

Phytochemical Profiles of Potato and their Roles in Human Health and Wellness

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ABSTRACT

This review provides updated information related to the chemistry, biochemistry and biological activities of the major phytochemicals including carotenoids, anthocyanins, flavonoids, phenolic acids in potato (*Solanum tuberosum* L.). The antioxidant activities of these phytochemicals, either in the form of extracts or purified states were discussed. The health beneficial effects of potato phytochemicals, particularly polyphenols and carotenoids and their roles in reducing risks associated with cancer, cardiovascular disease and diabetes were also discussed.

Keywords: anthocyanins, anti-cancer, antioxidants, cardiovascular disease, carotenoids, diabetes, flavonoids, health benefits, phenolic acids, phytochemicals, potato, *Solanum tuberosum* L.

Abbreviations: DPPH, 1,1-diphenyl-2-picrylhydrazyl; GI, glycemic index; LDL, low density lipoprotein; ORAC, oxygen radical absorbance capacity system; ROS, reactive oxygen species; TEAC, trolox equivalent antioxidant capacity; TOSC, oxyradical scavenging capacity

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INTRODUCTION

The concept that food and medicine share the same origin can be traced back as early as 1000 BC. Traditional medicines are mostly of plant origin, and some such as herbs and certain mushrooms are directly or indirectly used as food or in food preparations. Many food plants are packed with bioactive phytochemicals which in recent years have been proven to play a crucial part in maintaining good health and preventing diseases of humans. Fruits and vegetables in particular are rich in phytochemicals, especially those with antioxidant activity. Polyphenols and carotenoids are two most important phytochemical antioxidant groups in vegetables. They are plant secondary metabolites not essential to human health, but have been found to contribute significantly to the risk reduction of human chronic diseases such as cancer and heart disease. One-third of all cancers are

considered avoidable by changing dietary habits alone (Milner 1994). Cardiovascular and heart diseases are also found to be influenced by diet (Duthie and Brown 1994). These chronic degenerative diseases have been linked to oxidative stresses caused by excessive free radicals and reactive oxygen species (ROS) such as the superoxide anion ($\text{O}_2^{\bullet-}$), hydroxyl radical (OH^{\bullet}) and the peroxy radical (ROO^{\bullet}), which react with vital biomolecules such as lipids, proteins and nucleic acids (e.g. DNA), causing the aforementioned major health problems. Free radicals and ROS are neutralized by antioxidant defence mechanisms.

Potato (*Solanum tuberosum* L.) is one of the most important staple food crops of the world among wheat, rice, and maize. It provides humans with good quality macronutrients such as carbohydrates and proteins. However, potato provides more than these essential nutrients. Potatoes showed strong antioxidant capacity among most frequently

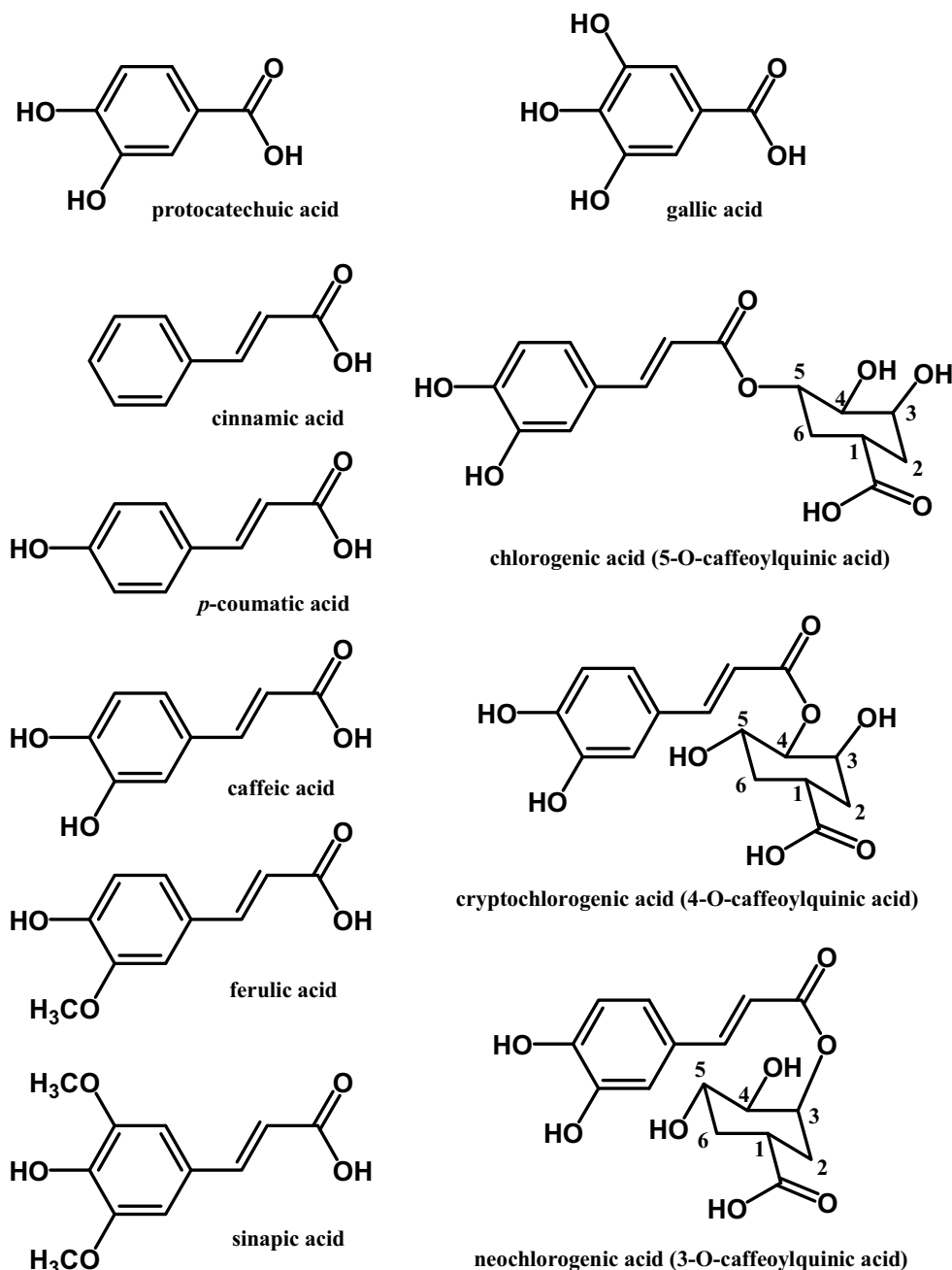


Fig. 1 Phenolic acids and derivatives from potato.

consumed vegetables (Wu *et al.* 2004). A Russet potato, one of the favorite varieties in North America, contains the second highest antioxidants only slightly after broccoli in its hydrophilic antioxidant capacity (Wu *et al.* 2004). Potato, as a staple crop, is well suited to delivering such antioxidative phytochemicals, and recent development in pigmented potatoes containing high concentrations of anthocyanins and carotenoids has generated even more interests in the potential health promoting role of potato.

In this review, the author will examine the phytochemical compositions of potato and discuss how they contribute to the antioxidant capacity, and ultimately to human health and wellness. The term “antioxidative phytochemicals” or “phytochemical antioxidants” used in this paper does not include those essential antioxidants such as ascorbic acid (vitamin C). These phytochemicals are plant secondary metabolites, and their original biological functions in plants are primarily for the defense against plants’ own enemies (insects and diseases) (Friedman 1997). Of the phytochemicals produced by the potato plants, the author will only focus on those with strong antioxidant capacities in the consumable part, i.e. the tuber. It is the author’s in-

tention to summarize the scattered literature on specific groups of phytochemicals so readers have a general picture of the phytochemical composition and the health benefits of potato. Phytochemicals with adverse effect such as the glycoalkaloids found in potato will not be the subject of the discussion in this review.

PHYTOCHEMICALS IN POTATO

Several different groups of phytochemicals have been reported for potato tubers, among them, polyphenols and carotenoids are the two most diverse and predominant. Polyphenols are a collective term for several sub-groups of phenolic compounds including phenolic acids, flavonoids and anthocyanins. Typical phytochemicals and their concentrations are shown in **Figs. 1-7** and **Table 1**. Caution should be taken in interpretation of the data in **Table 1** because different units have been used in reporting the concentrations of the same phytochemicals. Not all compounds are detected or reported in any single studies. Further more, quantitative data is not always available even in recent papers (**Table 1**). Nonetheless, several individual com-

Table 1 Phytochemical contents in potato tubers.

Phytochemicals	Concentrations	References	Notes
Phenolic acids	30-900 µg/g FW	1	
Benzoic acids	0.17 mg/g peel extract DW	2	Mainly gallic acid and protocatechuic acid
Cinnamic acids	0-4000 µg/g FW; 304-13807 µg/g DW, 72 mg/100 g DM; 9.3 mg/100 g FW; 11.5 mg/100 g FW	1, 3, 4, 5, 6	Mainly chlorogenic acid.
Flavan-3-ols			
Catechin	11.4 mg/100 g FW	6	Major flavan-3-ol
Epicatechin	trace	1	
Flavonols			
Quercetin-3-rutinoside (rutin)	0-196 µg/g DW	3	
Kaempferol-3 rutinoside	0-227 µg/g DW	3	
Anthocyanins	0-16330 µg/g DW	3	Mainly in red or purple fleshed potatoes
Plargonidins	200-2000 µg/g FW	1	
Petunidins	1000-2000 µg/g FW	1	
Delphinidins	NQ	1	
Cyanidins	NQ	1	
Peoidins	20-400 µg/g FW	1	
Malvidins	20-5000 µg/g FW	1	
Tocopherols			
α-Tocopherol	2.7-20.8 µg/g DW	3	
Carotenoids			Mainly in yellow and orange-fleshed potatoes
β-Carotene	0-2.0 µg/g DW	3	
Cryptoxanthin	0.3-5.8 µg/100 g FW	8	
Lutein	1.1-17.7 µg/g DW; 16.8-48.9 µg/100 g FW	3, 8	Major
Zeaxanthin	Trace-17.7 µg/g DW; 2.7-107.4 µg/100 g FW	3, 8	Major
Violaxanthin	0.1-13.3 µg/g DW; 4.9-70.6 µg/100 g FW	3, 8	Major
Antheraxanthin	0-10.0 µg/g DW; 7.7-66.1 µg/100 g FW	3, 8	Major
Neoxanthin ^a	0.4-5.3 µg/g DW	3	
Phytic acid	0.11-0.27% DW	7	
Folic acid	521-1373 ng/g DW; 125 µg/100 g FW	9, 10	

FW, Fresh weight; DW, Dry weight; NQ, not quantified. Trace, <0.4 µg/g DM.

1. Lewis *et al.* 1998; 2. Rodriguez de Sotillo *et al.* 1994b; 3. Andre *et al.* 2007; 4. Griffiths and Bain 1997; 5. Friedman 1997; 6. del Mar Verde Méndez *et al.* 2004; 7. Philipp *et al.* 2004; 8. Breithaupt and Bamedi 2002; 9. Goyer and Navarre 2007; 10. McKillop *et al.* 2002.

pounds or groups of compounds are universal in all potato varieties, or different types of potatoes. For example, chlorogenic acid is the main phenolic acid found in all potato tubers; anthocyanins are only found in red and purple-fleshed potatoes; carotenoids are only found in yellow and orange-fleshed potatoes (Table 1).

Polyphenols

Phenolic acids

The major phenolic acids in potato are cinnamic acid and its derivatives, although benzoic acids such as gallic and protocatechuic acid are also found to be present. The phenolic acid profile in potato was reported to contain chlorogenic acid (50.3%) caffeic acid (41.7%), gallic acid (7.8%), and protocatechuic acid (0.21%) (Rodriguez de Sotillo *et al.* 1998). In some cases, chlorogenic acid constitutes up to 90% of the total phenolic content (Friedman 1997). Fig. 1 shows the chemical structures of potato phenolic acids.

Phenolic compounds are distributed throughout the potato tuber, but the peel and adjoining tissues contain about 50% of the total with the remainder decreases in concentration from the outside toward the center of potato tubers (Hasegawa *et al.* 1966). Although other phenolic acids are found in potato, the majority are cinnamic acid derivatives (Fig. 1). Like in other plants, these benzoic acids or cinnamic acids are synthesized in potato via the shikimate pathway (Friedman 1997; Herrmann 1995; Schmidt and Amrhein 1995). Chlorogenic acid (5-*O*-caffeoylquinic acid) is an ester formed between the carboxyl group of caffeic acid and the 5-hydroxyl group of quinic acid (Fig. 1). The hydroxyl group at 4- or 3- position of quinic acid also forms esters with caffeic acid, resulting in isomers cryptochlorogenic acid and neochlorogenic acid, respectively, i.e. 4-*O*- or 3-*O*-caffeoylquinic acid (Fig. 1).

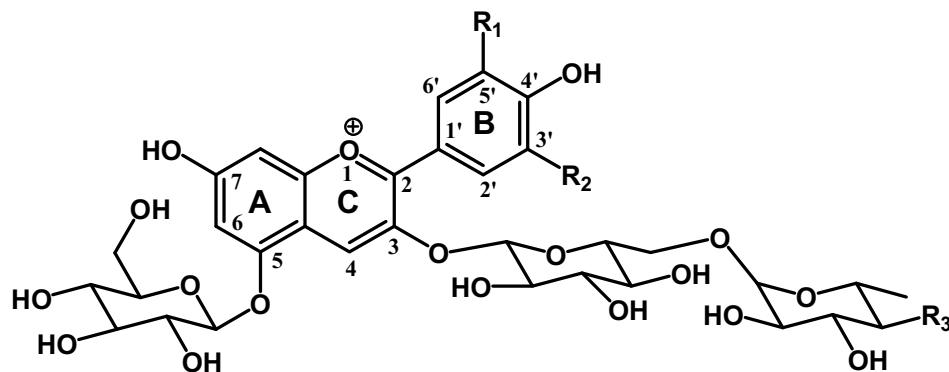
Phenolic acids play a significant part in the first line defense mechanism of potato against insects and pathogenic microbes. Compounds such as chlorogenic acids are parti-

cularly important in the development of host resistance of potato against phytopathogens such as *Erwinia* spp. (Friedman 1997). Phenolic compounds can either directly function as antimicrobials by inhibiting bacterial growth, or indirectly by affecting other biochemical processes of both the host plant (potato) and the pathogen in favor of the plant (Friedman 1997).

In foods, phenolic acids are found in nearly all plant-based diets, particularly fruits, vegetables and whole grains (Tsao and Akhtar 2005; Kim *et al.* 2006). Phenolic acid concentrations of the potato tuber are found to be in the range of 1-171 mg/100 g fresh weight (FW), but the highest amounts are often present in red and purple potatoes (del Mar Verde Mendez *et al.* 2004; Im *et al.* 2008). A normal potato peel, however, can contain as much as 177 mg gallic acid equivalent /100 g FW peel (Makris *et al.* 2007). The total phenolic content of potato depends on both genetic and environmental factors, however, other factors such as extraction and analytical methods may also influence the outcome of the results. A large portion of the phenolic acids are not extractable by conventional solvents, leading to significant underestimation of the total phenolics available in potato (Chu *et al.* 2002; Nara *et al.* 2006). Chu *et al.* (2002) hydrolyzed the insoluble residue of potato, and released nearly 40% more total phenolics. Nara *et al.* (2006) studied the bound phenolics in both the flesh and peel of potato, and found that the peel not only contained significantly higher concentrations of free phenolics (1.68 vs. 2.66 mg ferulic acid equivalent/g dry weight (DW) in the flesh and peel, respectively), but also in bound phenolics (0.02 and 1.26 mg ferulic acid equivalent/g DW in the flesh and peel, respectively). The major bound phenolic compound was identified as ferulic acid (Nara *et al.* 2006). Similar results were found by Leo *et al.* (2008).

Catechins

Catechins belong to flavan-3-ols which are often found in tea or fruits such as apple and grape (mainly in the skins)

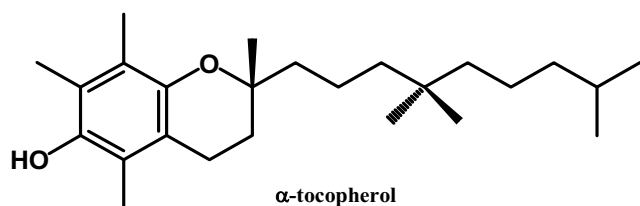


Anthocyanins

petunidin-3-rutinoside-5-glucoside	OCH ₃	OH	OH
petunidin-3-caffeoyl-rutinoside-5-glucoside	OCH ₃	OH	Caffeic acid
petunidin-3-coumaroyl-rutinoside-5-glucoside	OCH ₃	OH	<i>p</i> -Coumaric acid
petunidin-3-feruloyl-rutinoside-5-glucoside	OCH ₃	OH	Ferulic acid
delphinidin-3-coumaroyl-rutinoside-5-glucoside	OH	OH	<i>p</i> -Coumaric acid
cyanidin-3-coumaroyl-rutinoside-5-glucoside	OH	H	<i>p</i> -Coumaric acid
peonidin-3-rutinoside-5-glucoside	OCH ₃	H	OH
peonidin-3-coumaroyl-rutinoside-5-glucoside	OCH ₃	H	<i>p</i> -Coumaric acid
malvidin-3-rutinoside-5-glucoside	OCH ₃	OCH ₃	OH
malvidin-3-coumaroyl-rutinoside-5-glucoside	OCH ₃	OCH ₃	<i>p</i> -Coumaric acid

R₁ R₂ R₃

Fig. 4 Anthocyanins in red and purple-fleshed potatoes.



α -tocopherol

Fig. 5 α -Tocopherol is the major vitamin E found in potato.

however owing to their phenolic feature and the importance as antioxidants in human health, they have been included in discussions of this paper (Fig. 5). Potatoes contain very little fat-soluble content thus only minimum amount of tocopherols, mainly α -tocopherol (3-21 $\mu\text{g/g}$ DW) was found in potato tubers (Andre *et al.* 2007).

Carotenoids

In addition to the pigments in red and purple potatoes, some potatoes such as the Yukon Gold variety have yellow-colored flesh. The yellow pigments in these potatoes are carotenoids, and depending on the variety, the total carotenoid content in yellow fleshed potatoes can be as high as 54 $\mu\text{g/g}$ DW (Andre *et al.* 2007). In general, the total carotenoid contents range from 50-100 $\mu\text{g}/100$ g FW in white-fleshed varieties to 2000 $\mu\text{g}/100$ g FW in deeply yellow to orange-fleshed cultivars (Brown 2005). Different carotenoids have been found in yellow-fleshed potatoes (Fig. 6). Al-Saikhan *et al.* (1994) analyzed 10 yellow and orange fleshed Texas grown potato varieties and found lutein and zeaxanthin to be the major carotenoids. The orange-fleshed varieties were much higher in both compounds at 120-148 and 1242-2055 $\mu\text{g}/100$ g FW, respectively for lutein and zeaxanthin. Other carotenoids have been reported in recent studies (Breithaupt and Bamedi 2002; Tsao and Yang 2006). Breithaupt and Bamedi (2002) identified 4 major (violaxanthin, antheraxanthin, lutein, and zeaxanthin; total concentration 175 $\mu\text{g}/100$ g FW) and 3 minor carotenoids (neoxanthin, β -cryptoxanthin, and β -carotene). They also found carotenoid esters at 41-131 $\mu\text{g}/100$ g FW. We found lutein

to be the predominant carotenoid in an Ontario-grown Yukon Gold potato at 400 $\mu\text{g}/100$ g FW, and certain Yukon Gold potatoes contained up to 350 μg violaxanthin/100 g FW (Tsao and Yang 2006).

Phytic acid and folic acid

Phytic acid or inositol hexaphosphate (InsP_6 or IP_6) exists in many foods, particularly in grains and oil seeds (Fig. 7). Potatoes (*S. tuberosum*) contained 0.035-0.073% phytate on a wet basis (Phillippy *et al.* 2003), and 0.111% to 0.269% of dry weight (Phillippy *et al.* 2004). Despite the anti-nutrient image of phytic acid due the chelating ability to important minerals such as calcium, magnesium and iron (Porres *et al.* 2004), IP_6 or its lower phosphorylated forms (IP_{1-5}) has been shown in recent years to possess several health beneficial properties such as antioxidant (Graf and Eaton 1990), anti-cancer (Shamsuddin *et al.* 1997; Zhang and Song 2005), hypocholesterolemic (Lee *et al.* 2005; Lee *et al.* 2006) and hypolipidemic effects (Lee *et al.* 2007).

Folic acid (vitamin B9) is an essential micronutrient in the human diet (Fig. 7). A deficiency of folates in the diet is associated with the increased risk of neural tube defects, cardiovascular diseases, anemia, and some cancers (Scott 1999; Bailey *et al.* 2003; Finglas *et al.* 2006). Even though folic acid is found in most fruits, vegetables and grains, and is fortified in breakfast cereals in some developed countries, current folate intake is suboptimal in most of the world's populations (Scott *et al.* 2000). Potato contains 521 to 1373 ng/g DW of folate which was genotype and location dependent (Goyer and Navarre 2007). The highest folate concentration was found mostly in color-fleshed potatoes, and the skin contained 30% higher folate concentrations than the flesh (Goyer and Navarre 2007).

FACTORS AFFECTING PHYTOCHEMICALS IN POTATO

The phytochemical composition of potato tuber can be affected by several factors, including genetics, growth period, growing season, geographic location, post-harvest storage and processing conditions (Reddivari *et al.* 2007a). Detailed

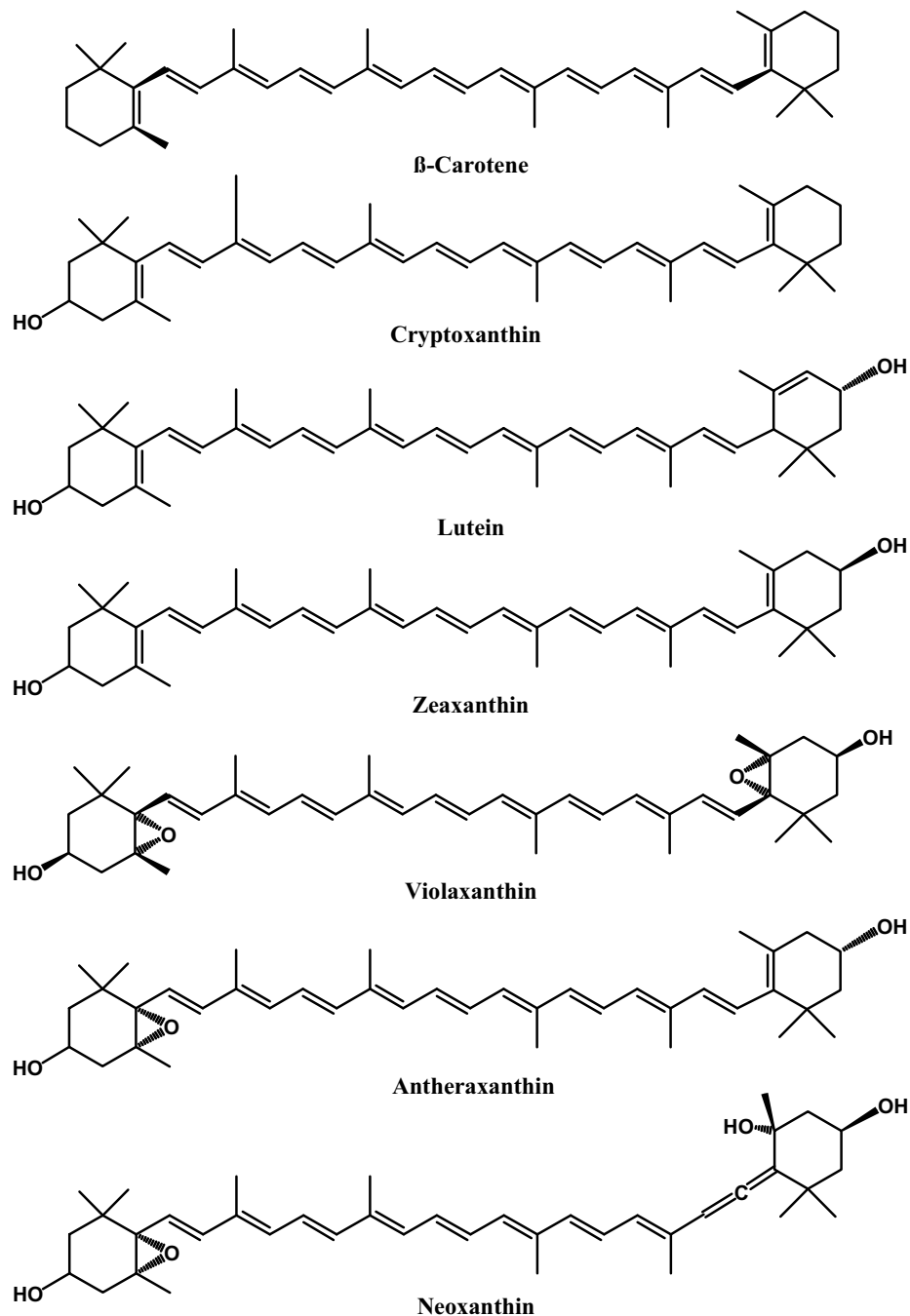


Fig. 6 Carotenoids in yellow and orange-fleshed potatoes.

discussions on these factors are beyond the scope of this mini review, however, the author would like to analyze the effect of food processing conditions on the quantity and quality of potato phytochemicals, as these conditions directly relate to what we consume as food. Because potato is consumed cooked, the effect of cooking or processes involved in food preparations on the phytochemical micro-nutrients is important.

Irradiation of potato peel with γ rays at 150 Gy was found to significantly increase the total phenolic contents by 26% (Kannat *et al.* 2005). The irradiation had even greater impact on the major phenolic acid, chlorogenic acid (increased by 60%). Physical damage such as fresh-cutting and subsequent cold storage can stimulate the production of flavonols such as quercetin glycosides in potato tubers, however, domestic cooking such as boiling, microwaving, and frying caused a partial loss of the flavonols, (Tudela *et al.* 2002). Similar results were found for caffeic acid derivatives in the same study.

Most recently Barba *et al.* (2008) studied the influence

of boiling and microwave baking on the amount of several phenolic acids in peeled and non-peeled potatoes (*S. tuberosum* cv. 'Agria'). They found that in general, greater loss was found in peeled potatoes regardless of the heating method. Loss of phenolics can be reduced by using less time in combination with appropriate power input during microwave baking. Reyes and Cisneros-Zevallos (2007) studied the effect of pH and heating on the stability of anthocyanins extracts from purple- and red-flesh potatoes. They found that potato anthocyanins had the potential to be used as natural colorants for the food industry, particularly the red-fleshed potato anthocyanins, which was found to be more stable than that from the purple-fleshed potato.

Phillippy *et al.* (2004) studied the phytate content in raw and cooked potatoes, and found that potato phytate was generally stable during common home cooking procedures such as boiling, baking and microwaving. Processed foods such as French fries, dehydrated potato flakes and potato chips were also found to retain much of their original phytate in the same study. Folic acid in potato seemed less

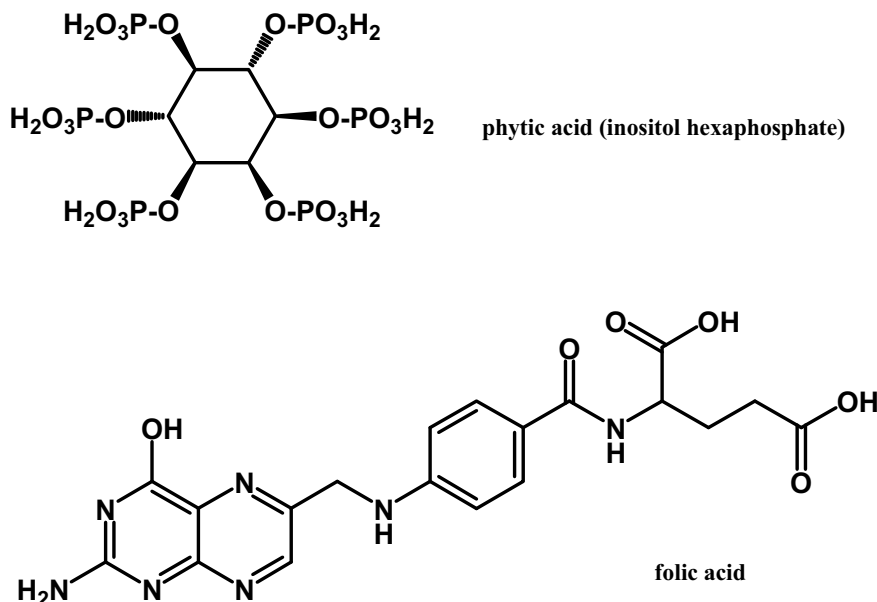


Fig. 7 Structures of phytic acid (inositol hexaphosphate) and folic acid.

affected by cooking. Boiling for 60 min did not result in a significant change in folate content of whole potatoes (125.1 and 102.8 mg/100 g for raw and boiled potato, respectively), nor in that of potatoes with or without skin during boiling (McKillop *et al.* 2002).

Cooking significantly increased the hydrophilic antioxidant capacity of potato, but significantly reduced the lipophilic antioxidant capacity (Wu *et al.* 2004), however, it was unclear whether or not the increase was caused by release of more hydrophilic antioxidants such as phenolics, or the decrease was caused by degradation of antioxidants such as carotenoids and tocopherols.

EFFECT OF PHYTOCHEMICALS ON HUMAN HEALTH AND WELLNESS

Many chronic diseases such as cancer, cardiovascular and coronary heart disease, diabetes and Alzheimer's disease have all been associated with the excessive free radicals and reactive oxygen species (ROS) (Willcox *et al.* 2004). These diseases have been the leading cause of death in industrialized countries. Research has also shown that both Type 1 and Type 2 diabetes are at least partially associated with oxidative stresses caused by free radicals (Maritim *et al.* 2003; Willcox *et al.* 2004). Neurodegenerative disorders such as Alzheimer's disease and other degenerative diseases, particularly age-related macular degeneration have also been associated with free radical damages (Hughes 1999; Christen 2000; Willcox *et al.* 2004).

Antioxidants thus play a significant role in alleviate these diseases as they can neutralize the act of free radicals and ROS. Ample evidence has been accumulated in recent years supporting strongly the positive correlation between dietary intake of phytochemical antioxidants and chronic diseases (Block *et al.* 1992; Anderson *et al.* 2000; Liu 2003; Willcox *et al.* 2004). Many of the studies have attributed the disease-fighting capability to the phytochemicals with antioxidant capacity. Also, although individual or groups of phytochemical compounds have been studied separately, increasingly more evidence suggests that it is a joint effort among the phytochemical antioxidants of different chemical genres in fighting the diseases, either additively or synergistically (Liu 2003).

Antioxidant capacity

Antioxidants play significant roles in preventing oxidation of food and in maintaining good human health. Potato peel

extracts indeed were found to prevent soybean oil oxidation, and phenolic acids (chlorogenic and protocatechuic) were the main active antioxidants (Onyeneho and Hettiaachy 1993). Similar results were obtained in other studies (Rodriguez de Sotillo *et al.* 1994a, 1994b; Al-Saikhani *et al.* 1995). These results suggest that potato peel extracts can be used as a potential preservative for the prevention of oxidative rancidity of oil or fat-rich foods. On the other hand, recent research discoveries suggest that the antioxidant capacity of potato phytochemicals may be of more interest in promoting human health.

Vinson *et al.* (1998) examined the total phenolic content of 23 commonly consumed vegetables and evaluated the antioxidant quality by the inhibition of low density lipoprotein (LDL) oxidation mediated by cupric ions. They developed an antioxidant index measuring both the quantity and the quality of antioxidants present, and found that potato contained the lowest quantity of total and free dry weight phenolics, yet had the second best antioxidant quality based on the total phenolic contents (Vinson *et al.* 1998). Phenolic acids are found in many dietary sources including fruits, vegetables and whole grains, and have been shown physiological and pharmacological functions (Shahidi and Wanasundara 1992; Mukhtar *et al.* 1994). In addition to the strong radical scavenging effect and antioxidant capacity, they have also been found to act as effective anti-inflammatory, anti-allergic, anti-mutagenic agents, and good protectant against oxidative DNA damage (Nardini *et al.* 1998; Tseng *et al.* 1998; Lodovici *et al.* 2001, 2003). Among the most important dietary benzoic acids and cinnamic acids, caffeic acid, ferulic acid and gallic acid were found to exhibit over 85 and 60% inhibitory effect toward UVB-induced oxidation in erythrocytes and LDL, respectively (Hsieh *et al.* 2005).

Andre *et al.* (2007) analyzed several major phytochemical groups in 74 native Andean cultivars including total phenolic, total carotenoid, and total vitamin C contents. A high linear correlation between the antioxidant capacity measured by the hydrophilic oxygen radical absorbance capacity system (H-ORAC) and the total phenolic content of potato was found. They concluded that such linear correlation suggests that the presence of the phenolic compounds, not the vitamin C, largely accounts for the hydrophilic antioxidant capacity of the potato tubers (Andre *et al.* 2007). However, the antioxidant capacity depends heavily on the assay system used. High H-ORAC value by the presence of phenolics only gives a partial view of the total antioxidant capacity of potato. For this reason, a lipophilic anti-

oxidant capacity system (L-ORAC) was developed and it was interesting to note that although cooking significantly increased the H-ORAC, it did the opposite to the L-ORAC value of potato (Wu *et al.* 2004).

Potato peel extracts rich in chlorogenic acid and caffeic acid showed excellent antioxidant activity as determined by β -carotene bleaching and radical scavenging activity of 1,1-diphenyl-2-picrylhydrazyl (DPPH). The antioxidant activity of the phenolics-rich extract was also found to be comparable to the synthetic food antioxidant butylated hydroxytoluene (BHT) in preventing lipid peroxidation of irradiated meat (Kannat *et al.* 2005). A linear correlation was also found between the total phenolic content and both the TEAC value (trolox equivalent antioxidant capacity) and the oxyradical scavenging capacity (TOSC) indicating phenolic acids are the major contributing phytochemicals to the total antioxidant capacity of potato (Leo *et al.* 2008). Nara *et al.* (2006) identified major phenolics in both free and bound forms and found the total amount of chlorogenic acid and caffeic acid in the free-form phenolics 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.

In potatoes with total carotenoids ranging from 35 to 795 $\mu\text{g}/100\text{ g FW}$, the lipophilic extract of potato flesh presented ORAC values ranging from 4.6 to 15.3 nmoles α -tocopherol equivalents per 100 g FW (Brown 2005). In red and purple potatoes with solidly pigmented flesh with levels of total anthocyanins ranging from 9 to 38 $\text{mg}/100\text{ g FW}$, ORAC ranged from 7.6 and 14.2 $\mu\text{mole}/\text{g FW}$ of Trolox equivalents (Brown 2005).

Phytic acid, although a minor phytochemical in potato, was found to be a strong antioxidant against lipid peroxidation (Graf *et al.* 1987). The study showed that phytic acid formed an iron chelate which greatly blocked iron-driven hydroxyl radical generation thus suppressed the lipid peroxidation. A similar mechanism of antioxidant activity was found by Midorikawa *et al.* (2001).

Anti-cancer activity

Despite the ample evidence that food phytochemicals contributes significantly to the lowered risks of cancer, only a handful studies have been conducted on the anti-cancer activity of potato phytochemicals. Kim *et al.* (1994) investigated the effect of potato extracts on the induction of glutathione *S*-transferase P-positive (GST-P+) altered hepatic foci in newborn Sprague-Dawley rats given single treatment with ^{60}Co gamma irradiation. The potato extract was given at a dose of 2 mg/ml in drinking water for 3 weeks. The extract decreased significantly the number, area and D_{max} of GST-P+ hepatic foci compared to the corresponding control. They therefore concluded that potato extracts can be used as radio-protective agent against carcinogenic gamma irradiation (Kim *et al.* 1994).

Phenolic extracts from four specialty potato cultivars and their organic acid, phenolic acid and anthocyanin fractions were examined against two prostate cancer cell lines, LNCaP (androgen dependent) and PC-3 (androgen independent) in a study by Reddivari *et al.* (2007b). Potato extracts and their anthocyanin fractions inhibited cell proliferation and increased the cyclin-dependent kinase inhibitor p27 levels, and induced apoptosis in both LNCaP and PC-3 cells. The cytotoxic activities of potato extract and the anthocyanin fraction in cancer cells were found to be due to activation of caspase-independent apoptosis (Reddivari *et al.* 2007b). Similar activity was shown against stomach cancer both *in vitro* and *in vivo* (Hayashi *et al.* 2006). Anthocyanins prepared from colored potatoes induced apoptosis in cultured human stomach cancer KATO III cells, and feeding the cooked red potato or purple potato, or 1% solution of red or purple potato anthocyanin extract significantly suppressed the growth of mouse stomach cancer as compared with the feeding with white-fleshed Irish Cobbler potato (by 37-48%). They concluded that anthocyanins were responsi-

ble for the anti-cancer activity (Hayashi *et al.* 2006).

Phenolic acids such as chlorogenic acid and caffeic acid have been reported to protect cells from carcinogens. The exact mechanisms of the protective property of phenolic acids are not known, however, deactivation through binding to the carcinogen or free radicals may be possible explanations for the protective effect of potato chlorogenic acid and caffeic acid esters (Camire *et al.* 1995; Nakayama *et al.* 1996). Chu *et al.* (2002) suggested that although the antioxidant activity and anti-proliferation of cancer cells by potato extracts were not as strong as by other vegetables, due to the high bound phenolic content, potato could release half of their phenolics locally in the colon, thus contributing to the prevention of colon cancer. Most recently, Leo *et al.* (2008) showed that proliferation of human mammalian cancer (MCF-7) cells was significantly inhibited in a dose-dependent manner after exposure to potato extracts.

Phytic acid IP_6 and its lower phosphorylated forms (IP_{1-5}) as well as inositol (Ins) are important in regulating vital cellular functions such as signal transduction, cell proliferation and differentiation in mammalian cells (Shamsuddin *et al.* 1997; Zhang and Song 2005). A striking anti-cancer action of IP_6 has been demonstrated both *in vivo* and *in vitro*, which is based on the hypotheses that exogenously administered IP_6 may be internalized, dephosphorylated to IP_{1-5} , and inhibit cell growth (Shamsuddin *et al.* 1997). There is additional evidence that Ins alone may further enhance the anti-cancer effect of IP_6 . Besides decreasing cellular proliferation, IP_6 also causes differentiation of malignant cells often resulting in a reversion to normal phenotype (Shamsuddin *et al.* 1997).

Midorikawa *et al.* (2001) monitored the formation of 8-oxo-7,8-dihydro-2'-deoxyguanosine in cultured cells treated with an H_2O_2 -generating system, and found a strong inhibitory effect of phytic acid on DNA damage by H_2O_2 and Cu(II).

Cardiovascular and heart diseases

Oxidation of LDL cholesterol is linked to atherosclerosis, arterial blockage, heart attacks and strokes. Due to the antioxidative nature of potato phytochemicals, and the fact that certain potatoes contain very high levels of these antioxidants, consumption of good quality potato can contribute to the prevention of LDL oxidation, therefore lower the risk of cardiovascular and heart diseases. Vinson *et al.* (1998) indeed showed that potato extracts rich in phenolics effectively prevented the Cu-induced LDL oxidation. *In vivo* study using rats showed that consumption of potato peel induced a lowering of cholesterol (Lazarov and Werman 1996). Even though the authors in the *in vivo* study ascribed this to the fibre content of the peel, as discussed above, the peel contains a variety of phytochemicals which are strong antioxidants that may contribute to the observed effect.

Robert *et al.* (2006) investigated in the rat the effect of a potato-enriched diet on lipid metabolism and antioxidant protection, and found that feeding 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%), and significantly improved the antioxidant status in plasma. These effects could be interesting for prevention of cardiovascular disease. Although the authors did not attribute their finding to any specific bioactive components, they did suggest that a combination of dietary fibre and phenolic content should be examined (Robert *et al.* 2006). A subsequent study by the same group indeed showed that a combination of different antioxidant micronutrients enhanced the antioxidant defences and improved lipid metabolism in rats as compared with starch or sucrose fed rats (Robert *et al.* 2008).

Similarly, Han *et al.* (2007) examined the antioxidant effects of polyphenol/anthocyanin-rich potato (*S. tuberosum* cv. 'Shadow-Queen') flakes in male rats fed a high-cholesterol diet. The thiobarbituric acid reactive substance (TBARS) levels in the serum and liver of the Shadow-

Queen potato were significantly lower than those in the control and the white-fleshed potato flake groups. The serum urate levels were significantly lower, the hepatic glutathione levels, and activities of hepatic glutathione reductase and glutathione-S-transferase were significantly higher than in the control and the white-fleshed potato groups as well. The authors suggested that the purple potato flake diet containing polyphenols/anthocyanins may play an important role in the protection against adverse effects related to oxidative damage in rats fed a high-cholesterol diet.

Shih *et al.* (2008) showed carotenoids such as β -carotene and canthaxanthin may also play an important role in altering the pro-oxidation and antioxidation balance and suppressed cholesterol-induced oxidative stress via modulation of antioxidant system and cholesterol metabolism in a similar study. This implies that yellow or orange-fleshed potatoes may act similarly, and together with the polyphenols/anthocyanins in red or purple-fleshed potatoes, carotenoids may be as important in lipid metabolism and in preventing cardiovascular diseases.

Diabetes

To date, several epidemiological studies have described associations between the dietary glycemic index (GI) and risks of type 2 diabetes (Salmeron *et al.* 1997a, 1997b; Hodge *et al.* 2004; Liu *et al.* 2004; Schulze *et al.* 2004). Furthermore, recent weight-loss intervention studies suggest that a diet with a low GI may represent a promising alternative to a low-fat diet (Slabber *et al.* 1994; Spieth *et al.* 2000; Ebbeling *et al.* 2003). Several prominently cited studies have reported that potatoes are characterized by a high GI value which leads to increased incidence of type 2 diabetes (Soh and Brand-Miller 1999; Foster-Powell *et al.* 2002; Montonen *et al.* 2005; Halton *et al.* 2006). For this reason potatoes have been ranked among the foods to be eaten sparingly, and sometimes given unjustified labels that all potatoes have a high GI (Buyken and Kroke 2005). When examined closely, however, contradictory results to the above have been reported in the past. Some research results showed no association between potato consumption and diabetes (Hodge *et al.* 2004; Liu *et al.* 2004) and others an association with lower 2-h glucose values during follow-up (Feskens *et al.* 1995). Intake of potato and its effect on glucose metabolism also depends on the gender and the amount consumed (Ylönén *et al.* 2007). Many factors can affect the GI values of potatoes. Cooking method, processing, variety and the composition of the meal (Lunetta *et al.* 1995; Foster-Powell *et al.* 2002; Fernandes *et al.* 2005) can all affect the GI values. Methods such as baking and microwave cooking tend to lead to high GI values whereas conventionally boiled potatoes appear to have a GI value on average below 70. The values of conventionally boiled potatoes again can vary considerably depending on the genetics (Buyken and Kroke 2005).

The physicochemical properties of carbohydrates certainly play significant parts in maintaining the GI of potatoes, however, other phytochemicals in the potato tubers may also contribute significantly to lowering GI. Phytochemicals, particularly phenolic antioxidants in common foods have been shown to strongly inhibit the carbohydrate digestive enzymes such as α -amylase and α -glucosidase activities, suggesting that these phytochemicals can be potentially contributing to the inhibition of carbohydrate breakdown and control of GI of food products (Matsui *et al.* 2001; McCue *et al.* 2005; Nasu *et al.* 2005). Worthy mentioning is the anti-hyperglycemic effect of acylated anthocyanins in purple sweet potatoes (*Ipomoea batatas*). Although the purple sweet potatoes belong to a different family than the purple-fleshed common potatoes (*S. tuberosum*), the acylated anthocyanin composition are similar (Matsui *et al.* 2002; Lachman and Hamouz 2005). In a subsequent *in vivo* study, Matsui *et al.* (2002) showed that enzyme inhibitory activity against α -glucosidase led to significant reduction of blood glucose level of male 8-week-old Sprague-Dawley

rats administered with a single dose of peonidin 3-*O*-[2-*O*-(6-*O*-*E*-feruloyl- β -D-glucopyranosyl)-6-*O*-*E*-caffeoyl- β -D-glucopyranoside]-5-*O*- β -D-glucopyranoside isolated from the purple sweet potato tubers. A reduction of serum insulin secretion was also observed corresponding to the decrease in blood glucose level. They then suggested that the anti-hyperglycemic effect of the anthocyanins was achieved by maltase inhibition, not by sucrase or glucose transport inhibition at the intestinal membrane (Matsui *et al.* 2002). Potato polyphenols have also been shown to negatively correlate with the blood glucose response (GI value) of normal and diabetic subjects in a controlled human clinical study (Thompson *et al.* 1983). The inhibitory activity of polyphenols against key enzymes such as α -amylase, α -glucosidase and phosphorylase that are important in starch and sugar metabolism is considered to be important in lowering the GI, and more importantly in reducing risks associated with diabetes.

Potatoes present a very significant source of antioxidants in human nutrition, e.g. among fruits and vegetables they insure an average daily intake of about 64 mg polyphenols per capita in the U.S.A. and occupy the second place after tomatoes (Al-Saikhan *et al.* 1995). Polyphenol-rich potatoes, particularly those containing high concentrations of anthocyanins will therefore play an important role in reducing the risks of diabetes because of the advantage of potato being a staple vegetable food. With more research focused on developing potato varieties with high anthocyanin content and on appropriate growing conditions for the enhancement of natural pigment and antioxidant yields, purple- and red-flesh potatoes can potentially be the favorite of health-conscious consumers and the food and nutraceutical industry (Brown *et al.* 2003).

CONCLUSION

Potatoes (*Solanum tuberosum* L.), being one of the most important staple food crops of the world, contains diverse biologically active phytochemicals, in addition to carbohydrates and proteins as major source of energy for human. Potatoes are a rich source of phenolic acids, flavonoids, folates, phytates and carotenoids. Anthocyanins are the major pigments responsible for the red and purple fleshed potatoes. In recent years, effort has been made in developing phytochemical-rich cultivars and in optimizing agronomic practices to increase the phytochemical content of potato, however, food processing conditions such as different heating methods can also significantly affect the phytochemical composition. As strong antioxidants, these phytochemicals, together with other essential nutrients such as tocopherols, have been shown in both *in vitro* and *in vivo* studies great potentials in human health. As antioxidants, they help fight the harmful free radicals and excess reactive oxygen species. Potato phytochemicals have been shown in both *in vitro* and *in vivo* studies to have anti-proliferation, anti-LDL peroxidation and GI lowering activities. These have significant implications in reducing the risks of cancer, cardiovascular diseases and diabetes. Reviewing the phytochemical composition of potato and the roles these bioactives play in human health and wellness, has led us to suggest that future research efforts should be made in developing phytochemical-rich varieties, particularly those deeply colored ones rich in phenolic acids, anthocyanins and carotenoids. Cooking or processing methods that maximize the retention of phytochemical nutrients should also be further examined, in addition to human clinical trials that help to understand how these phytochemicals are delivered and absorbed in our body.

REFERENCES

- Al-Saikhan MS, Howard LR, Miller JC, Jr. (1995) Antioxidant activity and total phenolics in different genotypes of potato (*Solanum tuberosum* L.). *Journal of Food Science* **60**, 341-343
- Anderson JW, Hanna TJ, Peng X, Kryscio RJ (2000) Whole grain foods and heart disease risk. *American Journal of Clinical Nutrition* **19**, 291S-299S

- Andre CM, Oufir M, Guignard C, Hoffmann L, Hausman JF, Evers D, Larondelle Y (2007) Antioxidant profiling of native Andean potato tubers (*Solanum tuberosum* L.) reveals cultivars with high levels of β -carotene, α -tocopherol, chlorogenic acid, and petanin. *Journal of Agricultural and Food Chemistry* **55**, 10839-10849
- Bailey LB, Rampersaud GC, Kauwell GP (2003) Folic acid supplements and fortification affect the risk for neural tube defects, vascular disease and cancer: evolving science. *Journal of Nutrition* **133**, 1961S-1968S
- Barba AA, Calabretti A, d'Amore M, Piccinelli AL, Rastrelli L (2008) Phenolic constituents levels in cv. Agria potato under microwave processing. *Food Science and Technology* **41**, 1919-1926
- Block G, Patterson B, Subar A (1992) Fruit, vegetables, and cancer prevention: a review of the epidemiological evidence. *Nutrition and Cancer* **18**, 1-29
- Breithaupt DE, Bamedi A (2002) Carotenoids and carotenoid esters in potatoes (*Solanum tuberosum* L.): New insights into an ancient vegetable. *Journal of Agricultural and Food Chemistry* **50**, 7175-7181
- Brown CR (2005) Antioxidants in potato. *American Journal of Potato Research* **82**, 163-172
- Buyken AE, Kroke A (2005) Glycaemic index of potatoes: myth and reality from a European perspective. *British Journal of Nutrition* **94**, 1035-1037
- Camire ME, Zhao J, Dougherty MP, Bushway RJ (1995) *In vitro* binding of benzo(a)pyrene by extruded potato peel. *Journal of Agricultural and Food Chemistry* **43**, 970-973
- Christen Y (2000) Oxidative stress in Alzheimer's disease. *American Journal of Clinical Nutrition* **71**, 621S-629S
- Chu YF, Sun J, Wu X, Liu RH (2002) Antioxidant and antiproliferative activities of common vegetables. *Journal of Agricultural and Food Chemistry* **50**, 6910-6916
- del Mar Verde Méndez C, Rodríguez Delgado MÁ, Rodríguez Rodríguez EM, Romero CD (2004) Content of free phenolic compounds in cultivars of potatoes harvested in Tenerife (Canary Islands). *Journal of Agricultural and Food Chemistry* **52**, 1323-1327
- Duthie GG, Brown KM (1994) Reducing the risk of cardiovascular disease. In: Goldberg I (Ed) *Functional Foods – Designer Foods, Pharmafoods, Nutraceuticals*. Chapman & Hall, New York, pp 19-38
- Ebbeling CB, Leidig MM, Sinclair KB, Hangen JP, Ludwig DS (2003) A reduced-glycemic load diet in the treatment of adolescent obesity. *Archives of Pediatrics and Adolescent Medicine* **157**, 773-779
- Eichhorn S, Winterhalter P (2005) Anthocyanins from pigmented potato (*Solanum tuberosum* L.) varieties. *Food Research International* **38**, 943-948
- Fernandes G, Velangi A, Wolever TM (2005) Glycemic index of potatoes commonly consumed in North America. *Journal of the American Dietetic Association* **105**, 557-562.
- Feskens EJ, Virtanen SM, Räsänen L, Tuomilehto J, Stengård J, Pekkanen J, Nissinen A, Kromhout D (1995) Dietary factors determining diabetes and impaired glucose tolerance: a 20-year follow-up of the Finnish and Dutch cohorts of the Seven Countries Study. *Diabetes Care* **18**, 1104-1112
- Finglas PM, de Meer K, Molloy A, Verhoef P, Pietrzik K, Powers HJ, van der Straeten D, Jägerstad M, Varela-Moreiras G, van Vliet T, Havenaar R, Buttriss J, Wright AJ (2006) Research goals for folate and related B vitamin in Europe. *European Journal of Clinical Nutrition* **60**, 287-294
- Fossen T, Øvstedal DO, Slimestad R, Andersen ØM (2003) Anthocyanins from a Norwegian potato cultivar. *Food Chemistry* **81**, 433-437
- Foster-Powell K, Holt SH, Brand-Miller JC (2002) International table of glycemic index and glycemic load values: 2002. *American Journal of Clinical Nutrition* **76**, 5-56
- Friedman M (1997) Chemistry, biochemistry, and dietary role of potato polyphenols. A review. *Journal of Agricultural and Food Chemistry* **45**, 1523-1540
- Goyer A, Navarre DA (2007) Determination of folate concentrations in diverse potato germplasm using a trienzyme extraction and a microbiological assay. *Journal of Agricultural and Food Chemistry* **55**, 3523-3528
- Graf E, Eaton JW (1990) Antioxidant functions of phytic acid. *Free Radical Biology and Medicine* **8**, 61-69
- Graf E, Empson KL, Eaton JW (1987) Phytic acid. A natural antioxidant. *The Journal of Biological Chemistry* **262**, 11647-11650
- Halton TL, Willett WC, Liu S, Manson JE, Sampfer MJ, Hu FB (2006) Potato and French fry consumption and risk of type 2 diabetes in women. *American Journal of Clinical Nutrition* **83**, 284-290
- Han KH, Matsumoto A, Shimada K, Sekikawa M, Fukushima M (2007) Effects of anthocyanin-rich purple potato flakes on antioxidant status in F344 rats fed a cholesterol-rich diet. *British Journal of Nutrition* **98**, 914-921
- Hasegawa D, Johnson RM, Gould WA (1966) Effect of cold storage on chlorogenic acid content of potatoes. *Journal of Agricultural and Food Chemistry* **14**, 165-169
- Hayashi K, Hibasami H, Murakami T, Terahara N, Mori M, Tsukui A (2006) Induction of apoptosis in cultured human stomach cancer cells by potato anthocyanins and its inhibitory effects on growth of stomach cancer in mice. *Food Science and Technology Research* **12**, 22-26
- Herrmann KM (1995) The shikimate pathway as an entry to aromatic secondary metabolism. *Plant Physiology* **107**, 7-12
- Hodge AM, English DR, O'Dea K, Giles GG (2004) Glycemic index and dietary fiber and the risk of type 2 diabetes. *Diabetes Care* **27**, 2701-2706
- Hsieh CL, Yen GC, Chen HY (2005) Antioxidant activities of phenolic acids on ultraviolet radiation-induced erythrocyte and low density lipoprotein oxidation. *Journal of Agricultural and Food Chemistry* **53**, 6151-6155
- Hughes DA (1999) Effects of dietary antioxidants on the immune function of middle-aged adults. *Proceedings of the Nutrition Society* **58**, 79-84
- Im HW, Suh B-S, Lee SU, Kozukue N, Ohnisi-Kameyama M, Levin CE, Friedman M (2008) Analysis of phenolic compounds by high-performance liquid chromatography and liquid chromatography/mass spectrometry in potato plant flowers, leaves, stems, and tubers and in home-processed potatoes. *Journal of Agricultural and Food Chemistry* **56**, 3341-3349
- Kanatt SR, Chander R, Radhakrishna P, Sharma A (2005) Potato peel extract—a natural antioxidant for retarding lipid peroxidation in radiation processed lamb meat. *Journal of Agricultural and Food Chemistry* **53**, 1499-504
- Kim K-H, Tsao R, Yang R, Cui SW (2006) Phenolic acid profiles and antioxidant activities of wheat bran extracts and the effect of hydrolysis conditions. *Food Chemistry* **95**, 466-473
- Kim TH, Kim SH, Lee YS, Choi SY, Yoo SY, Jang JJ (1994) Protective effects of potato extracts and 16,16-dimethyl prostaglandin E2 on the induction of hepatic foci by cotreatment of gamma radiation and diethylnitrosamine. *Anticancer Research* **14**, 1979-1982
- Lachman J, Hamouz K (2005) Red and purple coloured potatoes as a significant antioxidant source in human nutrition—a review. *Plant Soil and Environment* **51**, 477-482
- Lazarov K, Werman, MJ (1996) Hypocholesterolaemic effect of potato peel as a dietary fiber source. *Medicinal Science Research* **24**, 581-582
- Lee SH, Park HJ, Cho SY, Jung HJ, Cho SM, Cho YS, Lillehoj HS (2005) Effects of dietary phytic acid on serum and hepatic lipid levels in diabetic KK mice. *Nutrition Research* **25**, 869-876
- Lee SH, Park HJ, Chun HK, Cho SY, Cho SM, Jung HJ, Cho SM, Kim DY, Kang MS, Lillehoj HS (2007) Dietary phytic acid improves serum and hepatic lipid levels in aged ICR mice fed a high-cholesterol diet. *Nutrition Research* **27**, 505-510
- Lee SH, Park HJ, Chun HK, Cho SY, Cho SM, Lillehoj HS (2006) Effect of dietary phytic acid on the blood glucose level in diabetic KK mice. *Nutrition Research* **26**, 474-479
- Leo L, Leone A, Longo C, Lombardi DA, Raimo F, Zacheo G (2008) Antioxidant compounds and antioxidant activity in “early potatoes”. *Journal of Agricultural and Food Chemistry* **56**, 4154-4163
- Lewis, CE, Walker JRL, Lancaster JE, Sutton KH (1998) Determination of anthocyanins, flavonoids and phenolic acids in potatoes. I: Coloured cultivars of *Solanum tuberosum* L. *Journal of the Science of Food and Agriculture* **77**, 45-57
- Liu RH (2003) Health benefits of fruit and vegetables are from additive and synergistic combinations of phytochemicals. *American Journal of Clinical Nutrition* **78** (Suppl), 517S-520S
- Liu S, Serdula M, Janket SJ, Cook NR, Sesso HD, Willett WC, Manson JE, Buring JE (2004) A prospective study of fruit and vegetable intake and the risk of type 2 diabetes in women. *Diabetes Care* **27**, 2993-2996
- Lodovici M, Guglielmi F, Meoni M, Dolara P (2001) Effect of natural phenolic acids on DNA oxidation *in vitro*. *Food Chemistry and Toxicology* **39**, 1205-1210
- Lodovici M, Raimondi L, Guglielmi F, Gemignani S, Dolara P (2003) Protection against ultraviolet B-induced oxidative DNA damage in rabbit corneal-derived cells (SIRC) by 4-coumaric acid. *Toxicology* **184**, 141-147
- Lunetta M, Di Mauro M, Crimi S, Mughini L (1995) Influence of different cooking processes on the glycaemic response to potatoes in insulin-dependent diabetic patients. *Diabetes, Nutrition and Metabolism* **8**, 49-53
- Makris D, Boskou PG, Andrikopoulos NK (2007) Polyphenolic content and *in vitro* antioxidant characteristics of industry and other agri-food solid waste extracts. *Journal of Food Composition and Analysis* **20**, 125-132
- Maritim AC, Sanders RA, Watkins JB 3rd (2003) Diabetes, oxidative stress and antioxidants. *Journal of Biochemical and Molecular Toxicology* **17**, 24-37
- Matsui T, Ebuchi S, Kobayashi M, Fukui K, Sugita K, Terahara N, Matsumoto K (2002) Anti-hyperglycemic effect of diacylated anthocyanin derived from *Ipomoea batatas* cultivar Ayamurasaki can be achieved through the alpha-glucosidase inhibitory action *Journal of Agricultural and Food Chemistry* **50**, 7244-7248
- Matsui T, Ueda T, Oki T, Sugita K, Terahara N, Matsumoto K (2001) α -glucosidase inhibitory action of natural acylated anthocyanins. *Journal of Agricultural and Food Chemistry* **49**, 1952-1956
- McCallum JL, Yang R, Young JC, Strommer JN, Tsao R (2007) Improved high performance liquid chromatographic separation of anthocyanin compounds from grapes using a novel mixed-mode ion-exchange reversed-phase column. *Journal of Chromatography A* **1148**, 38-45
- McCue P, Kwon Y-I, Shetty K (2005) Anti-amylase, anti-glucosidase and anti-angiotensin I converting enzyme potential of select foods. *Journal of Food Biochemistry* **29**, 278-294
- McKillop DJ, Pentieva K, Daly D, McPartlin JM, Hughes J, Strain JJ, Scott JM, McNulty H (2002) The effect of different cooking methods on folate retention in various foods that are amongst the major contributors to folate intake in the UK diet. *British Journal of Nutrition* **88**, 681-688

- Midorikawa K, Murata M, Oikawa S, Hiraku Y, Kawanishi S** (2001) Protective effect of phytic acid on oxidative DNA damage with reference to cancer chemoprevention. *Biochemical and Biophysical Research Communications* **288**, 552-557
- Milner JA** (1994) Reducing the risk of cancer. In: Goldberg I (Ed) *Functional Foods –Designer Foods, Pharmafoods, Nutraceuticals*, Chapman & Hall, New York, pp 39-70
- Montonen J, Järvinen R, Heliövaara M, Reunanen A, Aromaa A, Knekt P** (2005) Food consumption and the incidence of type II diabetes mellitus. *European Journal of Clinical Nutrition* **59**, 441-448
- Mukhtar H, Katiyar SK, Agarwal R** (1994) Green tea and skinanticarcinogenic effects. *Journal of Investigative Dermatology* **102**, 3-7
- Naito K, Umemura Y, Mori M, Sumida T, Okada T, Takamatsu N, Okawa Y, Hayashi K, Saito N, Honda T** (1998) Acylated pelargonidin glycosides from red potato. *Phytochemistry* **47**, 109-112
- Nakayama T, Yamada M, Osawa T, Kawakishi S** (1996) Inhibitory effect of caffeic acid ethyl ester on H₂O₂-induced cytotoxicity and DNA single-strand breaks in Chinese hamster V79 cells. *Bioscience Biotechnology and Biochemistry* **60**, 316-318
- Nara K, Miyoshi T, Honma T, Koga H** (2006) Antioxidative activity of bound-form phenolics in potato peel. *Bioscience, Biotechnology, and Biochemistry* **70**, 1489-1491
- Nardini M, Pisu P, Gentili V, Natella F, Di M, Piccolella F** (1998) Effect of caffeic acid on *tert*-butyl hydroperoxide-induced oxidative stress in U937. *Free Radical Biology and Medicine* **25**, 1098-1105
- Nasu R, Miura M, Gomyo T** (2005) Effects of fruit, spices and herbs on a glucosidase activity and glycemic index. *Food Science and Technology Research* **11**, 77-81
- Onyeneho SN, Hettiarachchy NS** (1993) Antioxidant activity, fatty acids and phenolic acids compositions of potato peels. *Journal of the Science of Food and Agriculture* **62**, 345-350
- Phillippy BQ, Bland JM, Evens TJ** (2003) Ion chromatography of phytate in roots and tubers. *Journal of Agricultural and Food Chemistry* **51**, 350-353
- Phillippy BQ, Lin M, Rasco B** (2004) Analysis of phytate in raw and cooked potatoes. *Journal of Food Composition and Analysis* **17**, 217-226
- Porres JM, Lopez-Jurado M, Aranda P, Urbano G** (2004) Bioavailability of phytic acid-phosphorus and magnesium from lentils in growing rats. *Nutrition* **20**, 794-799
- Reddivari L, Hale AL, Miller JC Jr.** (2007a) Genotype, location, and year influence antioxidant activity, carotenoid content, phenolic content, and composition in specialty potatoes. *Journal of Agricultural and Food Chemistry* **55**, 8073-8079
- Reddivari L, Vanamala J, Chintharlapalli S, Safe SH, Miller JC Jr.** (2007b) Anthocyanin fraction from potato extracts is cytotoxic to prostate cancer cells through activation of caspase-dependent and caspase-independent pathways. *Carcinogenesis* **28**, 2227-2235
- Reyes LF, Cisneros-Zevallos L** (2007) Degradation kinetics and colour of anthocyanins in aqueous extracts of purple- and red-flesh potatoes (*Solanum tuberosum* L.). *Food Chemistry* **100**, 885-894
- Robert L, Nancy A, Rayssiguier Y, Mazur A, Rémésy C** (2008) Lipid metabolism and antioxidant status in sucrose vs potato-fed rats. *Journal of the American College of Nutrition* **27**, 109-116
- Robert L, Nancy A, Rock E, Demigne C, Mazur A, Rémésy C** (2006) Entire potato consumption improves lipid metabolism and antioxidant status in cholesterol-fed rat. *European Journal of Nutrition* **45**, 267-274
- Rodriguez de Sotillo D, Hadley M, Holm ET** (1994a) Phenolics in aqueous potato peel extract: extraction, identification and degradation. *Journal of Food Science* **59**, 649-651
- Rodriguez-Saona LE, Giusti MM, Wrolstad RE** (1999) Color and pigment stability of red radish and red-fleshed potato anthocyanins in juice model systems. *Journal of Food Science* **64**, 451-456
- Rodriguez de Sotillo D, Hadley M, Holm ET** (1994b) Potato peel waste stability and antioxidant activity of a freeze-dried extract. *Journal of Food Science* **59**, 1031-1033
- Rodriguez de Sotillo D, Hadley M, Wolf-Hall C** (1998) Potato peel extract a nonmutagenic antioxidant with potential antimicrobial activity. *Journal of Food Science* **63**, 907-910
- Salmeron J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ, Stampfer MJ, Wing AL, Willett WC** (1997a) Dietary fiber, glycemic load, and risk of NIDDM in men. *Diabetes Care* **20**, 545-550
- Salmeron J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC** (1997b) Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. *Journal of the American Medical Association* **277**, 472-477
- Schmidt J, Amrhein N** (1995) Molecular organization of the shikimate pathway in higher plants. *Phytochemistry* **30**, 737-749
- Schulze MB, Liu S, Rimm EB, Manson JE, Willett WC, Hu FB** (2004) Glycemic index, glycemic load, and dietary fiber intake and incidence of type 2 diabetes in younger and middle-aged women. *American Journal of Clinical Nutrition* **80**, 348-356
- Scott J, Rebeille F, Fletcher J** (2000) Folic acid and folates: the feasibility for nutritional enhancement in plant foods. *Journal of the Science of Food and Agriculture* **80**, 795-804
- Scott JM** (1999) Folate and vitamin B12. *Proceedings of the Nutrition Society* **58**, 441-448
- Shahidi F, Wanasundara PKJPD** (1992) Phenolic antioxidants *Critical Review in Food Science and Nutrition* **32**, 67-103
- Shamsuddin AM, Vucenic I, Cole KE** (1997) IP6: A novel anti-cancer agent. *Life Sciences* **61**, 343-354
- Shih CK, Chang JH, Yang SH, Chou TW, Cheng HH** (2008) β -Carotene and canthaxanthin alter the pro-oxidation and antioxidation balance in rats fed a high-cholesterol and high-fat diet. *British Journal of Nutrition* **99**, 59-66
- Si W, Gong J, Tsao R, Kalab M, Yang R, Yin Y** (2006) Bioassay-guided purification and identification of antimicrobial components in Chinese green tea extract. *Journal of Chromatography A* **1125**, 204-210
- Slabber M, Barnard HC, Kuyl JM, Dannhauser A, Schall R** (1994) Effects of a low-insulin-response, energy-restricted diet on weight loss and plasma insulin concentrations in hyperinsulinemic obese females. *American Journal of Clinical Nutrition* **60**, 48-53
- Soh NL, Brand-Miller J** (1999) The glycaemic index of potatoes: the effect of variety, cooking method and maturity. *European Journal of Clinical Nutrition* **53**, 249-254
- Spith LE, Harnish JD, Lenders CM, Raezer LB, Pereira MA, Hangen SJ, Ludwig DS** (2000) A low-glycemic index diet in the treatment of pediatric obesity. *Archives of Pediatrics and Adolescent Medicine* **154**, 947-951
- Thompson LU, Yoon JH, Jenkins DJA, Wolwer J, Jenkins AL** (1983) Relationship between polyphenol intake and blood glucose response of normal and diabetic individuals. *American Journal of Clinical Nutrition* **39**, 745-751
- Tsao R, Akhtar H** (2005) Nutraceuticals and functional foods: I. Current trend in phytochemical antioxidants research. *Journal of Food, Agriculture and Environment* **3**, 10-17
- Tsao R, Yang R** (2006) Lutein in selected Canadian crops and agri-food processing by-products and purification by high-speed counter-current chromatography. *Journal of Chromatography A* **1112**, 202-208
- Tsao R, Yang R, Xie S, Sockovie E, Khanizadeh S** (2005) Which polyphenolic compounds contribute to the total antioxidant activities of apple? *Journal of Agricultural and Food Chemistry* **53**, 4989-4995
- Tseng TH, Hsu JD, Lo MH, Chu CY, Chuo FP, Huang CL, Wang CJ** (1998) Inhibitory effect of Hibiscus protocatechuic acid on tumor promotion on mouse skin. *Cancer Letters* **126**, 199-207
- Tudela JA, Cantos E, Espín JC, Tomás-Barberán FA, Gil MI** (2002) Induction of antioxidant flavonol biosynthesis in fresh-cut potatoes. Effect of domestic cooking. *Journal of Agricultural and Food Chemistry* **50**, 5925-5931
- Vinson JA, Hao Y, Su X, Zubik L** (1998) Phenol antioxidant quantity and quality in foods: vegetables. *Journal of Agricultural and Food Chemistry* **46**, 3630-3634
- Wang SY, Chen CT, Sciarappa W, Wang CY, Camp MJ** (2008) Fruit quality, antioxidant capacity, and flavonoid content of organically and conventionally grown blueberries. *Journal of Agricultural and Food Chemistry* **56**, 5788-5794
- Willcox JK, Ash SL, Catignani GL** (2004) Antioxidants and prevention of chronic disease. *Critical Reviews in Food Science and Nutrition* **44**, 275-295
- Wu X, Gu L, Holden J, Haytowitz DB, Gebhardt SE, Beecher G, Prior RL** (2004) Development of a database for total antioxidant capacity in foods: a preliminary study. *Journal of Food Composition and Analysis* **17**, 407-422
- Ylönen SK, Virtanen SM, Groop L, Botnia Research Group** (2007) The intake of potatoes and glucose metabolism in subjects at high risk for Type 2 diabetes. *Diabetic Medicine* **24**, 1049-1050
- Zhang Z, Song Y** (2005) Inositol hexaphosphate-induced enhancement of natural killer cell activity correlates with suppression of colon carcinogenesis in rats. *World Journal of Gastroenterology* **11**, 5044-5046