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Nutritional attributes of spinach, silver beet and eggplant

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1 Executive summary

1.1 Introduction

This report covers spinach, silver beet and eggplant, important vegetables in the New Zealand market that have not been covered in previous reports. It is hoped to cover other exotic vegetables in a future report.

1.2 Spinach

Spinach is an extremely nutritious vegetable, rich both in core nutrients and phytochemicals. The major micronutrients in spinach are vitamins A (from β-carotene), C, K and folate, and the minerals, calcium, iron and potassium. Spinach also provides fibre and is low in calories. The phytochemicals of most importance are the carotenoids, β-carotene, lutein and zeaxanthin and phenolic compounds.

A number of studies have shown spinach to have strong antioxidant activity and high levels of antioxidant compounds such as phenolics and carotenoids. Antioxidant activity is important as many chronic diseases and health issues associated with ageing are believed to result from excessive oxidative stress.

One of the major health benefits attributed to two major compounds in spinach, lutein and zeaxanthin, is that of protecting against eye diseases such as macular degeneration (gradual loss of central vision, associated with old age). Epidemiological and laboratory studies have also shown that spinach, spinach extracts, and spinach compounds may delay or retard age-related loss of brain function, reduce the extent of post-ischaemic stroke damage to the brain, and protect against cancer through various different mechanisms.

1.3 Silver beet

Similar in composition to spinach, silver beet (or Swiss chard) is rich in core nutrients. Less is known about its phytochemical content, probably because it is less popular. However, like spinach it contains high levels of lutein and zeaxanthin. Multi-coloured stalks also contain betalains, which have strong antioxidant activity. Other phenolics in silver beet, such the flavonoid kaempferol, are also important antioxidants.

1.4 Eggplant

Compared with spinach and silver beet, eggplant is low in core nutrients. Studies have shown mixed results, ranging from low to high, for its antioxidant activity. Little is known of its phytochemicals, although the pigment that gives the purplish colour of some cultivars, nasunin, has received some research interest in its possible antioxidant and anti-cancer properties.

1.5 Conclusions

Spinach is a highly nutritious vegetable, with a wide range and high levels of phytochemicals. Silver beet has a similar profile of phytochemicals, but has been less specifically studied. Coloured silver beet cultivars may offer considerable potential because of the more unusual pigments they contain and this could be investigated further. Similarly, although eggplant appears to contain relatively small amounts of nutrients, research in future may discover new features of their anthocyanins or equally may identify more nutritious cultivars from the many that are grown worldwide.

2 Spinach (*Spinacia oleracea*)

2.1 Introduction

Spinach deserves its reputation as an extremely nutritious vegetable. Its nutrients include a range of vitamins and minerals (micronutrients), which can prevent deficiency diseases and are essential for normal physiological function, as well as phytochemicals (also known as non-nutrients, bioactives or phytonutrients) thought to help prevent chronic health problems such as cancer and heart disease, as well as other health problems associated with ageing.

2.2 Composition

2.2.1 Core nutrients

Spinach is best known for being a rich source of iron, and although it is a good vegetable source, some other vegetables such as watercress are more richly endowed and red meat is a much better source. But equally, there is a lot more to the nutritional value of spinach than just iron.

Spinach contains an array of micronutrients and phytochemicals. The major micronutrients in spinach are vitamins A (from β-carotene), C, K and folate and the minerals, calcium, iron and potassium. Other nutrients present in smaller quantities include vitamin E, some B vitamins – thiamine (B_1), riboflavin (B_2) and B_6, and the minerals magnesium, manganese and zinc (Table 1). Spinach also provides fibre and has the additional advantage of being low in calories.

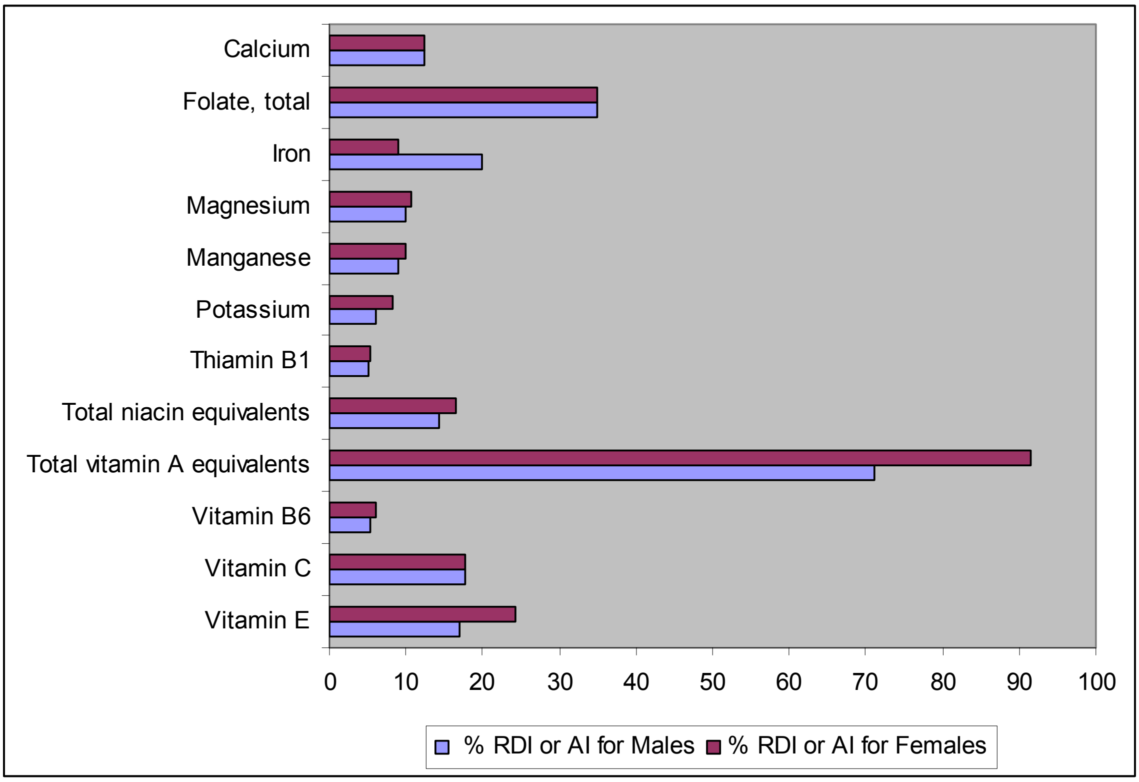

Figure 1: Contributions to RDI or AI by the major micronutrients in 100 g boiled, drained spinach leaves. Adapted from Athar et al. (2004) and NHMRC (2006).

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

2.2.2 Phytochemicals

The phytochemicals of most importance are the carotenoids, β-carotene, lutein and zeaxanthin, along with phenolic compounds. Other phytochemicals include chlorophyll, glutathione, α-lipoic acid and betaine (Joseph et al. 2002).

Carotenoids are a group of yellow-orange-red pigments, found in a variety of fruits and vegetables. 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 spinach and kale. Besides conferring colour, carotenoids also have 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.

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, or vitamin A, and so are referred to as having provitamin A activity. Lycopene, lutein and zeaxanthin are converted to vitamin A, but have other health benefits. Because of their similarity, lutein and zeaxanthin are often reported as a combined total.

Carotenoids are fat-soluble compounds and thus are best absorbed in the body if accompanied by a small amount of some form of oil or fat in a meal. Processing such as chopping and cooking assists in releasing carotenoids from the food matrix, which also increases their bioavailability. As with iron, New Zealand data give lower values for β-carotene than US data, but this may be the result of analysing different cultivars or using different analytical methods.

Table 1: Major carotenoids in spinach and other assorted vegetables (per 100 g) (Athar et al. 2004; USDA 2006).

Food	β-carotene	Lutein + zeaxanthin
Broccoli, raw	361	1403
Kale, raw	9226	39550
Lettuce (iceberg)	299	277
Lettuce (romaine)	3484	2312
Silver beet	3652	11015
Spinach, raw	5626	12198
Spinach, boiled	6288	11308
Spinach, frozen	7035	12651
Spinach, boiled (NZ data)	3840	NA

2.2.3 *Phenolic compounds*

Phenolic compounds are a large group of secondary plant products, present in most if not all plants. They differ in chemical structure and reactivity, but all have at least one benzene ring with a hydroxyl group bound to a carbon atom. Chemical structures range from quite simple compounds such as caffeic acid to highly polymerised substances such as tannins. 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). Flavonoids and phenolic acids are the most widely studied classes of compounds in this group. Major spinach flavonoids reported in the USDA flavonoid database include good amounts of luteolin and quercetin and small amounts of kaempferol and myricetin (Table 2) (USDA 2003).

Table 2: Levels of selected flavonoids in raw spinach (mg/100 g FW).

Luteolin	1.11
Quercetin	4.86
Kaempferol	0.01
Myricetin	0.01

A very recent prospective study showed a significant 40% decrease in epithelial ovarian cancer incidence for the highest versus lowest quintile of kaempferol intake and a significant 34% decrease in incidence for the highest versus lowest quintile of luteolin intake. Interestingly, however, this study found that there was no effect of several flavonoids together (Gates et al. 2007). According to Pandjaitan et al. (2005), spinach contains some unusual flavonoid compounds, including glucuronides and acylated di- and triglycosides of methylated and methylenedioxy derivatives of 6-oxygenated flavonols.

In vitro phenolic compounds have very strong antioxidant activity. However, their uptake and bioavailability, which are major factors in their *in vivo* effects, are not fully understood. It appears that they are not well absorbed and are taken into the bloodstream as metabolites, which tend to have lower antioxidant activity than the parent compound, so there is some conjecture as to the magnitude of their effects as antioxidants (Higdon 2005). However, it has also been shown that the antioxidant activity of plasma increases after ingestion of polyphenols (Scalbert et al. 2005). Polyphenols also have other important biological effects such as anti-inflammatory, anti-proliferative, anti-viral and anti-allergenic properties.

Spinach has been included in a number of comparative studies examining levels of phytochemicals, but again findings are not consistent, with amounts of phenolics varying considerably (Table 3). However, as a generalisation, spinach ranks just within the top third of vegetables and has moderate levels of phenolics.

Table 3: Total phenolics in fresh, raw spinach as reported in and adapted from scientific literature (where necessary, values converted to amounts per 100 g fresh weight according to USDA food composition data).

Total phenolics (mg/100 g)	Author
32.5 mg GAE	Chun et al.(2005)
90.0 mg GAE	Chu et al. (2002)
188.3 mg GAE (immature)	Pandjaitan et al. (2005)
256.3 mg GAE (mid-mature)	
196.9 mg GAE (mature)	
270 mg GAE	Wu et al. (2004)
109.6 mg GAE	Turkmen et al. (2005)
89.4 mg CAE	Ninfali et al. (2005)

GAE = gallic acid equivalents. CAE = caffeic acid equivalents.

2.3 Health benefits

The roles of core nutrients are outlined in Appendix II Table 1.

2.3.1 Studies involving spinach or spinach extracts

An early case-control study found that women who consumed spinach or carrots more than twice a week had a lower risk of developing breast cancer than those who consumed none, though the authors acknowledged that the data did not allow them to distinguish among several potential explanations (Longnecker et al. 1997). Another human study demonstrated that increased intake of spinach carotenoids increased serum carotenoid concentrations as well as macular pigment optical density, which is considered a possible predictor of macular degeneration (Kopsell et al. 2006).

An animal study involved feeding young rats a freeze-dried aqueous spinach extract and observing changes related to mental function as they aged. It was found that the rats who received the spinach extracts had overall the greatest retardation of age-related declines in neuronal and cognitive function, compared with those in other groups. Although two groups had been fed other diets high in antioxidants (strawberry extracts or vitamin E supplements), the effects were most pronounced overall in the spinach-fed group (Joseph et al. 1998). A subsequent study found that supplementing the diet with various antioxidants, including a spinach extract, resulted in reversing age-related declines in a number of neuronal and behavioural parameters (Joseph et al. 1999). It was hypothesised that the protective effect could be related to the antioxidant activity of the supplemented diets.

Wang et al. (2005) found that supplementing the diet with spinach reduced post-ischaemic stroke brain damage in rats, possibly via anti-apoptosis activity. Those authors also postulated that besides antioxidant activity, anti-inflammatory mechanisms might be involved. A lowering of blood pressure was noticed in spontaneously hypertensive rats fed peptides isolated from spinach leaf Rubisco, which were shown to have anti-cholinesterase (ACE) inhibitory properties (Yang et al. 2003).

There have also been studies using spinach or spinach extracts in cancer. Topical and oral administration of a water-soluble spinach extract reduced the number of induced papillomas in a cancer model using mice (Nyska et al. 2001); neoxanthin from spinach inhibited the proliferation of prostate cancer cells in a laboratory study (Asai et al. 2004), and 13 flavonoids from spinach showed anti-mutagenic activity in a bacteria-based model (Edenharder et al. 2001).

2.3.2 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. Phytochemicals may have antioxidant, anti-inflammatory, vasodilatory, anti-cancer or anti-bacterial activities. One of the most important ways in which fruit and vegetables are believed to exert their protective effects is through their antioxidant activity.

Antioxidants are compounds that 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 as 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 may oxidise fats in the blood, contributing to atherosclerosis and ultimately to 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 spinach are vitamin C, the carotenoids and various phenolic compounds. It should be noted that vitamin A does not exert antioxidant activity, but carotenoids (some of which may be converted to vitamin A) do.

Antioxidant activity of spinach

Several studies have examined the antioxidant activity of spinach and other vegetables. Cao et al. (1996) gave spinach an antioxidant score of 17 (based on ORAC scores using three different radicals), rating it third of the 22 vegetables examined. Ranked ahead of spinach were garlic and kale, but the former is only consumed in small amounts and the latter is rarely eaten. Similarly, Pellegrini et al. (2003) ranked spinach first, eighth and first respectively out of 31 popular vegetables as measured by the FRAP, TRAP and TEAC antioxidant assays. A similar result was found by Wu et al. (2004) and Chu et al. (2002). The latter not only ranked spinach extremely highly for antioxidant activity but also in terms of antiproliferative activity. By contrast, however, spinach was placed towards the middle of the field of 20 common vegetables in another recent study (Chun et al. 2005). Table 4 lists absolute values from some of these studies. It is apparent that considerable variation exists, even when the same assay is used. Various factors can account for such disparity, including the use of different assays, different methods of sample preparation, different cultivars etc. The Panjaitan study also illustrates another source of variation, that of maturity.

Table 4: Antioxidant activity of fresh raw spinach as reported in and adapted from scientific literature (where necessary values are converted to per 100 g fresh weight according to USDA food composition data).

Antioxidant activity (per 100 g FW)	Author	Assay
1445.7 µmol TE (immature) 2416.7 µmol TE (mid-mature) 1448.2 µmol TE (mature)	Pandjaitan et al. (2005)	ORAC
2732 µmol TE	Ninfali et al. (2005)	ORAC
2640 µmol TE	Wu et al. (2004)	ORAC
1307 µmol TE	Ou et al. (2002)	ORAC
849 µmol TE	Pellegrini et al. (2003)	TEAC (ABTS)
35.2 mg VCE	Chun et al. (2005)	VCEAC
362.9 µmol VCE	Chu et al. (2002)	TOSC

ORAC = Oxygen radical absorbance capacity; TEAC (ABTS) = Trolox equivalent antioxidant capacity using ABTS radical; VCEAC = Vitamin C equivalent antioxidant capacity; TOSC = Total oxyradical scavenging capacity; TE = Trolox equivalents; VCE = Vitamin C equivalents.

2.3.3 β-carotene

The health benefits associated with carotenoid-rich foods can in part be attributed to the β-carotene they contain. β-Carotene may help prevent the formation of lesions that lead to cancer, and *in vitro* cell experiments have indicated that carotenoids also have other properties consistent with anti-cancer activity. For instance, 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.

There have also been mixed results on 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 has been thought that β-carotene, which itself is carried in LDL, might help prevent this oxidation because several *in vitro* studies had shown that it could scavenge 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 on the ability of β-carotene to stabilise LDL against oxidation (Cooper et al. 1999).

2.3.4 Lutein and zeaxanthin

Amounts of lutein and zeaxanthin in some common vegetables are shown in Table 4. Spinach contains some of the largest amounts of lutein and zeaxanthin from vegetable sources. Although kale contains more, it is not commonly eaten and is therefore not a major food source.

Studies have shown that these compounds are selectively accumulated in different parts of the eye, where they are by far the most abundant of the major carotenoids present. This 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. There is some epidemiological evidence to support this (Sies & Stahl 2003; Mares-Perlman et al. 2002). However, data are scarce and study findings not always consistent (Granado et al. 2003; Mares-Perlman et al. 2002).

The fact of their antioxidant activity has led to speculation that these carotenoids, particularly lutein, which is more widely dispersed in the body, could protect against diseases such as cancer and cardiovascular disease as well as positively affecting immune function. Epidemiological research on 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 (Mares-Perlman et al. 2002). Again, however, results are not clear, with some studies finding no associations and others reporting only inconsistent results.

In terms 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).

2.3.5 *Phenolic compounds*

Phenolic compounds are particularly important antioxidant compounds. Because of their structure, they are very efficient scavengers of free radicals and they also serve as metal chelators (Shahidi & Naczk 1995). They comprise two main groups – flavonoids and phenolic acids, both of which are present in spinach (Pandjaitan et al. 2005). Phenolic acids have been studied largely in relation to their antioxidant activity, but flavonoids, in addition to antioxidant properties, have other potential health-promoting activities including 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 further help to prevent heart disease through inhibiting blood platelet aggregation and providing antioxidant protection for low density lipoprotein (Frankel et al. 1993).

2.3.6 *Other phytochemicals in spinach*

Chlorophyll

Relatively little is known of the health effects of chlorophyll, the pigment that causes the green colour in plants and is the primary photosynthetic compound. Some research suggests that it may be important in protecting against some forms of cancer, as it is thought that the chlorophyll binds to the mutant DNA and prevents it proliferating. A recent study found that chlorophyll had phase 2 enzyme inducing potential and although its activity was relatively weak, because it is present at high concentrations in so many edible plants, it may have some of the protective effects observed with diets rich in green vegetables (Fahey et al. 2005).

Glutathione

An extremely important endogenous antioxidant (synthesised within the body), glutathione is relatively rare in foods. One of its major functions is to protect DNA from oxidation, but it also detoxifies carcinogens, boosts the immune system, supports liver health and reduces inflammation (Joseph et al. 2002).

α-Lipoic acid

Like glutathione, α-lipoic acid is a vital antioxidant largely synthesised in the body, but also present in some foods. It is important for energy metabolism and its antioxidant activity may protect against chronic diseases. In addition, it may assist memory (Joseph et al. 2002).

D-Glucaric acid

It is believed that D-glucaric acid may lower blood cholesterol (Joseph et al. 2002).

Coenzyme Q_{10}

Another endogenous compound, coenzyme Q_{10} is a critical component in energy metabolism, but also acts as an antioxidant in cell membranes and lipoproteins. The best food sources are meat, fish and oils, but spinach is one of the best vegetable sources (Joseph et al. 2002).

Betaine

This is a lesser known compound and does not appear to have been extensively researched. It is thought that it may prevent cardiovascular disease by lowering levels of homocysteine, a compound associated with the development of heart disease (Joseph et al. 2002).

2.4 *Anti-nutritive compounds*

Plants also contain compounds which can potentially compromise health. These are termed ‘anti-nutritive’ compounds and include oxalates, which are present in spinach. In plant tissues these compounds are present as end-products of metabolism, but in humans they compromise nutrient absorption (especially of minerals such as calcium and possibly iron) as well as contributing to the formation of kidney stones and gout. Along with rhubarb and beet, spinach is high in oxalates, though amounts can vary according to a number of factors including cultivar, growing conditions and cooking method (Noonan & Savage 1999). The large amount of oxalates in spinach compromises the absorption of the calcium and iron that the food also contains, but there is no evidence of it causing toxicity problems. Blanching spinach lowers oxalate amounts. Soaking and cooking, particularly boiling, reduces oxalates in other foods such as soybean and yams (Noonan & Savage 1999), and may have a similar effect with spinach. Neither Joseph et al. (2002) nor Pratt & Matthews (2004) consider the oxalates in spinach a major issue and the consensus appears to be that a moderate intake as part of mixed diet should not pose any health problems.

2.5 *Factors affecting nutrient levels*

Several factors combine to determine the amounts of core nutrients and other phytochemicals in a food. These include the variety/cultivar of the plant, agronomic issues such as soil type, cultivation protocols (irrigation, pest control, use of fertiliser), the degree of maturity at harvest, and processing practices (harvesting, storage, method of processing).

The fact of inter-cultivar variation in general is well established and spinach is no exception to this. A study of 11 commercial lines and 15 breeding lines showed large variations in antioxidant activity and phenolic content. Variations were also notable by growing season, with significantly higher levels of antioxidant activity and phenolic content in over-winter spinach (sown in late autumn and harvested in early spring) than that sown in early autumn and harvested in late autumn (Howard et al. 2002). A subsequent study also showed phenolic content variation according to genotype, as well as level of maturity, with amounts significantly higher at the mid-maturity stage (Pandjaitan et al. 2005).

Processing such as freezing also affects the nutrient profile of spinach (Table 3). The amounts of some nutrients such as vitamin C and folate are reduced with freezing, but others, such as β-carotene, lutein and zeaxanthin, are improved. Similar effects have been observed with other forms of processing in other vegetables, such as cooked tomatoes. It is believed that that this occurs in part because freezing disrupts the food matrix, making these compounds more easily available for absorption in the body, and for extraction and measurement in the laboratory.

Cooking has both beneficial and deleterious effects upon nutrients. Whilst it degrades vitamin C and folate, it can make carotenoids like β-carotene and lutein and zeaxanthin more bioavailable. Light cooking or steaming is often recommended to enhance carotenoid bioavailability while minimising the loss of other nutrients (Joseph et al. 2002).

2.6 *Quotes and trivia*

- Spinach was the first vegetable to be sold in a frozen form (www.foodreference.com).
- According to a number of internet websites, the cartoon character Popeye is credited with increasing the consumption of spinach in the US by 33% in the 1930s.
- In the US, 56% of readers surveyed by the food magazine, Bon Appetit, in 2005 ranked spinach as their favourite vegetable, ahead of more predictable choices such as asparagus and broccoli. The survey asked 10 000 readers to rank a dozen vegetables in terms of preference. The availability of washed, bagged, baby spinach has added considerably to its popularity (Sagon 2005).

- The myth about spinach and its high iron content may have first been propagated by Dr E von Wolf in 1870, because a misplaced decimal point in his publication led to an iron-content figure that was 10 times too high. In 1937, German chemists reinvestigated this "miracle vegetable" and corrected the mistake. It was described by TJ Hamblin in the British Medical Journal, December 1981 (Wikipedia 2007).
- *"One man's poison ivy is another man's spinach."* George Ade (1866-1944) American humorist (www.foodreference.com/html/qspinach.html).

3 Silver beet /Swiss chard (*Beta vulgaris var. cylca / cicla*)

3.1 Introduction

A staple in many domestic gardens, silver beet is both decorative and nutritious. It is the same species as beetroot, but is a variety which does not develop a swollen taproot. Both the stalk and leaves are edible, with differing cuisines preferring one over the other. These days, multi-coloured cultivars are available, which provide visual interest as well as additional kinds of phytochemicals.

3.2 Composition

Nutritionally silver beet deserves to be highly valued, as it is an excellent source of many core nutrients as well as phytochemicals. Its slightly bitter taste is perhaps to blame for its lack of popularity, but if served mixed with other sweeter vegetables, it can provide an interesting contrast in flavour.

Its nutritional profile is very similar to that of its close relative, spinach. Besides its many nutrients, it too contains anti-nutritive oxalates (Section 2.4), but there is similarly no evidence of this being a major health issue.

3.2.1 Core nutrients

Silver beet is particularly rich in vitamins A (through β-carotene), C and, unusually for stalky/leafy material, vitamin E. In addition, it provides useful amounts of a wide range of minerals (Figure 2).

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

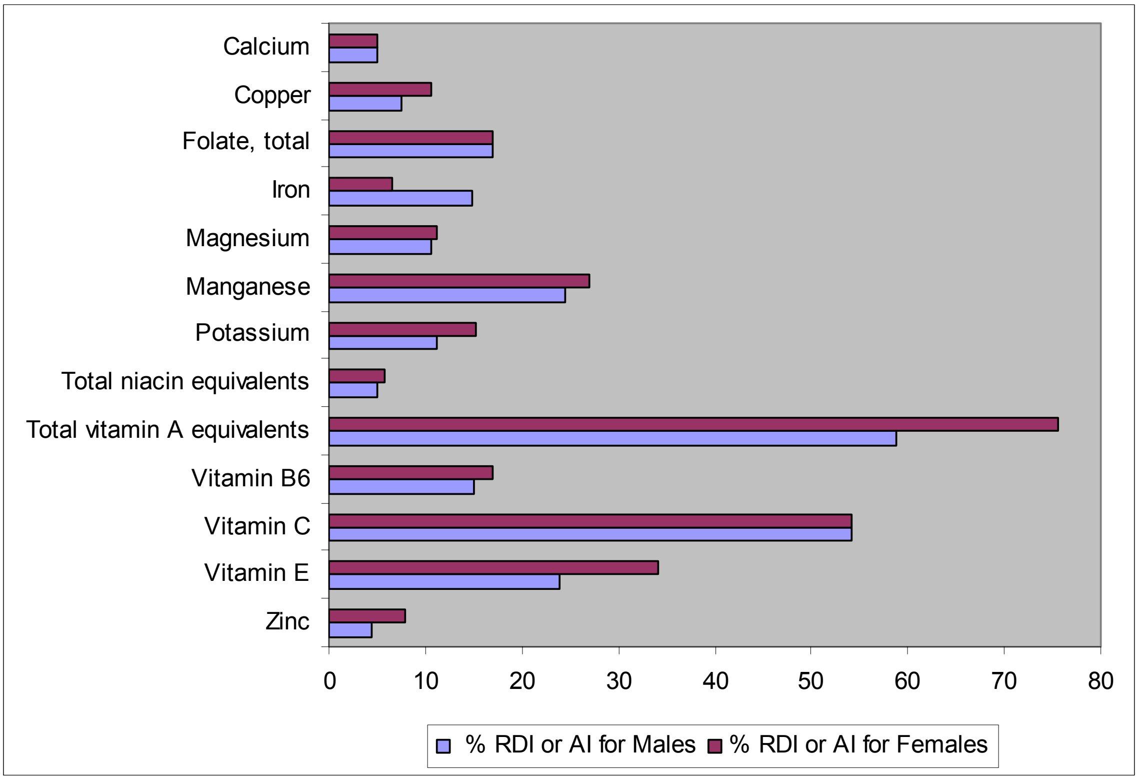

Figure 2: Contributions to RDI or AI by the major micronutrients in 100 g raw silver beet, adapted from Athar et al. (2004) and NHMRC (2006).

3.2.2 *Phytochemicals*

Compared with spinach, there is relatively little research on silver beet, although it has some unusual and interesting phytochemicals, such as vitexin, an apigenin derivative (Gil et al. 1998). Besides the green pigment, chlorophyll, the multi-coloured cultivars also contain betalains, which include the red betacyanins and yellow betaxanthins.

Carotenoids

Silver beet shares many of the same major phytochemicals with spinach. Of particular interest, because they are less common, are the high levels of the carotenoids lutein and zeaxanthin (Table 1).

3.2.3 Phenolics

Pyo et al. (2004) found that the major phenolic acid in silver beet was syringic acid and the major flavonoid was kaempferol. Phenolic composition as well as content differed between leaves and stems, with leaves containing more than stems and a red cultivar containing more than a white cultivar. Levels of phenolics correlated well with antioxidant activity, which was in the order red leaf > white leaf > red stem > white stem (Table 5).

Table 5 Total phenolics in differently coloured cultivars of Swiss chard (GAE/100 g fresh weight) (Pyo et al. 2004).

Red leaf	128.1
Red stem	29.7
White leaf	124.7
White stem	23.2

Flavonoids

Table 6 shows flavonoids listed for Swiss chard in the USDA Flavonoid database. There may, however, be other flavonoids present, as this database only lists certain more common flavonoids. For example, three less common flavonoids were also identified in an Italian study, vitexin-2"*O*-rhamnoside, its demethylated form 2"-xylosylvitexin, isorhamnetin 3-gentiobioside, and rutin (Ninfali et al. 2007).

Table 6: Levels of selected flavonoids in Swiss chard (mg/100 g FW) (USDA 2007).

Catechins	2.15
Kaempferol	4.3
Myricetin	1.35

Betalains

Betalains are relatively uncommon phytochemicals, occurring in only 13 families of the Caryophyllales order and in some genera of the Basidiomycetes (Kugler et al. 2004). Although visually similar to anthocyanins, they are chemically different. These two classes of compounds are also 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 the stresses of drought, low temperatures or wounding (Stintzing & Carle 2004).

Nineteen betaxanthins and nine betacyanins were identified in the stalks of multicoloured silver beet cultivars (Kugler et al. 2004). A very recent study of members of the Amaranthaceae, to which both silver beet and spinach belong, investigated structure-activity relationships of various betaxanthins and betacyanins in terms of their free-radical scavenging capacities (Cai et al., 2003). Antioxidant potential was found to be related to structural features of the betalains. In betaxanthins, an increasing number of hydroxy and imino residues increased free radical scavenging. In betacyanins, glycosylation reduced activity whereas it increased with acylation. Also, 5-*O*-glycosylated betacyanins produced lower antioxidant values than their 6-*O*-glycosylated counterparts.

3.3 Health benefits

See sections 2.3.1, 2.3.2, and 2.3.3 for the health effects of β-carotene, lutein and zeaxanthin, and phenolic compounds, respectively.

3.3.1 Antioxidant activity

Silver beet ranked in about the top third (n = 33), according to one of the few studies in which it is included, measured according to three different methods which reflect different modes of antioxidant activity (Table 7).

Table 7: Ferric reducing-antioxidant power (FRAP), total radical trapping antioxidant parameter (TRAP) and Trolox equivalent antioxidant capacity (TEAC) of extracts of eggplant, silver beet and spinach (Pellegrini et al. 2006).

	FRAP		TRAP		TEAC	
Vegetable	Value	Rank	Value	Rank	Value	Rank
	Mmol Fe^{2+}/kg fresh weight		Mmol trolox/kg fresh weight			
Eggplant	3.77	24	2.82	15	1.10	25
Silver beet	11.60	10	2.91	13	3.53	10
Spinach	26.94	1	5.79	8	8.49	1

Extracts of a red-stemmed variety showed high antioxidant activity, superior to both the synthetic antioxidant buylated hydroxytoluene (BHT) and tocopherol according to the DPPH radical scavenging assay. White-stemmed extracts were also higher than BHT, though slightly lower than tocopherol in this assay. However, BHT performed best according to the thiocyanate method, with the red-stemmed cultivar approximately the same as tocopherol, and the white-stemmed cultivar lower. Antioxidant activity of the stem extracts was around one half to two-thirds that of the leaves (Pyo et al. 2004).

3.3.2 Betalains

Studies relating to betalains in silver beet are lacking, but it is likely that findings for beetroot can be extrapolated to silver beet. 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). As already discussed, the radical scavenging capacity of different betalains is related to different structural features (Cai et al. 2005).

A number of studies have ranked the antioxidant capacity of beetroot highly, with betalains credited at least in part for this (Cao et al. 1996, Halvorsen et al. 2002, Kähkönen et al. 1999, Ou et al. 2002, Vinson et al. 1998, Wettasinghe et al. 2002a). As mentioned earlier, betalains have been identified in the stalks of differently coloured silver beet cultivars (Kugler et al. 2004).

3.3.3 Chlorophyll

See Section 2.3.6.

3.4 Factors affecting health benefits

As with spinach, cooking degrades vitamin C and folate in silver beet, but makes the carotenoids more bioavailable. An 80% loss of vitamin C was observed after boiling for 10 minutes. Around 50% of the flavonoids from a green cultivar leached into cooking water during boiling, although less leaching was observed with a yellow cultivar (Gil et al. 1998). In that study, vitamin C also decreased under modified atmosphere packaging, though no effect upon flavonoid content was observed.

3.5 Quotes and trivia

- In Korea, silver beet is used to reduce inflammation and stop bleeding.
- According to Wikipedia, Europeans prefer silver beet stalks, whereas Americans prefer the leaves.

4 Eggplant/aubergine (Solanum melongena)

4.1 Introduction

“Eggplant” may seem an odd name for today’s large purplish, pear-shaped vegetables, but is actually an accurate description of early varieties, which were indeed egg-shaped and white in colour. In fact, eggplants come in a variety of colours from dark purplish black, to pale purple, white, orange and green and can be solid colours, striped or mottled. Equally, they have diverse shapes from egg-shaped to sausage-shaped and pear-shaped, and can vary in weight from around 20 to over 400 g (Hanson et al. 2006).

Eggplants originated from Asia and are particularly valuable vegetables in tropical countries as they are some of the few vegetables that produce high yields in both hot and wet environments (Hanson et al. 2006). They belong to the same family (Solanaceae) as tomatoes, potatoes, capsicum and deadly nightshade.

Eggplants are usually harvested before they are physiologically mature (Whitaker & Stommel 2003). Bitterness can be a problem with eggplants, and the consensus appears to be that this is a function of variety and maturity – the sausage-shaped Asian varieties tend to be less bitter, and the more mature a fruit is, the more likely it is to have accumulated bitter compounds. Prolonged storage in the refrigerator is also said to encourage their build-up.

4.2 Composition

Eggplant is not rich in core nutrients, but it can contain unusual pigments and large amounts of other phytochemicals, particularly phenolic compounds, which are thought to confer much of its high antioxidant activity. The different varieties can contain different antioxidant compounds and/or proportions of these compounds (Whitaker & Stommel 2003).

Some sources refer to bitterness in eggplant and relate it to the presence of alkaloids (McGee 2004), but there is little information on alkaloids in eggplant fruit. Alkaloids in other members of the Solanaceae cause allergic reactions in some people.

4.2.1 Core nutrients

In comparison with spinach and silver beet, eggplant provides little in the form of micronutrients (Figure 3). It is, however, an important source of energy in those less-developed countries where it is more of a staple.

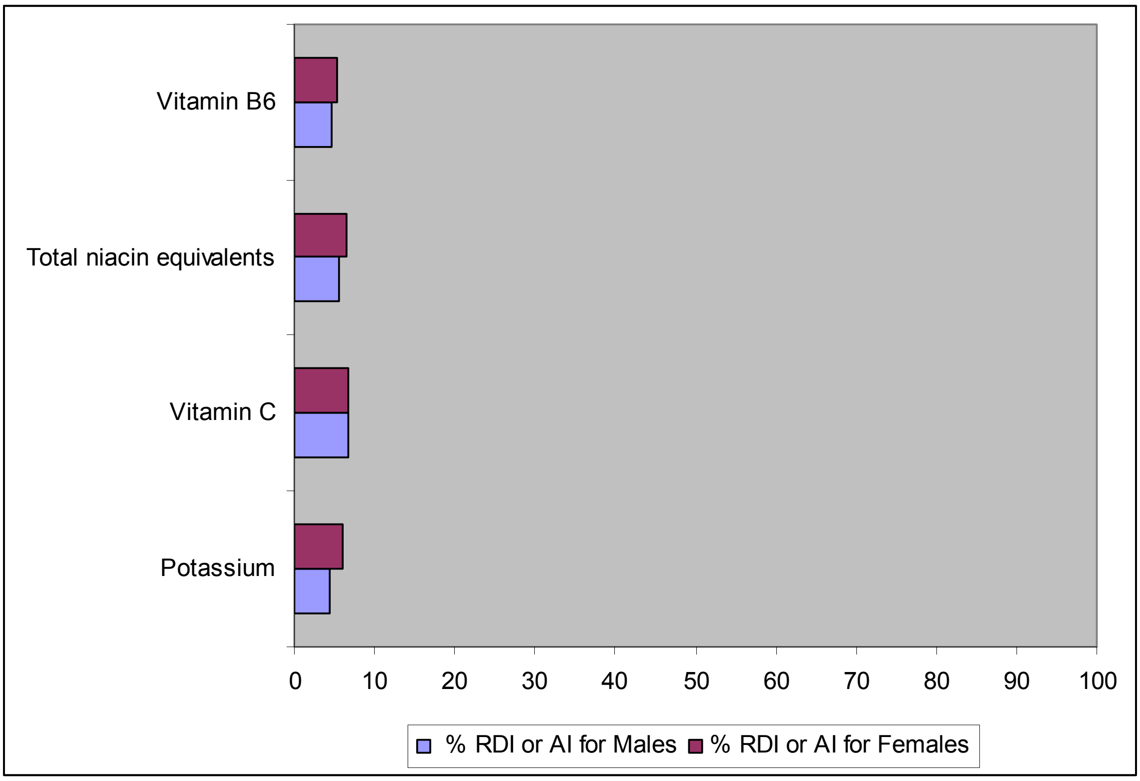

Figure 3: Contributions to RDI or AI by the major micronutrients in 100 g raw eggplant, adapted from Athar et al. (2004) and NHMRC (2006).

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

4.2.2 *Phytochemicals*

The eggplant phytochemicals that have received most research attention are the phenolic compounds. Chlorogenic acid is the major phenolic in eggplant (Whitaker & Stommel 2003; Kahlon et al. 2007), accounting for 99% of total phenolics in one study (Kalogeropoulos et al. 2007). Chlorogenic acid is one of the most abundant phenolic acids in fruit and vegetables, and *in vitro* and animal studies have shown its antioxidant and anti-cancer activities (Gonthier et al. 2003). Chlorogenic acid was present in all cultivars studied by Whitaker & Stommel (2003), and in tissues from all zones of the eggplant.

Like purple sweet potato, purple-coloured varieties of eggplant contain anthocyanins that are relatively unusual because they are acylated, and are considered to be more stable than non-acylated forms (Ichiyanagi et al. 2006). Their stability has made them of interest for use as natural colourants in the food industry, but they also have particular physiological functions, such as α-glucosidase inhibitory activity (Matsui et al. 2001). Nasunin (delphinidin-3-(p-coumaroylrutinoside)-5-glucoside), the major anthocyanin component of eggplant, has been studied for its antioxidant and anti-cancer activity (Noda et al. 2000; Matsubara et al. 2005).

Orange and yellow cultivars would be expected to contain carotenoids, which would account for their colour. Similarly, green cultivars would contain chlorophyll. However, no detail on the composition of these cultivars has been found.

4.3 Health benefits

4.3.1 Antioxidant activity

Some studies have rated the *in vitro* antioxidant activity of eggplant as high (Wu et al. 2004), though others have ranked it average (Table 5, Ninfali et al. 2005), and low (Halvorsen et al. 2002). As already discussed with respect to spinach, these differences could be the result of a number of different factors, including different eggplant cultivars, growing conditions or assay mechanisms.

4.3.2 Cardiovascular disease

Eggplant is believed to lower blood cholesterol in South American countries (Botelho et al. 2004), which has prompted some of the research into its possible effects on cardiovascular disease. However, an early trial in humans showed only a modest and transitory effect of consumption of a powdered eggplant preparation in terms of total cholesterol and its fractions, triglycerides and apolipoproteins in blood (Guimaraes et al. 2000). Of eight commonly consumed vegetables, eggplant showed amongst the lowest bile acid binding capability, several-fold less than okra and beets (Kahlon et al. 2007). (By binding bile acids, their circulation in the body is prevented, and results in reduced fat absorption, the excretion of toxic metabolites and the utilisation of cholesterol from the bloodstream to synthesise more bile acids, thereby lowering levels of cholesterol in the blood.) Also contrary to expectations, Bothelo et al. (2004) found that rather than decreasing plasma cholesterol and preventing the development of atherosclerosis, in a mouse study eggplant appeared to increase oxidative stress.

Other studies have not directly investigated the cardiovascular system, but have findings that may also be relevant in terms of protecting against cardiovascular disease. A study comparing the protective effects of various vegetable extracts upon mouse liver microsome lipid peroxidation showed that although not the best of the extracts investigated, a water-soluble eggplant extract showed a high, though somewhat variable, level of protection. Boiling and freezing slightly reduced the protective effect, whereas freeze-drying slightly increased it (Gazzani et al. 1998). Anti-inflammatory activity, which may be relevant to heart disease and cancer as well as other diseases, was observed in a mouse study in which an extract of white eggplant ripened to yellow prevented oedema and vascular permeability (Han et al. 2003).

4.3.3 Cancer

A number of processes are involved in the progression of events that result in cancer, including the growth of new blood vessels (angiogenesis) to enable the tumour to grow and metastasise. Some polyphenols are able to prevent this process. Nasunin, the major anthocyanin in eggplant skins, has antioxidant activity (Noda et al. 2000) and it suppressed microvessel growth in an *ex vivo* animal study and an *in vitro* human cell assay (Matsubara et al. 2005).

4.4 Factors affecting health benefits

Hanson et al. (2006) tested antioxidant activity in 35 differently coloured and shaped eggplant cultivars from different parts of the world. Many, though not all, of the top radical scavengers were from purple cultivars, but the best was a white variety with green stripes from Indonesia, followed by a white and purple striped variety from Malaysia. Smaller vegetables tended to have more radical scavenging power than larger ones, and levels of phenolics correlated well with radical scavenging ability. Phenolics were twice as concentrated in the eggplant skins than the pulp, and the types of phenolics were also different. Different growing seasons also affected levels of phenolics and ascorbic acid. Similar inter-cultivar differences were found by Whitaker & Stommel (2003), as well as differences in the composition of tissue from different parts of the vegetable.

Using an animal model, a very recent study demonstrated that nasunin isomers were quickly absorbed in their original acylated forms and that their bioavailability was similar to that of other (non-acylated) anthocyanins (Ichiyanagi et al. 2006). However, anthocyanins in general appear to among the least well absorbed polyphenols (Manach et al. 2005).

4.5 Quotes and trivia

- Some people claim to be able to identify the "sex" of an eggplant; this is important apparently because male eggplants are supposed to be less bitter than female eggplants.
- The spongy structure of raw eggplant is caused by tiny air pockets between the cells. When cooked, the air pockets collapse into an interestingly textured mass (McGee 2004).

5 Conclusions

Spinach and its constituent compounds have received a good amount of research attention, which can substantiate spinach's reputation as a highly nutritious vegetable. Silver beet probably has similar health benefits, since it contains many of the same phytochemicals and at reasonable levels, but because it has been less studied, it is not possible to state this unequivocally. It is also difficult to estimate whether its more unique compounds, such as the vitexin family, have particular health attributes. Research does not appear to have demonstrated particular health attributes for eggplant or eggplant compounds at this time, although further research may add weight to early promise identified in compounds such as nasunin.

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Appendices

Appendix I Nutritional information on boiled spinach, raw silver beet and eggplant (per 100 g edible portion) from Athar et al. (2004)

	1	Spinach, leaves, boiled, drained	Silverbeet, leaves and upper stem, raw	Eggplant, raw
Water	g	91.8	90.6	92.4
Energy	kcal	22	23	18
Protein	g	2.2	2.57	1.1
Total fat	g	0.8	0.26	0.3
Carbohydrate, available	g	1.5	2.5	2.6
Dietary fibre (Englyst, 1988)	g	2.1	2.78	2
Ash	g	0.59	1.29	0.71
Sodium	mg	120	138	5
Phosphorus	mg	28	39.2	31
Potassium	mg	230	426	170
Calcium	mg	160	65.4	23
Iron	mg	1.6	1.18	0.2
Beta-carotene equivalents	µg	3840	3170	22
Total vitamin A equivalents	µg	640	529	4
Thiamin	mg	0.06	0.018	0.05
Riboflavin	mg	0.05	0.036	0.04
Niacin	mg	0.9	0.253	0.7
Vitamin C	mg	8	24.4	3
Cholesterol	mg	0	0	0
Total saturated fatty acids	g	0.08	0.047	0
Total monounsaturated fatty acids	g	0.06	0.057	0
Total polyunsaturated fatty acids	g	0.48	0.106	0
Dry matter	g	8.2	9.37	7.6
Total nitrogen	g	0.35	0.41	0.19
Glucose	g	0.8	1.08	1.1
Fructose	g	0.5	0.77	0.8
Sucrose	g	0	0.4	0.1
Lactose	g	0	0	0
Maltose	g	0	0	0
Total available sugars	g	1.3	2.3	2
Starch	g	0.2	0.21	0.6
Alcohol	g	0	0	0
Total niacin equivalents	mg	2.3	0.8	0.9

	1	Spinach, leaves, boiled, drained	Silverbeet, leaves and upper stem, raw	Eggplant, raw
Soluble non-starch polysaccharides	g	0.8	1.09	1
Insoluble non-starch polysaccharides	g	1.3	1.69	1
Energy	kJ	92	94	73
Magnesium	mg	34	35.9	8
Manganese	µg	500	1350	100
Copper	mg	0.01	0.127	0.01
Zinc	mg	0.5	0.63	0.1
Selenium	µg	0.38	0.238	1
Retinol	µg	0	0	0
Potential niacin from tryptophan	mg	1.4	0.5	0.2
Vitamin B6	mg	0.09	0.255	0.08
Folate, total	µg	140	68	18
Vitamin B12	µg	0	0	0
Vitamin D	µg	0	0	0
Vitamin E	mg	1.7	2.39	0.03

Appendix II Major functions of main micronutrients contained in spinach, silver beet and eggplant

Table1: Main micronutrients in legumes 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 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 CNS 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