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Health attributes of roots and tubers

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1 Executive summary

1.1 Background

This report is intended to provide information from which material can be identified for incorporation into one of a series of promotional and educational booklets for the various VegFed sector groups. We have gathered relevant literature, including medical research and scientific papers, and, where possible, included information specific to New Zealand. This report focuses on the nutritional attributes of root vegetables and tubers: carrot, kumara, parsnip, taro and yam. The depth of information available varies considerably; it is very sparse for the lesser known vegetables such as taro and yams. Factors that may influence the nutritional profile of these vegetables, such as agronomical issues, cooking or processing and storage are covered. Some additional material of general interest has also been included.

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

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

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

1.2 *Carrots*

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

1.3 *Kumara*

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

1.4 *Beetroot*

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

1.5 *Parsnips*

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

1.6 *Taro*

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

1.7 *Yams*

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

2 *Carrots* (Daucus carota)

2.1 *Introduction*

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

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

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

2.2 *Composition*

A number of factors combine to determine the levels of both core nutrients and other phytochemicals in a food. These include not only the variety/cultivar of the plant, but also issues relating to the agronomy involved – soils, cultivation protocols (irrigation, pest control, use of fertiliser), degree of ripeness at harvest, and processing practices (harvesting, storage, method of processing). In addition, there can be issues such as the form in which the food was analysed – raw, fresh, canned, boiled, frozen – as well as analytical techniques and variations between the laboratories doing the analysis. This makes it difficult to be exact when comparing levels of these compounds.

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

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

2.2.1 *Core nutrients*

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

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

2.2.2 *Other phytochemicals*

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

Carotenoids

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

Carotenoids are lipids and consist of a long-chain hydrocarbon molecule with a series of central, conjugated double bonds. (See Appendix III for structural diagrams of the major carotenoids in carrots.) These conjugated (alternating) double bonds not only confer colour, but also cause the compounds' antioxidant properties. These compounds have been found to be especially effective in quenching singlet oxygen and peroxyl radicals. They appear to act synergistically with other carotenoids and other antioxidants. In plants, these pigments assist in the light-capturing process in photosynthesis and protect against damage from visible light. In humans, one of their various benefits is believed to be protecting both the skin and the macula lutea of the eye against the same photoxidative damage (Sies & Stahl 2003).

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

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

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

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

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

Falcarinol and falcarindiol

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

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

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

2.3 Health benefits

2.3.1 Core nutrients

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

2.3.2 Phytochemicals

Carotenoids

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

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

β-carotene has been the focus of most research. Epidemiological studies have demonstrated that high intakes of fruit and vegetables protect against a range of chronic diseases and problems associated with ageing. Carotenoid-rich foods have also been associated with health benefits for some time and this has been attributed largely to the β-carotene they contain. It was hypothesised that β-carotene might help prevent the formation of lesions that led to cancer, and *in vitro* cell experiments have indicated that carotenoids also possess properties consistent with anti-cancer activity, e.g. they may play an important role in the cell communication that leads to the removal of pre-cancerous cells. However, results have been somewhat inconsistent. For example, although a review of case control studies looking at diet and breast cancer found a significant inverse association between β-carotene intake and breast cancer in four studies, five studies found no association and seven studies found only a loose association, which was not statistically significant

(Cooper et al. 1999). Similarly, although early studies observed a protective effect of β-carotene on lung cancer, more recent studies have found no significant association between dietary β-carotene intake and lung cancer risk. A study evaluating the effect of β-carotene supplements on lung cancer risk in smokers and other at-risk groups, found that the risk of developing lung cancer actually increased in those taking supplements. However, no such effect has been found in studies where the β-carotene was consumed as part of a food as opposed to a supplement form, where the compound has been isolated and concentrated. Mixed results have also been reported from studies relating to prostate and colorectal cancer.

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

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

α-carotene

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

β-cryptoxanthin

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

Lutein & zeaxanthin

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

Falcarinol

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

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

Phenolic compounds

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

2.4 *Factors affecting health benefits*

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

2.4.1 *Cultivar*

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

2.4.2 *Storage and processing*

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

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

2.4.3 *Growing conditions*

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

2.4.4 *Bioavailability*

Bioavailability broadly addresses the issue of how well a compound is absorbed so that it can be utilised by the body. It involves the degree and rate at which a substance is absorbed into a living system or is made available at the site of physiological activity. Absorption may be determined by a range of variables, such as the chemical structure and nature of the compound, the amount consumed, the food matrix in which it is contained, the presence of other compounds within the meal, and the nutrient status of the subject.

Carotenoids

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

Carotenoids occur in plants in three forms:

- as part of the photosynthetic apparatus, where they are complexed to proteins in chromoplasts and trapped within the cell structures, and are thus protected from absorption (green, leafy vegetables);

- dissolved in oil droplets in chromoplasts, which are readily extracted during digestion (mango, papaya, pumpkin and sweetpotato) (West & Castenmiller 1998); and
- as semi-crystalline membrane-bound solids (carrot, tomato), which, though soluble in the intestinal tract, probably pass through too quickly to allow much solubilisation.

These differences in location and form strongly affect absorption and explain differences in bioavailability in different food matrices (Borel 2003). Particle size and cooking, which breaks down the cell matrix of the food, also influence uptake, presumably by making the carotenoid more available for absorption in the lumen.

It should be noted that hydrocarbon carotenoids (e.g. β-carotene, lycopene) are absorbed differently from xanthophylls (e.g. lutein, zeaxanthin). Within the intestinal lumen, the non-polar carotenes are thought to locate in the hydrophobic core of lipid emulsions and bile salt micelles, whereas the more polar xanthophylls are thought to locate at the surface (Borel et al. 1996).

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

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

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

High bioavailability

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

Carotenoids – oil form (natural or synthetic)

Fruits (peach, apricot, melon)

Tubers (sweet potato, yam, squash)

Processed juice with fat containing meal (e.g. tomato)

Lightly cooked yellow/orange vegetables (carrots, peppers)

Raw juice without fat (tomato)

Raw yellow/orange vegetables (carrots, peppers)

Raw green leafy vegetables (spinach, silver beet)

Low bioavailability

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

Falcarinol

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

2.5 Quotes and trivia

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

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

3.1 *Introduction*

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

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

3.2 *Composition*

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

3.2.1 *Core nutrients*

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

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

3.2.2 *Other phytochemicals*

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

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

β-carotene

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

Phenolic compounds

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

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

Phenolic acids

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

Anthocyanins

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

Flavonoids

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

Coumarins

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

Antioxidant storage proteins

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

Antidiabetic acidic glycoprotein

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

3.3 Health benefits

3.3.1 Core nutrients

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

3.3.2 Phytochemicals

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

Phenolic compounds

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

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

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

Anthocyanins

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

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

3.4 *Factors affecting health benefits*

3.4.1 *Cultivar*

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

3.4.2 *Cooking*

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

3.4.3 *Bioavailability*

Carotenoids

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

Phenolic compounds

There have been few studies on the bioavailability of hydroxycinnamic acids, and none specifically examining those in sweet potato. However, in two studies reviewing the bioavailability of dietary polyphenols, phenolic acids appeared to be among the best absorbed (Scalbert et al. 2002; Karakaya 2004). Anthocyanins, conversely, were the least well absorbed, but this area has not been thoroughly investigated and it is possible that anthocyanin metabolites have not yet been identified.

3.5 Quotes and trivia

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

  "Have another sweet potato?"

  Said Plato unto Aristotle,

  "Thank you, I prefer the bottle."

  Owen Wister (1860-1938) American novelist

4 *Beetroot* (Beta vulgaris)

4.1 Introduction

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

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

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

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

4.2 Composition

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

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

4.2.1 Core nutrients

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

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

4.2.2 Other phytochemicals

Betalains

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

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

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

4.3 Health benefits

4.3.1 Core nutrients

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

4.3.2 Phytochemicals

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

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

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

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

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

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

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

4.4 Factors affecting health benefits

4.4.1 Bioavailability

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

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

4.5 Processing

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

4.6 Quotes and trivia

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

5 *Parsnips* (Pasinaca sativa)

5.1 Introduction

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

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

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

5.2 Composition

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

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

5.2.1 *Core nutrients*

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

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

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

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

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

5.2.2 *Other phytochemicals*

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

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

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

See section 2.2.2, Falcarinol, for further detail.

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

5.3 Health benefits

5.3.1 Core nutrients

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

5.3.2 Phytochemicals

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

5.4 Factors affecting health benefits

5.4.1 Bioavailability

See section 2.4.4 regarding the bioavailability of falcarinol.

5.5 Quotes and trivia

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

6 *Taro* (Colocasia esculenta)

6.1 Introduction

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

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

6.2 Composition

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

6.3 Core nutrients

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

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

6.3.1 Other phytochemicals

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

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

6.4 Health benefits

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

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

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

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

6.5 Quotes and trivia

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

7 *Yams* (Oxalis tuberosa)

7.1 *Introduction*

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

7.2 *Composition*

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

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

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

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

7.3 *Health benefits*

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

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

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

7.4 *Quotes and trivia*

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

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Appendices

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

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

T = trace

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

T = trace

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

T = trace

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

T = trace

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

T = trace

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

T = trace

Appendix II Activities of Vitamins and Minerals

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

Name	Major function
Vitamin A Retinol (animal origin) Carotenoids (plant origin, converted to retinol in the body) Note: Retinol Equivalents (RE) 1 RE =1 mcg retinol or 6 mcg beta-carotene 1IU = 0.3 mcg or 3.33 mcg = 1 mcg retinol = 1RE	Important for normal vision and eye health Involved in gene expression, embryonic development and growth and health of new cells Aids immune function May protect against epithelial cancers and atherosclerosis
Vitamin E A group of tocopherols and tocotrienols Alpha tocoferol most common and biologically active	Provides dietary support for heart, lungs, prostate, and digestive tract Reduces peroxidation of fatty acids Non-specific chain-breaking antioxidant May protect against atherosclerosis and some cancers
Vitamin K Occurs in various forms including phyllo- and menaquinone	Coenzyme in the synthesis of proteins Involved in blood clotting (prothrombin and other factors) and bone metabolism Involved in energy metabolism, especially carbohydrates May also be involved in calcium metabolism
Vitamin C Ascorbic acid	Neccesary for healthy connective tissues – tendons, ligaments, cartilage, wound healing and healthy teeth Assists in iron absorption A protective antioxidant – may protect against certain cancers Involved in hormone and neurotransmitter synthesis
Thiamin vitamin B_1 Aneurin	Coenzyme in the metabolism of carbohydrates and branched-chain amino acids Needed for nerve transmission Involved in formation of blood cells
Riboflavin vitamin B_2	Important for skin and eye health Coenzyme in numerous cellular redox reactions involved in energy metabolism, especially from fat and protein

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

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

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

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

Appendix III Chemical structures

Chemical structures of major phytochemicals in root vegetables and tubers

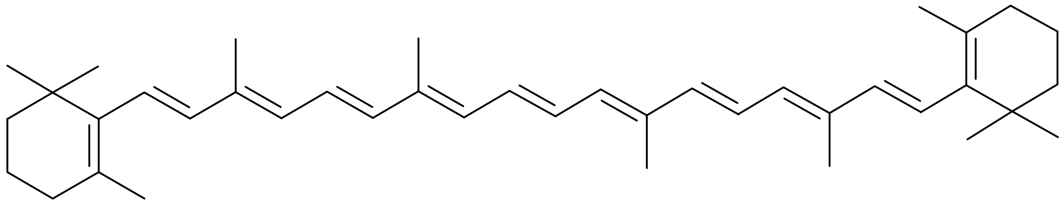

Figure 1: β-carotene

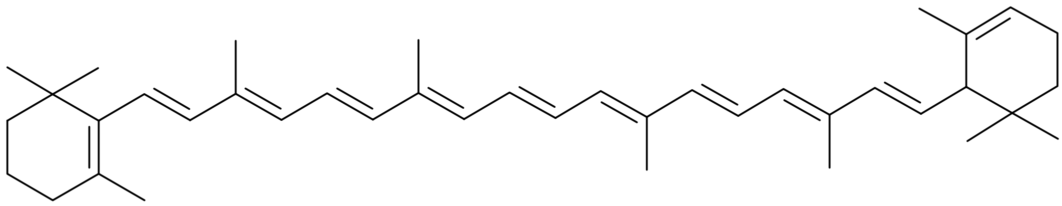

Figure 2: α-carotene

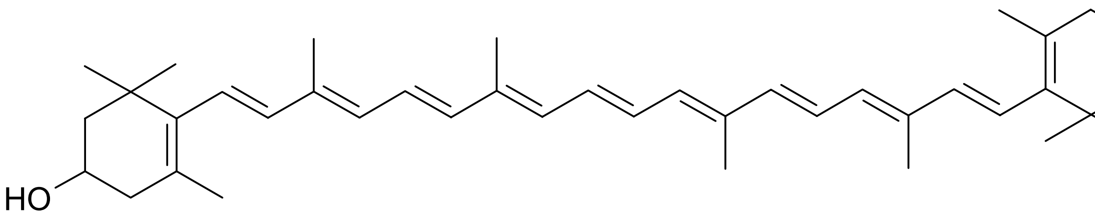

Figure 3: β-cryptoxanthin

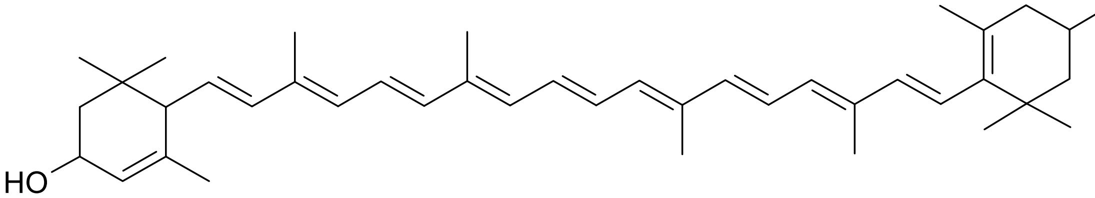

Figure 4: Lutein

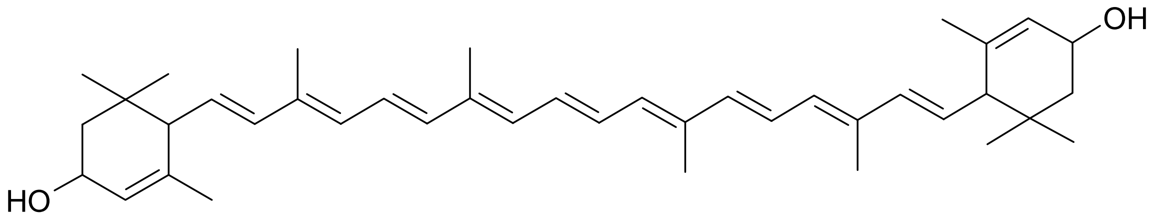

Figure 5: Zeaxanthin

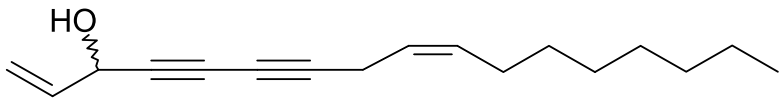

Figure 6: Falcarinol

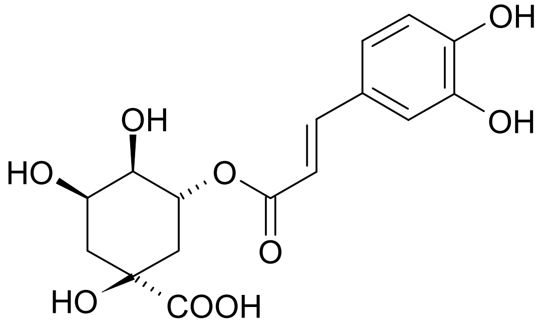

Figure 7: Chlorogenic acid

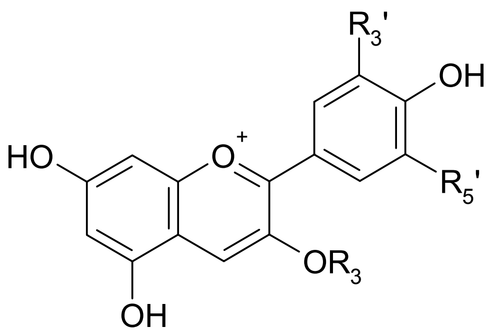

Figure 8: Basic anthocyanin

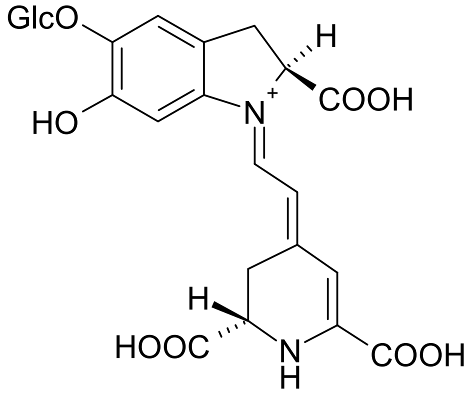

Figure 9: Betanin