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Nutrition & health qualities of potatoes – an update (2001–09)

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A report prepared for
Horticulture New Zealand

Copy 6 of 6

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Contents

1 Executive summary

This report describes the results of a literature review undertaken for Potatoes New Zealand to summarise current knowledge about the nutritional status and health benefits of potatoes. It builds on two earlier reviews, conducted in 2000 and 2001. There has been considerable new research since that time, with some on standard nutritional components, but a large amount of information has been published on phytochemicals and their antioxidant attributes, among other benefits.

Although the potato is considered a starchy food, it is also included in the category of vegetables by its micronutrient content. Potato tubers offer a range of nutritional benefits. They provide a substantial contribution to the daily supply of selected minerals, vitamins and phytochemicals, as well as carbohydrates and small amounts high quality protein. Potatoes have the highest satiety index of all plant foods tested.

There has been growing research on the health benefits of potatoes beyond basic nutrition. Most studied is antioxidant activity, but there is evidence for wider benefits including:

- Anti-carcinogenic
- Cholesterol-lowering
- Improving digestive health
- Prevention of heart disease
- Improvements in bone health
- Anti-inflammatory
- Anti-arthritis
- Anti-hepatotoxicity

Many of these benefits still have to be demonstrated in human clinical trials, but evidence from *in vitro* studies and animal trials is certainly very promising.

Alongside these positive aspects only a few adverse factors have been identified, including the existence of glycoalkaloids and acrylamide, but the right management and preparation can reduce these anti-nutritional factors substantially. Potatoes are often regarded as being fattening and having a high glycaemic index, and hence there is the implication that they contribute to diabetes and obesity. Evidence shows that it is not the potatoes themselves that are fattening but how they are prepared. Although potatoes by themselves may have a high glycaemic index, they are generally consumed as part of a meal and that decreases their impact considerably. In addition because potatoes contain a range of other nutrients besides carbohydrates they play an important role in the diet and have benefits above other carbohydrate sources such as pasta and rice. Unfortunately, many consumers have a limited and often biased knowledge about all the above facts. Education campaigns could help to promote nutritionally positive methods of preparation and thus increase the daily potato intake.

To maximise the nutrition and health benefits of potatoes the following factors should be considered:

- Chose small potatoes: small potatoes have more skin relative to flesh and many nutrients and phytochemicals are present in higher concentrations in the skin. Also small potatoes can be more easily cooked whole and this helps retain nutritional components.
- Select coloured cultivars: these have high contents of phenolics and contain anthocyanins, both of which have antioxidant activity. Coloured cultivars may also

have higher concentrations of some other nutrients, e.g. folate. In some studies coloured varieties have been shown to have other health benefits, such as prevention of metabolic diseases, anti-obesity and improving digestive health.

- Cook with the skin on: some nutrients and particularly the phytochemicals are present in much higher concentrations in the skin. In addition, keeping the skin on can help prevent loss of some nutrients during cooking.
- Avoid chopping potatoes: chopping potatoes increases the number of cut surfaces that can be oxidised and there are greater losses of nutrients due to leaching.
- Choose cooking methods such as baking & microwaving: these methods don’t use water and hence avoid loss of nutrients by leaching into the cooking water.
- Avoid green potatoes: the green is an indicator that glycoalkaloids may be present. Glycoalkaloids are considered toxic although there is still considerable debate about this and there is some evidence that glycoalkaloids may actually have health benefits. However, until there is more evidence it is best to avoid consuming green potatoes.
- Don’t add salt: to minimise the amount of sodium in the diet try not to add too much salt when cooking potatoes. However, the high potassium content of the potato will balance the sodium content of added salt.

Consumers have become increasingly aware of potential health benefits from diets rich in fruits and vegetables. While potato has not yet surfaced as a headline-grabber in this respect, there is increasing evidence that some genotypes may possess health attributes that warrant attention. This is particularly relevant, as potatoes are consumed much more regularly and in higher amounts than fruit and other vegetables that are often touted for their exceptionally high antioxidant activity. Plant breeders rely on germplasm biodiversity to advance their programmes and are also acutely aware of current marketing trends that relate to health attributes. In this regard there is considerable potential to increase the health benefits of potatoes further by breeding for increased nutrient and phytochemical content, particularly some minerals, such as zinc and iron, and antioxidants, such as phenolics and carotenoids.

2 Background

In 2000 a report was prepared for the Potato sector of Vegfed on the nutrition and health qualities of potatoes (Lister & Monro 2000). This was followed by an update of the literature the following year (Lister 2001a). The executive summaries of these two earlier reports are provided below. As a follow-up to these reports a further update of the literature from 2001 to date has been completed. This report summarises searches of the scientific literature since 2001 for information on the nutritional and health qualities of potatoes. In addition to general searches on POTATO* and NUTRITION or HUMAN HEALTH, specific searches were conducted on the following terms along with POTATO*:

- ANTIOXIDANT
- CARBOHYDRATE
- CAROTENOID
- COOKING
- FOLATE
- GLYCAEMIA/GLYCAEMIC
- GLYCOALKALOID
- MINERAL
- OBESITY
- PHENOLIC
- PROTEIN
- SATIETY
- VITAMIN

2.1 Executive summary of Lister & Monro (2000) report

This report describes the results of a literature review undertaken for the potato sector of Vegfed to describe the nutritional status and health benefits of potatoes. It highlights current knowledge and identifies some prospects for the future. It also explores the next generation of key attributes that may be used for product development and in marketing strategies. The key points are noted below.

- Potatoes are a vegetable whose nutritional value is underestimated. They are often believed to be a high energy food that provides little in the way of nutrients. However, potatoes are a considerably richer source of nutrients than of energy. In brief, potatoes are:
    - a source of several vitamins, especially vitamin C and some important B group vitamins,
    - rich in minerals such as potassium and iron,
    - a source of phenolics, compounds that may have an important role in health,
    - virtually free of fat, although they are easily turned into fatty foods,
    - almost free of soluble sugar,
    - of low energy density – they ‘fill you up’ without providing many calories,
    - a source of high quality protein, although they are deficient in the essential amino acid methionine,
    - readily digested but they also have a high water content so weight for weight there is a relatively low impact on blood sugar.
- On the other side of the ledger, potatoes may also contain glycoalkaloids (often found in green tubers) although the risk that they contain toxic levels is minimal.

- Despite potatoes already having a number of desirable nutritional qualities there is still considerable scope to improve the composition of potatoes in a number of areas. These improvements may be achieved through traditional plant breeding, genetic modification, and/or changes in agronomic and postharvest handling procedures. They include:
    - boosting nutritional quality by increasing the levels of essential amino acids, β-carotene (a precursor of vitamin A) or other antioxidants,
    - removing or limiting the levels of glycoalkaloids,
    - developing new cultivars that absorb less fat during frying,
    - using potatoes to produce genetically engineered vaccines and other high value pharmaceutical products,
    - developing novelty coloured potato products that have added health benefits.
- Initially new potato cultivars could be developed followed by new potato products tailored to meet specific nutritional requirements of certain sectors of the population.
- As new cultivars are developed with additional health benefits there will be a need to re-evaluate the potential of potato wastes to better utilise key components with the aim of improving human or animal health.

2.2 Executive summary of Lister (2001) report

The potato has recently been described as a phytochemical jewel box. Despite the growing pool of evidence for compounds within potato with health benefits (e.g. vitamins, antioxidants, resistant starch) the potato still sometimes comes under fire nutritionally. There is a growing trend with fad diets to cut out carbohydrates. There is a notion that high carbohydrate foods, such as potatoes, are fattening. Carbohydrates are an important nutritional component and provide energy for the body. However, potatoes do have one downside in that they have a high glycaemic index (GI), although on a weight for weight basis with other starchy foods (e.g. bread) they have a relatively low impact on blood glucose. As more nutritionists recommend low GI foods, one avenue is to develop potato products that have a low GI and another is to promote other health attributes of potatoes.

Health attributes of potatoes that could be promoted include:

- Vitamins: Potatoes are high in vitamin C and are a good source of vitamin B6.
- Micronutrients: Potatoes are rich in minerals such as potassium and iron and make an important contribution to daily copper intake.
- Resistant starch: Raw potato starch and some processed potatoes contain resistant starch, which may lower the risk of colorectal cancer and promote large bowel health.
- Antioxidants: Potatoes, and particularly potato peels, are a good source of antioxidants and may play a very important part in dietary antioxidant intake. Antioxidants may have a role in the prevention of various diseases associated with ageing (e.g. cancer, heart disease).

The value of vitamins and micronutrients is well founded and nutrient claims can be made for these. Research is ongoing to provide further evidence of the value of antioxidants and resistant starch in potatoes in disease prevention. However, initial results are promising.

3 Nutritional composition

As identified in earlier reports (Lister & Monro 2000; Lister 2001), and highlighted in Section 2, potatoes contain a range of valuable nutrients and phytochemicals. There has been considerable new research over the last 8 years, although there has been greater focus on the phytochemicals (see Section 4) rather than core nutrients because of the increasing awareness of their health benefits (see Section 5). Despite this there has been quite a bit of work on some nutrients, mainly vitamin C.

3.1 Carbohydrate

Carbohydrates make up the greatest proportion of the dry weight of potato tubers and are an important source of energy. Carbohydrates are present in the form of starch, sugars and non-starch polysaccharides (cell wall components, often termed dietary fibre). In recent years work on the carbohydrate content of potatoes has largely related to glycaemic impact and this is discussed in Section 5.3. Aside from this there has been a small amount of other research.

Some work has been conducted on changes in starch during storage of New Zealand potato cultivars (Singh et al. 2008a). Potato starch is an important part of many processed food products and is a raw material for industry. Starch occurs in a number of forms that differ in molecular structure and their susceptibility to digestion. Starch may be classified into digestible starch (DS) and resistant starch (RS). From a health perspective, susceptibility to digestion is important for several reasons and is discussed in Lister & Monro (2000). Singh et al. (2008a) analysed fresh tubers from four traditional Taewa (Maori potato) cultivars (Karuparera, Tutaekuri, Huakaroro and Moemoe) and one modern potato cultivar (Nadine) of New Zealand, stored at 4°C and 80-90% relative humidity for 6 months after harvest. Post-harvest storage of potatoes was observed to be an important factor affecting the morphological, physicochemical, thermal and rheological characteristics of starches from different cultivars. Starches isolated from all of the cultivars showed a general shift in granule size distribution to smaller granule size, changes in the granule surface and a decrease in solubility with increasing low temperature storage time. In contrast, thermal parameters and peak viscosities increased with storage time. The extent of the changes in starch properties during post-harvest storage differed between the cultivars. The results of this study may be useful in the selection of suitable storage times and cultivars with desirable starch characteristics for specific end-uses. These results may also have significance from a health point-of-view.

Another study examined the effect of a number of laboratory-scale pretreatments on the proportions of rapidly digested (RDS), slowly digested (SDS) and resistant starch (RS) in raw and cooked potato (Mishra et al. 2008). Potatoes of the variety Frisia were prepared in three states: raw, cooked, and cooked followed by a cold treatment (4°C, 2 days). In raw potato, very little RDS and SDS (< 5% total starch (TS)) were present, and the mechanical treatments of the potato did not affect the amounts of RDS and SDS. Cooking resulted in an almost complete conversion to RDS (> 95% TS) in freshly-cooked potato, but after post-cooking cold treatment much of the RDS transformed to SDS, which reached a maximum of about 45% TS. SDS formation was independent of the degree of tissue disruption after cooking, and was generally associated with formation of RS. However, freezing after cooking allowed SDS formation without prolonged cold treatment and with very little associated RS (SDS 35% and RS 4% of TS). Freeze-drying caused an increase in RS in most treatments of the cooked potatoes. The observed effects provided guidance for sample handling in potato research, but also suggested several approaches to the enrichment of SDS and/or RS, with a concurrent reduction in RDS, that could be used to improve the nutritional profile of potato products by decreasing RDS (lowered glycaemic impact), and increasing SDS (more sustained energy availability) and RS (prebiotic benefits).

3.2 Minerals

There are a number of important minerals that potatoes contain. Potatoes are a great source of potassium (Figure 1), especially in and under the skin. Minerals are an important part of a healthy diet. Nutrition professionals recommend that they be consumed as part of a balanced diet, primarily as fruits and vegetables, rather than in the form of dietary supplements. The recommended daily allowance for potassium is much higher than for other minerals, such as calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn). Potassium is required in relatively large amounts because it functions as an important electrolyte in the nervous system. Potassium is used to regulate heartbeat, conduct nerve impulses and contract muscles. Potassium also plays a role in osmoregulation. High levels of potassium can help to control high blood pressure (Adrogue & Madias 2007) and may decrease the risk of stroke (Ascherio et al. 1998, Ding & Mozaffarian 2006). Despite its importance for good health, many people, especially individuals with hypertension, do not get sufficient K in their diet (Anonymous 2005). In addition to potassium there are moderate quantities of other minerals including phosphorus, chlorine, sulphur and magnesium, along with some iron (iron from potatoes is more bioavailable than most plant sources (Fairweather-Tait 1981)).

The recent studies conducted have looked at variation in germplasm and also effects of processing on content on various minerals, mainly potassium, iron and zinc.

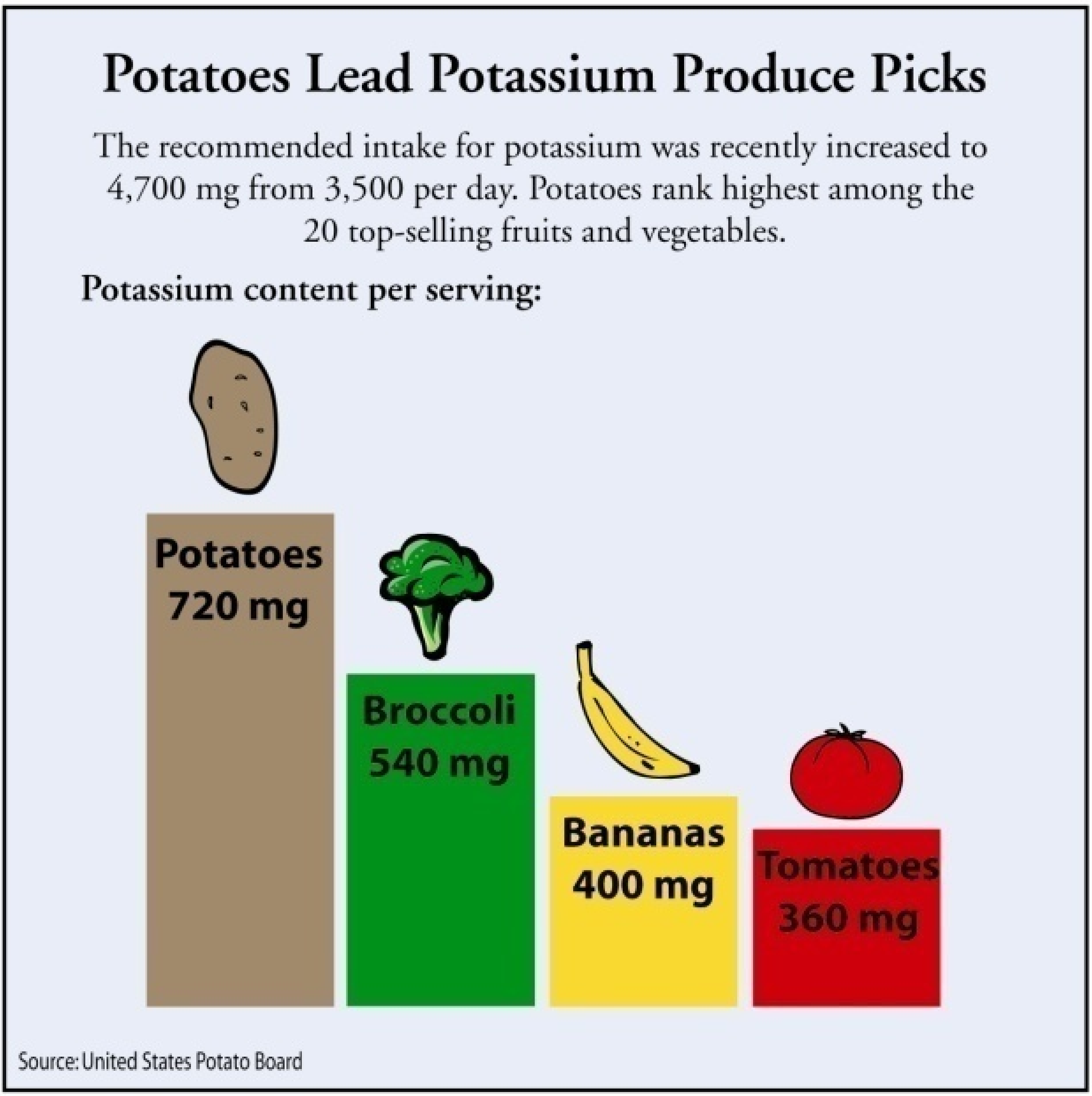


Figure 1: Potassium content of potatoes compared to other common dietary sources.

3.2.1 Cultivar variation

Most of the studies examining mineral content have looked at native South American germplasm. There has been once recent study examining varieties more typically grown in the USA. Burrowes & Ramer (2008) reported potassium contents of 295 to 448 mg/100 g in raw potatoes. A study has been undertaken to determine the effects of leaching and boiling on levels of potassium and other minerals in potato tubers (Bethke & Jansky 2008) – these changes are discussed in section 3.2.3. These researchers also looked at cultivar variation in mineral content. Significant differences in mineral levels were detected between cultivars (Figure 2), but they were too small to be nutritionally important.

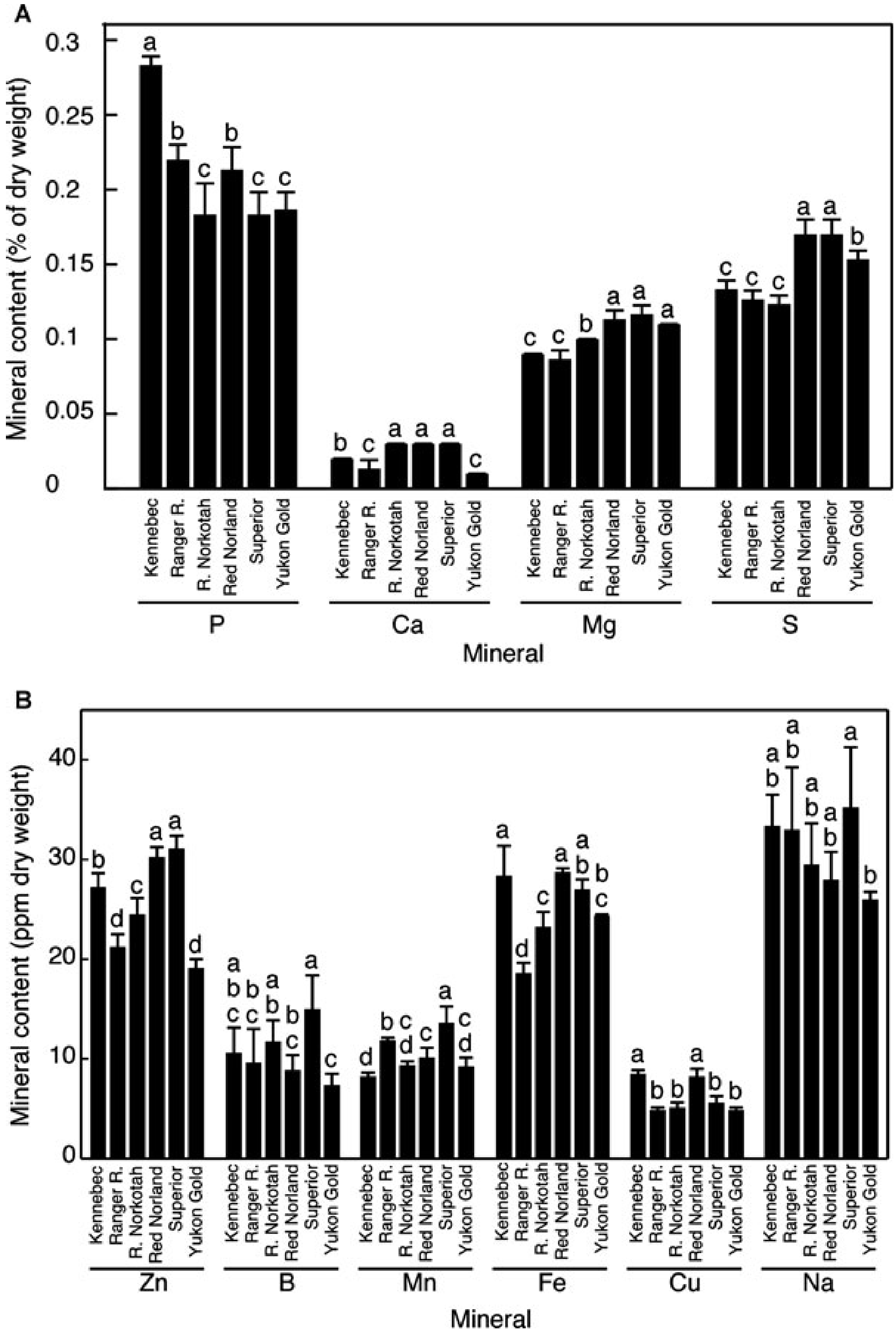
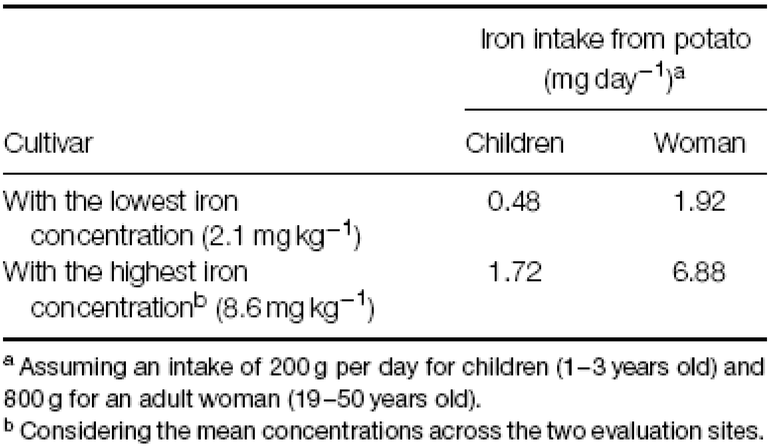


Figure 2: (A) Phophorus, calcium, magnesium and sulphur levels in tubers of six potato cultivars. (B) Zinc, boron, manganese, iron, copper and sodium levels in tubers of six potato cultivars. Different letters indicate significant differences between treatments for the same mineral (*P* = 0.05) (from Bethke & Jansky 2008).

Studies with a wide range of Andean potato germplasm have also revealed significant variation in content of other minerals. Burgos et al. (2007) determined iron and zinc concentrations in 49 native Andean potato varieties. Comparison of mineral concentrations of 37 of these germplasm accessions grown in two highland locations further revealed significant variation due to environments and genotype x environment interaction. Iron content of peeled tubers ranged from 0.22 to 1.05 mg/100 g and zinc from 0.22 to 0.56 mg/100 g. Iron and zinc concentrations were significantly and positively correlated on a fresh weight basis in each site. This variation indicates there is potential to considerably increase dietary contribution of these important minerals (Table 1). Andre et al. (2007a) also studied a genetically diverse sample of potato cultivars native to the Andes of South America that was obtained from a collection of nearly 1000 genotypes and was distinguished by microsatellite markers. From the collection, 74 landraces, representing at best the genetic diversity among potato germplasm, were analysed for iron, zinc and calcium as well as total phenolic, total carotenoid and total vitamin C contents (these three later components are discussed in the following sections). The iron content ranged from 29.87 to 157.96 µg/g dry weight (equates to 0.9-4 mg/100 g fresh weight), the zinc content from 12.6 to 28.83 µg/g DW (equates to 0.4-0.8 mg/100 g fresh weight) and the calcium content from 271.09 to 1092.93 µg/g DW (equates to 8.4-27.3 mg/100 g fresh weight). A strong relationship between iron and calcium contents was also found (r = 0.67). A similar positive and highly positive correlation between iron and calcium content was also observed in a study of the predominant potato cultivars cultivated in Uzbekistan (Carli & Khalikov 2008). In general, the calcium and zinc contents measured by Carli & Khalikov (2008) are similar to those reported by other authors for unpeeled raw potatoes (Rivero et al. 2003; USDA 2006; True et al. 1978). The iron contents reported by Carli & Khalikov (2008) are in the same range as those published by Anderson et al. (1999) (11.71-131.05 µg/g DW) for unpeeled potatoes from the United States and Canada, but the mean value from Andre 2007a (54.95 µg/g DW) is slightly higher than those reported in the food composition table of the U.S. Department of Agriculture (37.754 µg/g DW) (USDA 2006). Differences in metal concentrations could be explained by several factors. First of all, the potato sampling carried out can be of major importance. Indeed, the elemental distribution may vary within the potato tuber. There is evidence that some elements may be more concentrated in the potato skin relative to the potato flesh (Wszelaki et al. 2005). Secondly, variations might also exist between the stem end and the distal end of the potato tuber (Al-Saikhan 1995). Hence, the way in which samples are prepared may impact on the results on analysis and in some cases may be responsible for difference between studies.

Table 1: Iron intake provided by the potato cultivars with the lowest and highest iron concentration (from Burgos et al. 2007).



	Iron intake from potato (mg day^{-1})[a]	
Cultivar	Children	Woman
With the lowest iron concentration (2.1 mg kg^{-1})	0.48	1.92
With the highest iron concentration[b] (8.6 mg kg^{-1})	1.72	6.88

[a] Assuming an intake of 200 g per day for children (1–3 years old) and 800 g for an adult woman (19–50 years old).

[b] Considering the mean concentrations across the two evaluation sites.

Adequate dietary intake of iron, zinc and calcium is essential to human health. More than 2 billion people worldwide are anaemic, and this can be mainly attributed to iron deficiency. Iron deficiency during childhood and adolescence impairs physical and mental development. Dietary iron requirements depend on numerous factors, for example, host factors (e.g. age, sex, physiological status) and diet composition. Cereals, fruits and vegetables, such as potatoes, contain non-heme iron, which is poorly absorbed. Non-hemic iron absorption may be enhanced by ascorbic acid, meat and fish, whereas phytate, calcium and polyphenols may inhibit the absorption. However, there has been a study demonstrating that the iron in potatoes is more bioavailable than from other plant sources (Fairweather-Tait 1981). A high-iron potato tuber of 150 g of FW could contribute from 10 to 54.5% to the dietary iron intake (Andre et al. 2007a).

Zinc is an essential micronutrient, and deficiency has serious consequences for health. Zinc deficiency may cause stunted growth. Randomised controlled trials showed that zinc supplementation can reduce the severity of morbidity from common childhood infections (Black 1998; Umeta et al. 2000). In addition, zinc plays an important role in protecting cellular components from oxidation, and dietary deficiencies may enhance the risk of cancer (Ho 2004). Following the example of iron, zinc bioavailability depends on the overall composition of the diet. Dietary proteins may facilitate zinc absorption, whereas, in contrast, organic compounds such as phytate-forming stable and poorly soluble complexes with zinc can impair absorption. A high zinc potato cultivar could contribute from 8 to 37.5% to the dietary zinc intake.

Calcium plays a crucial role in providing rigidity to the skeleton and is involved in neuromuscular function, blood clotting and many metabolic processes. Calcium deficiency may lead to rachitism and osteomalacy and is involved in osteoporosis. Sodium and protein intakes are presumed to increase the calcium requirement. In contrast, vitamin D can promote calcium absorption. A single potato tuber from a high calcium genotype could contribute only 3.9% to the dietary calcium intake. In relation to potato production, increased calcium content in tubers may also be beneficial because it increases tuber quality and storability (Olsen et al. 1996).

In summary, certain potato cultivars should be regarded as a significant source of iron and zinc in the human diet. In contrast, potato cannot be considered as a relevant source of dietary calcium. The ranges of micronutrient concentrations reported in the above studies indicate ample genetic diversity that might be exploited in breeding programmes seeking to increase iron and zinc levels in human diets. There may also be potential for other minerals that have not yet been studied.

3.2.2 Effect of growing and storage practices

Growing practices may influence nutritional composition of crops. There is often concern that modern cultivars and/or agronomic practices have resulted in reduced nutritional value, including lower concentrations of mineral elements essential to human nutrition. In other crops increased yields are often associated with reduced concentrations of mineral elements in produce, and a number of recent studies have indicated that, when grown under identical conditions, the concentrations of several mineral elements are lower in genotypes yielding more grain or shoot biomass than in older, lower-yielding genotypes. A recent study on potatoes reports that the application of fertilisers influences tuber elemental composition in a complex manner, presumably as a consequence of soil chemistry and interactions between mineral elements within the plant (White et al. 2009). In addition, considerable variation exists between potato genotypes in the concentrations of mineral elements in their tubers, and like in other crops, higher-yielding genotypes occasionally have lower concentrations of some mineral elements in their edible tissues than lower-yielding genotypes.

Mourao et al. (2008) examined yield and quality of organic versus conventionally-grown potato crops. They found that although foliage nitrogen content was increased for conventional crops there was no difference in the nitrogen content of organic and conventional tubers. There were also no significant differences for potassium, calcium and magnesium. A study was conducted in Spain to determine the effect of compost, farmyard manure and/or chemical fertilisers on potato yield and tuber nutrient content (Alvarez et al. 2006). Although in some cases there was variation in yield, no clear behaviour of mineral concentrations in tubers (nitrogen, phosphorous, potassium, calcium, magnesium, copper, iron, manganese and zinc) was detected in relation to treatments.

The effect of minimal processing on the ascorbic acid content in five potato cultivars has also been studied (Tudela et al. 2002a). In contrast to what happens in almost all vegetables, fresh-cut potatoes can retain their initial vitamin C content after 6 days of air storage at 4°C, and even increase vitamin C, as demonstrated in 'Agria' fresh-cut potatoes from new-season tubers. These results may be important not only for consumers but also for potato processors who handle and process fresh-cut potatoes. Modified atmosphere packaging storage was found to reduce the vitamin C content of fresh-cut potatoes (36% in some cases). This is may be due to high CO_2 concentrations accumulating inside the packages. These results demonstrate that the low O_2 permeability plastic films commonly commercially used are inadequate for ascorbic acid preservation. Further research will be necessary to find the optimal atmospheric composition that may inhibit potato cut surface discoloration and maintain potato ascorbic acid content. Moreover, it would be of interest to determine how other storage techniques such as vacuum packaging may affect the ascorbic acid content of fresh-cut potatoes. In addition, ascorbic acid retention was better in fresh-cut potato strips stored at 4 °C, rather than frozen storage at −22 °C.

3.2.3 Influence of cooking/processing

Cooking is often associated with loss of nutrients, and different cooking methods may affect nutrients in different ways. Although most studies are conducted to try and determine the optimal cooking method to retain maximum levels of certain nutrients some studies with potatoes have been the reverse (although the learning from these studies also benefits those wanting to retain maximum nutrients). While most consumers benefit from high levels of potassium in potato tubers, individuals with compromised kidney function must minimise their potassium intake. A study was undertaken to determine the effects of leaching and boiling on levels of potassium and other minerals (boron, calcium, copper, iron, magnesium, manganese, phosphorus, sulphur, zinc) in potato tubers (Bethke & Jansky 2008). Leaching alone did not significantly reduce levels of potassium or other minerals in tubers. Boiling tuber cubes and shredded tubers decreased potassium levels by nearly 50% and 75%, respectively (Figure 3). Several other minerals are found in potato tubers, and their relative amounts after leaching and boiling followed the same general trend as potassium with respect to their retention (Figures 4 & 5). Phosphorus (P), magnesium (Mg), sulphur (S), zinc (Zn), manganese (Mn) and iron (Fe) levels were significantly reduced following the leaching plus boiling or boiling alone treatments. Calcium (Ca), boron (B), and copper (Cu) levels did not always follow this trend. Levels of Mg, S, Mn and Zn were all reduced by an average of 50% or more in the shredding and boiling treatment. Of these, the largest percentage loss was observed for Mg. Only 30% of the control Mg content was found in shredded and boiled samples (Figure 4). Cubed and boiled samples lost 35% of their total Mg. Zn and Mn are present in low amounts, but both showed significant, large losses of approximately 50% on average following shredding and boiling, and 25% to 30% following cubing and boiling (Figure 5). Individuals wishing to maximise the mineral nutrition benefits of consuming potatoes should boil them whole or bake, roast or microwave them. Those who must reduce potassium uptake for medical reasons should boil small pieces before consuming them.

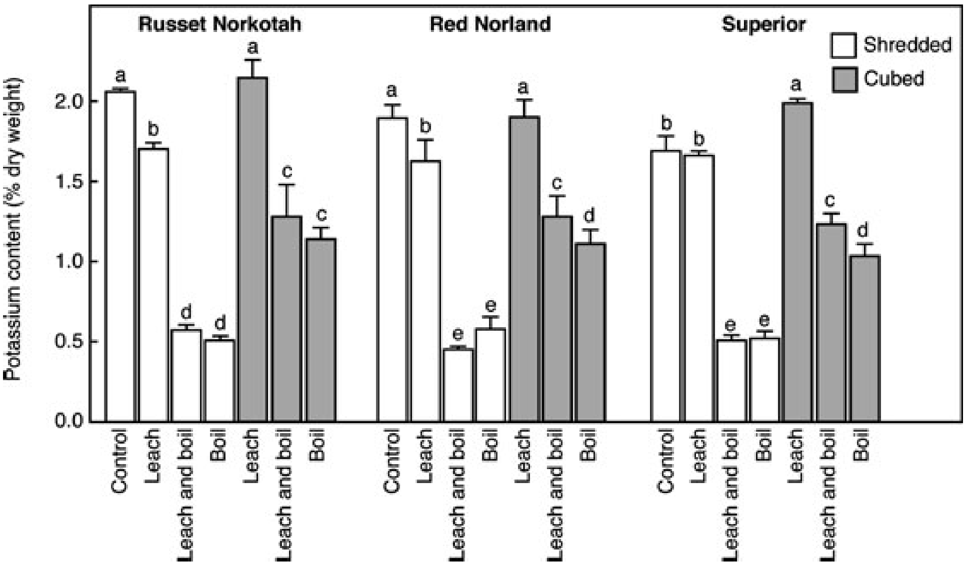


Figure 3: Potassium content remaining in tubers of three potato cultivars following cubing or shredding prior to leaching and/or boiling treatments. Different letters indicate significant differences between treatments (*P* = 0.05) (from Bethke & Jansky 2008).

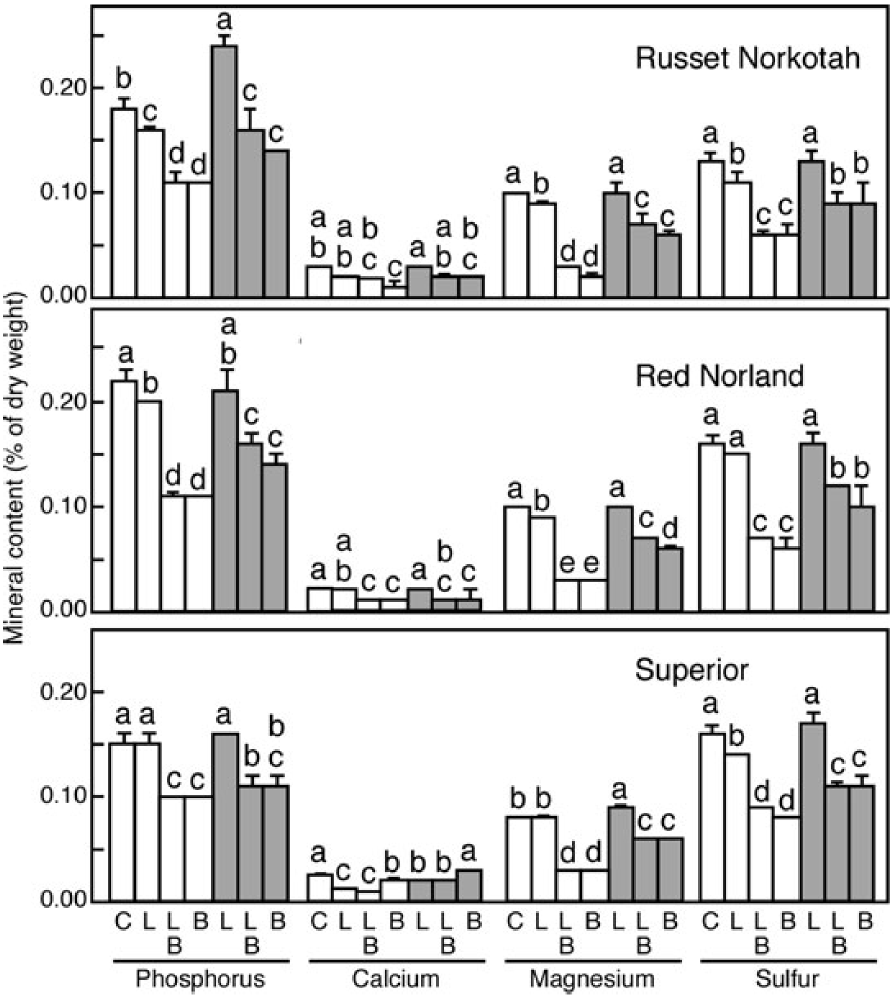


Figure 4: Phosphorus, calcium, magnesium and sulphur levels in three potato cultivars after leaching and boiling treatments of shredded and cubed potatoes. Different letters indicate significant differences between treatments for the same mineral (*P* = 0.05). Clear bars = shredded samples, grey bars = cubed samples, C = control, L = leached, LB = leached and boiled, B = boiled (from Bethke & Jansky 2008).

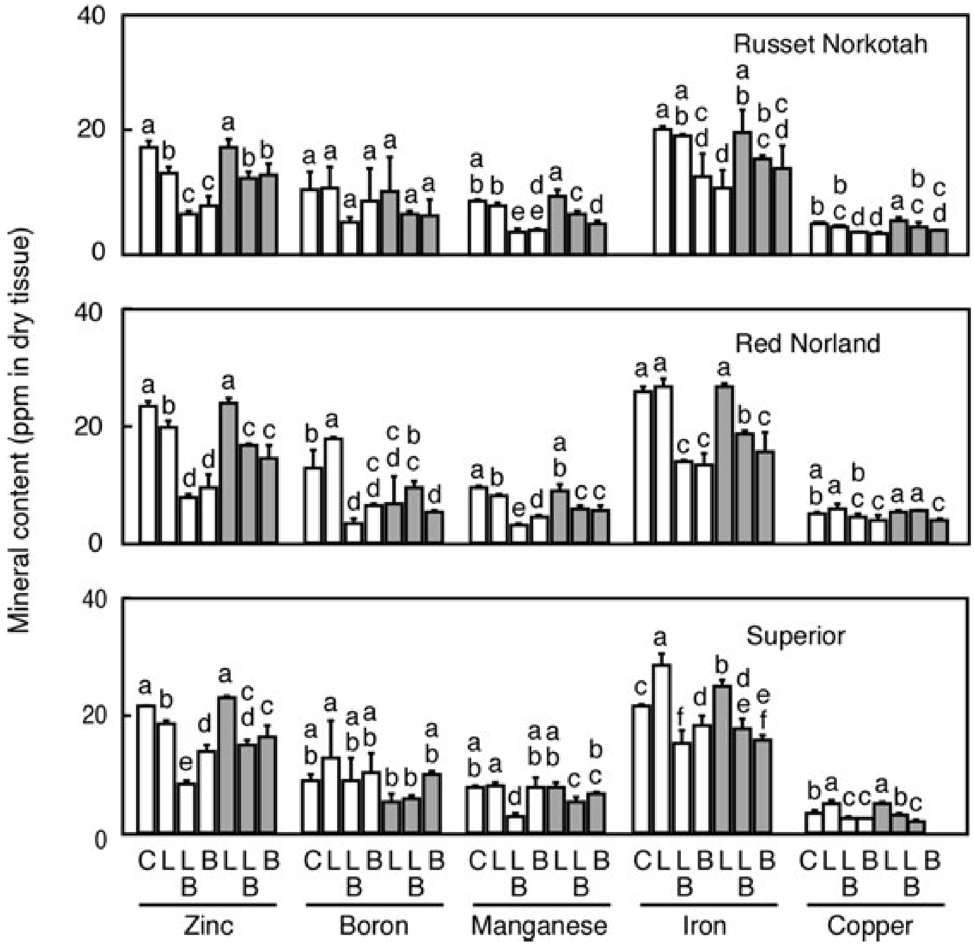
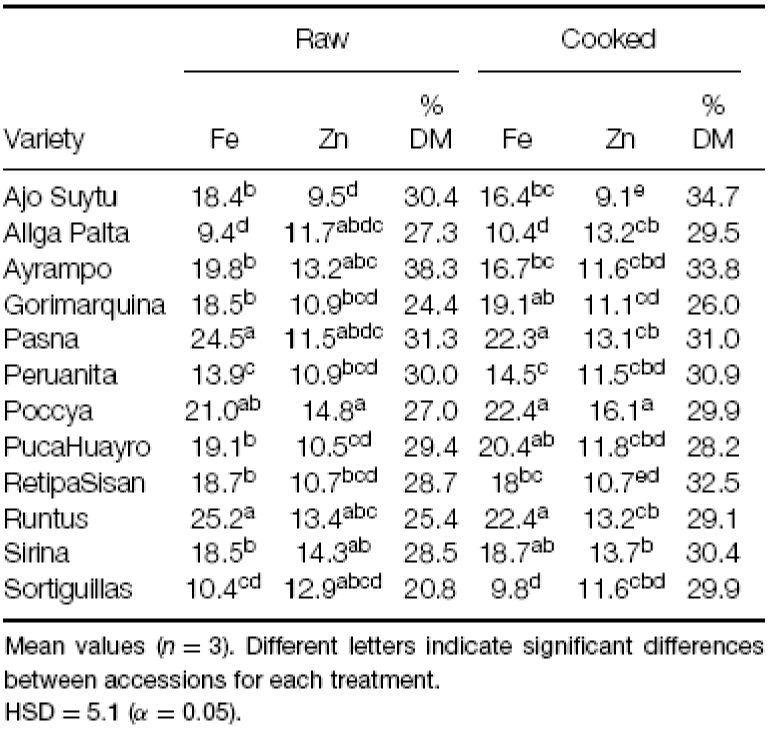


Figure 5: Zinc, boron, manganese, iron and copper levels in three potato cultivars after leaching and boiling treatments of shredded and cubed potatoes. Different letters indicate significant differences between treatments for the same mineral ($P = 0.05$). Clear bars = shredded samples, gray bars = cubed samples, C = control, L = leached, LB = leached and boiled, B = boiled (from Bethke & Jansky 2008).

Burrowes & Ramer (2008) have also analysed the potassium content of different varieties of raw potatoes and determined the amount of potassium that can be extracted or leached from raw potatoes by cooking. Six different varieties of fresh potatoes were examined and two different cooking methods (normal cooking [NC] and double cooking [DC]) were applied to each potato. Mean potassium content was highest in the purple Viking potato (448.1 mg/100 g) and lowest in the Idaho potato (295 mg/100 g). All raw potatoes had a mean potassium content of about 300 mg/100 g or greater. The DC method resulted in a greater reduction in potassium from raw potatoes than the NC method. All potatoes retained a mean potassium content greater than 200 mg/100 g, using the NC versus the DC method. The potassium content of the raw potatoes studied varied considerably, with most tubers retaining a moderate amount of potassium after leaching. This study showed that the DC method appears to be more effective than the NC method in leaching potassium from the potatoes studied.

Burgos et al. (2007) assessed iron and zinc retention during processing. Unlike the other studies, they boiled the potatoes unpeeled. When prepared this way there were no losses due to cooking (Table 2). These authors also examined the distribution of iron and zinc within the tuber, and the only significant differences found in iron content of peeled versus unpeeled potatoes could be attributed to contamination with soil iron, as confirmed by elevated levels of aluminium in the samples.

Table 2: Iron and zinc concentration (mg kg^{-1} DW) and dry matter percentage (% DM) of raw and cooked tubers of 12 predominant native potato varieties consumed in Huancavelica (from Burgos et al. 2007).



	Raw			Cooked		
Variety	Fe	Zn	% DM	Fe	Zn	% DM
Ajo Suytu	18.4^{b}	9.5^{d}	30.4	16.4^{bc}	9.1^{e}	34.7
Allga Palta	9.4^{d}	11.7^{abdc}	27.3	10.4^{d}	13.2^{cb}	29.5
Ayrampo	19.8^{b}	13.2^{abc}	38.3	16.7^{bc}	11.6^{cbd}	33.8
Gorimarquina	18.5^{b}	10.9^{bcd}	24.4	19.1^{ab}	11.1^{cd}	26.0
Pasna	24.5^{a}	11.5^{abdc}	31.3	22.3^{a}	13.1^{cb}	31.0
Peruanita	13.9^{c}	10.9^{bcd}	30.0	14.5^{c}	11.5^{cbd}	30.9
Poccya	21.0^{ab}	14.8^{a}	27.0	22.4^{a}	16.1^{a}	29.9
PucaHuayro	19.1^{b}	10.5^{cd}	29.4	20.4^{ab}	11.8^{cbd}	28.2
RetipaSisan	18.7^{b}	10.7^{bcd}	28.7	18^{bc}	10.7^{ed}	32.5
Runtus	25.2^{a}	13.4^{abc}	25.4	22.4^{a}	13.2^{cb}	29.1
Sirina	18.5^{b}	14.3^{ab}	28.5	18.7^{ab}	13.7^{b}	30.4
Sortiguillas	10.4^{cd}	12.9^{abcd}	20.8	9.8^{d}	11.6^{cbd}	29.9

Mean values ($n = 3$). Different letters indicate significant differences between accessions for each treatment.
HSD = 5.1 ($\alpha = 0.05$).

In a study of different cooking methods (e.g. frying, braising, boiling, deep frying and steaming), the method resulting in the greatest loss of minerals was boiling (Pan et al. 2007). Unfortunately, the details of this paper were unavailable as it is not written in English.

3.3 Vitamins

Potatoes are a source of several vitamins, especially vitamin C and some important B group vitamins (in particular vitamin B1/thiamine, B6 and folate). Most of the recent research has been on vitamin C.

3.3.1 Vitamin C (ascorbic acid)

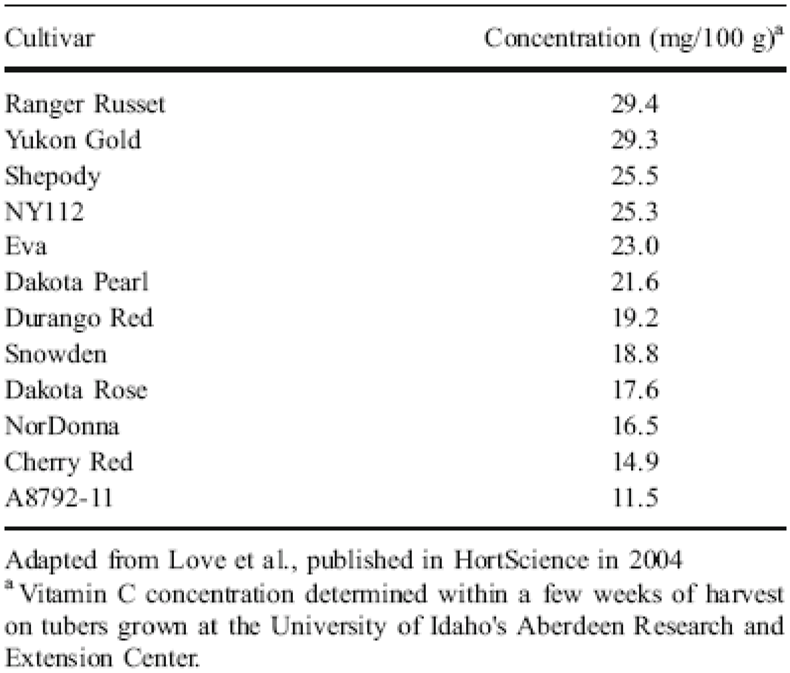
Vitamin C is a critical nutrient in the human diet. Its discovery resulted from efforts to understand and cure scurvy, a disease associated with vitamin C deficiency. Vitamin C is a water-soluble vitamin and its main component is ascorbic acid. However, dehydroascorbic acid has properties similar to vitamin C if it is reduced to ascorbic acid in the organism. In our earlier report we noted that the total amount of the two acids in potato tubers ranges from 1 to 54 mg/100 g fresh weight, although most frequently it is between 10 and 25 mg/100 g (Lister & Monro 2000).

Love & Pavek (2008) have recently reviewed the role potatoes can play as a primary food source of vitamin C. Ascorbic acid, better known as vitamin C, is a crucial nutrient in the human diet. It performs many physiological functions in its primary roles as an electron donor and antioxidant. Vitamin C has been directly linked to collagen formation, iron absorption, cancer prevention, immunomodulation and maintenance of normal nerve function. It is suspected to decrease the likelihood of strokes, cataracts, hypertension and lead toxicity. Vitamin C deficiency leads to a condition called scurvy, accompanied by a weakening of blood vessels, bones and connective tissues, hair and tooth loss, joint swelling and eventually death. Intake of vitamin C is considered inadequate, even among some parts of the population in developed countries where diet is not restricted, but more especially for at-risk populations in developing countries. Potatoes are an important worldwide source of vitamin C, contributing about 20% of the dietary intake in Europe (can be up to 50% in some people/populations). They are a vital source of vitamin C not only because of the relatively high content, but also because they can be stored, leading to consistent availability. Any improvement in the vitamin C content of potato products will have a beneficial impact on human nutrition. A three-pronged approach can be used to increase the vitamin C content of potatoes involving breeding, improved crop management and modification of cooking processes. Breeding has tremendous potential for increasing vitamin C content in tubers, as evidenced by research results in studies documenting germplasm variability and inheritance patterns.

Cultivar variation

One essential factor for the success of traditional breeding is access to genetic variability. Many studies, conducted as far back as 1945, have shown cultivar differences for tuber vitamin C content (various papers cited in Love & Pavek 2008). In 2004, Love et al. further explored the potential for genetic improvement by documenting the variability among breeding parents from North American breeding programs (Table 3). They found a four-fold difference in tuber vitamin C concentration between parental clones. Other studies of potato germplasm have also shown considerable variation in content. The total ascorbate content of potato tubers from 33 genotypes grown at three geographically diverse sites in Europe in each of 2 years was determined immediately post-harvest and after approximately 4 months of storage at 4°C (Dale et al. 2003). Statistically significant differences in total ascorbate concentration were observed between genotypes both at harvest and after storage (a summary of the results is shown in Table 4). There was a 2.4-fold difference between the lowest to highest levels at harvest and a 1.8-fold difference in levels following storage (note that analysis was conducted on freeze-dried samples). Levels post-storage exceeded some of the levels observed at harvest. Han et al. (2004) conducted a study of ascorbic acid levels within four Korean potato cultivars (Chaju, Sumi, Deso and Dejima). The ascorbic acid content for the four cultivars ranged from 16 to 46 mg/100 g FW. Andre et al. (2007a) have also studied a genetically diverse sample of potato cultivars native to the Andes of South America, which were analysed for a range of components including total vitamin C content. In this study, vitamin C content varied between 218 and 689 µg/g DW (equates to 5.6-15.2 mg/100 g FW. However, the analysis was conducted on freeze-dried material and this processing may have resulted in some losses of vitamin C, hence values may be underestimated).

Table 3: Vitamin C concentration in tubers of select potato parental germplasm (from Love & Pavek 2008).

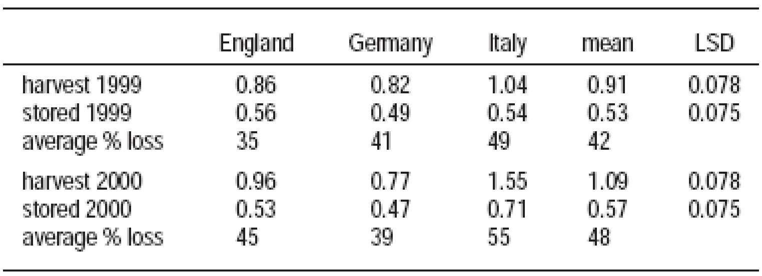


Cultivar	Concentration (mg/100 g)[a]
Ranger Russet	29.4
Yukon Gold	29.3
Shepody	25.5
NY112	25.3
Eva	23.0
Dakota Pearl	21.6
Durango Red	19.2
Snowden	18.8
Dakota Rose	17.6
NorDonna	16.5
Cherry Red	14.9
A8792-11	11.5

Adapted from Love et al., published in HortScience in 2004

[a] Vitamin C concentration determined within a few weeks of harvest on tubers grown at the University of Idaho's Aberdeen Research and Extension Center.

Table 4: Overall mean ascorbic acid values for years, sites and treatments (at harvest, stored) (from Dale et al. 2003).



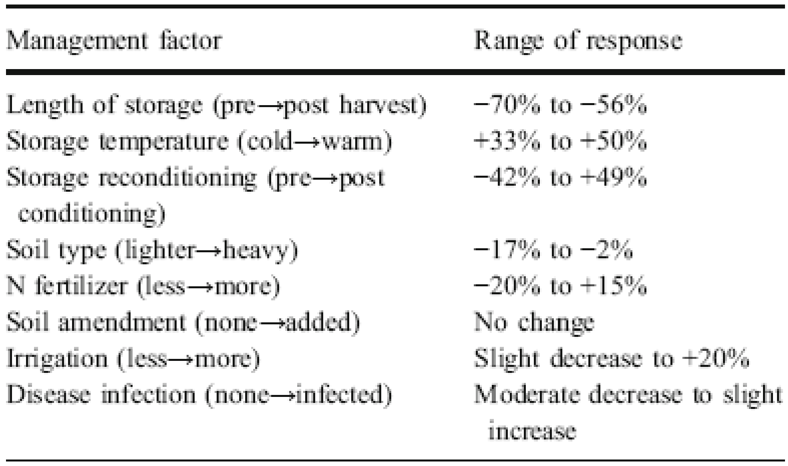
	England	Germany	Italy	mean	LSD
harvest 1999	0.86	0.82	1.04	0.91	0.078
stored 1999	0.56	0.49	0.54	0.53	0.075
average % loss	35	41	49	42	
harvest 2000	0.96	0.77	1.55	1.09	0.078
stored 2000	0.53	0.47	0.71	0.57	0.075
average % loss	45	39	55	48	

These significant genotype effects and the fact that in some studies there is consistency of observed levels across sites and years would indicate a degree of heritability that could be exploited within breeding programs to improve vitamin C content and hence the nutritive status.

Effect of growing and storage practices

A review of potato management studies reveals that length of storage period is the single major factor in determining vitamin C concentration in fresh tubers (Love & Pavek 2008; Table 5). Dale et al. (2003) also showed storage resulted in significant losses of vitamin C (Table 4). Other controllable crop management factors influence vitamin C but in many cases conflicting results cloud understanding of true impact. This suggests that we do not yet understand enough about the role of crop management on vitamin C concentration in tubers. Additional research is needed to separate causal factors from those that are associative. Recent research results indicate that vitamin C increases as a result of specific stresses on the growing crop. Potentially, investigating methods for applying selective stresses could give interesting results. Management research may define practices that will slow the natural decline that occurs near the end of field growth and storage, a response partially conditioned by plant stress.

Table 5: Range of documented vitamin C % response to various management variables (from Love & Pavek 2008).



Management factor	Range of response
Length of storage (pre→post harvest)	−70% to −56%
Storage temperature (cold→warm)	+33% to +50%
Storage reconditioning (pre→post conditioning)	−42% to +49%
Soil type (lighter→heavy)	−17% to −2%
N fertilizer (less→more)	−20% to +15%
Soil amendment (none→added)	No change
Irrigation (less→more)	Slight decrease to +20%
Disease infection (none→infected)	Moderate decrease to slight increase

The effect of conditions of locality, variety and fertilisation on ascorbic acid content in potato tubers was investigated in precise field trials in 2004 and 2005 in the Czech Republic (Hamouz et al. 2007a). The highest ascorbic acid content occurred in the region with the highest average temperature values during both experimental years (6.7 to 11.5% higher in ascorbic acid in comparison to other localities). Similarly, the effect of variety was also very significant; Marabel variety had the highest ascorbic acid content (20.7 mg/100 g FW) and exceeded seven other varieties by 15-49%. A negative effect on ascorbic acid content in tubers was observed in the case of an increased intensity of N fertilisation (at 180 kg N/ha, ascorbic acid was lower by 6.1% compared to 100 kg N/ha). On the contrary, a favourable effect was determined at increased levels of potassium and magnesium fertilisation (at 166 kg K/ha and 60 kg Mg/ha ascorbic acid increase was 6.2% higher compared to the levels of 108 kg K/ha and 30 kg Mg/ha).

In another recent study, Stushnoff et al. (2008) conducted investigations of antioxidant components (including vitamin C) for over 90 genotypes in the Colorado potato breeding program. Even though a few promising genotypes had higher vitamin C content than most at harvest, after several months storage all dropped to very near the same level (Figure 6). Apparently, any advantage from selecting high vitamin C genotypes at harvest was not preserved in a relative sense after 7 months in storage with the genotypes tested in this study.

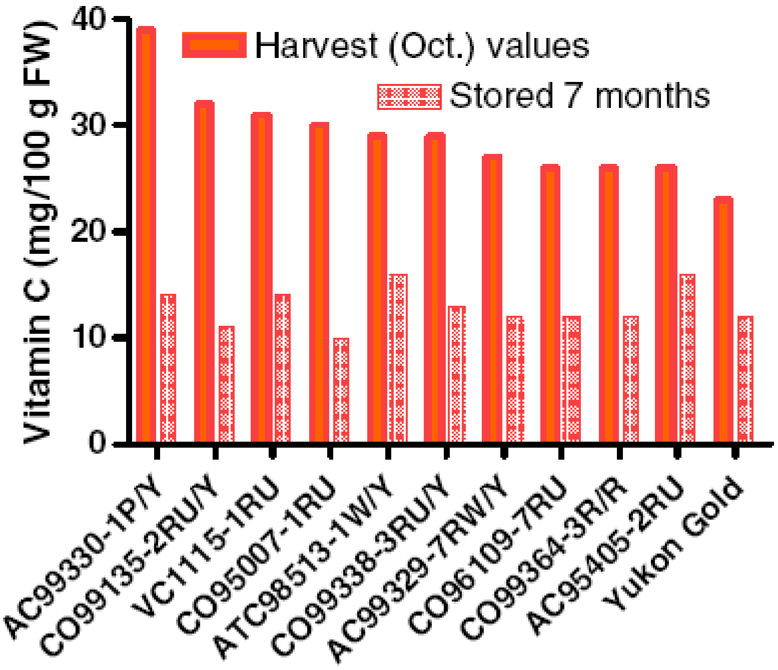
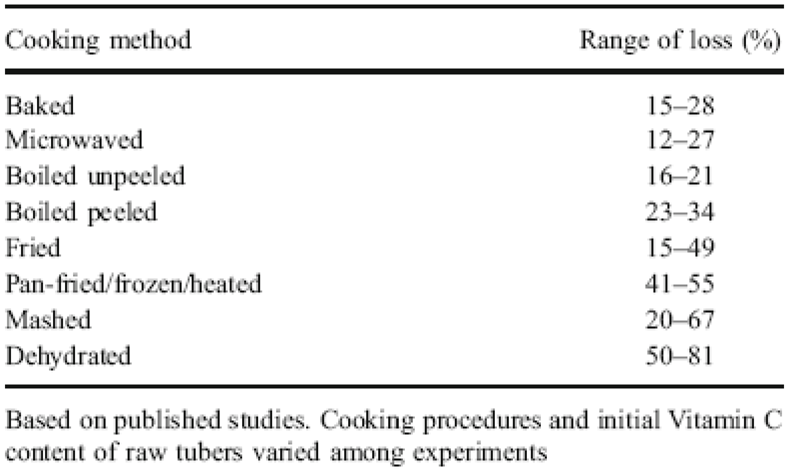


Figure 6: Vitamin C content of the top ten genotypes after 7 months of storage at 5±1°C (from Stushnoff et al. 2008).

Influence of cooking/processing

Research into cooking procedures may help reduce the oxidative and enzymatic degradation of vitamin C that results from exposure to moisture, heat, and air. The process of cooking destroys a portion of vitamin C present in raw potato tubers. Quantification of vitamin C losses has been the object of numerous researchers (various cited in Love & Pavek 2008). The range of reported losses from this review is summarised in Table 6.

Table 6: Range of Vitamin C losses in potatoes exposed to various cooking methods (from Love & Pavek 2008).



Cooking method	Range of loss (%)
Baked	15–28
Microwaved	12–27
Boiled unpeeled	16–21
Boiled peeled	23–34
Fried	15–49
Pan-fried/frozen/heated	41–55
Mashed	20–67
Dehydrated	50–81

Based on published studies. Cooking procedures and initial Vitamin C content of raw tubers varied among experiments

Other recent research has also shown losses of vitamin C can vary with cooking method. Stushnoff et al. (2008) reported that microwave cooking was less destructive of vitamin C than baking (Figure 7). With some genotypes, tubers that were microwave cooked within 1 month of harvest, differed very little from uncooked samples. Han et al.

(2004) examined the effects of cooking methods (baked, boiled, braised, fried, microwaved, pressure-cooked and sautéed potato slices) on three Korean potato cultivars. Losses of ascorbic acid observed during home-processing of three varieties with low (Dejima, 16 mg/100 g), intermediate (Sumi, 32 mg/100 g) and high (Chaju, 42 mg/100 g) ascorbic acid contents were as follows: boiling in water, 77-88%; boiling in water containing 1-3% NaCl, 61-79%; frying in oil, 55-79%; sautéing, 61-67%; pressure-cooking in water, 56-60%; braising, 50-63%; baking, 33-51%; and microwaving, 21-33%. Pan et al. (2007) found the retention of vitamin C was higher during braising than that during frying, boiling, deep frying and steaming. All the studies examined provided evidence that cooking method has a large influence on the amount of vitamin C available for consumption.

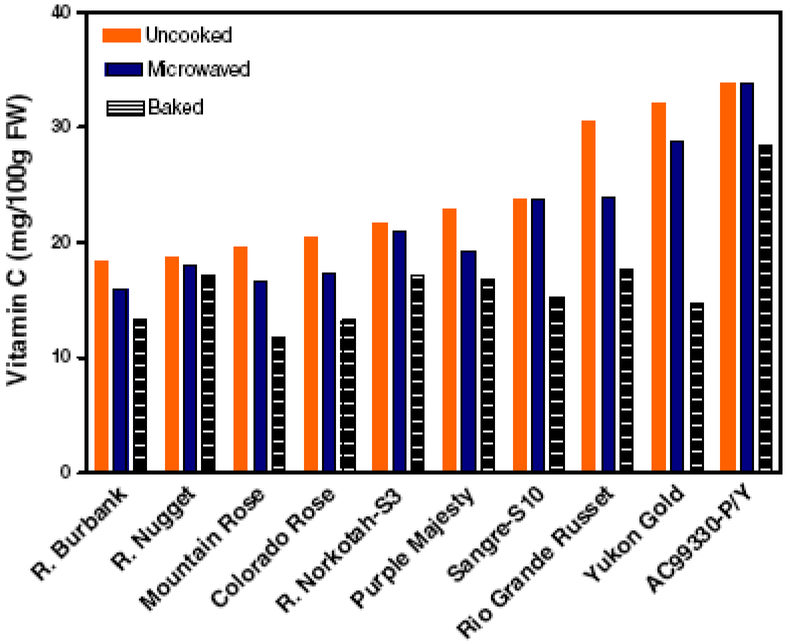


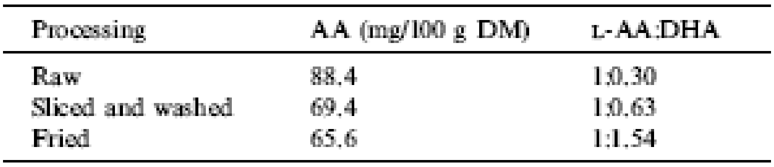
Figure 7: Vitamin C (mg/100 g FW) content of uncooked, microwave cooked (1.0 min/30 g tuber) and baked tubers (60 min at 170°C in foil) in the ten cultivars with the highest vitamin C content (from Stushnoff et al. 2008).

The fate of ascorbic acid during processing of French fries and potato chips has also been studied (Haase & Weber 2003). Both products still contained a significant amount of ascorbic acid, despite losses during processing (Tables 7 & 8). This effect depended on the variety being processed. The main reduction is ascorbic acid was after blanching (French fries) and washing (potato chips). A high concentration of dehydroascorbic acid was detected in processed potatoes, especially potato chips.

Table 7: Relationship between L-ascorbic acid and dehydroascorbic acid and total ascorbic acid content during French fry production (mean of three varieties) (from Haase & Weber 2003).

Processing	AA (mg/100 g DM)	L-AA:DHA
Raw	94.6	1:0.32
Cut	98.9	1:0.33
Blanched	69.7	1:1.04
Par-fried and frozen	54.6	1:0.62
End-fried	45.2	1:1.03

Table 8: Relationship between L-ascorbic acid and dehydroascorbic acid and total ascorbic acid content during potato chip production (mean of three varieties) (from Haase & Weber 2003).



Processing	AA (mg/100 g DM)	L-AA:DHA
Raw	88.4	1:0.30
Sliced and washed	69.4	1:0.63
Fried	65.6	1:1.54

Although much work has gone into documenting nutrient loss during cooking processes, little research has been completed with intent to modify cooking conditions. Modification of cooking parameters for existing products may reduce vitamin C breakdown. Such modifications could include increasing the dimensions of sliced products, reducing cooking time or temperature, steaming rather than boiling, or preparing products with the skin left intact (Love & Pavek 2008).

3.3.2 Vitamin E

Vitamin E is the collective term for eight structurally related tocochromanol compounds, four tocopherols (α, γ, β and δ) and four tocotrienols (α, γ, β and δ), which differ from one another based on the number and position of methyl groups on the chromanol ring. α-Tocopherol appears to be the most biologically active of these compounds in humans, and is the most powerful lipid-soluble antioxidant known (Schneider 2005). Evidence suggesting important roles for the other isomers, notably tocotrienols and γ-tocopherol, has recently emerged (Jiang et al. 2004; Kamal-Eldin & Appelqvist 1996). In addition to serving as a potent antioxidant,α-tocopherol has also been shown to act as a signalling molecule in muscle tissue (Ricciarelli et al. 1998). Humans and other animals are not capable of synthesising tocopherols or tocotrienols autonomously and must obtain them from their diet. Approximately 90% of children and adults in the United States do not consume the recommended amount of vitamin E (Drewel et al. 2006; Ahuja et al. 2004).

Typically the amounts of vitamin E (tocopherols) in potatoes are very low, making insignificant contribution to daily intake. However, the amounts of alpha-tocopherol found in Andean potato tubers, extended from 2.73 to 20.80 µg/g DW (roughly 68-520 µg/100 g FW; note these calculations are based on an estimated dry matter of 25%), and were clearly above the quantities generally reported for commercial varieties (Andre et al. 2007b).

In addition there has been investigation of the possibilities of increasing the vitamin E content of potato tubers by genetic modification (Crowell et al. 2008). In potato tubers, over-expression of a gene involved in tocopherol biosynthesis (p-hydroxyphenyl-pyruvate dioxygenase) resulted in a maximum 266% increase in α-tocopherol, and over-expression of another gene (homogentisate phytyltransferase) yielded a 106% increase. However, tubers from transgenic plants still accumulated approximately 10- and 100-fold less α-tocopherol than leaves or seeds, respectively. The results indicate that physiological and regulatory constraints may be the most limiting factors for tocopherol accumulation in potato tubers. Studying regulation and induction of tocopherol biosynthesis should reveal approaches to more effectively engineer crops with enhanced tocopherol content.

3.3.3 Folate

Potatoes can contribute around 10% of the required daily intake of folate. Optimal folate status may have a role in the prevention of cardiovascular disease via plasma homocysteine-lowering, and possibly in the prevention of certain cancers. However, the most compelling evidence for the benefit of optimal folate status is its link with the prevention of neural tube defects.

There has been limited study of folate in potatoes. Goyer & Navarre (2007) determined total folate concentrations of potato tubers from 67 cultivars, advanced breeding lines, or wild species. Folate concentrations varied from 521 to 1373 ng/g dry weight and were genotype and location dependent. Interestingly, the highest folate concentrations were mostly found in coloured-fleshed potatoes. Variations of folate concentrations within either coloured- or white-fleshed tubers were similar (~2-fold). Skin contained around 30% higher folate concentrations than flesh. Storage of tubers for 7 months generally led to an increase in folate contents (Goyer & Navarre 2007).

In general folate intake is strongly influenced by various methods of cooking that can degrade the natural forms of the vitamin in foods. However, the exact impact depends on the particular food(s) consumed. McKillop et al. (2002) determined the effect of different cooking methods on folate retention in various foods that contribute to folate intake in the UK diet. Compared with raw values, boiling of whole potatoes (skin and flesh) for 60 min did not result in a significant change in folate content (125.1 and 102.8 mμg/100g for raw and boiled potato respectively), nor was there any effect on folate retention whether or not skin was retained during boiling.

3.4 Protein/amino acids

The nutritional quality of a crop is not only dependent on its energy supply in the form of sugars/starch, but also on the amino acid composition of its storage proteins. Although potatoes are not particularly high in protein they are regarded as a source of high quality protein (Lister & Monro 2000). Despite this, potatoes are deficient in the sulphur containing amino acids, methionine and cysteine. Manipulation of the targeted amino acid biosynthesis can be a way to circumvent this problem. It has recently been shown that the cysteine content of potato tubers can be enhanced by genetic modification (Stiller et al. 2007; Stiller & Dancs 2008). The alterations observed had no effect on tuber yield and sprouting behaviour. Gas chromatography coupled to mass spectrometry showed that all amino acids other than cysteine were unaffected. How acceptable this approach is from a consumer viewpoint remains to be seen.

4 Phytochemical composition

The potato is regarded as an exceptionally high-yielding carbohydrate-rich crop and other notable features often cited are a high-quality protein and a significant level of vitamin C. Until recently other components have received little attention. Yet science is discovering that many of these plant secondary compounds may have a range of other health benefits (these are discussed further in section 5). Potato composition encompasses a highly diverse list of phenolic compounds (including flavonoids, such as flavonols and anthocyanins) and carotenoids. Many of these compounds are antioxidants, and the potato has only recently gained recognition for this class of phytonutrient benefit (Brown 2008). Diets rich in antioxidant flavonoids and carotenoids have been associated with a lower incidence of atherosclerotic heart disease, certain cancers, macular degeneration and severity of cataracts (Kruezer 2001; Cao et al. 1998a, 1999; Knekt et al. 1996; Hertog et al. 1993; Wang et al. 1999).

4.1 Phenolics

The chemistry, biochemistry and dietary role of potato polyphenols have been reviewed by Friedman (1997), and more recently Brown (2005) has reviewed the antioxidants in potatoes. It was reported that in potatoes the predominant phenolic compound is chlorogenic acid, which constitutes about 80% of the total phenolic acids. The tuber skin can contain much higher levels of phenolic compounds than the flesh. The predominant flavonoids are catechin and epicatechin. Red and purple potatoes derive their colour from anthocyanins. The skin alone may be pigmented, or the flesh may be partially or entirely pigmented. Red-fleshed potatoes have acylated glucosides of pelargonidin, while purple potatoes have, in addition, acylated glucosides of malvidin, petunidin, peonidin and delphinidin. Note that there are some inconsistencies in the concentrations of phenolics and flavonoids reported in the paper by Brown (2005) and hence they have not been stated here.

4.1.1 Cultivar variation

There has been considerable investigation into the phenolic levels and composition of a range of potato cultivars, particularly those from South America. Some key findings are:

- In the purple flesh Valfi cultivar, total phenolic content was higher by 74 to 141% in comparison to yellow flesh varieties (Hamouz et al. 2007b).
- Tubers of 38 native potato cultivars of different taxonomic groups from South America were analysed to determine antioxidant components and activity (Brown et al. 2007). Total anthocyanin ranged from zero to 23 mg cyanidin equivalents/100 g fresh weight (FW).
- The anthocyanin and phenolic contents of different purple- and red-fleshed potato genotypes ranged from 11 to 174 mg cyanidin-3-glucoside/100 g fresh weight and from 76 to 181 mg chlorogenic acid/100 g fresh weight, respectively (Reyes et al. 2005).
- Total phenolic content of a genetically diverse sample of potato cultivars native to the Andes of South America varied between 1.12 and 12.37 mg of gallic acid equiv/g DW (Andre et al. 2007a).
- Significant differences were found in total polyphenolic content between the yellow-fleshed cultivars Karin, Impala, Ditta and Saturna (Lachman et al. 2008). Significant differences between yellow and purple-fleshed potatoes were also found: the yellow-fleshed cultivars had an average of 2.96 g gallic acid equivalents (GAE) per kg DM, while the purple-fleshed cultivars had 4.68 g GAE per kg DM.

- A statistically significant difference was found in total phenolic content between yellow- and purple-fleshed potatoes from the Czech Republic (Sulc et al. 2008). Purple-fleshed cultivars showed 60% higher TP content than yellow-fleshed cultivars. Average total phenolic content in yellow-fleshed cultivars was 2.96 GAE (gallic acid mg/g DM) and in purple-fleshed cultivars 4.68 GAE was found.
- Investigations of antioxidant properties for over 90 genotypes were conducted to characterise antioxidant profiles for the Colorado potato breeding programme and to identify those genotypes especially rich in antioxidants (Stushnoff et al. 2008). In agreement with other studies, Stushnoff et al. (2008) found genotypes with red or purple flesh and skin had the highest gallic acid equivalent total phenolics content (Figure 8). Total phenolic levels in raw tubers varied from around 7 up to about 35 mg/g DW.

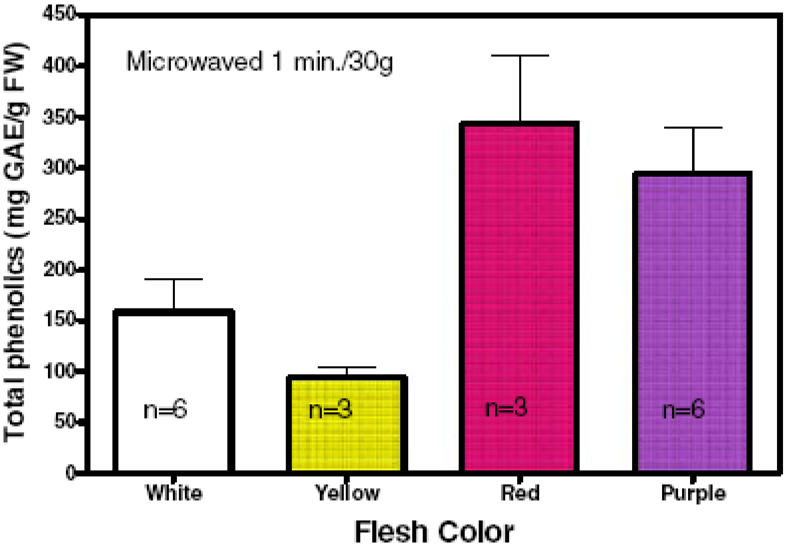
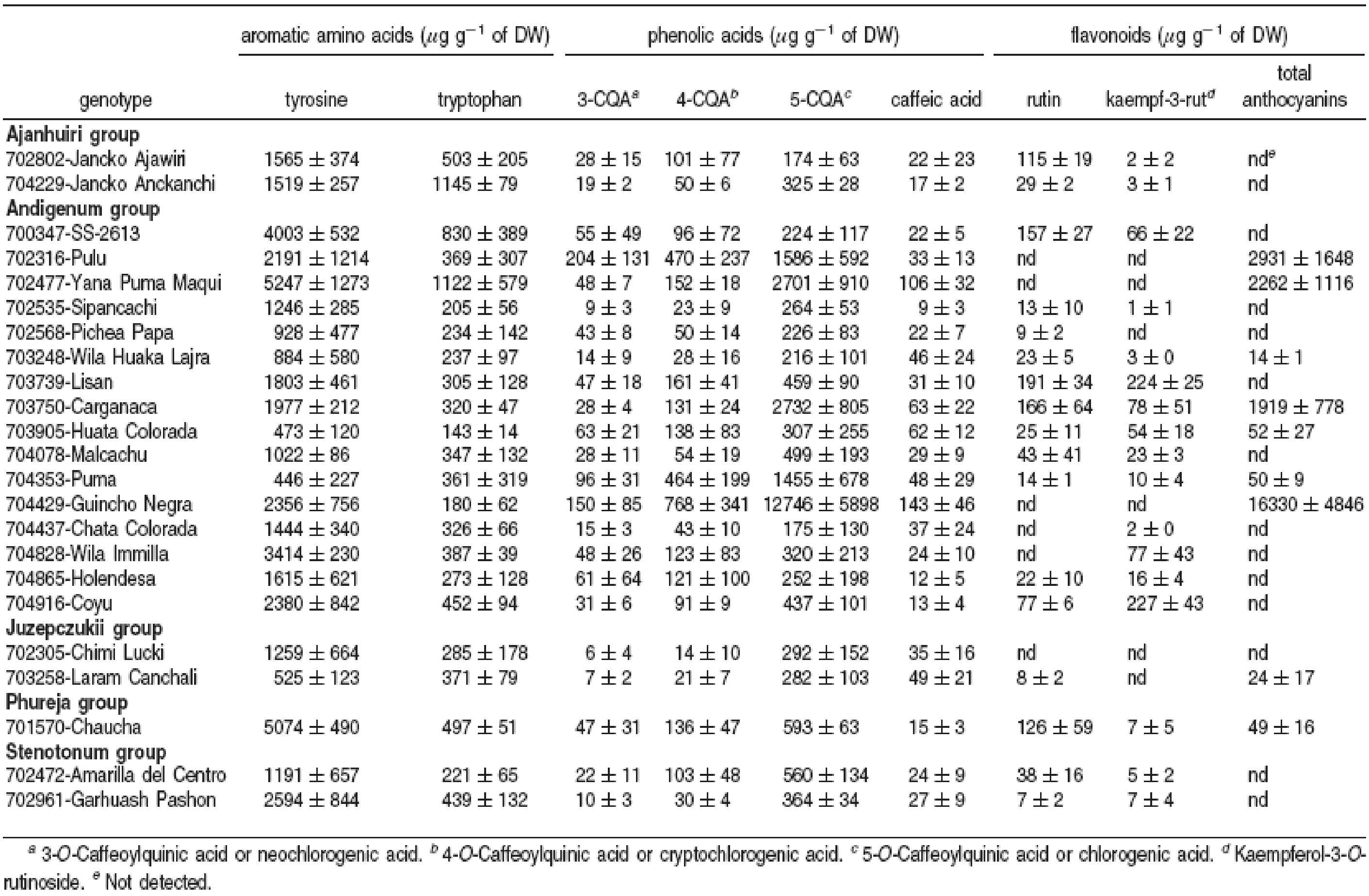


Figure 8: Gallic acid equivalent total phenolics (GAE mg/g FW ±SEM), measured during 2002 to 2005, in four tuber flesh colour categories (from Stushnoff et al. 2008).

- Studies of the heritability of clones containing high levels of anthocyanins were conducted (Brown et al. 2003). Total anthocyanin content ranged from 6.9 to 35 mg per 100 g fresh weight in the red-fleshed and 5.5 to 17.1 in the purple-fleshed clones. Red-fleshed clones contained predominantly acylated glycosides of pelargonidin, while the purple-fleshed clones contained predominantly acylated glycosides of petunidin and peonidin.
- Specialty (coloured) potato selections from the Texas Potato Variety Development Programme were analysed for total phenolics (Reddivari et al. 2007). Total phenolics ranged from 221 pg chlorogenic acid equivalents (CGAE)/g FW to 1252 pg CGAE/g FW. Chlorogenic acid accounted for 50 to 70% of total phenolics, followed by catechin, gallic acid and caffeic acid.
- The antioxidant profile of 23 native Andean potato cultivars has been investigated from a human nutrition perspective (Andre et al. 2007b). Chlorogenic acid was the predominant phenolic acid present in these potato cultivars, as has previously been reported in numerous studies on potato polyphenols. Other phenolics were quantified and there was considerable variation in all components (Table 9).

Table 9: Polyphenol contents in tubers of 23 native Andean cultivars. Values are the means for analyses of three samples from three different plants (from Andre et al. 2007b).



	aromatic amino acids (μg g^{-1} of DW)		phenolic acids (μg g^{-1} of DW)				flavonoids (μg g^{-1} of DW)		
genotype	tyrosine	tryptophan	3-CQA[a]	4-CQA[b]	5-CQA[c]	caffeic acid	rutin	kaempf-3-rut[d]	total anthocyanins
Ajanhuiri group									
702802-Jancko Ajawiri	1565 ± 374	503 ± 205	28 ± 15	101 ± 77	174 ± 63	22 ± 23	115 ± 19	2 ± 2	nd[e]
704229-Jancko Anckanchi	1519 ± 257	1145 ± 79	19 ± 2	50 ± 6	325 ± 28	17 ± 2	29 ± 2	3 ± 1	nd
Andigenum group									
700347-SS-2613	4003 ± 532	830 ± 389	55 ± 49	96 ± 72	224 ± 117	22 ± 5	157 ± 27	66 ± 22	nd
702316-Pulu	2191 ± 1214	369 ± 307	204 ± 131	470 ± 237	1586 ± 592	33 ± 13	nd	nd	2931 ± 1648
702477-Yana Puma Maqui	5247 ± 1273	1122 ± 579	48 ± 7	152 ± 18	2701 ± 910	106 ± 32	nd	nd	2262 ± 1116
702535-Sipancachi	1246 ± 285	205 ± 56	9 ± 3	23 ± 9	264 ± 53	9 ± 3	13 ± 10	1 ± 1	nd
702568-Pichea Papa	928 ± 477	234 ± 142	43 ± 8	50 ± 14	226 ± 83	22 ± 7	9 ± 2	nd	nd
703248-Wila Huaka Lajra	884 ± 580	237 ± 97	14 ± 9	28 ± 16	216 ± 101	46 ± 24	23 ± 5	3 ± 0	14 ± 1
703739-Lisan	1803 ± 461	305 ± 128	47 ± 18	161 ± 41	459 ± 90	31 ± 10	191 ± 34	224 ± 25	nd
703750-Carganaca	1977 ± 212	320 ± 47	28 ± 4	131 ± 24	2732 ± 805	63 ± 22	166 ± 64	78 ± 51	1919 ± 778
703905-Huata Colorada	473 ± 120	143 ± 14	63 ± 21	138 ± 83	307 ± 255	62 ± 12	25 ± 11	54 ± 18	52 ± 27
704078-Malcachu	1022 ± 86	347 ± 132	28 ± 11	54 ± 19	499 ± 193	29 ± 9	43 ± 41	23 ± 3	nd
704353-Puma	446 ± 227	361 ± 319	96 ± 31	464 ± 199	1455 ± 678	48 ± 29	14 ± 1	10 ± 4	50 ± 9
704429-Guincho Negra	2356 ± 756	180 ± 62	150 ± 85	768 ± 341	12746 ± 5898	143 ± 46	nd	nd	16330 ± 4846
704437-Chata Colorada	1444 ± 340	326 ± 66	15 ± 3	43 ± 10	175 ± 130	37 ± 24	nd	2 ± 0	nd
704828-Wila Immilla	3414 ± 230	387 ± 39	48 ± 26	123 ± 83	320 ± 213	24 ± 10	nd	77 ± 43	nd
704865-Holendesa	1615 ± 621	273 ± 128	61 ± 64	121 ± 100	252 ± 198	12 ± 5	22 ± 10	16 ± 4	nd
704916-Coyu	2380 ± 842	452 ± 94	31 ± 6	91 ± 9	437 ± 101	13 ± 4	77 ± 6	227 ± 43	nd
Juzepczukii group									
702305-Chimi Lucki	1259 ± 664	285 ± 178	6 ± 4	14 ± 10	292 ± 152	35 ± 16	nd	nd	nd
703258-Laram Canchali	525 ± 123	371 ± 79	7 ± 2	21 ± 7	282 ± 103	49 ± 21	8 ± 2	nd	24 ± 17
Phureja group									
701570-Chaucha	5074 ± 490	497 ± 51	47 ± 31	136 ± 47	593 ± 63	15 ± 3	126 ± 59	7 ± 5	49 ± 16
Stenotonum group									
702472-Amarilla del Centro	1191 ± 657	221 ± 65	22 ± 11	103 ± 48	560 ± 134	24 ± 9	38 ± 16	5 ± 2	nd
702961-Garhuash Pashon	2594 ± 844	439 ± 132	10 ± 3	30 ± 4	364 ± 34	27 ± 9	7 ± 2	7 ± 4	nd

[a] 3-*O*-Caffeoylquinic acid or neochlorogenic acid. [b] 4-*O*-Caffeoylquinic acid or cryptochlorogenic acid. [c] 5-*O*-Caffeoylquinic acid or chlorogenic acid. [d] Kaempferol-3-*O*-rutinoside. [e] Not detected.

As with other nutrients these data indicate that there is considerable potential for breeding potatoes with high levels of phenolics. Our studies with New Zealand potato varieties have also shown considerable variation in levels of phenolics (Lister 2001b). Coloured varieties contain anthocyanins but also in general have much higher levels of phenolics.

4.1.2 Effect of growing and storage practices

Beside cultivar effects, there are many different factors that can impact on the levels of phenolics in potatoes. Wounding purple-fleshed ‘All Blue’ increased phenolic content (Reyes & Cisneros-Zevallos 2003). Other studies have looked at location and environmental influences. In the years 2005 and 2006 the effect of site conditions, yellow and purple fleshed varieties and mineral fertilisation on the content of total polyphenols in potato tubers was investigated (Hamouz et al. 2007). In both years, total phenolic content was significantly higher (by 5.7 to 56.3%) at the Stachy locality than in other localities, and this was ascribed to apparently lower temperatures in the vegetation period at this locality of higher altitude. Total phenolic content was not significantly affected by fertilisation with mineral fertilisers.

In a study of antioxidant profiles for the Colorado potato breeding programme, various influences on phenolic levels were studied (Stushnoff et al. 2008). Environmental conditions produced year to year variation in total phenolics. In addition seven pigmented and one white-fleshed genotype, ‘Rio Grande Russet’, were analysed for total phenolics after 112 and 263 days storage in 2006 (Figure 9). ‘Adirondack Blue’ and CO97227-2P/PW had a sharp rise in total phenolics; others increased less, while 'Purple Valley' and 'Rio Grande Russet' changed little. While these data are from only 1 year's crop, similar increases in total phenolics of other pigmented genotypes have been detected in previous investigations by these researchers. Blessington et al. (2007) also found that the phenolic content of potatoes increased with storage. These researchers also investigated the effects of gamma irradiation (used to prevent sprouting during storage). Phenolic content increased more with storage than with gamma irradiation. However, levels of some phenolic compounds, such as quercetin, decreased with storage. Irradiation dose exerted a limited influence on phenolic contents, and interaction between storage time and irradiation dose was significant for phenolic content.

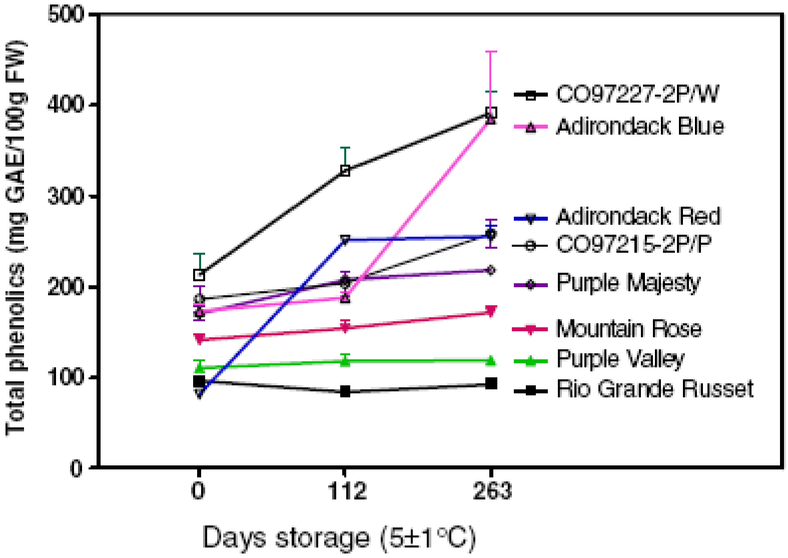


Figure 9: Total phenolics measured during storage of eight potato genotypes (from Stushnoff et al. 2008).

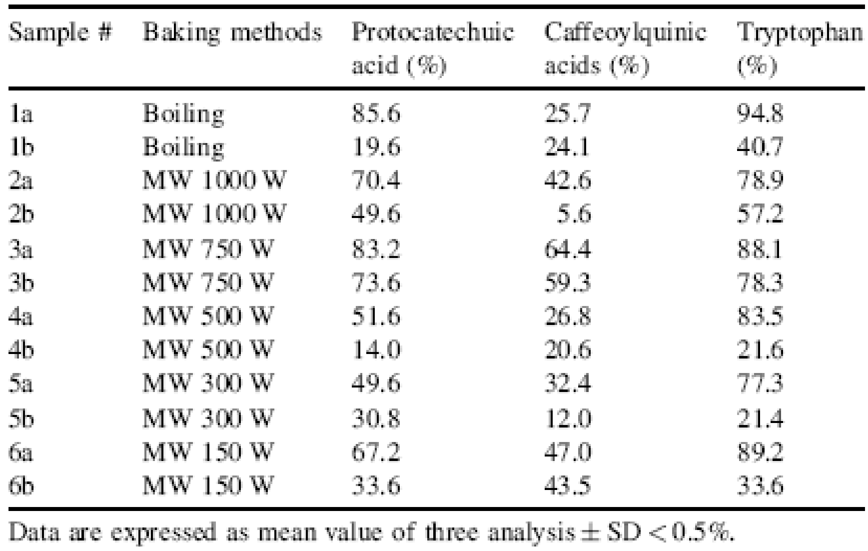
The antioxidant content and the antioxidant capacity of both hydrophilic and lipophilic antioxidant extracts from four "early potato" cultivars, grown in two different locations (Racale and Monteroni), were examined (Leo et al. 2008). An increase in both methanol/water (8:2 v/v) and phosphate buffer soluble (PBS) free phenols (70%) and bound phenols (28%) in the extracts from the cultivars grown at Racale compared to the Monteroni site was found. Examination of individual phenols revealed that chlorogenic acid and catechin were the major phenols present in potato tuber extracts; a moderate amount of caffeic acid and ferulic acid was also detected.

Increases in antioxidant properties during storage of potato genotypes may represent a positive marketing and nutrition feature.

4.1.3 Influence of cooking/processing

There has been limited study of the effects of cooking on phenolics in potatoes. Barba et al. (2008) examined the influence of different power input of microwave baking on the amount of protocatechuic acid, tryptophan, chlorogenic acid, neo-chlorogenic acid and cryptochlorogenic acid in peeled and unpeeled potatoes of the cultivar Agria (Table 10). These results were compared to analysis of boiled potatoes. Dielectric behaviour of the irradiated tubers was also investigated to examine whether microwave treatments are suitable for food processing in terms of nutritional factor preservation. The best result in terms of a short baking time and reduced water and phenolic losses was obtained using 500 W as the power input.

Table 10: Phenolic loss (%) in potato tubers (cv. Agria) after conventional boiling and microwave baking at different power levels (from Barba et al. 2008).



Sample #	Baking methods	Protocatechuic acid (%)	Caffeoylquinic acids (%)	Tryptophan (%)
1a	Boiling	85.6	25.7	94.8
1b	Boiling	19.6	24.1	40.7
2a	MW 1000 W	70.4	42.6	78.9
2b	MW 1000 W	49.6	5.6	57.2
3a	MW 750 W	83.2	64.4	88.1
3b	MW 750 W	73.6	59.3	78.3
4a	MW 500 W	51.6	26.8	83.5
4b	MW 500 W	14.0	20.6	21.6
5a	MW 300 W	49.6	32.4	77.3
5b	MW 300 W	30.8	12.0	21.4
6a	MW 150 W	67.2	47.0	89.2
6b	MW 150 W	33.6	43.5	33.6

Data are expressed as mean value of three analysis ± SD < 0.5%.

Stushnoff et al. (2008) also studied the effects of cooking on phenolic content. Baking at 170°C reduced total phenolic levels the most, while microwave cooking (1.0 min/30 g FW at 700 W full power), and boiling for 30 min reduced total phenolic levels the least. In another study, domestic cooking, such as boiling, microwaving and frying, induced a partial loss of the flavonols, which were retained in the range of 4-16 mg per serving (213 g). Steam-cooking resulted in the highest retention of caffeic acid derivatives and aromatic amino acids compared with the other cooking methods studied (Tudela et al. 2002b).

4.2 Carotenoids

Plant carotenoids are lipid soluble pigments that play key roles in numerous plant functions. They also play significant roles in the human diet by serving as precursors for vitamin A synthesis and by reducing the occurrence of certain diseases. Carotenoids are present in the flesh of all potatoes to varying degrees (Brown 2005). According to this review, the contents mentioned in the literature range from 50 to 100 μg/100 g fresh weight in white-fleshed varieties to 2,000 μg/100 g FW in deeply yellow to orange-fleshed cultivars. The carotenoids in potato are primarily lutein, zexanthin and violaxanthin, all of which are xanthophylls. There is just a trace of either alpha- or beta-carotene, meaning that potato is not a source of pro-vitamin A carotenes.

The carotenoids in potatoes have received less study than the phenolics, probably because they are present in lower amounts and in most cases are insignificant in a dietary context. However, there have been several recent studies looking at the variation in levels in of South American germplasm. Tubers of 38 native potato cultivars of different taxonomic groups from South America were analysed to determine various antioxidant components. Total carotenoids ranged from 38 to 2,020 μg zeaxanthin equivalents/100 g FW (Brown et al. 2007). Total carotenoids were higher than previously reported, suggesting that native cultivars of South America with high levels of total carotenoids and high lipophilic ORAC are a unique germplasm source for introgression of these traits into specific potato cultivars outside the center of origin. In a study of the antioxidant profile of 23 native Andean potato cultivars concentrations of the carotenoids, lutein and zeaxanthin, ranged from 1.12 to 17.69 μg/g DW and from 0 to 17.7 μg/g DW, with cultivars 704353 and 702472 showing the highest levels of lutein and zeaxanthin, respectively (Andre 2007b). Whereas beta-carotene is rarely reported in potato tubers, remarkable levels of this dietary provitamin A carotenoid were detected in 16 native varieties, ranging from 0.42 to 2.19 µg/g DW. Andre et al. (2007a) have also studied a genetically diverse sample of potato cultivars native to the Andes of South America obtained from a collection of nearly 1000 genotypes using microsatellite markers. From the collection, 74 landraces, representing at best the genetic diversity among potato germplasm, were analysed, and total carotenoid content was between 2.83 and 36.21 µg/g DW.

During storage of potatoes total carotenoid content determined via spectrophotometry decreased, while lutein content increased (Blessington et al. 2007). Irradiation dose exerted a limited influence on carotenoid content. The interaction between storage time and irradiation dose was not significant for carotenoid content. Overall, storage exerted a much greater influence on carotenoid content than did low-dose gamma irradiation.

Genetic modification has been shown to have the potential to increase the content of two health-promoting carotenoids, beta-carotene and lutein, in potato (Eck et al. 2007). However, the levels achieved to date were still not high enough to make a significant contribution to the human recommended dietary intake. In addition, whether or not this approach of genetic modification is acceptable to the consumer remains to be seen.

4.3 Glycoalkaloids

The Solanaceae plant family contains members that produce beneficial as well as potentially toxic compounds, both during growth and during postharvest marketing. These compounds include alkaloids and glycoalkaloids. Glycoalkaloids are secondary plant metabolites that at certain levels may be toxic to bacteria, fungi, viruses, insects, animals and humans. The potential human toxicity of glycoalkaloids has led to the establishment of guidelines limiting the glycoalkaloid content of new cultivars before they can be released for commercial use. Following harvest, the glycoalkaloid content can increase during storage and transportation and under the influence of light, heat, cutting, slicing, sprouting and exposure to phytopathogens. Although glycoalkaloids are perceived as potentially toxic, studies during the past 10 years suggest that they may also possess beneficial effects, depending on dose and conditions of use (Friedman 2006). Moreover, in addition to glycoalkaloids, potatoes contain other biologically active compounds (calystegine alkaloids, antioxidative phenolic compounds, chlorophyll, protease inhibitors, lectins, vitamins) as well as processing-induced browning compounds and acrylamide. These may affect the dietary roles of glycoalkaloids.

The two major glycoalkaloids in domestic potatoes are -chaconine and -solanine. The majority of glycoalkaloids in the potato tuber are located within the first 1 mm from the outside surface and decrease toward the centre of the tuber (Friedman et al. 2003; Kozukue et al. 1987). The major interest in potato glycoalkaloids is due to the fact that several papers have suggested that they may be toxic to humans. Guidelines limiting maximum levels of glycoalkaloids to 200 mg/kg of fresh weight of potatoes are designed to minimise overconsumption of high-glycoalkaloid potatoes. Because glycoalkaloids are present in all commercial potatoes to varying degrees, they are a widely consumed dietary secondary metabolite. For example, the daily per capita intake of glycoalkaloids from potatoes in the United Kingdom is estimated to be ~14 mg (Hopkins 1995). Although the glycoalkaloid concentration of most commercial potatoes is usually below a safety guideline of 200 mg/kg of fresh potatoes, the concentration can increase substantially on exposure of potatoes to light and as a result of mechanical injury (reviewed by Friedman & McDonald 1999). However, the levels of glycoalkaloids in potato can be controlled effectively by adopting appropriate post-harvest practices (Nema et al. 2008).

A recent study showed that oral consumption of mashed potatoes with a total glycoalkaloid content of ~200 mg/kg equivalent did not induce acute systemic effects in human volunteers (Mesinga et al. 2005). However, the safety of glycoalkaloids for humans is still being debated (Friedman et al. 1997, 2003, 2005; Korpan et al. 2004; Rietjens et al. 2005; Smith et al. 1996). It has more recently been discovered that there is synergism between α-chaconine and α-solanine in inducing both adverse and beneficial effects (Friedman & McDonald 2005; Friedman et al. 2003a &b; Rayburn et al. 1995; Roddick et al. 1988). Because of synergy, it may not be possible to predict the toxicity of a mixture of the two glycoalkaloids using the results of the individual compounds or of mixtures of differing ratios present in different potato varieties. Mixtures can vary in their adverse effects depending on the ratio used. Glycoalkaloids may be either synergistic or additive at one concentration ratio, whereas the interactions may differ at others.

Glycoalkaloids may also have beneficial effects:

- Potential cholesterol-lowering effect (Roddick 1979)
- Antiallergic, antipyretic and anti-inflammatory effects (Choi & Koo 2005; Delporte et al. 1998; Golubeva 1966).
- Glycemic effects in rats (Sato 1967).
- Antibiotic activities against pathogenic bacteria, viruses, protozoa and fungi (Paquin & Lachance 1964; Thorne et al. 1985; Ikeda et al. 2000; Chataing et al. 1999; Giron et al. 1988; Chataing et al. 1998; Doan & Davidson 2000).
- Destruction of human cancer cells (Lee et al. 2004; Friedman et al. 2005).

More on the anticarginogenic effects of glycoalkaloids is covered in Section 5.2.

5 Health benefits

When we completed our last reports (Lister & Monro 2000; Lister 2001) there had been relatively little study of the health benefits of potatoes. There were only a handful of papers that had examined antioxidant activity and most research was focussed on the negative aspects (e.g. GI and glycoalkaloids). Since that time there has been a diversity of research on the health benefits of potatoes and particularly their antioxidant activity. Consumers have become increasingly aware of potential health benefits from diets rich in fruits and vegetables. While potato has not yet surfaced as a headline-grabber in this respect, there is increasing evidence that some genotypes may possess health attributes in addition to their nutritional value that warrant attention. Plant breeders rely on germplasm biodiversity to advance their programmes and are also acutely aware of current marketing trends that relate to health attributes.

5.1 Antioxidants

During the last couple of decades potato has received increasing attention, including a comprehensive review by Friedman (1997), as an important source of secondary metabolites and antioxidant compounds. Al-Saikhan et al. (1995) reported on cultivar differences and different antioxidant components, including chlorogenic acid, glutathione, quercetin and patatin. More recently Brown et al. (2003) examined potential for breeding high antioxidant potatoes based on carotenoids and phenolic anthocyanins. Antioxidant activity has also been detected from the patatin family of glycoproteins found only in potato (Liu et al. 2003). For example, patatin protein hydrosylate from potato peels suppressed oxidation of beef patties (Mansour & Khalil 2000; Wang & Xiong 2005) and from potato peel waste retarded oxidation in radiation-processed lamb meat (Kanatt et al. 2005).

There have been numerous studies of the antioxidant activity of potatoes. Potatoes are a significant antioxidant source in human nutrition (Lachman et al. 2005). The main potato antioxidants are polyphenols, L-ascorbic acid, carotenoids, tocopherols, alpha-lipoic acid and selenium. As noted earlier, major phenolic constituents in potatoes are amino acid L-tyrosine, and polyphenolic antioxidants scopolin and caffeic, chlorogenic, cryptochlorogenic and ferulic acids. Red and purple potatoes contain anthocyanins acylated with hydroxycinnamic acids (such as ferulic and caffeic acid). Pigmented potatoes show a higher antioxidant potential than white-flesh potatoes. Red potato tubers contain glycosides of pelargonidin and peonidin, while purple potatoes contain glycosides of malvidin and petunidin. New red- and purple-flesh potato varieties are being introduced due to their higher antioxidant contents and their use in food and non-food industries.

Brown (2005) also conducted a review of the antioxidants in potatoes. In potatoes with total carotenoids ranging from 35 to 795 µg/100 g FW, the lipophilic extract of potato flesh presented oxygen radical absorbance capacity (ORAC) values ranging from 4.6 to 15.3 nmoles alpha-tocopherol equivalents per 100 g FW. The hydrophilic antioxidant activity of solidly pigmented red or purple potatoes is comparable to Brussels sprouts or spinach. In red and purple potatoes with solidly pigmented flesh that have levels of total anthocyanin ranging from 9 to 38 mg per 100 g FW, ORAC ranged from 7.6 and 14.2 µmole/g FW of Trolox equivalents. Potato contains on average 20 mg/100 g FW of vitamin C, which may account for up to 13% of the total antioxidant capacity. Potatoes should be considered to be in the category of vegetables that may have a high antioxidant capacity depending on the flesh composition.

However, looking at all the published data the antioxidant activity of potatoes would generally appear unremarkable when compared with fruits and other vegetables. Our studies have looked at comparisons between potatoes and other common vegetables, both on an equal weight basis and related to the amount consumed (Lister unpublished results). Typically comparisons of antioxidant activity between different vegetables are made on an equal weight basis (Figure 10). In this case a typical white-fleshed potato cultivar ranks poorly compared with asparagus, kumara and watercress, for example. However, the purple-fleshed Purple Heart potato performs quite well. But it is more important to factor in the amount of a vegetable consumed and how often we eat them as part of our normal diet. Figure 11 shows the contribution various vegetables make to our daily antioxidant intake. Because potatoes are consumed much more frequently and typically in larger quantities than other vegetables they are actually a very important source of dietary antioxidants.

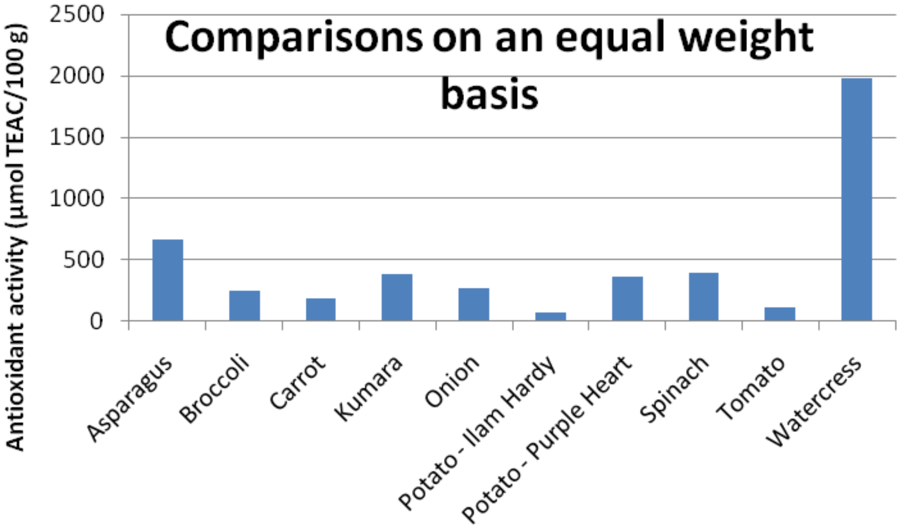


Figure 10: Comparison of the antioxidant activity of potatoes with other common vegetables on an equal weight basis.

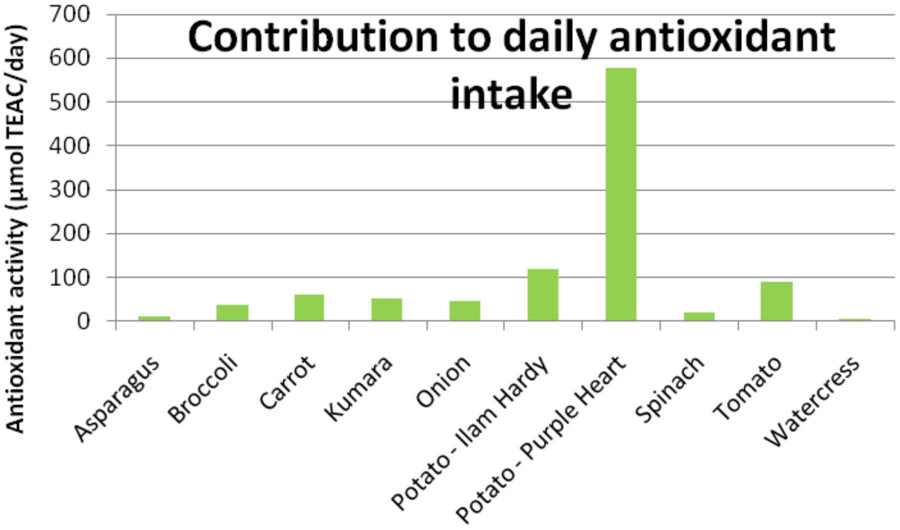


Figure 11: Comparison of the antioxidant activity of potatoes with other common vegetables on the basis of amounts typically consumed in the diet.

5.1.1 Cultivar variation and influence of colour

There has been considerable study looking at variation in antioxidant activity in different potato cultivars:

- A genetically diverse sample of potato cultivars native to the Andes of South America was obtained from a collection of nearly 1000 genotypes using microsatellite markers (Andre et al. 2007a). This collection of 74 landraces, representing at best the genetic diversity among potato germplasm, was analysed for various components (as discussed in Section 3), as well as the hydrophilic antioxidant capacity measured using the oxygen radical absorbance capacity (ORAC) assay. The range of hydrophilic ORAC values was 28.25-250.67 µmol of Trolox equiv/g DW. The hydrophilic antioxidant capacity and the total phenolic content were highly and positively correlated (r = 0.91).
- Investigations of antioxidant properties for over 90 genotypes were conducted to characterise antioxidant profiles for the Colorado potato breeding programme and to identify those genotypes especially rich in antioxidants (Stushnoff et al. 2008). There were several fold differences in antioxidant activity between the cultivars examined (Figure 12).

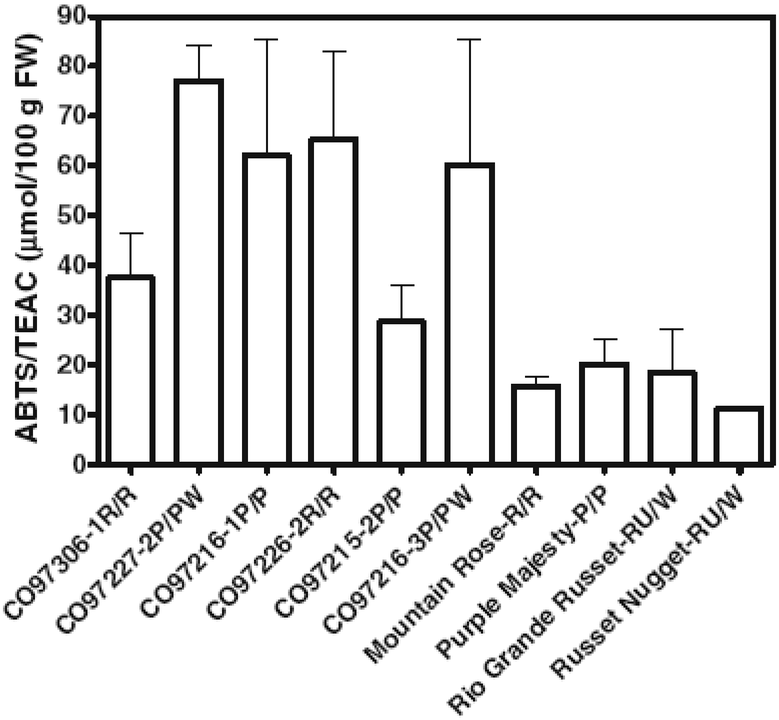


Figure 12: Radical scavenging capacity based on 2,2’-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), Trolox equivalent antioxidant capacity (TEAC), µM/100 g FW in microwaved and freeze-dried samples from 2002, 2003 and 2004. (R/R), (P/PW), (P/P), (RU/W) designate: red, purple, purple + white, russet, and white skin/tuber tissues (from Stushnoff et al. 2008).

- Significant differences in antioxidant activity between the yellow and purple-fleshed cultivars were determined (Lachman et al. 2008). Yellow-fleshed potatoes contained an average of 139.3 mg equivalents of ascorbic acid (EAA)/kg DM while purple-fleshed had 332.3 mg EAA/kg DM. There were also differences between the purple-fleshed cultivars Valfi (298 mg EAA/kg DM) and Violette (366 mg ascorbic acid/kg DM).
- Pigmented potatoes contain acylated anthocyanins and exhibit 2-3 fold higher antioxidant potential in comparison with white-flesh potatoes (Lachman & Hamouz 2005a & b).

- In a study of potatoes from the Czech Republic, results showed a statistically significant difference in antioxidant activity (as measured by the DPPH assay) between yellow- and purple-fleshed potatoes (Sulc et al. 2008). Antioxidant activity in purple-fleshed cultivars was double that in yellow-fleshed cultivars. A significant linear correlation between total phenolics and antioxidant activity was found ($r^2 = 0.747$). Average antioxidant activity in yellow-fleshed cultivars was 11.26 AAE (ascorbic acid equivalent mg/100 g DM) and was 24.79 AAE in purple-fleshed cultivars. Purple-fleshed potatoes showed a lower variation between localities (6% only). The results showed that antioxidant activity of freeze-dried tubers is very low when compared to other plants or sources (wine, tea, chocolate and blueberries) although a high potato intake or consumption of potatoes with higher antioxidant activity changes the dietary contribution.
- In order to identify elite parental lines for use in breeding programmes seeking to emphasise human health benefits, specialty (coloured) potato selections from the Texas Potato Variety Development Programme were analysed for antioxidant activity using 2,2-diphenyl-l-picrylhydrazyl (DPPH) and 2,2-azinobis (3-ethyl-benzothiazoline-6-sulfonic acid) (ABTS) radical assays (Reddivari et al. 2007). Total antioxidant activity ranged from 157 µg Trolox equivalents (TE)/g FW to 832 µg TE/g FW and 810 µg TE/gfw to 1622 µg TE/g FW using the DPPH and ABTS assays, respectively. Purple flesh selections had the highest antioxidant activity, followed by red flesh and yellow flesh selections. Selections with similar flesh colour did not differ significantly in antioxidant activity. A significant positive correlation was observed between antioxidant activity and total phenolics. Chlorogenic acid contributed 28 to 45% to antioxidant activity, followed by gallic acid, catechin and caffeic acid.
- Tubers of 38 native potato cultivars of different taxonomic groups from South America were analysed to determine antioxidant components and activity (Brown et al. 2007). Oxygen radical absorbance capacity (ORAC) was measured for the anthocyanin (hydrophilic) and carotenoid (lipophilic) extracts. The hydrophilic ORAC ranged from 333 to 1408 µM Trolox equivalents/100 g FW. The lipophilic ORAC ranged from 4.7 to 30 nM alpha-tocopherol equivalents/100 g FW. Among clones with less than 2 mg cyanidin equivalents/100 g FW, total carotenoid and lipophilic ORAC were correlated, but this was not true for analysis of all 38 clones. Although total anthocyanins or hydrophilic ORAC values reported here were not outside of the ranges found in North American and other breeding materials, total carotenoids and lipophilic ORACs are higher than previously reported, suggesting that native cultivars of South America with high levels of total carotenoids and high lipophilic ORAC are a unique germplasm source for introgression of these traits into specific potato cultivars outside the centre of origin.
- Our studies with New Zealand cultivars have also shown that there is considerable variation in antioxidant activity (Table 11 & Lister 2001b). Activity is usually related to the colour of both the skin and the flesh (in general red flesh >> white flesh/red skin > white flesh/brown skin) and the darker the colour the higher the antioxidant activity.

Table 11: Antioxidant activity of selected New Zealand potato cultivars as measured by the ABTS assay.

	Antioxidant activity (µmol TEAC/100 g)		
Cultivar	Whole	Flesh only	Skin only
Ilam Hardy	75.86	60.17	495.07
Red Rascal	95.32	74.6	833.09
Purple Heart	366.3	-	-
Urenika	755.54	698.01	1729.49

5.1.2 Effect of growing and storage practices

As noted in Sections 3.3.1 and 4.1.2, antioxidant components can vary with growing conditions/practices and also change during storage, hence antioxidant activity can be expected to vary. There has been less study of activity changes in comparison to components though.

Antioxidant levels in tubers of 14 specialty potato clones grown at four production sites (two conventional, two organic), both fresh and stored, were examined across 2 years (Rosenthal & Jansky 2008). Antioxidant activity of fresh tubers at all locations was higher in 2006 than in 2005. Cooler late-season temperatures in 2006 may have been responsible for the increased levels of antioxidants compared to 2005. Stored tubers had higher levels of antioxidant activity than fresh tubers, with a larger storage effect in 2005, when antioxidant levels in fresh tubers were lower. There was no consistent effect of production system (organic versus conventional) on antioxidant activity in tubers. For the specialty potato clones evaluated in this study, antioxidant levels were generally highest in potatoes grown in high-yielding production environments, and they increased during storage. Therefore, potatoes with high nutritional value, in terms of antioxidant activity, can be produced using conventional production and storage systems.

The antioxidant content and the antioxidant capacity of both hydrophilic and lipophilic antioxidant extracts from four "early potato" cultivars, grown in two different locations (Racale and Monteroni), were examined (Leo et al. 2008). The total equivalent antioxidant capacity (TEAC) was higher in the Racale extracts and a highly positive linear relationship ($R^2 = 0.8193$) between TEAC values and total phenolic content was observed. The oxyradical scavenging capacity (TOSC) of methanol/water and PBS extracts of peel and whole potatoes against the reactive oxygen species (ROS) peroxyl radicals, peroxynitrite and hydroxyl radicals was also analysed. A highly significant linear correlation ($R^2 = 0.9613$) between total antioxidant capacity (as a sum of peroxyl radicals + peroxynitrite) and total phenol content of methanol/water extracts was established. Moreover, proliferation of human mammalian cancer (MCF-7) cells was significantly inhibited in a dose-dependent manner after exposure to potato extracts. These data can be useful for "early potato" tuber characterisation and suggest that the "early potato" has potential as a dietary source of antioxidants.

In a study of cultivars and selections from the Colorado potato breeding programme, various influences on antioxidant activity were investigated (Stushnoff et al. 2008). Environmental conditions produced year to year variation in radical scavenging capacity as measured by the ABTS assay (Figure 13).

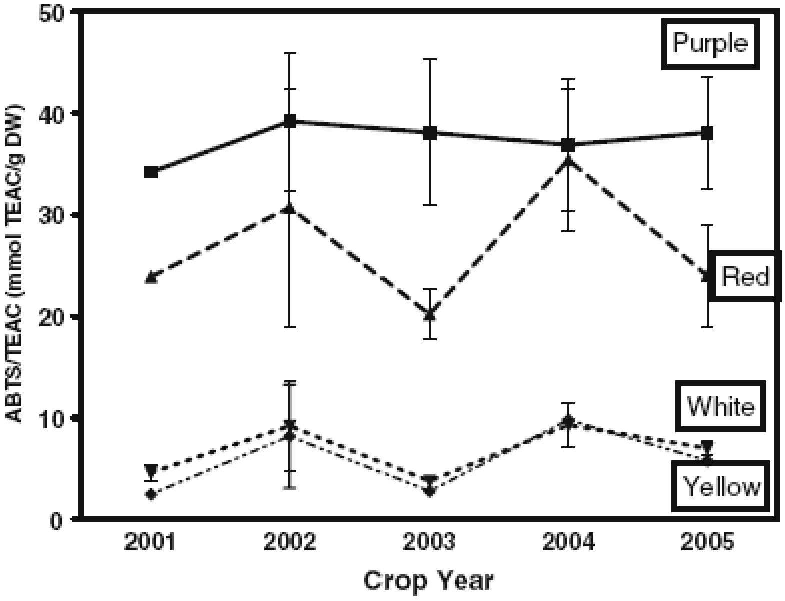


Figure 13: Radical scavenging capacity based on 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) and Trolox equivalent antioxidant capacity (TEAC) mM/g DW. Data are mean ± SEM for five crop years (total genotypes n=70) (Stushnoff et al. 2008).

Antioxidant properties of traditional and new potato cultivars with pigmented flesh were studied in relation to growing and processing conditions (Gromes & Herrmann 2008). Peeling reduced the antioxidative capacity of the produce, but cooking temperature was of secondary importance. No effect of N fertilisers or the way in which the potatoes are grown (organic farming/conventional farming) on their antioxidative capacity was found.

Potatoes are stored to ensure a continuous supply, but losses due to shrinkage and sprouting can be large. It is believed that low-dose ionising irradiation will become more prominent method for sprout inhibition due to the increasingly higher operating costs of low-temperature storage and the possible phase-out of chemical sprout inhibitors. The effects of storage and gamma irradiation on antioxidant components and antioxidant activity have been analysed for the potato cultivar Atlantic (Blessington et al. 2007). Antioxidant activity appeared to first decrease and then increase, possibly due to dehydration, concentration and/or induced stress. Irradiation dose exerted a limited influence on antioxidant activity. The interaction between storage time and irradiation dose was significant for antioxidant activity but overall, storage exerted a much greater influence on antioxidant activity than did low-dose gamma irradiation.

5.1.3 Influence of cooking/processing

Although there has been some study of the impact of cooking on antioxidant components there has been little investigation into the effects on antioxidant activity. In our studies, cooked potatoes actually have higher antioxidant activity than raw potatoes and the effects of different cooking methods varies (Figure 14) (Lister unpublished results). The same trends were observed for both a white-fleshed cultivar (Maris Anchor) and a purple-fleshed cultivar (Purple Heart). Baking is the optimal method for maximum antioxidant activity and it is also ideal for retaining many other nutritional components. The increase in activity may be due to release of bound phenolics. These studies were only conducted using whole potatoes with skin on, and hence on the basis of results with other components greater losses would be expected if skin was removed and potatoes chopped. Note that in most studies, including ours, potatoes are analysed freeze-dried and this allows more efficient extraction of the phenolics and is probably analogous to cooking. n our study the raw potatoes were analysed with no processing other than grinding.

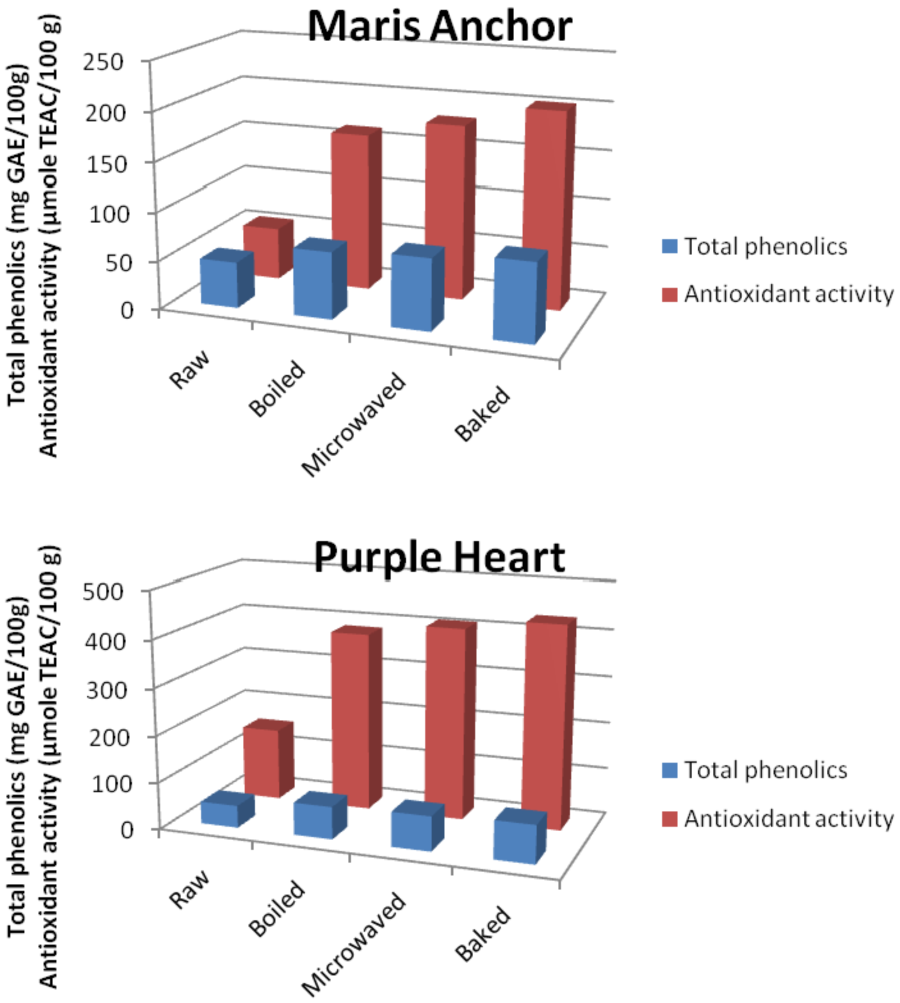


Figure 14: Changes in the phenolic content and antioxidant activity with cooking of two potato cultivars.

5.1.4 The health effects of potato antioxidants

As summarised above there has been considerable work using *in vitro* assays to look at the antioxidant activity of potatoes. However, these may not always reflect exactly what happens *in vivo* (i.e. once the potato has been eaten). Some research is starting to look at this and the effects of high antioxidant potato consumption on various health effects/markers.

Han et al. (2007a) examined the antioxidant effects of polyphenol/anthocyanin-rich potato flakes in male rats fed a high-cholesterol diet. The rats were served either a high-cholesterol (0.5 % cholesterol plus 0.125 % sodium cholate) diet, or a high-cholesterol diet containing a mixture of 243 g alpha-maize starch/kg supplemented with one of the following (per kg diet): 300 g medium purple potato (Shadow-Queen), 300 g white potato (Toyoshiro) or 300 g dark purple sweet potato (*Ipomoea batatas* cv. Ayamurasaki) flakes for 28 days. At this dosage, TBARS levels in the serum and liver of the Shadow-Queen and Ayamurasaki groups were significantly lower than those in the control and Toyoshiro groups. The serum urate levels in all the flake groups were significantly lower than that in the control group. The hepatic glutathione levels in the

Shadow-Queen and Ayamurasaki groups were significantly higher than in the control and Toyoshiro groups. The activities of hepatic glutathione reductase and glutathione S-transferase in the Shadow-Queen and Ayamurasaki groups were significantly greater than those in the control group. These results show that modulation of antioxidant enzymes and oxidative status in the serum and liver by the purple potato flake diet (Shadow-Queen) containing polyphenols/anthocyanins may play an important role in protection against adverse effects related to oxidative damage in rats fed a high-cholesterol diet.

The combination of antioxidants together with the complex carbohydrates in potato may also be important with regards to health benefits. Consumption of high levels of simple carbohydrates is associated with several metabolic disorders in humans and in laboratory animals, including symptoms of an early stage of metabolic syndrome (syndrome X). This disorder has several cardiovascular risk factors, such as hypertriglyceridemia, and is associated with an increase in oxidative stress. In contrast to sucrose, potato, a source of complex carbohydrates and antioxidant micronutrients, is thought to improve lipid metabolism and antioxidant protection. Hence, Robert et al. (2008) investigated the effects of diets containing (i) complex dietary carbohydrates and antioxidant micronutrients (potato), (ii) complex carbohydrates (starch) or (iii) a simple carbohydrate (sucrose), on lipid metabolism and antioxidant status in rats. An increase in short chain fatty acid (SCFA) pools was observed in the caecum of rats fed a potato-based diet, resulting from an increase in all SCFAs, especially propionate (+360%, $P < 0.0001$). Feeding rats a potato-based diet for 3 weeks led to a decrease in cholesterol (-37% for potato vs control and -32% for potato vs sucrose) and triglyceride (-31% for potato vs control and -43% for potato vs sucrose) concentrations in triglyceride-rich lipoproteins (TGRLP) fractions. The antioxidant status was decreased by sucrose consumption and improved by potato consumption. These results suggest that consumption of complex carbohydrates (provided as cooked potatoes), in combination with different antioxidant micronutrients, may enhance antioxidant defences and improve lipid metabolism, when compared with s sucrose consumption (source of simple sugar). These effects limit oxidative stress and reduce the risk of developing the associated degenerative diseases, including cardiovascular disease, and could have potential in cardiovascular disease prevention. Philantro et al. (2008) studied proteins isolated from potato tubers and by-products from the potato industry and evaluated their ACE-inhibitory and radical-scavenging potencies. The results of this study suggest that potato is a promising source for the production of bioactive compounds as ingredients for developing functional foods with a beneficial impact on cardiovascular health.

As noted above investigations of antioxidant properties for over 90 genotypes were conducted for the Colorado potato breeding programme to identify those especially rich in antioxidants (Stushnoff et al. 2008). The pigmented cultivars 'Purple Majesty' and 'Mountain Rose' contained considerably higher levels of chlorogenic acid isomers than the non-pigmented genotypes. In the non-pigmented genotypes, chlorogenic acid and glycolalkaloid content were highest in 'Rio Grande Russet'. Chlorogenic acid has been demonstrated to exhibit several desirable anticarcinogenic properties in recent biochemical investigations (Feng et al. 2005; Friedman 1997), as have several of the phenolic based anthocyanin pigments found in many colourful fruits and vegetables (Matsubara et al. 2005; Yeh & Yen 2005; Zhang et al. 2005). Preliminary tests with phosphate buffered saline (PBS) extracts of baked tubers from six potato cultivars revealed that 'Rio Grande Russet' was most effective in inhibiting growth of breast cancer cultures MCF-7 and MDA-MB-468 (Stushnoff et al. 2008). 'Purple Majesty' inhibited to some extent, while 'Mountain Rose' and 'Yukon Gold' had no inhibitory effect. A subsequent study with 21 genotypes, where the initial extract was made with 80% acetone followed by drying and extraction in aqueous PBS, differed from direct

PBS extraction. Five genotypes including 'Russet Nugget' inhibited growth of breast cancer cell cultures at 0.187% to 0.375% w/v of the cell culture solution. However, IC50 inhibition data were not strongly related to the *in vitro* chemical data for these cultivars. This may indicate other compounds are involved or there are interactions between components that are not so simply explained.

Han et al. (2007b) examined the effects of red potato flakes (RPF) on serum antioxidant potential and hepatic mRNA in rats. The serum thiobarbituric acid-reactive substances concentration and hepatic superoxide dismutase mRNA level in rats fed RPF were significantly lower and higher respectively than those in control rats. These results suggest that RPF might improve the antioxidant system by enhancing hepatic SOD mRNA.

5.2 Anticarcinogenic effects

As noted above the antioxidants in potatoes (e.g. the phenolics) may have anticarcinogenic effects. There has also been a study of the anticarcinogenic effects of the glycoalkaloids present in potatoes (reviewed by Friedman 2006). A study by Friedman et al. (2005) looked at: (a) the isolated pure glycoalkaloids separately, (b) artificial mixtures of the two glycoalkaloids, and (c) the total glycoalkaloids isolated from each of five potato varieties. All samples tested reduced the numbers of the following human cell lines: cervical, liver, lymphoma, stomach cancer cells and normal liver cells. The results show that (a) the effects of the glycoalkaloids were concentration dependent in the range of 0.1-10 µg/mL (0.117-11.7 nmol/mL); (b) alpha-chaconine was more active than was alpha-solanine; (c) some mixtures exhibited synergistic effects, whereas others produced additive ones; (d) the different cancer cells varied in their susceptibilities to destruction; and (e) the destruction of normal liver cells was generally lower than that of cancer liver cells. Many previous studies have showed that various glycoalkaloids may have effects on cancer cells (Kupchan et al. 1965; Cham 1994; Daunter & Cham 1990; Hu et al. 1999; Kuo et al. 2000; Liu et al. 2004; Yang et al. 2006; Gao et al. 2006; Lavie et al. 2001; Esteves-Souza et al. 2002; Nakamura et al. 1996).

So what is the significance of this for the human diet? Because it is difficult to translate results from cell assays to *in vivo* effects, the observed destruction of a broad range of cancer cells by glycoalkaloids suggests the need for animal and human experiments designed to confirm the *in vitro* data by corresponding effects *in vivo*. It will also be necessary to ascertain whether the concurrent consumption of dietary glycoalkaloids, which may exert their effects by disrupting cell membranes (Blankemeyer et al. 1992) and enhancing the immune system (Gubarev et al. 1998 a & b), will increase the effectiveness of other anticarcinogenic food ingredients (e.g. phenolics and carotenoids), which may act by different mechanisms. The important thing is that the presence of glycoalkaloids shouldn’t always be viewed in a negative light and within non-toxic levels they may actually confer a health advantage. Because humans may consume at least six glycoalkaloids in their diet (α-chaconine and α-solanine from potatoes; α-tomatine and dehydrotomatine from tomatoes; and solamargine and solasonine from eggplants), there is need to further define possible beneficial effects of combinations of dietary glycoalkaloids against cancer cells and tumors. Effectiveness as well as safety considerations should govern the dietary consumption of glycoalkaloids.

5.3 Glycaemia and diabetes

In recent years, potatoes have fallen into disrepute (Ludwig 2000; Willett 2001; Worm 2003). One reason for this may be recent promotion of the health benefits of a diet with a low dietary glycaemic index (GI) or a low dietary glycaemic load (GL) (Ludwig 2002). The GI reflects the quality of carbohydrates, and ranks carbohydrate sources according to the glycaemic responses produced when ingesting 50 g of available carbohydrate from food (Jenkins et al. 1981), whereas the GL – the product of the food's GI and the dietary carbohydrate content per serving (g) – accounts for the total glycaemic effect of the ingested carbohydrate-containing food (Salmeron et al. 1997b). To date, several epidemiological studies have described associations between the dietary GI or GL and risks of type 2 diabetes and CHD (Salmeron et al. 1997a, b; Liu et al. 2000; Hodge et al. 2004; Schulze et al. 2004). Furthermore, recent weight-loss intervention studies suggest that a diet with a low GI or GL may represent a promising alternative to a low-fat diet (Slabber et al. 1994; Spieth et al. 2000; Ebbeling et al. 2003). Although these findings have not been confirmed by all studies (Meyer et al. 2000; van Dam et al. 2000; Stevens et al. 2002), particularly in the USA, new dietary concepts for food selection have been developed, promoting radical changes to current dietary recommendations, e.g. the 'Low glycaemic index pyramid' (Ludwig 2000), the 'Healthy eating pyramid' (Willett 2001) and 'Low-carbohydrate diets' (Worm 2003). Common to these concepts is the ranking of potatoes among the foods to be eaten sparingly, since a number of prominently cited studies have reported that potatoes are characterised by a high GI value (Soh & Brand-Miller 1999; Foster-Powell et al. 2002).

Saying that all potatoes have a high glycaemic index is an unjustified generalisation. As with all GI data, the GI values of potatoes may depend on cooking method, processing, variety and the composition of the meal (Lunetta et al. 1995; Fernandes et al. 2005; Foster-Powell et al. 2002). The glycaemic response to eight potato varieties commercially available in Great Britain was compared against a glucose standard in a non-blind, randomised, repeated measure, crossover design trial (Henry et al. 2005). The eight potato varieties exhibited a wide range in GI values from 56 to 94. A trend was seen whereby potatoes with waxy textures produced medium GI values, whilst floury potatoes had high GI values. In general mashed potatoes, French fries, baked potatoes and potatoes cooked in a microwave are characterised by GI values mostly exceeding the upper limit for a high GI value of 70 (Figure 15), whereas conventionally boiled potatoes appear to have a GI value on average below 70. The values of conventionally boiled potatoes do vary considerably though, so it may also be that some potato varieties have an inherently low GI whatever the cooking method (Najjar et al. 2004; Fernandes et al. 2005). In fact in one relatively recent study, cooking method, peeling method, or slicing or mashing did not affect the GIs (Tahvonen et al. 2006). It should be considered that most currently available GI values are based on mature potato varieties (e.g. Ontario, Prince Edward Island, Desiree, Pontiac, Sebago) (Hambloch 2005, cited in Buyken & Kroke 2005). The starch of more mature potatoes is, however, easier to digest, presumably due to increased amylopectin branching and hence lower resistance to gelatinisation, which in turn results in a higher GI (Soh & Brand-Miller 1999). Finally, recent studies have shown that potatoes consumed cold have a lower GI because the digestibility of starch decreases with cooling, thus cold potato preparations such as potato salad can be expected to have a low GI (Najjar et al. 2004; Fernandes et al. 2005).

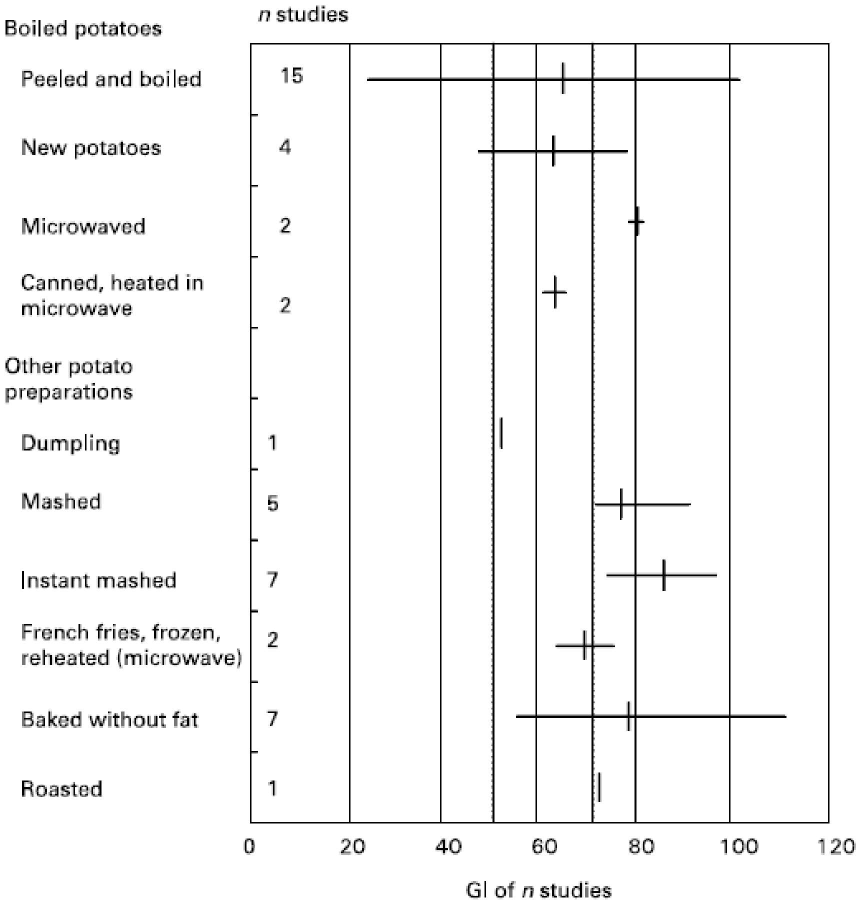


Figure 15: Glycaemic index (GI) values (glucose reference) for potatoes by different cooking methods (Chantelau, 2000; Foster-Powell et al. 2002). Values are means with the range (minimum to maximum) depicted by horizontal bars. Dotted vertical lines represent the cut-off levels proposed for a low GI (≤55) and a high GI (≥70) of a food (Brand-Miller et al. 2003, taken from Buyken & Kroke 2005).

Potatoes are not usually eaten alone and in most cases are consumed as part of a meal or with additional toppings. The GI of potatoes may be changed dramatically by parallel consumption of proteins and fats (Gulliford et al. 1989). Thus, considering the GI of a potato alone is relatively meaningless. There has been some investigation of the influence of the addition of various toppings/fillings on the glycaemic response to baked potato, pasta or toast (Henry et al. 2006). In this study no significant difference was found among the various toppings: cheddar cheese, chilli con carne, baked beans and tuna added to the carbohydrate source. However, the addition of toppings to a carbohydrate-rich food had a consistent lowering effect on glycaemic index. In particular, the addition of cheddar cheese to potato, pasta and toast reduced the GI of the test meal to a value that is considered to be low-GI (39, 27 and 35, respectively). This is particularly notable for potatoes, which, when eaten alone, had the highest GI value of all the staples. These findings emphasise the importance of investigating the GI of composite meals.

The effects of cold storage and vinegar addition on glycaemic and insulinaemic responses to a potato meal in healthy subjects has been investigated (Leeman et al. 2005). Cold storage of boiled potatoes generated appreciable amounts of resistant starch (up from 3.3 to 5.2%). Cold storage and addition of vinegar reduced acute glycaemia (-43%) and insulinaemia (-31%) in healthy subjects after a potato meal. The results show that the high glycaemic and insulinaemic features commonly associated with potato meals can be reduced by use of vinegar dressing and/or by serving cold potato products. Other studies have noted similar effects. For example, cooled potato resulted in a significantly lower postprandial blood glucose and area under the glucose curve as compared to hot potato (Najjar et al. 2004). Postprandial triglyceride values significantly decreased from fasting levels after eating cooled potato, whereas an increase was observed after eating hot potato. In addition, the glycemic index of cooled potato was significantly lower than hot potato. After consumption of hot potatoes, greater incremental changes in glucose and insulin were observed in hyperinsulinemic as compared to normoinsulinemic subjects. These results emphasise the importance of starch temperature at consumption as a factor that influences the glycemic index and may allow patients with hyperinsulinemia and diabetes to have a wider selection of starchy foods, if consumed at the appropriate temperature. In another study, cooling and cold storage, despite reheating, lowered GIs of potato products by about 25% (Tahvonen et al. 2006).

Potatoes, because they are a high glycemic form of carbohydrate, are hypothesised to increase insulin resistance and risk of type 2 diabetes. As a result Halton et al. (2006) examined the relationship between potato consumption and the risk of type 2 diabetes. This involved a prospective study of 84,555 women in the Nurses' Health Study. Potato and French fry consumption were both positively associated with risk of type 2 diabetes after adjustment for age and dietary and nondietary factors. The multivariate relative risk (RR) in a comparison between the highest and the lowest quintile of potato intake was 1.14 (95% CI: 1.02, 1.26; *P* for trend = 0.009). The multivariate RR in a comparison between the highest and the lowest quintile of French fry intake was 1.21 (95% CI: 1.09, 1.33; *P* for trend < 0.0001). The RR of type 2 diabetes was 1.18 (95% CI: 1.03, 1.35) for 1 daily serving of potatoes and 1.16 (95% CI: 1.05, 1.29) for 2 weekly servings of French fries. The RR of type 2 diabetes for substituting 1 serving potatoes/day for 1 serving whole grains/day was 1.30 (95% CI: 1.08, 1.57). The association between potato consumption and risk of type 2 diabetes was more pronounced in obese women. These findings suggest a modest positive association between the consumption of potatoes and the risk of type 2 diabetes in women. This association was more pronounced when potatoes were substituted for whole grains. However, another study recently published in the American Journal of Epidemiology concluded that consuming a variety of cooked vegetables, including potatoes, prepared in healthful ways (i.e. not fried), was associated with a reduced risk of developing Type 2 diabetes (Hodge et al. 2007). Interestingly it is reported that in Peru as junk food is replacing potatoes it is leading to an increase in type 2 diabetes (Wedman 2007).

An animal study has also indicated that potatoes may have a role to play in ameliorating diabetes. The potential of dietary potato peel (PP) powder in ameliorating oxidative stress (OS) and hyperglycemia was investigated in streptozotocin (STZ)-induced diabetic rats (Singh et al. 2005). In a 4-week feeding trial, incorporation of potato peel powder (5 and 10%) in the diet of diabetic rats was found to significantly reduce the plasma glucose level and also reduce drastically the polyuria of STZ diabetic rats. Total food intake was significantly reduced in the diabetic rats fed 10% PP powder compared to the control diabetic rats. However, the body weight gain over 28 days was nearly four times greater in PP powder supplemented diabetic rats (both at 5 and 10%) compared to the control diabetic rats. PP powder in the diet also decreased the elevated activities of serum transaminases (ALT and AST) and nearly normalised the hepatic MDA and GSH levels as well as the activities of specific antioxidant enzymes in liver of diabetic rats. The results of these studies clearly establish the modulatory propensity of PP against diabetes-induced alterations in metabolic parameters. Considering that potato peels are discarded as waste and not effectively utilised, these results suggest the possibility that PP waste could be effectively used as an ingredient in health and functional food to ameliorate certain disease states such as diabetes.

Lynch et al (2008) conducted a review of Glycaemic Index and the implications for the potato industry. They drew the following conclusions: “GI and GL provide useful guides to control the glycaemic response associated with the consumption of carbohydrate sources. However, more research is required to accurately define GI and GL for individual potato cultivars and processed products. There is an opportunity to ensure the more frequent inclusion of potato in diabetic diets by identifying and developing low GI cultivars, modifying processing techniques to reduce the GI of potato products and identifying the GL of the common serving sizes of individual potato products.”

In addition the WHO makes the following advice:

> “In choosing carbohydrate foods, both glycaemic index and food composition must be considered. Some low GI foods may not always be a good choice because they are high in fat. Conversely, some high GI foods may be a good choice because of convenience or because they have low energy and high nutrient content. It is not necessary or desirable to exclude or avoid all high GI foods.”

5.3.1 Obesity and satiety

Potatoes are often regarded as fattening and in part responsible for growing obesity rates. However, some data indicate this is not the case. For example, potato consumption patterns and obesity rates are not correlated (Figure 16). In addition, increases in calories in the diet have come from fat and oils plus grains rather than vegetables including potatoes (Table 12). It is the way in which potatoes are prepared (e.g. fried) and foods that are coingested with them that may be responsible. In fact there is some evidence that potatoes may play a role in the diet in prevention of obesity.

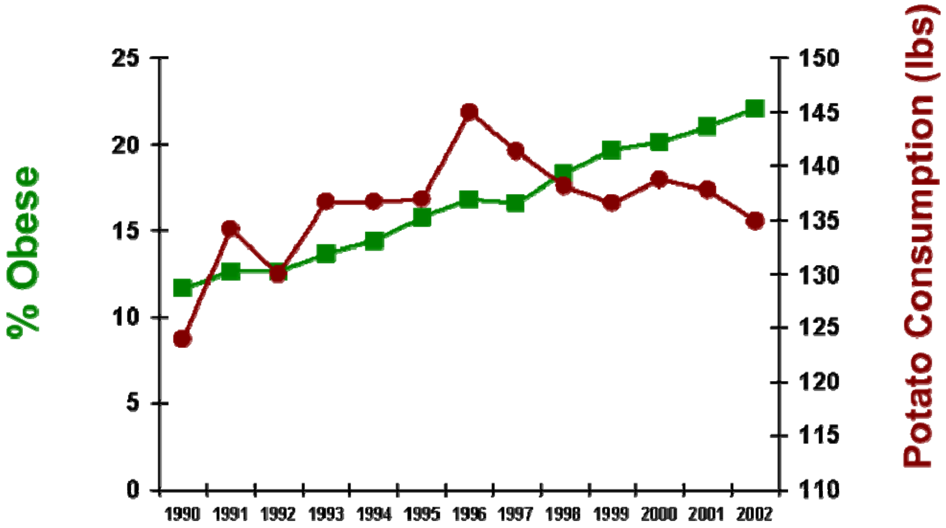
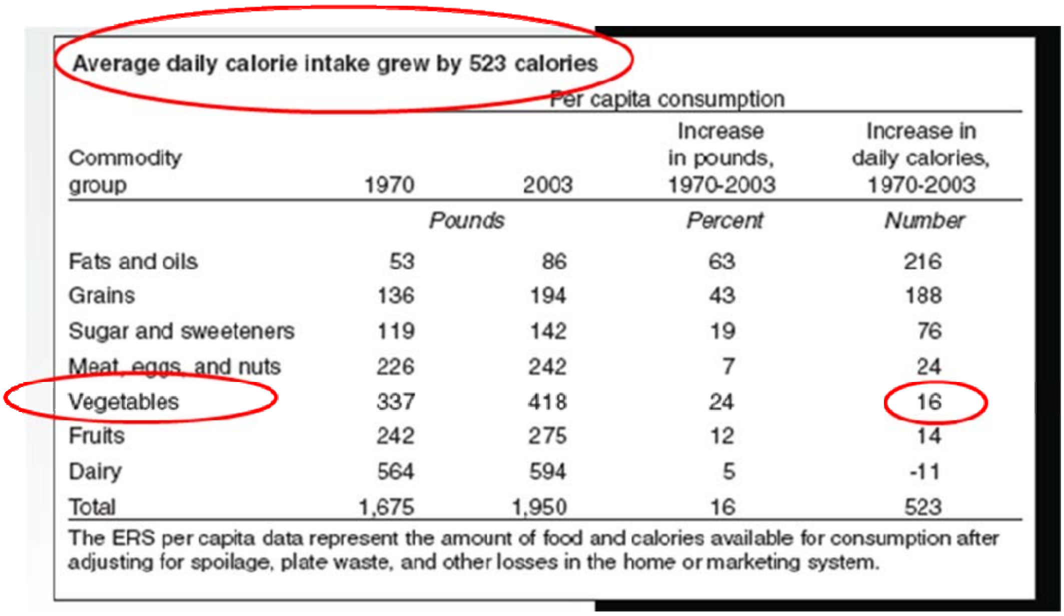


Figure 16: Potato consumption compared to obesity rates in the USA (Source: Center for Disease Control, Economic Research Service, USDA, Vegetables and Specialties Situation and Outlook Yearbook, July 2003).

Table 12: Dietary components responsible for increase in calories in US diet between 1970 and 2003.



Average daily calorie intake grew by 523 calories

Commodity group	1970	2003	Increase in pounds, 1970-2003	Increase in daily calories, 1970-2003
	Per capita consumption			
	Pounds		*Percent*	*Number*
Fats and oils	53	86	63	216
Grains	136	194	43	188
Sugar and sweeteners	119	142	19	76
Meat, eggs, and nuts	226	242	7	24
Vegetables	337	418	24	16
Fruits	242	275	12	14
Dairy	564	594	5	-11
Total	1,675	1,950	16	523

The ERS per capita data represent the amount of food and calories available for consumption after adjusting for spoilage, plate waste, and other losses in the home or marketing system.

A purple potato variety has been used as a folk remedy in Korea for the prevention of metabolic diseases. Yoon et al. (2008) have conducted a study to elucidate the anti-obesity mechanism of this variety (Bora Valley). An ethanol extract of this potato significantly inhibited the fat accumulation of 3T3-L1 differentiated adipocytes, suggesting that it can be a potent functional food to show anti-obesity activity via inhibition of adipocyte differentiation and fat accumulation. The purple potato extract also significantly inhibited the levels of insulin and leptin in rats fed a high fat diet. Leptin and insulin are typical adiposity signals. Most obese subjects display increased levels of circulating leptin, indicating obesity as a state of leptin resistance (Considine et al. 1996). Excessive lipid metabolism can increase fatty acid, triglyceride, total and LDL cholesterol levels and lower HDL cholesterol content in the body and subsequently induce obesity-related diseases. The extract significantly reduced total fat and whole body lipid, and levels of total cholesterol, triglyceride and low density lipoprotein (LDL) were significantly reduced. These results strongly imply that the variety Bora Valley can regulate lipid metabolism including cholesterol and triglyceride through both preventive and therapeutic activities against hyperlipidemic obesity. Furthermore, body weight gain was significantly suppressed over 4 weeks of treatment with the potato extract compared with control. The authors concluded that this purple potato variety has anti-obesity potential via inhibition of lipid metabolism. It is likely that the anthocyanins in the purple variety may be responsible, as in other studies anthocyanin (cyanidin or cyanidin-3-glucoside) pigments were reported to prevent obesity or diabetes (Tsuda et al. 2003, 2004).

There is a Canadian patent for an extract of or the raw juice from purple potatoes of use for the prevention of obesity as well as functional foods containing it (Lim et al. 2008). The bioactive potato composition prevents differentiation of cells to adipocytes, via a reduction in the leptin level, and has hypolipaemic, including hypocholesterolaemic, activity.

Complex carbohydrates, such as potato, rice and pasta, are frequently-consumed accompaniments of meat meals and have different effects on satiety, food intake, glucose and insulin concentrations. The orexigenic gastric hormone ghrelin contributes to feeding regulation (effects on subsequent food intake). Erdmann et al. (2008) conducted a study with human subjects to examine the effect of satiating amounts of potatoes, rice or pasta consumed together with 150 g pork steak. They examined hunger/satiety ratings, food intake, plasma insulin, glucose and ghrelin concentrations. All meals led to comparable quantities of food intake while energy intake was significantly lower after potatoes. Satiety/hunger ratings were significantly different from basal for the entire 4 h period after rice and pasta meals, while they had returned to basal during the 4th hour after potatoes. After rice and pasta, insulin rose significantly for 4 h. Ghrelin decreased during the 2nd and 3rd hour. In contrast, potatoes stimulated insulin for the initial 2 h only while ghrelin rose significantly by 120 pg/ml over the 4 h period. A significant correlation was observed between ghrelin and hunger ratings while subsequent second meal food and energy intake did not differ irrespective of the preceding ghrelin concentration. Compared to rice and pasta, satiating amounts of potatoes coingested with meat result in lower energy intake and postprandial insulin concentrations, which is not counterbalanced during subsequent food intake despite higher ghrelin concentrations. The present data support the concept that ghrelin can affect hunger sensations but not necessarily food and energy intake.

The role of glycaemic index (GI) on satiety sensation and weight maintenance has been the subject of a number of studies. Leeman et al. (2008) investigated the glycaemic and satiating properties of potato products in healthy subjects using energy-equivalent or carbohydrate-equivalent test meals, respectively. Boiled potatoes induced higher subjective satiety than French fries when compared on an energy-equivalent basis. The French fries elicited the lowest early glycaemic response and were less satiating in the early postprandial phase. No differences were found in glycaemic or satiety response between boiled or mashed potatoes. In a second study French fries resulted in a significantly lower glycaemic response (glycaemic index (GI) = 77) than boiled potatoes either with or without addition of oil (GI = 131 and 111, respectively). No differences were found in subjective satiety response between the products served on carbohydrate equivalence. It was concluded that boiled potatoes were more satiating than French fries on an energy-equivalent basis, the effect being most prominent in the early postprandial phase, whereas no difference in satiety could be seen on a carbohydrate-equivalent basis. The lowered GI for French fries, showing a typical prolonged low-GI profile, could not be explained by the fat content per se.

5.3.2 Improvement in digestive health

Studies have shown that feeding rats potato resistant starch improves large bowel health. Some starch in the normal diet remains undigested in the small intestine and enters the large bowel in humans. This is called resistant starch (RS) (Topping et al. 2003). Like dietary fibre, RS is also fermented by microflora in the hindgut, leading to production of short-chain fatty acids (SCFA), mostly acetate, propionate and butyrate (Cumings & Englyst 1991). According to several studies SCFA from complex carbohydrates are involved in health benefits effects such as lowering the colon cancer risk (Mortensen et al. 1996; Scheppach et al. 1995). One of the possible mechanisms suggested to explain the anticancer effects of SCFA is that butyrate could prevent secondary bile acid-mediated toxic effects (Velazquez et al. 1996), as secondary bile acids are believed to be tumour promoters (Nagengast et al. 1995). In addition, products of SCFA decrease infectious intestinal diseases by inhibiting putrefactive and pathogenic bacteria due to the lowered pH in the hindgut (Malhotra 1982).

A recent study has investigated the effects of the consumption of various coloured potato (white, red and purple) flakes on caecal fermentation and faecal bile acid excretions in rats (Han et al. 2008). The samples examined were: Hokkai kogane flakes (HK, white), Hokkai No. 91 flakes (H91, red) or Hokkai No. 92 flakes (H92, purple). This study found that there were no significant differences in the body weight, food intake and caecum weight between the groups. However, there were changes in caecal pH values, – the groups fed potato flakes were significantly lower than rats fed the basal diet, and matter excretion in the H91 group was significantly higher than in the BD and HK groups. Caecal short-chain fatty acid concentrations in the HK, H91 and H92 groups were significantly higher than in the BD group, and the molar ratio of butyrate to total SCFA in the HK, H91 and H92 groups was greatly increased compared with the BD group. Rats fed the HK, H91 and H92 potato flake diets presented significantly higher counts of total anaerobes in the cecum than rats fed the BD. The caecal *Lactobacillus* count in the H91 group was significantly increased compared to the BD group and the *Bifidobacterium* count was similar for all groups. Faecal total bile acid excretion in the H92 flake group and secondary bile acid excretions in the H91 and H92 groups were significantly greater than those in the other groups and in the BD and HK groups, respectively. The results indicate that potato flakes act like resistant starch and raise bowel SCFA, probably through anaerobic bacterial activities and fermentation of residual starch. These actions are helpful for the improvement of the colonic environment.

5.3.3 Cholesterol lowering

As noted earlier antioxidants may confer benefits for rats fed a high cholesterol diet. In addition components of potato may have cholesterol lowering properties. Dietary plant and animal peptides have been shown to reduce serum lipids. However, the potential of food-derived peptides has yet to be fully elucidated. Liyanage et al. (2008) investigated the physiological importance of potato peptides in rats fed on a cholesterol-free diet containing 20% potato peptides (PP), when compared with two diets containing either 20% casein (CN) or 20% soy peptides (SP). The high-density lipoprotein (HDL)-cholesterol (+13.8%) and serum triglyceride (- 38%) concentrations in the PP-fed group, non-HDL-cholesterol level in the PP- (- 22.5%) and SP- (- 15.7%) fed groups, and serum total cholesterol concentration (- 12%) in the SP-fed group, were significantly different from the control group at the end of the experiment. The faecal excretion of neutral and acidic sterols was higher in the PP- and SP-fed groups, respectively, relative to the control group. These results indicate that the observed changes in the serum cholesterol levels in rats fed on soy and potato peptide appear to have been due to different mechanisms.

It has been demonstrated that retrograded starch, a kind of resistant starch, of beans reduced serum lipid levels in rats. Hence it was investigated whether retrograded starch in potato pulps could reduce serum lipid concentrations (Hashimoto et al. 2006). Rats were given diets containing 15 g of retrograded starch in potato pulps from the Benimaru potato (BM) or Hokkaikoganc potato (HK) in a 100 g diet for 4 weeks. At the 4th week, the total cholesterol level in the serum in the BM group and serum triglyceride level in the HK group were significantly lower than those in the control group. In the BM group, the contents of faecal bile acids were significantly higher than those in the control group. These results suggested that BM pulp promoted the excretion of bile acids, which resulted in a low concentration of serum cholesterol. On the other hand, HK pulp inhibited the synthesis of fatty acids, which might lead to a reduction of the serum triglyceride level. These results suggest that retrograded starches in potato pulps may be useful for reduction of serum lipid levels.

5.4 Other health benefits

There have been various other studies looking at different health aspects of potatoes:

- Heart disease: Robert et al. (2006) investigated the effect of a potato-enriched diet on lipid metabolism and antioxidant protection in rats. Feeding rats a potato-enriched diet for 3 weeks led to a significant decrease in cholesterol and triglyceride levels in plasma (respectively, -30% and -36%) and cholesterol level in liver (-42%). Antioxidant status was also improved by potato consumption. TBARS levels in heart were decreased and vitamin E/ triglycerides ratio in plasma was improved. These results suggest that consumption of cooked potatoes (consumed with skin) may enhance antioxidant defence and improve the lipid metabolism. These effects could be interesting for prevention of cardiovascular disease.

- Bone health: Excessive dietary salt (NaCl) in association with a paucity of plant foods, major sources of potassium alkaline salts, is a common feature in Western eating habits, which may lead to acid-base disorders and to Ca and Mg wasting. A study in rats has shown that cooked potato may be effective in alkalinising urine, enhancing citrate excretion and ameliorating Ca and Mg balance (Narcy et al. 2006). Cooked potato, as opposed to wheat starch, led to a significant rise in Ca and Mg intestinal absorption (Ca from 39 to 56%; Mg from 37 to 60%). Urinary Ca and Mg elimination represented respectively 17 and 62% of the daily absorbed mineral in rats fed the high-salt, wheat starch diet compared with 5 and 28 % in rats fed the high-salt cooked potato diet. Increasing the consumption of potato, sources of alkali agents mainly constituted by organic salts of K and Mg, may prove to be a practical means to maintain cation reserves in the body and, in the long term, to protect bone, notably in individuals at risk of developing osteoporosis. Park et al. (2005) have attempted to use biotechnology to increase the Ca content of potatoes. They achieved a three-fold increase over wild type tubers. Such an approach may also increase calcium in the diet and lead to improvements in bone health.
- Anti-inflammatory: An ethanolic extract of potato tubers was evaluated for antinociceptive activity and anti-inflammatory activity in mice (Choi & Koo 2005). Acute treatment of mice orally with the ethanolic extract at 100 and 200 mg/kg produced a marked anti-nociceptive effect in acetic acid-induced writhing, formalin-induced pain licking and hot plate-induced pain. Ethanolic extracts also markedly inhibited carrageenan- and formalin-induced inflammation in mice, as well as arachidonic acid-induced ear oedema. Results support use of ethanol extracts from potatoes to relieve inflammatory pain and provide insight into the development of new agents for treating inflammatory diseases.
- Arthritis: Potato extract has been shown to have suppressive effects on type II collagen-induced arthritis, an animal model for human rheumatoid arthritis (Choi 2007). Clinical assessment of disease and measurement of paw edema were conducted throughout the study. The arthritis score and paw edema were markedly suppressed in the groups treated with potato extract. Levels of rheumatoid factor, anti-type 11 collagen antibody, interleukin (IL)-1, IL-6, LDL-cholesterol, and malondialdehyde in sera were also reduced by potato extract treatment. The activities of glutathione peroxidase and glutathione reductase were increased in the spleens of CIA mice treated with potato extract.
- Anti-Hepatotoxicity: The protective effects of red potato extract (RPE) against liver damage were determined rats (Han et al. 2006b). Increases in serum aspartate aminotransferase, alanine aminotransferase and lactate dehydrogenase activities (all of which were induced chemically), decreased in rats fed the red potato extract, suggesting that this extract acts as a functional food showing anti-hepatotoxicity. Other research also suggests that coloured potato flakes are useful as a prophylactic agent against oxidative liver damage (Ohba et al. 2007). Further investigation by this research group indicates that potato peptide may improve the caecal fermentation and prevent the GalN-induced liver damage in rats (Ohba et al. 2008).

5.5 Utilisation of potato peel for health benefits

There are a number of studies that have looked at potato peel as a source of antioxidants:

- Free and bound-form phenolics were isolated from potato (cv. Toyoshiro) flesh and peel (Nara et al. 2006). The free and bound-form phenolics in the peel showed high DPPH radical scavenging activity, while those in the flesh showed low activity. The total amount of chlorogenic acid and caffeic acid in the free-form phenolics from the peel was highly correlated with the DPPH radical scavenging activity. Ferulic acid was identified as the active radical scavenging compound in the bound-form phenolics from the peel. The potato peel may therefore offer an effective source of antioxidants.
- The antioxidant potency of freeze-dried aqueous extract of potato peel was investigated employing various established *in vitro* systems, such as lipid peroxidation in rat liver homogenate, 1, 1-diphenyl-2-pierylhydrazyl (DPPH)/superoxide/hydroxyl radical scavenging, reducing power and iron ion chelation (Singh & Rajini 2004). Freeze-dried aqueous extract of potato peel powder (PPE) showed strong inhibitory activity toward lipid peroxidation of rat liver homogenate induced by the FeCl2-H2O2 system. Furthermore, PPE exhibited a strong concentration-dependent inhibition of deoxyribose oxidation. PPE also showed a considerable antioxidant activity in the DPPH radical assay system. The multiple antioxidant activity of PPE was evident as it showed strong reducing power, superoxide scavenging ability and also ferrous ion chelating potency. The data obtained in the *in vitro* models clearly establish the antioxidant potency of freeze-dried extract of potato peel.
- As a follow on, the same researchers investigated the ability of PPE to protect erythrocytes against oxidative damage *in vitro* (Singh & Rajini 2008). PPE was found to inhibit lipid peroxidation with similar effectiveness in two systems (about 80-85% inhibition by PPE at 2.5 mg/ml). While PPE *per se* did not cause any morphological alteration in the erythrocytes, under the experimental conditions, PPE significantly inhibited the H_2O_2-induced morphological alterations in rat RBCs as revealed by scanning electron microscopy. Further, PPE was found to offer significant protection to human erythrocyte membrane proteins from oxidative damage induced by ferrous-ascorbate. These results indicate that PPE is capable of protecting erythrocytes against oxidative damage probably by acting as a strong antioxidant.
- In another follow on study, PPE was investigated for its potential to offer protection against acute liver injury in rats (Singh et al. 2008). Pretreatment of rats with PPE significantly prevented the increased activities of transaminase enzymes in serum, prevented the elevation of hepatic malondialdehyde formation as well as protected the liver from reduced glutatione depletion. PPE pretreatment also restored CCl4-induced altered antioxidant enzyme activities to control levels. The protective effect of PPE was further evident through the decreased histological alterations in liver. These findings provide evidence to demonstrate that PPE pretreatment significantly offsets CCl4-induced liver injury in rats, which may be attributable to its strong antioxidant activity.
- The effective utilisation of potato peel, a waste generated in large quantities by the food industry, as an antioxidant was investigated (Kanatt et al. 2005). PPE exhibited high phenolic content (70.82 mg of catechin equivalent/100 g), with chlorogenic acid (27.56 mg/100 g of sample) being the major component. The yield of total phenolics and chlorogenic acid increased by 26 and 60%, respectively, when the extract was prepared from gamma irradiated (150 Gy) potatoes. PPE showed excellent antioxidant activity as determined by beta-carotene bleaching and radical scavenging activity of 1,1-diphenyl-2-picrylhydrazyl (DPPH). The suitability of PPE for controlling lipid oxidation of radiation-processed lamb meat was also investigated. PPE (0.04%) when added to meat before radiation processing was

found to retard lipid peroxidation of irradiated meat as measured by TBA number and carbonyl content. The antioxidant activity of PPE was found to be comparable to butylated hydroxytoluene (BHT).

- Potato peel extract, as natural antioxidant was evaluated during 60 days storage of refined soyabean oil at 25 and 45°C (Rehman et al. 2004). Free fatty acids (FFA), peroxide values (POV) and iodine values (IV) were used as criteria to assess the antioxidant activity of PPE. The results illustrated that PPE, at various concentrations, exhibited very strong antioxidant activity, which was almost equal to synthetic antioxidants (BHA & BHT). Therefore, PPE in oils, fats and other food products can safely be used as natural antioxidant to suppress lipid oxidation.
- Pihlanto et al. (2008) have also investigated the utilisation of potato wastes. Their findings imply that potato isolates and by-products from the potato industry comprise a source of bioactive compounds with ACE-inhibitory and antioxidant activities. The bioactivities of protein hydrolysates were most likely related to peptides and/or free amino acids liberated during digestion. However, the possibility of other unknown compounds should also be kept in mind. The phenolic compounds presumably induce the observed ACE-inhibitory and radical-scavenging potencies of the by-products – the pulp, liquid and peel fractions. The results of this study indicate that potato proteins are a promising source for the production of bioactive compounds as materials for developing functional foods with a positive impact on cardiovascular health. Further studies are still required to identify the active compounds and to investigate the *in vivo* antihypertensive activity of the hydrolysates.

Considering that potato peels are discarded as waste and not effectively utilised, these *in vitro* and animal trial results suggest the possibility that potato peel waste could be effectively employed as an ingredient in health or functional food, to alleviate oxidative stress. However, comprehensive studies need to be conducted to ascertain the *in vivo* safety of such extracts in experimental animal models.

6 Conclusions

Potatoes are a constituent of many diets. Nutritionists have identified several positive aspects of potatoes, but negative attributes have also often been emphasised and in some cases have given the potato bad press. Therefore, when considering the healthiness of the potato it is important to take into account all the new knowledge about natural constituents and food-borne substances. Many reviews of the nutritional benefits of potatoes (e.g. Finotti et al. 2006; Haase 2008) consider three main aspects: carbohydrates, toxins (glycoalkaloids and acrylamide) and antioxidants. The balance between these components is important. It has been the carbohydrate content that has given the potato much negative press. However, the glycaemic load is not a very relevant criterion for healthy subjects. In fact, studies have shown that potatoes are satiating and may have benefits for metabolic syndromes including diabetes and obesity. Many of the health benefits of potatoes are due to their antioxidant components. Antioxidants in potato include vitamin C, phenolics and carotenoids and are several-fold higher in coloured cultivars compared to traditional white-fleshed cultivars. South American germplasm shows great potential for developing varieties with high antioxidant activity.

Consumers have become increasingly aware of potential health benefits from diets rich in fruits and vegetables. While potato has not yet surfaced as a headline-grabber in this respect, there is increasing evidence that some genotypes may possess health attributes that warrant attention. This is particularly relevant, as potatoes are consumed much more regularly and in higher amounts than fruit and other vegetables that are often touted for their exceptionally high antioxidant activity. Plant breeders rely on germplasm biodiversity to advance their programmes and are also acutely aware of current marketing trends that relate to health attributes. In this regard there is considerable potential to increase the health benefits of potatoes further by breeding for increased nutrient and phytochemical content, particularly some minerals, such as zinc and iron, and antioxidants, such as phenolics and carotenoids. Coloured potato varieties in particular have added health benefits over white tubers and can make a significant contribution to antioxidants in the human diet along with other valuable nutrients.

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