing the AP of raw whole onions to boiled whole onions (where enzymes are inactivated). The raw onions had significantly higher AP than cooked onions (Ali et al. 2000). However, when the onions were chopped, left for 30 minutes and then boiled they had similar AP to the raw onions.

Quercetin, the flavonoid responsible for the yellow pigmentation, has been shown to inhibit platelet aggregation both *in vitro* (Hubbard et al. 2003) and *ex vivo* (Janssen et al. 1998). Cepaenes have been demonstrated to be strong antiflammatory chemicals with as much potency as aspirin to inhibit platelet aggregation (Block & Zhao 1992). Similarly, saponins have been found have anti-inflammatory activity (Sparg et al. 2004).

3.2.3 Cancer preventative effects

Research has indicated that onions may have a role in the prevention of a wide range of different cancers, including colorectal, stomach, liver, renal, lung, bladder, breast, ovarian, brain and oesophagus cancer. A large and recent European study, published in 2006 in the American Journal of Clinical Nutrition, found that moderate frequency of onion consumption protected against colorectal, laryngeal and oesophageal cancers. More frequent consumption was even more strongly protective and was also significant for oral cavity and oesophageal but not for prostate, breast or renal cell cancers (Galeone et al. 2006). Hsing et al. (2002) also showed the anti-tumour effects of onions, with men consuming 10 g of onions a day being 70% less likely to develop prostate cancer than those consuming less than 2 g of onions a day. The organosulfur compounds in onions proved to be strong anticarcinogens in cell experiments and animal and human trials (Fukushima et al. 1997; Munday & Munday 2001; Hatono et al. 1996; Chu et al. 2002). This is thought to be partially because of their role in the activation of detoxifying enzymes, which remove potentially cancer-causing substances. Flavonoids have also been shown to activate the detoxifying enzymes (Myhristad et al. 2002; Munday & Munday 2001).

No studies have demonstrated direct cancer-preventative effects of cepaenes and fructans. However, fructans promote the growth of beneficial bacteria that aid gut health, including protecting against colonic cancer. Studies have shown that when they are fermented in the bowel, fructans produce short chain fatty acids (SFAs). These are thought to have several beneficial effects, including providing energy for colonic mucosa, protection against various diseases of the colon, including cancer, and lowering colonic pH, so preventing the transformation of primary bile acids to co-carcinogenic secondary bile acids (Ekvall et al. 2006).

3.2.4 Antibacterial effects

Although thought to be less active than garlic, onions have been shown to possess antibacterial and antifungal properties (Hughes & Lawson 1991; Augusti 1996). Onion oil has been shown to be highly effective against gram positive bacteria and some fungi, and inhibits the growth and aflatoxin production of fungi genera (Zohri et al. 1995). In fact, Welsh onion extracts have inhibited aflatoxin production more than the preservatives sorbate and propionate at pH values near 6.5, even at concentrations 3-10 fold higher than maximum levels used in foods (Fan & Chen 1999). Organosulfur compounds were cited as protective agents by researchers finding antibacterial effects of onion extract against oral pathogenic bacteria (Kim 1997).

In addition to inhibitory effects against pathogenic bacteria, onions have been found to promote beneficial microorganisms. Fructans encourage the growth of beneficial bacteria in the intestines. This reduces the abundance of potentially detrimental bacteria present, which is beneficial as the detrimental bacteria can cause gastric cancer (Gibson et al. 1995; Kleessen et al. 2001).

3.2.5 *Cardioprotective effects*

As well as anti-thromobotic effects, the various components of onions have other benefits to the heart. These relate to their ability to reduce the susceptibility of lipids to oxidation, and potentially alter beneficially the cholesterol and lipid levels.

Flavonoids have high antioxidant activity, and have been shown to reduce the susceptibility of LDL cholesterol to oxidation (O'Reilly et al. 2000; Hertog et al. 1993). Oxidation of LDL cholesterol is an important step in the development of atherosclerosis so prevention has significant health benefits.

Sulfur-containing compounds in onions have also exhibited antioxidant activity *in vitro* (Higuchi et al. 2003). They probably achieve this by activating detoxifying enzymes (as discussed under anti-cancer properties).

Fructans have been shown to reduce lipids and insulin levels in humans and so potentially have a cardioprotective effect (Jackson et al. 1998). This is also the case for sulfur-containing compounds, but these experiments have only been performed with cells and not with humans, so are inconclusive.

Cepaenes have no demonstrated cardioprotective health benefits. It has been suggested that fructans promote resorption of calcium and, therefore, potentially reduce the risk of osteoporosis (Ritsema & Smeekens 2003).

3.2.6 *Eye health*

The carotenoids in spring onions may protect against macular degeneration. Some epidemiologic evidence does suggest that lutein and zeaxanthin protect against age-related eye disease and this is summarised below (from Sies & Stahl 2003 and Mares-Perlman et al. 2002). Lower risk of eye disease has been found in conjunction with consumption of foods rich in lutein and zeaxanthin (Goldberg et al. 1988); higher overall levels of lutein and zeaxanthin in the diet (Mares-Perlman et al. 2002; (Seddon et al. 1994); higher levels of lutein and zeaxanthin in the blood (Eye Disease Case-Control Study Group 1992); and higher levels of lutein and zeaxanthin in the retina (Bone et al. 2000; Beatty et al. 2001). However, these relationships were not observed in other studies, or were only observed in subgroups of the study population (Granado et al. 2003; Mares- Perlman et al. 2002).

Mares-Perlman et al. (2002) described findings with respect to the relationship between lutein and zeaxanthin and reducing cataract risk as "somewhat consistent". Two studies showed a higher incidence of cataracts in those in the lowest quintile of lutein and zeaxanthin intake compared with the highest, and three prospective studies found that those in the highest quintiles had a 20–50% lower risk of experiencing cataract problems.

Although concentrations are generally highest in ocular tissue, a number of studies have established the presence of lutein and zeaxanthin in serum and body tissues. Their antioxidant activity has led to speculation that higher consumption of these chemicals will lead to higher levels in body tissues, and that this may lower the risk of chronic disease. Lutein is more widely dispersed in the body that zeaxanthin and it is possible that, along with other carotenoids with antioxidant activity, it may confer protection against diseases such as cancer and cardiovascular disease as well as positively affecting immune function.

Cataracts, characterised by lens opacification, have been shown to be instigated by oxidative stress, primarily from hydrogen peroxide (H_2O_2) (Spector 1995), and quercetin can prevent this oxidative stress (Juurlink & Peterson 1998). Daily consumption of more than 500 ml of tea, a large source of quercetin, was associated with decreased risk of cataracts (Robertson et al. 1991). It has been reported that the percentage of quercetin absorbed from onions is approximately twice that from tea (de Vries et al. 1998). Therefore, high daily intake of onions may provide some protection against the risk of cataract formation.

3.2.7 *Other*

Quercetin's anti-inflammatory effect on prostaglandins, leukotrienes, histamine release and subsequent anti-asthmatic activity has been investigated (Wagner et al. 1990). Inflammation is part of the body's natural immune response to trauma. Thiosulfinates and capaenes responsible for the anti-inflammatory activities also cause inhibition of the immune response (Dorsch et al. 1990; Chisty et al. 1996). The organosulfur compounds of onions also have been credited with anti-asthmatic effects (Dorsch & Wagner 1991; Augusti 1996). Thiosulfinates formed from onion tissue degradation (i.e. chopping) have been credited with inhibition of arachidonic acid metabolic pathways and subsequent anti-inflammatory and anti-asthmatic effects (Wagner et al. 1990). Saponins have also been shown to have anti-inflammatory activity (Sparg et al. 2004).

Significant research has been done on the effect of onion consumption on diabetic conditions. Two organosulfur compounds were linked to significant amelioration of weight loss, hyperglycemia, low liver protein and glycogen, and other characteristics of diabetes mellitus in rats (Sheela et al. 1995). Similarly, Suresh Babu & Srinivasan (1997) found that a 3% onion powder diet also reduced hyperglycemia, circulating lipid peroxides and blood cholesterol (LDL-VLDL exclusively). Analysis of the effects of quercetin on human diabetic lymphocytes showed a significant increase in protection against DNA damage from hydrogen peroxide at the tissue level (Lean et al. 1999). Further human studies are needed to assess the ability of a high flavonoid diet to attenuate diabetic conditions.

There has been recent interest in the effects of allium-derived compounds on memory impairment. An animal study showed onion extract and a compound found in onions, di-n-propyl trisulfide, improved memory function in a mouse model and demonstrated that its efficacy was due to antioxidant activity (Nishimura et al. 2006).

3.3 Factors affecting health benefits

3.3.1 Genetic and environmental factors

Quantities of phytochemicals in onions can vary greatly due to varietal differences (Bilyk et al. 1984). In addition, geographical location and storage factors also affect the levels of quercetin found in onions (Patil et al. 1995a & b). Some varieties appear to contain only the quercetin glycosides (Crozier et al. 1997). White varieties contain only very low levels of flavonols (Patil et al. 1995a). Yellow, red and pink onions contain higher amounts of quercetin than white varieties (Table 2), but flesh colour is not the only determining factor for quercetin levels (Patil et al. 1995a). In contrast, accessibility to light (i.e. skin colour) has been associated with flavonoid development (Patil & Pike 1995).

Table 2: Quercetin content (mg/kg FW) of different coloured onions (data from Patil et al. 1995a).

	Min	Max	Average
Red (6)	117.38	202.2	153.58
Pink (3)	118.2	158.19	134.87
Yellow (55)	54.34	286.40	123.00
White (11)	0.21	1.41	0.51

Both fructans and sulfur compounds also vary considerably with variety and growing conditions. High bulb sulfur content and percent solids were associated with increased antiplatelet activity (Goldman et al. 1996). Therefore, highly pungent genotypes may confer more health benefits than mild varieties. The levels of fructans are usually higher in high dry matter onions, with low dry matter onions containing relatively little fructan and proportionately higher amounts of simple sugars (glucose, sucrose, fructose) (Griffiths et al. 2002).

Storage temperature and duration have significant effects on quercetin content, but a relative pattern was not elucidated (Patil et al. 1995b). Differences in concentration due to growing location were also found, but exact environmental factors were not determined. Fructan content drops during storage with the release of free sugars (Jaime et al. 2001a).

These factors indicate that genetic and environmental conditions may be manipulated and there are opportunities to select for superior phytochemical properties to produce improved cultivars.

3.3.2 Processing

Tannins and anthocyanins from the skin of red onion have been reported to have antioxidant activity (Augusti 1996), but in one study no appreciable amounts remained in the edible portion once the outer skin had been removed (Rhodes & Price 1996). However, this is not true for all varieties, with some still containing appreciable amounts. In peeled Tropea Red onions the edible portion contained only 27% of the anthocyanins, although 79% of the flavonols. Quercetin content is highest in the dry skin and decreases from the outer to inner rings (Patil & Pike 1995). Thus, peeling may significantly reduce the flavonoid content (especially anthocyanins and to a lesser extent flavonols) and hence some of the health benefits of onions. In contrast, fructans are richest in the fleshy layers (Jaime et al. 2001b), as are sulfur compounds.

Chopping may also affect the phytochemical content. As mentioned above, many of the sulfur compounds that have health benefits are not formed until the onion tissue is chopped. However, if left too long these compounds can be changed further and loose activity. Rhodes & Price (1997) showed that quercetin 3,4'-diglucoside was rapidly degraded in macerated tissues (50% decline after 5 hours), being converted to the quercetin monoglycoside and free quercetin. All these compounds have antioxidant activity so this feature of onions might not be affected by chopping. In a different study (Makris & Rossiter 2001), chopping was shown to have no significant effect on flavonol content or antioxidant activity. Ewald et al. (1999) showed the greatest loss of flavonoids in onion occurred during the pre-processing step when the onion was peeled, trimmed and chopped before blanching.

Ioku et al. (2001) measured the effects of various cooking methods on the flavonoid content in onion. Microwave cooking without water retained both flavonoids and ascorbic acid. Frying did not affect flavonoid intake. However, boiling onions leads to about a 30% loss of quercetin glycosides, which transfers to the boiling water (flavonoids are water-soluble). Crozier et al. (1997) also examined the effects of cooking on onions and found boiling reduced flavonoid content significantly, while microwaving had slightly less of an effect and frying resulted in the lowest loss (Table 3). Makris & Rossiter (2001) showed a flavonol loss of 20% on boiling and antioxidant activity also decreased.

Table 3: The quercetin content of onions after various cooking methods.

Cooking method	Quercetin content	
	µg/g	% of uncooked
None	342	100
Fried	269	79
Boiled	87	25
Microwaved	124	36

Adam et al. (2000) examined quality changes in onion during drying. The results showed that drying temperatures above 65°C exerted a pronounced influence on colour. The pyruvate content decreased with increasing temperature and slice thickness. The sugar content was also significantly influenced by the drying temperature. The rate of ascorbic acid degradation decreased with increasing temperature and slice thickness.

Because carotenoids present in spring onions 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.

3.4 *Quotes and trivia*

- “Banish (the onion) from the kitchen and the pleasure flies with it. Its presence lends colour and enchantment to the most modest dish; its absence reduces the rarest delicacy to hopeless insipidity, and dinner to despair.”

American columnist, Elizabeth Robbins Pennell.

- "Life is like an onion.
  You peel it off one layer at a time;
  And sometimes you weep."

Carl Sandburg, American poet

- Onions were highly revered by the Ancient Egyptians, who saw their structure of circles within circles as symbolising eternity.

4 *Garlic* (Allium sativum)

Garlic has been valued as a flavouring and medicinal over many centuries and in cultures around the world. Medicinal applications are recorded in ancient Egyptian, Greek, Roman, Indian and Chinese writings, for a host of complaints from bee stings to dog bites and headaches to hair loss. Over the last decade alone, it has been investigated in over 1000 research publications (Amagase 2006) and an assortment of therapeutic effects have been reported, including hypolipidaemic, antiatherosclerotic, hypoglycaemic, anticancer, anticoagulant, as an antidote for heavy metal poisoning, antihypertensive, liver protective, antimicrobial and immunomodulatory (Banerjee et al. 2003). Recently, besides these medicinal uses, garlic or extracts derived from garlic are being incorporated into functional foods and investigated as natural antimicrobial agents to replace synthetic preservatives.

Note: there is a growing body of research into aged garlic extract (also known as Kyolic garlic). As the processing involved gives rise to bioactives that are not present in fresh garlic, this has not been covered in this report.

4.1 *Composition*

On a per weight basis, garlic is a rich source of many micronutrients and phytochemicals, but it should be remembered that because it is consumed less frequently and in smaller quantities than other *Allium* species, particularly onions, its dietary contribution is less. It has been estimated that in the US the average daily intake of garlic is 3 g/day, in contrast to 23.5 g/day of onions (Chun et al. 2005).

4.1.1 *Core nutrients*

As with onions, the major micronutrient in garlic is vitamin C (Figure 4). However, it is also apparent that garlic contains other vitamins, particularly B_6, which is present at high levels, as well as an assortment of minerals in small but useful amounts. It has a relatively low water content (around 65%), with the bulk of the dry weight comprising fructooligosaccharides, followed by sulfur compounds, protein, fibre and free amino acids (Rahman & Lowe 2006). More detail on garlic's macro and micronutrient content is included in Appendix I and the health effects of these in Appendix II.

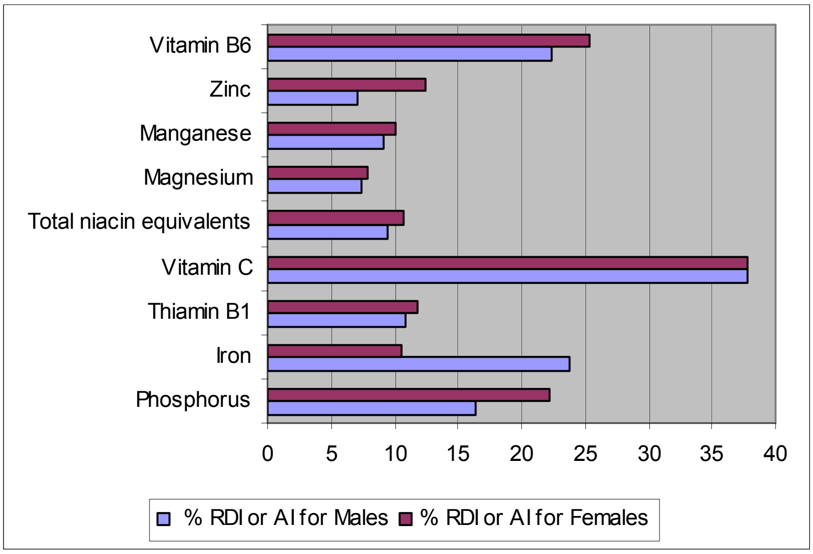

Figure 4: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw garlic, adapted from Athar et al. (2004) and NHMRC (2006).

4.1.2 *Phytochemicals*

Besides the sulfur compounds, garlic has high levels of saponins, some phenolics and moderate levels of provitamin A (Rahman & Lowe 2006). It is the organosulfur compounds that have been of particular research interest in relation to garlic.

Organosulfur compounds

The organosulfur compounds in garlic differ slightly from those in onion and consequently may have different health effects. There are two kinds of organosulfur compounds present in garlic – gamma glutamylcysteines and cysteine sulfoxides (Figure 5).

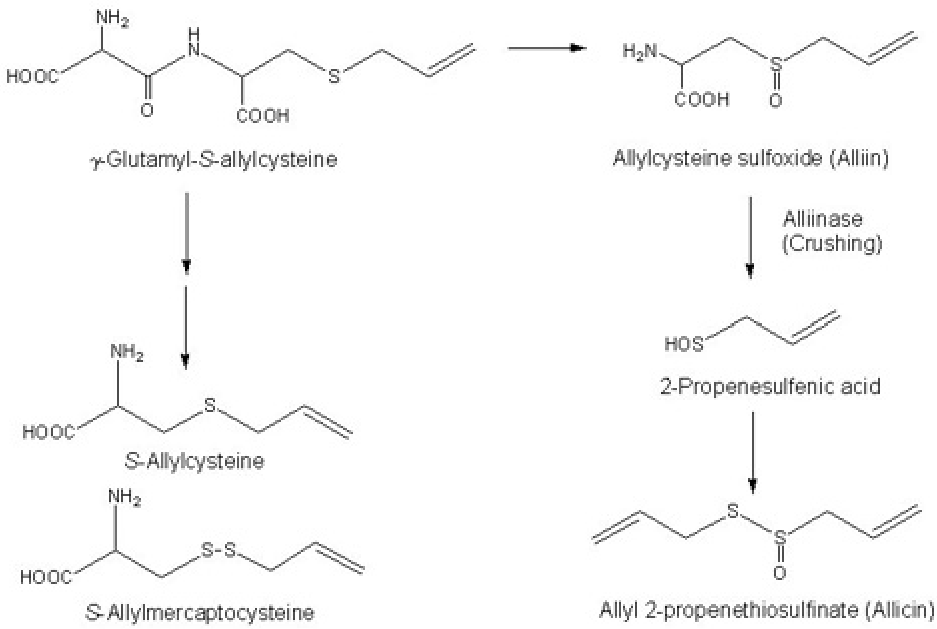

Figure 5: Some organosulfur compounds derived from garlic (from Higdon 2005).

Allylcysteine sulfopoxide, or alliin, is considered the parent substance from which the most important organosuphur compounds in garlic are derived. Allicin, an intermediate breakdown product of alliin is thought to be responsible for the odour of fresh garlic and is itself further broken down into various other compounds, including diallyl sulfide, diallyl disulfide and diallyl trisulfide, or, in the presence of oil, ajoene or vinyl dithiins (Figure 6) (Rahman 2003; Higdon 2005).

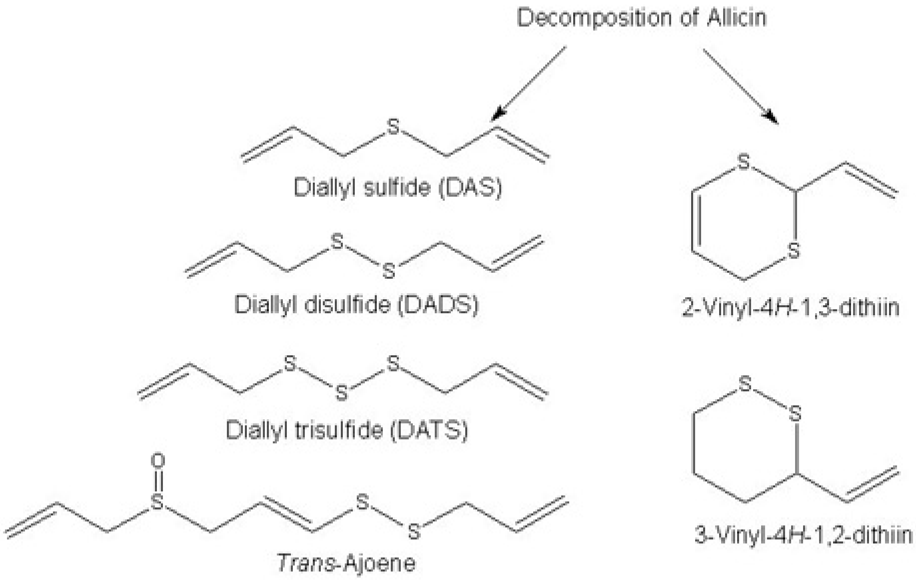

Figure 6: Some organosulfur compounds derived from the decomposition of allicin (from Higdon 2005).

Flavonoids

The major flavonoids in garlic are the flavonols, myricetin and apigenin and, in marked contrast to onions, only low levels of quercetin (Lanzotti 2006). Phenolic compounds are of interest largely because of their antioxidant activity. For further detail see Section 3.1.2.

Vinson et al (1998) found garlic to have the third highest levels of total phenolics out of the 23 common vegetables studied. Similarly, garlic ranked highly in studies by both Chun et al. (2005) and Ninfali et al. (2005). Unexpectedly, however, a study investigating antioxidants in the *Allium* genus, measured only low levels of phenolic compounds in garlic. In this study of three garlic bulb cultivars neither quercetin nor kaempferol, the major flavonoids in onions, were detected (Nuutila et al. 2003).

Saponins

A number of sapogenins (the aglycone base) and saponins have been identified in garlic, (Matsuura 2001; Lanzotti 2006). Matsuura (2001) postulated that the cholesterol lowering effect observed in this animal study was attributable particularly to spirostanol saponins. See Section 3.1. 2. for general information on saponins.

4.2 Health benefits

4.2.1 Antioxidant activity

Garlic is a concentrated mixture of phytochemicals, which are likely to interact and have synergistic effects. As mentioned earlier, a range of therapeutic effects of garlic have been reported, including many relating to the major chronic diseases, cardiovascular disease and cancer. As with onions some of these benefits relate to their antioxidant activity. High to very high levels of antioxidant activity have been reported for garlic in a number of studies (Cao et al. 1996; Vinson et al. 1998; Chun et al. 2005; Ninfali et al. 2005), although this was not the case in all studies (Halvorsen et al. 2002). Two studies both found high levels of phenolic compounds, which have strong antioxidant activity (Vinson et al. 1998; Chun et al. 2005).

The major antioxidants in garlic are vitamin C, certain organosulfur compounds and some phenolic compounds. See also Section 3.2.

There is evidence that organosulfur compounds can stimulate the synthesis of the endogenous antioxidant glutathione. Seven studies relating to the effect of garlic upon oxidative stress were reviewed by Rahman & Lowe (2006). It is difficult to compare results as different forms of garlic were used, including aged garlic extract, garlic pearls and garlic tablets and although results were mixed, the majority (5 out of 7) showed improvements in markers of oxidative stress.

4.2.2 Cardioprotective effects

A number of factors are implicated in the development of cardiovascular disease. These include high cholesterol and lipid levels, increased platelet aggregation, increased plasma fibrinogen and coagulation factors, increased platelet activation, alterations in glucose metabolism and lipid oxidation, high blood pressure and smoking. Epidemiological studies have shown that garlic consumption may protect against the development of cardiovascular disease and several *in vitro* studies have shown that this was achieved through attenuating a number of the factors listed above (Rahman & Lowe 2006). Reviews by Higdon (2005) and Rahman & Lowe (2006) document the following cardioprotective effects.

- **Cholesterol and lipid lowering activity**

  Garlic and garlic-derived compounds have been shown to inhibit enzymes involved in cholesterol and fatty acid synthesis *in vitro*. Clinical trial results have been mixed. Of the 25 clinical trials reviewed by Rahman & Lowe (2006), 14 showed no effect of garlic on cholesterol levels, although 11 showed a reduction is serum cholesterol. However, the authors discussed disparities in the methodology of the studies showing no effects, with differences in the study population and the form of garlic used. A recent Chinese study found that long term garlic supplementation had no effect upon lipid profiles (Zhang et al. 2006).

- **Blood coagulation and circulatory effects**

  Garlic and some of its constituent compounds can significantly reduce platelet clumping and clot formation. A proposed mechanism relating to the inhibition of calcium mobilisation has been proposed. Garlic in various forms given to subjects in various states of states of health had a positive effect on the inhibition of platelet aggregation.

  Fibrinolysis (the breakdown of blood clots) is also enhanced by garlic. One study showed improved the fluidity of red blood cells isolated from garlic-supplemented hypercholesteremic rats (Kempaiah & Srinivasan 2005) Garlic juice was shown to have a favourable effect upon heart rate, although at higher levels there was a detrimental effect (Yadav & Verma, cited in Rahman & Lowe 2006). Studies reviewed by Rahman & Lowe (2006) showed mixed results relating to blood pressure. Six of the 9 studies reviewed showed a reduction in blood pressure, although 3 did not. Again the kind of garlic differed between studies. An earlier meta-analysis similarly concluded that garlic consumption had insignificant effects upon blood pressure (Ackermann et al. 2001). Supplementation with garlic increased peripheral blood flow in healthy subjects and improved the elasticity of blood vessels in elderly subjects.

- **Anti-inflammatory activity**

  Inflammation is involved in the aetiology of atherosclerosis (hardening of the arteries). Garlic and its constituent compounds have been found to inhibit the activity of inflammatory enzymes as well as inhibiting the activity of other components involved in the process of inflammation (Higdon 2005).

4.2.3 Cancer protective activity

Epidemiological evidence is strong in support of high intakes of garlic and other *Allium* species protecting against gastric and colorectal cancer. Although other cancers have been studied, results have been inconsistent. Results with animal studies over a range of different cancers are promising, but further research is necessary before similar efficacy can be claimed for human cancers. Nonetheless, there is already a good body of evidence regarding a number of aspects of its bioactivity, which can provide a basis for understanding the mechanisms that would help explain why they exert these beneficial effects.

- **Inhibition of Phase1 enzymes**

  Phase I enzymes are endogenous enzymes that can transform potential carcinogens into active carcinogens. Animal, *in vitro* and a small number of human studies have shown that garlic compounds, particularly DAS, can inhibit the activity of particular phase 1 enzyme families.

- **Induction of Phase 2 enzymes**

  Phase 2 enzymes have varied functions.

  – They are involved in promoting the elimination of potentially harmful substances from the body.

- They enhance the production of the important endogenous antioxidant, glutathione.
- They are involved with the induction of cell cycle arrest. Cell cycle arrest is important in ensuring the proliferation of healthy normal cells. It allows for DNA damage to either be repaired or for processes to be initiated to encourage the self-destruction of the aberrant cell (apoptosis). Cancerous cells would normally proliferate uncontrolled.
- Induction of apoptosis. Damaged or abnormal cells are unresponsive to the signals that would normally encourage apoptosis. Garlic organosulfur compounds have been found to induce apoptosis in *in vitro* cell experiments and animal studies.

Antioxidant activity

As explained earlier, antioxidants have a range of cancer-protective effects, including neutralizing free radicals, protecting DNA from damage,and assisting in the maintenance of normal cell function (see Section 3.2.1).

4.2.4 *Brain protective effects*

Oxidative stress is believed to be involved in many of the processes contributing to loss of brain function, such as Alzheimer's disease and dementia. This can have a multitude of effects, including vascular impairment through atherosclerosis, disturbance of cell structure and function, protein inactivation, mitochondrial and DNA damage and collagen cross linking (Rahman 2003). Thus the strong antioxidant activity of garlic could have a protective role. However, most studies on this topic involve the use of aged garlic extract, which shows considerable promise, but whose major bioactive, S-allylcysteine, does not exist in fresh garlic (Higdon 2005).

4.2.5 *Diabetes*

Many ethnic treatments for diabetes involve the use of *Allium* species. A number of animal and *in vitro* studies have suggested mechanisms by which this is achieved. For example, it was demonstrated *in vitro* that certain garlic compounds protected human erythrocytes and platelets against glucose-induced oxidation and protected native LDL against oxidation and glycation (Chan et al. 2002). A further study identified specific roles for various bioactive compounds, finding that diallyl sulfide and diallyl disulfide showed greater oxidative-delaying effects than cysteine-containing compounds, although the latter were more effective at delaying glycative deterioration (Huang et al. 2004). In a recent animal study, Liu et al. (2006) found that long term treatment with a garlic oil improved glucose tolerance and renal function in diabetic rats, but established that this was not through the activity of diallyll disulfide.

4.2.6 *Antimicrobial activity*

Garlic has long been recognised for its antibacterial and antifungal effects and recently the search for natural preservatives has led to interest in its potential for preventing microbial contamination in foods. It has been reported to inhibit *Aerobacter*, *Aeromonas*, *Bacillus*, *Citrella*, *Citrobacter*, *Clostridium*, *Enterobacter*, *Escherichia*, *Klebsiella*, *Lactobacillus*, *Leuconostoc*, *Micrococcus*, *Mycobacterium*, *Proteus*, *Providencia*, *Pseudomonas*, *Salmonella*, *Serratia*, *Shigella*, *Staphylococcus*, *Streptococcus* and *Vibrio* (Sivam 2001). Two studies have also shown it to have potential in protecting against *Helicobacter pylori* infections, and it was postulated that this effect could be responsible for the inverse association between *Allium* species consumption and gastric cancer, which is linked to *H. pylori* infection (Sivam 2001). Another recent study found that allicin showed promise in preventing and treating malaria (Coppi et al. 2006).

Various organosulfur components, but particularly allicin derivatives, have been shown to have an important role in the antimicrobial activity of garlic. However, polyphenol extracts from garlic were also demonstrated to have high inhibitory effects against the bacterias *Staphylococcus aureus* and *Salmonella enteriditis,* and against three fungi, *Aspergillus niger, Penicillium cyclopium* and *Fusarium oxysprorum* (Benklebia et al. 2005).

4.2.7 Other

Rahman (2003) cites a smattering of additional studies relating to garlic's protective properties in relation to disorders associated with ageing, including:

- improving the immune system,
- preventing cataracts and macular degeneration,
- preventing arthritis,
- improving circulation and
- decreasing skin wrinkling.

4.3 Factors affecting health benefits

4.3.1 Bioavailability

Although various health effects have been attributed to allicin-derived compounds, their absorption is not well understood, and it is not clear which of them or their metabolites reach target tissues and exert the effect. It is thought that allicin and its derivatives are rapidly metabolised, as they have never been identified in human blood, urine or stool. It has been proposed that allyl methyl sulfide in breath may be indicative of the bioavailability of allicin-derived compounds as concentrations in human breath correlate with amounts consumed (Higdon 2005).

4.3.2 Cooking / processing

Many of the bioactive components in garlic are not present as such in the intact garlic clove, but are catalysed by enzymes after cutting, crushing, chewing or some such cellular disruption or processing. The enzyme allinase, which is involved in the formation of allicin, is inactivated by heat, so the desirable bioactive is not formed if heating takes place before cell disruption. Because many of the compounds catalysed by allinase are those which offer particular health benefits, it is sometimes recommended that crushed or chopped garlic be left to stand for at least 10 minutes before cooking, to allow sufficient time for these reactions to take place (Higdon 2005).

A recent study also found that the bioactive compounds in garlic together with their antioxidant activity (measured according to four different methods), significantly decreased after cooking for 20 minutes at 100°C (Gorinstein et al. 2005).

In the production of aged garlic extract, fresh, sliced garlic cloves are soaked in an ethanol/aqueous solution for up to 20 months at room temperature. During this process allicin is largely converted to water soluble organosulfur compounds, notably S-allylcysteine and S-allylmercaptocysteine (Amagase et al. 2001; Higdon 2005; Borek 2006). This process deodorises garlic, but the extract is rich in antioxidants and has shown promise in preventing a number of major diseases (Borek 2006).

4.3.3 Agronomic practices

There is a multitude of factors that impact upon the composition of any plant food, including differences between cultivars and growing conditions. However, one international study comparing fresh Polish, Ukrainian and Israeli garlic found that bioactive compounds, antioxidant potential and protein profiles were comparable, although there were slight differences (Gorinstein et al. 2005). In contrast, Lee et al. (2005) found significant differences in antioxidant activity and thiosulfinate contents in garlic grown in three different locations in Korea.

4.4 Quotes and trivia

- Mention of garlic as a medicinal plant was made in an Ancient Egyptian papyrus, dating back to 1550 BC. It recorded that garlic was useful as a remedy for such diverse complaints as heart problems, headaches, bites, worms and tumours.
- Modern scientific interest in garlic was prompted by Louis Pasteur's recording of garlic's antibacterial properties in 1858.
- Historically, garlic has been particularly useful for its antibacterial and antifungal properties, and is sometimes referred to as Russian penicillin, because, even until quite recently, it was widely used by Russian doctors to treat infections.

5 *Leeks* (Allium porrum)

There is very little information pertaining specifically to leeks, although other research regarding the *Allium* genus in general may be relevant. That relating to spring onions is likely to be the most useful, since the two growth forms are similar.

5.1 *Composition*

5.1.1 *Core nutrients*

Leeks contain excellent amounts of vitamin C, as well as folate and useful amounts of some of the B vitamins, vitamin E, copper, potassium and iron (Figure 5). More detail on their macro and micronutrient content is included in Appendix I and the health effects of these in Appendix II.

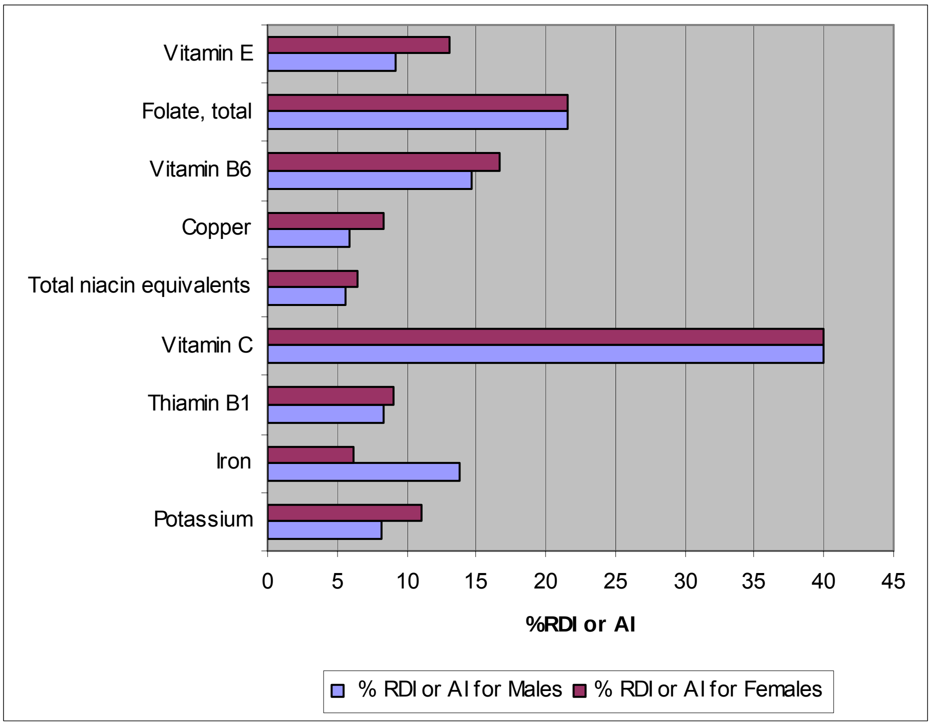

Figure 5: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw leeks (bulb), adapted from Athar et al. (2004) and NHMRC (2006).

5.1.2 Phytochemicals

A comprehensive analysis of the phytochemicals in leeks has not been found, but they are likely to contain the same classes of compounds as those in onions. Like spring onions they also contain carotenoids and chlorophyll (Section 3.1).

Eight leek saponins were identified by Fattorusso et al. (2000) and five kaempferol glyocosides by Fattorusso et al. (2001). The USDA Flavonoid Database (2003) also lists kaempferol as the major leek flavonoid, although additionally lists a very small amount of quercetin (0.10 mg/100 g in leeks compared with 13.27 in ordinary onions and 19.93 in red onions). Moderate levels of phenolics were measured by Turkmen et al. (2005) and in two cultivars investigated by Ninfali et al. (2005). However, a third cultivar in the latter study had quite high levels of phenolics and also one of the highest levels of antioxidant activity of the 40 samples and 27 vegetables tested (Table 4).

Table 4: Total phenolics and antioxidant activity measured in leeks.

Cultivar	Total phenolics (mg/100 g fresh weight)	ORAC (µmol TE/100 g fresh weight)	Author
Atal	41.6	490	Ninfalli et al. (2005)
Rossa di Trento	88.2	3323	Ninfalli et al. (2005)
Romana	54.7	910	Ninfalli et al. (2005)
unknown	42.1*	unknown	Turkmen et al. (2005)

*Converted to fresh weight according to Athar et al. (2004).

Leeks have also been found to contain moderately high levels of certain carotenoids (Heinonen et al. 1989), which are likely to be present in the leaves. According to the latter study, leeks contain about the same amount (1000 µg/100 g fresh product) of β-carotene as broccoli and although markedly lower than in carrots and spinach, this is relatively high in comparison with other vegetables in the study. Similarly their lutein+zeaxanthin content was similar to that in broccoli at 1900 µg/100 g fresh product, ranking it third of the vegetables studied. USDA data reflect similar levels (Table 1).

The leaves of a related onion family member, *Allium fistulosum,* which appears to be similar to leeks and is some countries are grown as spring onions, were found to have potent antioxidant activity and radical scavenging properties and were able to protect protein from oxidative damage (Wang et al. 2006).

5.2 Health benefits

The presence of several antioxidant compounds suggests that leeks would have good antioxidant properties, although this has not been confirmed by research. Thus, it is likely that consumption of leeks would have health effects consistent with antioxidant activity, as already described in Sections 3.2 and 4.2.

Two of the kaempferol glycosides identified by Fattorusso et al. (2001) were shown to inhibit platelet aggregation, an activity previously established by Landolfi et al. (1984), cited in this paper. An earlier study by Tzeng et al. (1991), also cited in this paper, showed that kaempferol had further anti-atherosclerotic properties through acting as a thromboxane receptor antagonist.

5.3 Factors affecting health benefits

According to Turkmen et al. (2005), phenolic content in leeks dropped to around 65% of its original value with boiling. Phenolic content was also reduced with steaming (85%) and microwaving (82%).

A few studies have shown effects of differing agronomic practices upon the composition of leeks, although they relate largely to micro and macronutrient rather than phytochemical content (Gray & Steckel 1993; Sorensen et al. 1995; Eppendorfer & Eggum 1996).

5.4 Quotes and trivia

- The use of the leek as the Welsh emblem dates back to AD 633 when Welsh soldiers, who had placed leeks in their hats to differentiate themselves from the enemy, defeated opposing Saxon soldiers

6 *Shallots* (Allium ascalonicum)

Although they look like small onions, shallots differ from the common onion in that they form clumps of small bulbs, as does garlic. They are also much milder in taste than most onions.

6.1 Composition

No New Zealand data have been found on shallots, so American data have been used for Figure 6 and appear in Appendix I in more detail.

6.1.1 Core nutrients

The major core nutrient in shallots is vitamin B6. Although not present in such high levels as other *Allium* species, shallots also contain a good amount of vitamin C. Vitamin A is present as a result of carotenoids in the leaves. Shallots also provide small but useful amounts of a variety of other micronutrients.

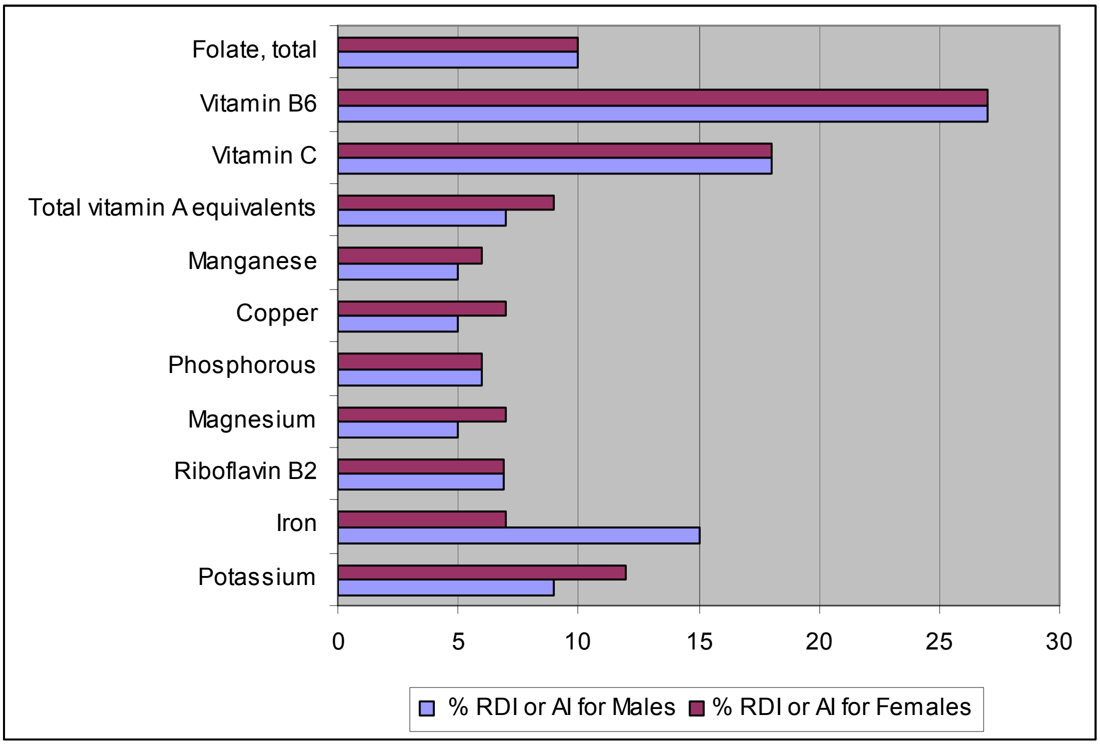

Figure 6: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients shallots, adapted from USDA (2006) and NHMRC (2006).

6.1.2 *Phytochemicals and health benefits*

Fattorusso et al. (2002) identified saponins and high levels of quercetin, isorhamnetin and their glycosides in shallots. In a comparison with garlic, Leelarungrayub et al. (2006) found that the lesser studied shallots had antioxidant activity similar to that of garlic, and that this was associated most closely with the phenolic and diallyl sulfide content of the bulbs.

7 Conclusion

The onion family appears to be as useful to human health as it is in the kitchen. Its bioactive compounds are being found to provide a wide range of protective properties across the major chronic western diseases of the 21st century, as well as established antimicrobial activity. As more research is undertaken on *Allium* species and their constituent compounds, it is highly possible that stronger scientific evidence will emerge to justify their prominence in traditional remedies throughout history and around the globe.

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Appendices

Appendix I Micro and macronutrients in Allium vegetables

Composition of onions, spring onions, garlic and leeks taken from Athar et al. (2004).

Composition	Units	Onion, flesh, raw	Spring onion, flesh of bulb, raw	Garlic cloves, raw, peeled	Leeks,bulb, raw
Water	g	87.9	86.8	64.3	86
Energy	kcal	40	40	97	35
Protein	g	1.27	0.9	7.9	1.9
Total fat	g	0.12	0.3	0.6	0.4
Carbohydrate, available	g	8.53	8.5	15	5.9
Dietary fibre (Englyst 1988)	g	2.36	1.7	8	3.3
Ash	g	0.46	0.9	1.5	1
Sodium	mg	2.21	13	4	9
Phosphorus	mg	39.5	24	170	43
Potassium	mg	184	230	620	310
Calcium	mg	21.2	140	19	63
Iron	mg	0.24	1.2	1.9	1.1
Beta-carotene equivalents	µg	10	586	T	49
Total vitamin A equivalents	µg	1.7	98	T	8
Thiamin	mg	0.043	0.05	0.13	0.1
Riboflavin	mg	0.015	0.09	0.04	0.05
Niacin	mg	0.734	1	0.4	0.6
Vitamin C	mg	7.1	25	17	18
Cholesterol	mg	0	0	0	0
Total saturated fatty acids	g	0.023	0.058	0.122	0.061
Total monounsaturated fatty acids	g	0.02	0.049	0.015	0.006
Total polyunsaturated fatty acids	g	0.054	0.133	0.342	0.253
Dry matter	g	12.1	13.2	35.7	14
Total nitrogen	g	0.2	0.15	1.27	0.31
Glucose	g	3.6	3.5	0.4	2.4
Fructose	g	2	4.2	0.6	2.4
Sucrose	g	2.4	0.6	0.57	1.1
Lactose	g	0	0	0	0
Maltose	g	0	0	0	0

Composition	Units	Onion, flesh, raw	Spring onion, flesh of bulb, raw	Garlic cloves, raw, peeled	Leeks,bulb, raw
Total available sugars	g	8	8.3	1.6	5.9
Starch	g	0.53	0.2	13.4	0
Alcohol	g	0	0	0	0
Total niacin equivalents	mg	1.04	1.2	1.5	0.9
Soluble non-starch polysaccharides	g	1.31	0.9	5.5	1.6
Insoluble non-starch polysaccharides	g	1.06	0.8	2.5	1.6
Energy	kJ	166	167	402	144
Magnesium	mg	8.43	11	25	10
Manganese	µg	161	208	500	188
Copper	mg	0.059	0.13	0.06	0.1
Zinc	mg	0.25	0.1	1	0.4
Selenium	µg	0.16	0.16	2	
Retinol	µg	0	0	0	0
Potential niacin from tryptophan	mg	0.304	0.2	1.1	0.3
Vitamin B6	mg	0.036	0.1	0.38	0.25
Folate, total	µg	26.9	40	5	86
Vitamin B12	µg	0	0	0	0
Vitamin D	µg	0	0	0	0
Vitamin E	mg	0.3	0.3	0.01	0.92

Composition of raw shallots, taken from USDA (2006) (Nutrient values and weights are for edible portion, 12% refuse (skins).

Nutrient	Units	Value per 100 g
Proximates		
Water	g	79.8
Energy	kcal	72
Energy	kj	302
Protein	g	2.5
Total lipid (fat)	g	0.1
Ash	g	0.8
Carbohydrate, by difference	g	16.8
Minerals		
Calcium, Ca	mg	37
Iron, Fe	mg	1.2
Magnesium, Mg	mg	21
Phosphorus, P	mg	60
Potassium, K	mg	334
Sodium, Na	mg	12
Zinc, Zn	mg	0.4
Copper, Cu	mg	0.088
Manganese, Mn	mg	0.292
Selenium, Se	mcg	1.2
Vitamins		
Vitamin C, total ascorbic acid	mg	8
Thiamin	mg	0.06
Riboflavin	mg	0.02
Niacin	mg	0.2
Pantothenic acid	mg	0.29
Vitamin B-6	mg	0.345
Folate, total	mcg	34
Folic acid	mcg	0
Folate, food	mcg	34
Folate, DFE	mcg_DFE	34
Vitamin A, IU	IU	1190
Vitamin A, RAE	mcg_RAE	60
Retinol	mcg	0

Lipids		
Fatty acids, total saturated	g	0.017
14:00	g	0
16:00	g	0.015
18:00	g	0.001
Fatty acids, total monounsaturated	g	0.014
18:1 undifferentiated	g	0.014
Fatty acids, total polyunsaturated	g	0.039
18:2 undifferentiated	g	0.037
18:3 undifferentiated	g	0.002
Cholesterol	mg	0
Phytosterols	mg	5
Amino acids		
Tryptophan	g	0.028
Threonine	g	0.098
Isoleucine	g	0.106
Leucine	g	0.149
Lysine	g	0.125
Methionine	g	0.027
Phenylalanine	g	0.081
Tyrosine	g	0.072
Valine	g	0.11
Arginine	g	0.181
Histidine	g	0.043
Alanine	g	0.113
Aspartic acid	g	0.231
Glutamic acid	g	0.517
Glycine	g	0.124
Proline	g	0.165
Serine	g	0.113

Appendix II Major functions of main micronutrients in Allium species

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 Assists in immune function May protect against 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 alpha-tocopherols and tocotrienols	Non-specific chain-breaking antioxidant Reduces peroxidation of fatty acids May protect against atherosclerosis
Thiamin Vitamin B1	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells
Riboflavin Vitamin B2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein
Niacin Vitamin B3 Nicotinic acid, nicotinamide	Coenzyme or cosubstrate in many biological reduction and oxidation reactions required for energy metabolism and fat synthesis and breakdown Reduces LDL cholesterol and increases HDL cholesterol
Vitamin B6 Pyridoxine, pyridoxal, pyridoxamine	Coenzyme in nucleic acid metabolism, neurotransmitter synthesis, haemoglobin synthesis. Involved in neuronal excitation Reduces blood homocysteine levels Prevents megaloblastic anaemia
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 B12 May protect against colonic and rectal cancer

Name	Major function
Calcium	Structural component of bones and teeth Role in cellular processes, muscle contraction, blood clotting, enzyme activation, nerve function
Copper	Aids in utilization of iron stores, lipid, collagen, pigment Role in neurotransmitters synthesis
Iron	Component of haemoglobin and myoglobin in blood, needed for oxygen transport Role in cellular function and respiration
Magnesium	Component of bones Role in enzyme, nerve, heart functions, and protein synthesis
Manganese	Aids in brain function, collagen formation, bone structure, growth, urea synthesis, glucose and lipid metabolism and central nervous system functioning
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
Zinc	Major role in immune system Required for numerous enzymes involved in growth and repair Involved in sexual maturation Role in taste, smell functions

Herbs – the original functional foods

By Lesley Hedges, Crop & Food Research

Lauded by the emperor Charlemagne as "the friend of the physician and the praise of cooks", herbs provide more than just flavour and basic nutrients, and have long been valued for their special health-enhancing properties. Although eclipsed for common use by modern medicines, many herbs still form the basis of a large proportion of modern pharmaceuticals. Scientists today are also discovering why herbs are indeed good for you, with fields of research often identified from traditional ethnobotanical uses.

By definition, herbs comprise leafy and stalk material only, as opposed to spices which can be derived from the seed, bark, flowers or roots of plants. They contain an assortment of bioactive compounds, including some that are ubiquitous and some that are relatively uncommon, such as compounds found in the essential oil fraction which give many of the unique flavours or aromas in herbs. Often such compounds are common to a number of herbs from the same family.

Herbs can contain large amounts of core nutrients (on a weight-for-weight basis), but it is the compounds that contribute to their high levels of antioxidant and antimicrobial activity that have received most research attention. Phenolic compounds, including flavonoids and phenolic acids, are present at high levels in many herbs and, besides being powerful antioxidants, they have other effects in the body, one of the most significant being anti-inflammatory activity. Both antioxidant and anti-inflammatory activity are important as it is now believed that oxidative stress and inflammation are involved in the development of many chronic diseases as well as health problems associated with ageing. Many essential oils have been shown to have antimicrobial qualities, and some, or their major components (such as carnosol, carnosic acid and rosmarinic acid) have promising anti-cancer activity.

Most research into the health properties of herbs has focused upon cancer. Various anti-cancer effects have been shown, such as increasing the body's own protective enzymes, protecting DNA from free radical-induced structural damage, encouraging the self-destruction of aberrant cells (apoptosis) and inhibiting tumour growth. Some herbs, or their compounds, have also shown protective effects against aspects of cardiovascular disease, loss of mental function and diabetes. However, there have been very few human studies in relation to herbs, most being laboratory-based involving animals or cells.

Because herbs can be such concentrated sources of antioxidant compounds they have come to the attention of the natural preservatives industry. Experiments have shown that in many cases herbal extracts, or particular compounds from herbs, perform at least as well as, if not better than synthetic preservatives such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA). Oregano and rosemary have shown particular promise in this area. Many herbs also have antimicrobial properties, which also add to their attractiveness as food preservatives.

On a weight-for-weight basis, many herbs are concentrated sources of various health-enhancing compounds, such as vitamin C in parsley. However, it should always be borne in mind that because we generally only eat small quantities of herbs, their contribution of major nutrients to the diet will not be substantial. Dr Carolyn Lister, a nutritional biochemist at Crop and Food Research, with a particular interest in how plant chemicals affect human health explains, “Apart from a few exceptions, where herbs are used as a main ingredient (such as parsley in tabbouleh) rather than as a seasoning, herbs will not contribute substantially to your daily nutrient intake. It is better to think of them as a useful and easy way to increase your daily nutrient and antioxidant intake, and in herbs you get a range of different compounds with different bioactivity. A sprinkling on an omelette, or a handful in your pasta sauce or casserole also provides lots of flavour, looks good and means you can cut down on ingredients like salt and sugar. With herbs, as with many things, it is worth following the principle of ‘a little and often’.”