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The nutritional attributes of Allium *species*

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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.

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1 Executive summary

1.1 Introduction

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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.

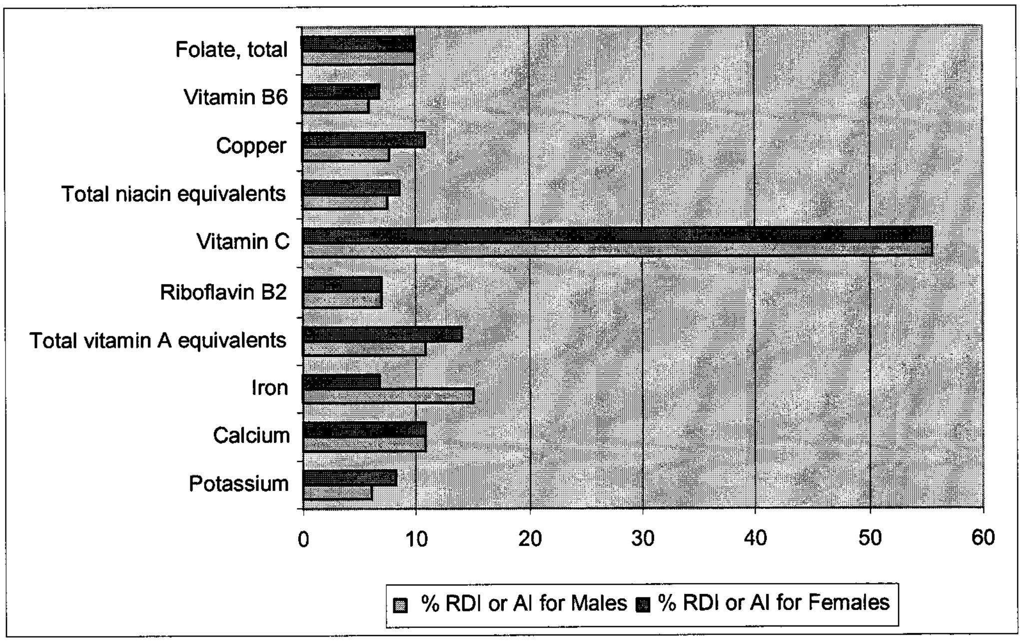

Figure 2: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw spring onions (flesh of bulb), adapted from Athar et al. (2004) and NHMRC (2006).

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.

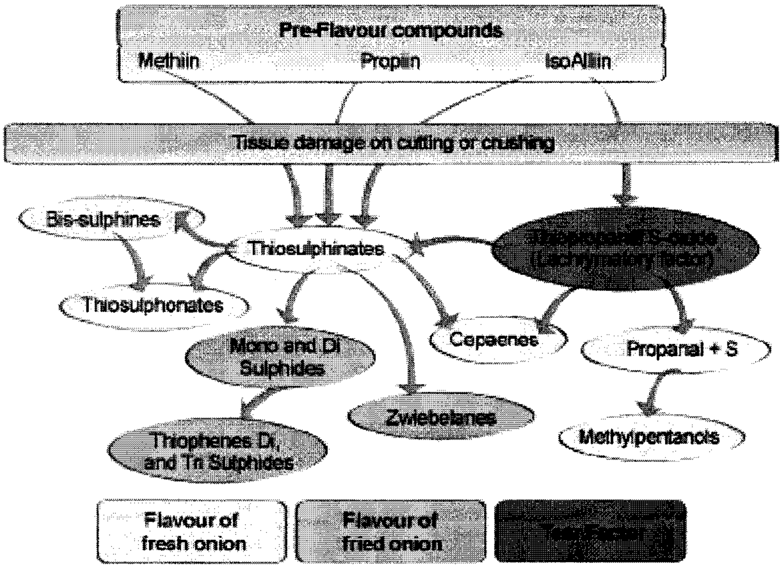

Figure 3: Generation of the major flavour groups in onions (from Griffiths et al. 2002).

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.

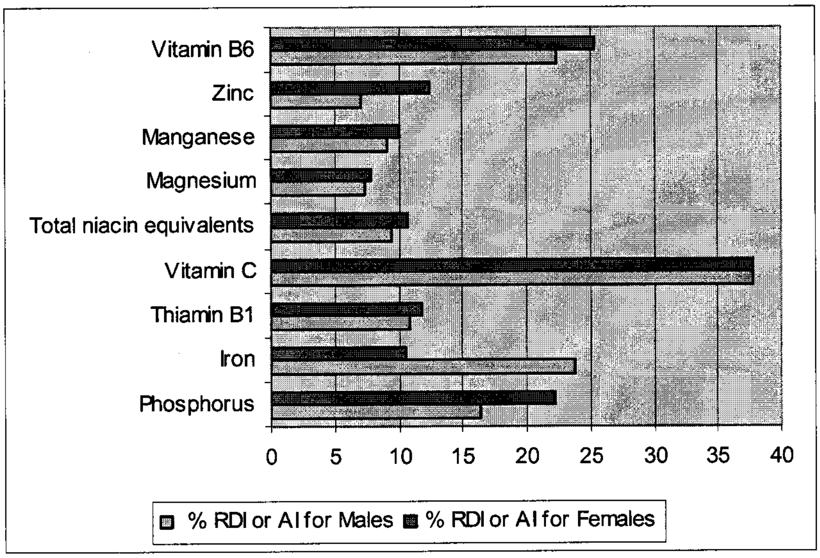

Figure 4: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw garlic, adapted from Athar et al. (2004) and NHMRC (2006).

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).

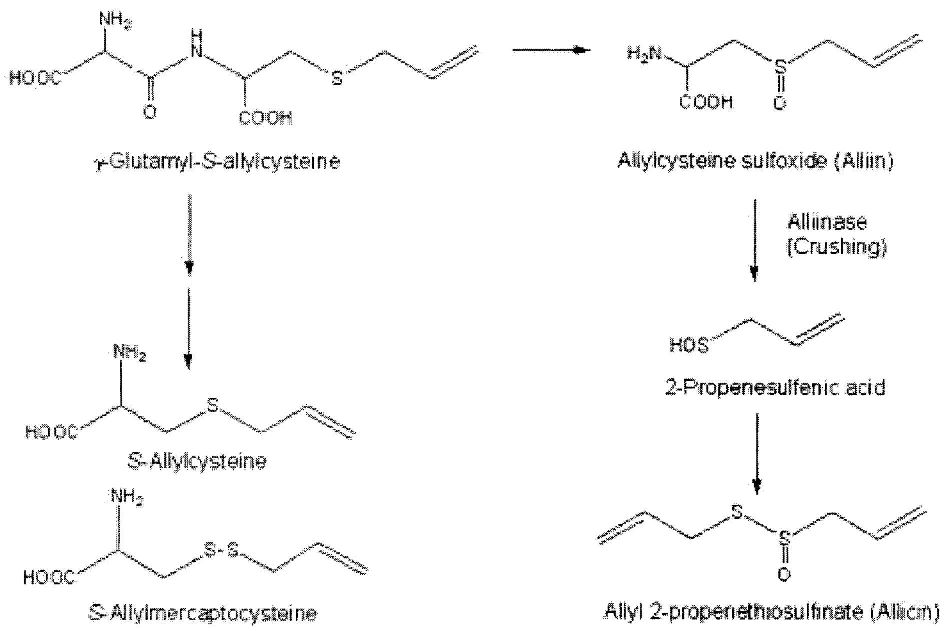

Figure 5: Some organosulfur compounds derived from garlic (from Higdon 2005).

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).

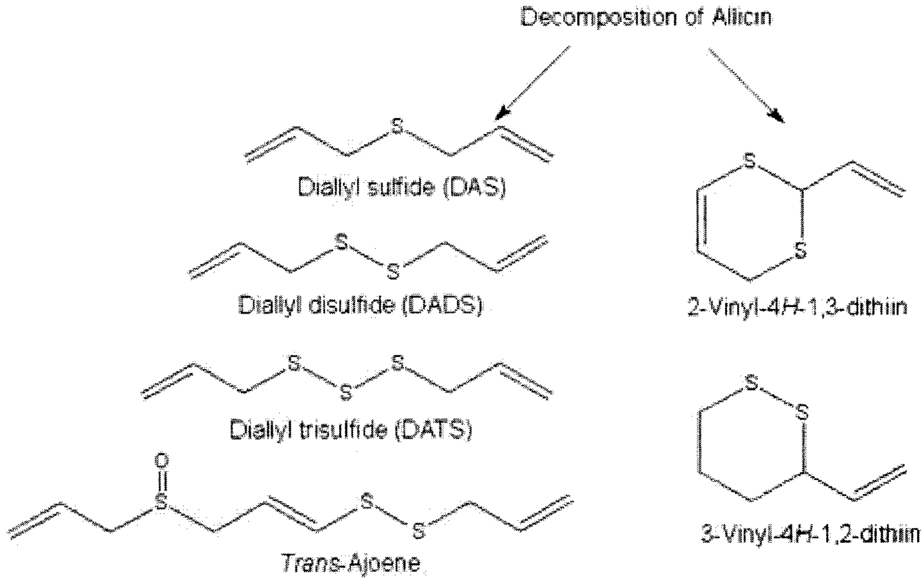

Figure 6: Some organosulfur compounds derived from the decomposition of allicin (from Higdon 2005).

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.

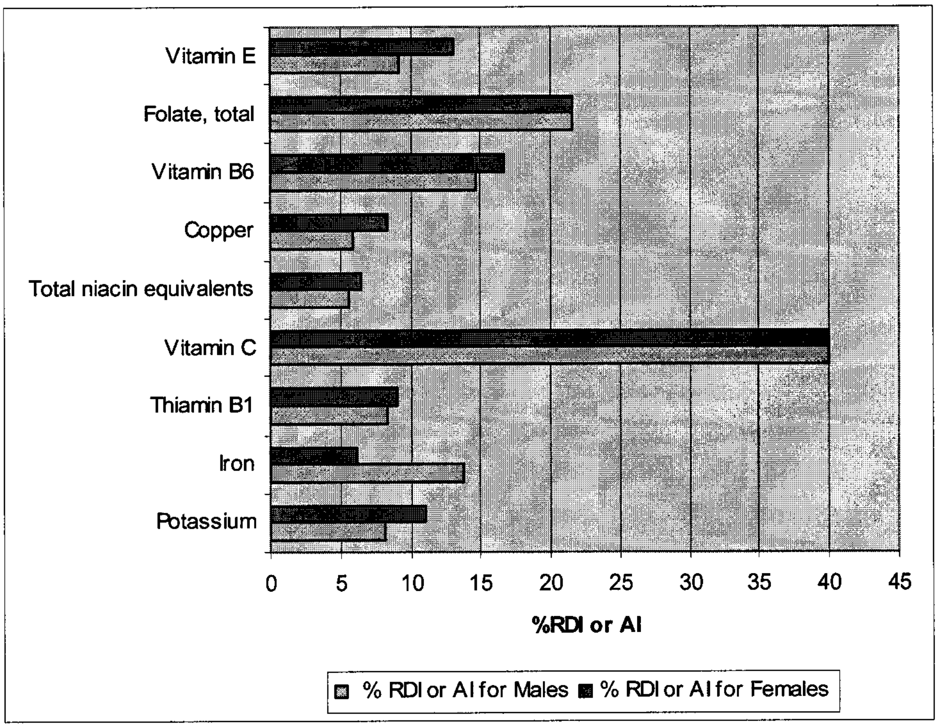

Figure 5: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients in raw leeks (bulb), adapted from Athar et al. (2004) and NHMRC (2006).

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.

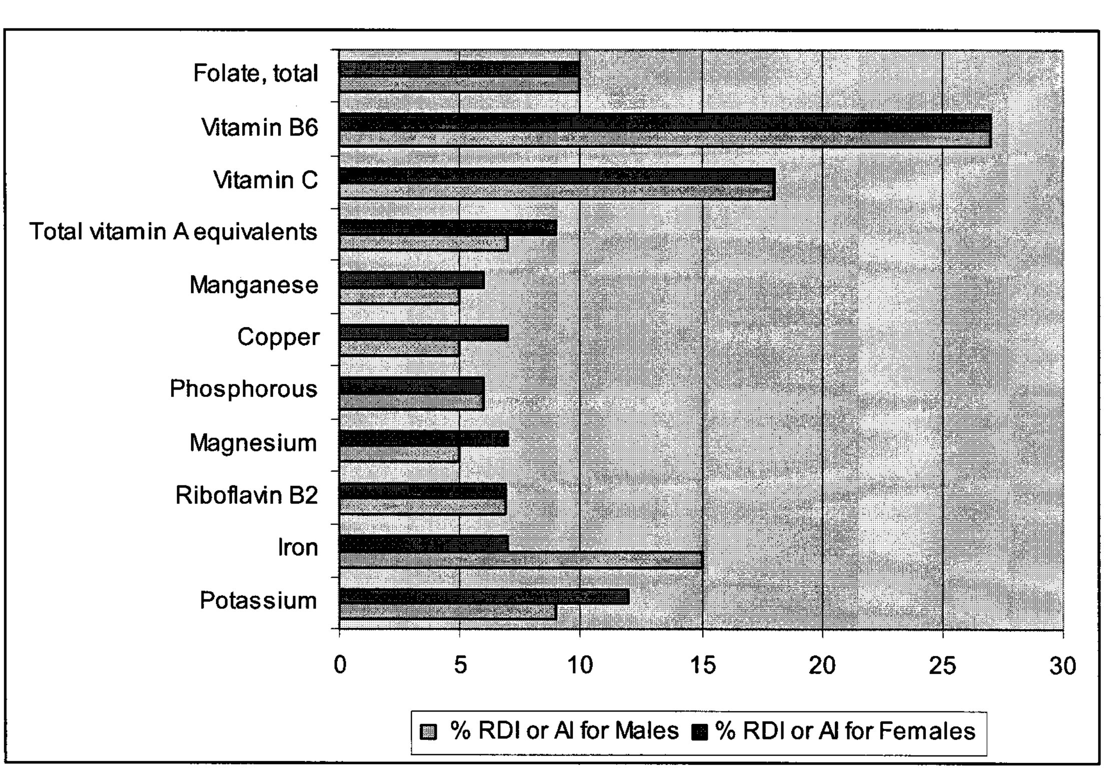

Figure 6: Contributions to Recommended Dietary Intake (RDI) or Adequate Intake (AI) by major micronutrients shallots, adapted from USDA (2006) and NHMRC (2006).

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