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Potato Peels: A Source of Nutritionally and Pharmacologically Interesting Compounds – A Review

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ABSTRACT

In October 2007, the United Nations declared 2008 as The Year of the Potato, highlighting the importance of this crop as a staple food in human nutrition. While fresh potato consumption is decreasing in many countries, more potatoes are currently processed into value-added products to meet the demand especially from the fast food and convenience food industries. Potatoes are usually peeled during processing, either by steam, lye or abrasive peeling, depending on the type of product. As a consequence, large quantities of peels are generated which represent a severe disposal problem to the industry, especially with the increasing awareness and aims of minimising environmental impact and sustainability. However, potato peels contain a number of nutritionally and pharmacologically interesting compounds such as polyphenols and glycoalkaloids, which may be recovered and used as natural antioxidants and precursors for steroid hormones, respectively. Furthermore, applications of the dietary fibre fraction have been described. This review summarizes the available literature on potato peel utilization, focusing on the above mentioned constituents, and highlights the potential of an important by-product of the food industry as a source of valuable compounds.

Keywords: dietary fibre, glycoalkaloids, phenolic compounds, potato peel utilization

CONTENTS

INTRODUCTION

Potatoes (*Solanum tuberosum* L.) are one of the most important staple crops for human consumption, together with wheat, rice, and corn. Presently, the global potato sector is undergoing major changes. While fresh potato consumption, which used to be the mainstay of potato utilization, is continuously decreasing especially in developed countries, increasing quantities are currently processed into value-added products to meet the demand especially of the fast food and convenience food industries (FAO 2008). In 2005, for the first time potato production in the developing world exceeded that of the developed world. At present, China is the biggest potato producer with an output of 72,000,000 tons, followed by Russia (35,718,000 tons), India (26,280,000 tons), Ukraine (19,102,300 tons), USA (17,653,920 tons), Germany (11,604,500 tons), and Poland (11,221,100 tons) in 2007. Per capita consumption of fresh and processed potatoes is highest in Belarus (338 kg), followed by Kyrgyzstan (152 kg), Russian Federation (142 kg), Ukraine (142 kg), Latvia (136 kg), Armenia (132 kg), Lithuania (131 kg), and Poland (128 kg). However, almost half of the world's potato supply is consumed in Asia, especially in China (52,882,000 tons) (FAO 2008).

Potatoes are a source of dietary energy due to their carbohydrate levels and also contain a high value protein. However, their overall protein content is generally low. They are rich in a number of organic micronutrients such as vitamin C and some B vitamins, and also contain appreciable levels of minerals. The fat content of raw and cooked potatoes is very low, whereas in fried products the caloric value is significantly increased. The proximate composition of raw potato tubers is given in **Table 1**. Potatoes are processed into a variety of products such as mashed potatoes, chips, fries, and deep-frozen and dehydrated products like granules and flakes. Furthermore, starch is an economically important product obtained in large quantities from the tubers (Bergthaller *et al*. 1999).

Table 1 Proximate composition of potato tubers (raw, skin)[1].

Nutrient	g/100 g
Water	83.29
Protein	2.57
Total lipid (fat)	0.1
Ash	1.61
Carbohydrate, by difference	12.44
Fibre, total dietary	2.5

[1] Data taken from United States Department of Agriculture National Nutrient Database (USDA 2008)

Potatoes are usually peeled during processing, which may be accomplished either by steam, abrasive, or lye peeling, depending on the product to be produced. Abrasion peeling is typically applied in chips production, whereas

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Invited Mini-Review

steam peeling is used for frozen and dehydrated potato products. The use of lye necessitates a neutralization step after peeling, which creates large amounts of salt as a secondary disposal issue. As a consequence of growing production figures of processed potato products, considerable quantities of waste are generated. According to Charmley *et al.* (2006), who estimated that approximately 40 to 50% of potato production is unsuitable for human consumption, the by-products can be divided into cull potatoes, which are whole potatoes not destined for human consumption, and potato processing waste derived from the manufacture of potato-based products. On one side, the peels, which are the major portion of processing waste, represent a severe disposal problem to the potato industry, especially since the wet peels are prone to rapid microbial spoilage. On the other side, potato peels contain an array of nutritionally and pharmacologically interesting components such as phenolic compounds, glycoalkaloids, and cell wall polysaccharides, which may be used as natural antioxidants, precursors of steroid hormones, and dietary fibre. In view of the growing rejection of synthetic food additives by consumers, functional ingredients obtained from natural sources may be a promising alternative. The utilization of by-products also contributes to reduced amounts of waste and thus to sustainable production (Schieber *et al*. 2001). This review summarizes the available literature on potato peel utilization, focusing on the above-mentioned constituents, and highlights the potential of an important by-product of the food industry as a source of high value compounds.

Table 2 Phenolic compounds in potatoes.

Hydroxycinnamic acids
5-*O*-Caffeoylquinic acid (chlorogenic acid)
4-*O*-Caffeoylquinic acid (*crypto*-chlorogenic acid)
3-*O*-Caffeoylquinic acid (*neo*-chlorogenic acid)
Caffeic acid
p-Coumaric acid
Ferulic acid
Hydroxybenzoic acids
Gallic acid
Protocatechuic acid
Vanillic acid
Salicylic acid
Non-anthocyanin flavonoids
Catechin
Epicatechin
Eriodyctiol
Naringenin
Kaempferol glycosides
Quercetin glycosides
Anthocyanins
Petunidin glycosides
Malvidin glycosides
Pelargonidin glycosides
Peonidin glycosides
Dihydrocaffeoyl polyamines
N^1,N^{12}-Bis(dihydrocaffeoyl)spermine (kukoamine A)
N^1,N^8-Bis(dihydrocaffeoyl)spermidine
N^1,N^4,N^{12}-Tris(dihydrocaffeoyl)spermine
N^1,N^4,N^8-Tris(dihydrocaffeoyl)spermidine

PHENOLIC COMPOUNDS IN POTATOES

Phenolic compounds are an extremely heterogeneous class of secondary plant metabolites which can broadly be classified in phenolic acids (C_6-C_1 and C_6-C_3 structures) and flavonoids (C_6-C_3-C_6 backbone). The latter components represent a very large subclass, with approximately 9,000 compounds identified up to 2004 (Williams and Grayer 2004). Among the flavonoids, the most widespread compounds are flavonols, flavan-3-ols, flavones, flavanones, and anthocyanins. Apart from modifications to the C_6-C_3-C_6 core, the marked structural variety of the flavonoids is also due to their conjugation to sugars at different sites of the molecule, usually to one or more hydroxyl groups or, less frequently, *C*-glycosidically to an aromatic carbon atom. Additional variations may occur through acylation of the sugar moiety with organic acids. Phenolic compounds protect plants against biotic stress caused by herbivores, insects, and pathogens such as bacteria, fungi, and viruses, and also against tissue damages caused by excessive UV light and free radicals (abiotic stress) (Friedman 1997; Pourcel *et al*. 2007).

A list of phenolic compounds present in potato tubers is shown in **Table 2**. The hydroxycinnamate derivative 5-*O*-caffeoylquinic acid, or chlorogenic acid, is by far the most abundant phenolic component and may constitute up to 90% of the total phenolics (Friedman 1997; Im *et al*. 2008). Isomers of this compound, i.e. *neo*-chlorogenic acid (3-caffeoylquinic acid) and *crypto*-chlorogenic acid (4-caffeoylquinic acid) are usually present in lower quantities (Griffiths and Bain 1997). Chlorogenic acid is assumed to be involved in blackspot formation of potato tubers after subcellular decompartmentalization (Stevens and Davelaar 1996), but the content of free tyrosine appears to be the predominant determinant for biochemical blackspot synthesis (Stevens and Davelaar 1997). Apart from chlorogenic acid and its isomers, caffeic, *p*-coumaric and ferulic acids as well as various benzoic acid derivatives such as gallic, protocatechuic, vanillic, and salicylic acids have also been found, however, usually in lower amounts (Onyeneho and Hettiarachchy 1993; Rodriguez de Sotillo *et al*. 1994a; Lewis *et al*. 1998a; Mattila and Hellström 2007). The structures of

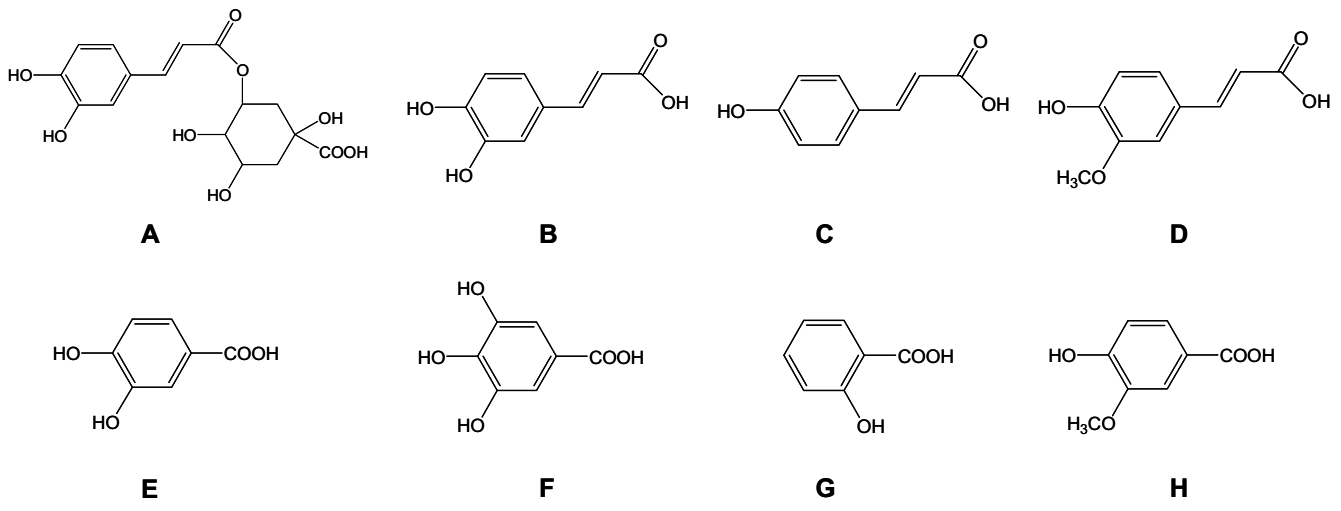


Fig. 1 Structures of hydroxycinnamic acids (A-D) and hydroxybenzoic acids (E-H) found in potato peels. A) chlorogenic acid (5-*O*-caffeoylquinic acid), B) caffeic acid, C) *p*-coumaric acid, D) ferulic acid, E) protocatechuic acid, F) gallic acid, G) salicylic acid, H) vanillic acid.

these phenolic acids are shown in **Fig. 1**. The dihydrocaffeoyl polyamines, kukoamine and related compounds, have been detected in potato tubers during metabolite profiling (Parr *et al*. 2005). It should also be noted that in potato peels phenolic acids are not only present in their free form but occur also in bound form, as recently shown for ferulic acid (Nara *et al*. 2006).

Studies on non-anthocyanin flavonoids in potato tubers are scarce compared to investigations on phenolic acids (e.g. Harnly *et al.* 2006). In skin extracts of coloured potato cultivars, Lewis *et al*. (1998a) found catechin, epicatechin, eriodictyol, kaempferol 3-rutinoside and naringenin at levels between 10 and 150 µg per g fresh weight, and lower concentrations of quercetin glycosides. In a subsequent study on wild *Solanum* species the same authors reported that in the skin and flesh the major flavonoids were catechin, epicatechin, eriodictyol and naringin (Lewis *et al*. 1998b).

The increased interest in coloured potato cultivars is mainly due to their color appeal, taste and "mashability" and their potential use in salads and novelty crisps. It has entailed investigations into the chemical structure of these pigments, especially since their color is retained after cooking and frying (Rodriguez-Saona *et al*. 1998). Andersen *et al*. (1991) elucidated the detailed structure of petanin, an acylated anthocyanin isolated from potatoes, by means of nuclear magnetic resonance spectroscopy as petunidin 3-*O*-[6-*O*-(4-*O*-*E*-*p*-coumaroyl-α-L-rhamnopyranosyl)-β-D-glucopyranoside]-5-*O*-β-D-glucopyranoside.

In tubers of coloured cultivars of *Solanum tuberosum* grown in New Zealand, Lewis *et al*. (1998a) found petunidin, malvidin, pelargonidin, and peonidin glycosides acylated with *p*-coumaric acid. Cold storage of the tubers over 5 months led to a significant increase in anthocyanin concentrations (Lewis *et al*. 1999). In red-fleshed potato cultivars (*Solanum tuberosum* and *Solanum stenotomum*), Rodriguez-Saona *et al.* (1998) detected pelargonidin glycosides acylated with *p*-coumaric or ferulic acids. The acylation of the saccharide moiety with hydroxycinnamtes is considered the main reason for the increased stability of these anthocyanins compared to non-acylated pigments. Acylated anthocyanins from natural sources such as black carrots (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef) are increasingly used as ingredients in various foodstuffs like smoothies and functional drinks to improve the visual appearance of these products. For a review of the history and perspectives of black carrots we refer to a recent review published by Kammerer *et al*. (2005). In the case of potato extracts, the recovery of anthocyanins may pose a problem since toxic glycoalkaloids might be concentrated during processing. A procedure for the separation of glycoalkaloids from he pigments using alkaline precipitation was described by Rodriguez-Saona *et al.* (1999) and later patented (Wrolstad and Rodriguez-Saona 2001), which however caused substantial loss of the anthocyanins (**Fig. 2**).

Polyphenols, together with carotenoids and vitamin C, significantly contribute to the antioxidant capacity of potatoes (Brown 2005). The presence of phenolic compounds in potato peels and the abundant availability of the latter have stimulated numerous investigations into the antioxidant activities of extracts obtained from potato waste and their potential applications. Selected studies on polyphenol extraction, also for analytical purposes, solvents used and compounds determined are summarized in **Table 3**. Onyeneho and Hettiarachchy (1993) characterized fatty acids and phenolic acids from potato peels and showed that 95% ethanolic extracts of red-skinned cultivars had antioxidative activities similar to butylated hydroxyanisole (BHA)-butylated hydroxytoluene (BHT)-corn oil mixtures (2:2:6) in the carotene bleaching and linoleic acid oxidation assays. Chlorogenic, caffeic and protocatechuic acids were the phenolic compounds that contributed most to the antioxidant activity, which may be explained by the *o*-dihydroxy structure that is common to all three components. Freeze-dried aqueous extracts from potato peel waste containing chlorogenic, gallic, protocatechuic and caffeic acids proved to be stable during 15 days of storage and were as effective as butylated hydroxyanisole in inhibiting lipid oxidation of sunflower oil (Rodriguez de Sotillo *et al*. 1994b).

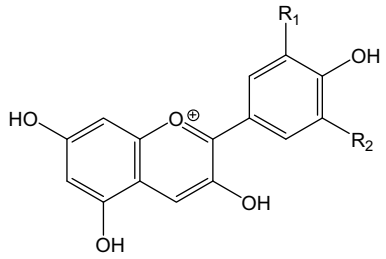
Furthermore, aqueous extracts also showed free radical scavenging activities in various *in vitro* assays (Singh and Rajini 2004). Mansour and Khalil (2000) found that 90% ethanolic extracts of potato peels exhibited antioxidative activity in model systems (β-carotene/linoleic acid emulsions) and ground beef patties. However, potato peel extracts were inferior to fenugreek and ginger rhizome extracts in inhibiting lipid oxidation and color changes during cold storage of the patties. Zia-ur-Rehman *et al*. (2004) extracted washed and dried potato peels with various organic solvents such as ethanol, methanol, hexane, petroleum ether, and diethyl ether. Maximum extract yields of approximately 21% were obtained for the petroleum ether extract, which was used for stability tests with refined soybean oil. The antioxidant activity of the extract was attributed to the presence of phenolic acids, based on a previous study by Onyeneho and Hettiarachchy (1993). However, as Zia-ur-Rehman *et al*. (2004) did not characterize the composition of the extract and phenolic acids are poorly soluble in petroleum ether, these studies should be reproduced to unambiguously establish the nature of the petroleum ether-soluble antioxidant agents present in potato peels. Ethanolic extracts of potato peels showed excellent antioxidant activities when added at concentrations of 0.04% to minced lamb meat which was subsequently irradiated at 2.5 and 5 kGy (Kanatt *et al*. 2005). Steamed potato peels added to degermed corn meal which was subsequently processed in a twin-screw extruder significantly darkened the extrudates in comparison to the control group (Camire *et al*. 2005). The authors suggested that consumer research be conducted to determine whether these color differences are acceptable. Oatmeal cookies containing extruded potato peels had lower peroxide values compared to the control (Arora and Camire 1994).

Table 3 Selected studies on the extraction of phenolic compounds from potatoes.

Potato part	Extraction solvent(s)	Compounds determined	Reference
Tubers	Acetic acid (15%)	Anthocyanins, flavonoids, phenolic acids	Lewis *et al*. 1998, 1999
Tubers	Acetone	Anthocyanins	Rodriguez Saona *et al*. 1998
Tubers	Methanol/0.1% HCl	Anthocyanins	Andersen *et al*. 1991
Tubers	Methanol/2 mM trifluoroacetic acid	Dihydrocaffeoyl polyamines	Parr *et al*. 2005
Tubers, peels	Methanol/10% acetic acid (85:15), 2 g/L BHA	Phenolic acids	Mattila and Hellström 2007
Peels	Methanol (4°C); water (25°C; 100°C reflux)	Phenolic acids	Rodriguez de Sotillo *et al*. 1994a
Peels	Ethanol (90%)	Not specified	Mansour and Khalil 2000
Peels	Ethanol	Phenolic acids	Kanatt *et al*. 2005
Peels	Water	Not specified	Singh and Rajini 2004
Peels	Methanol/acetone/water (60:30:10)/0.1% HCl	Total polyphenols, total flavonoids, total flavanols	Makris *et al*. 2007
Peels	Ethanol (95%)	Phenolic acids	Onyeneho and Hettiarachchy 1993
Peels	Water	Phenolic acids	Rodriguez de Sotillo *et al*. 1998
Various parts	Ethanol (80%) for flowers, leaves, stems; ethanol (80%) under reflux (80°C) for peels and pulp	Phenolic acids	Im *et al*. 2008

In a very recent investigation, potato peels were shown to have low levels of total polyphenols and consequently lower antioxidant activities as opposed to other by-products such as grape seeds and olive tree leaves (Makris *et al*. 2007). The authors found 977 ± 96 mg gallic acid equivalents (GAE) per 100 g and 702 ± 18 mg catechin equivalents (CTE) per 100 g on a dry weight basis in potato peels. In contrast, red and white grape seeds contained over 10,000 mg GAE and CTE per 100 g. It needs to be emphasized that the quantification was based on spectrophotometric tests, which are known to be very unspecific, tend to overestimate the 'real' contents, and do not allow any conclusions as to the profile of phenolic compounds. Furthermore, a comparison of potato peels with other by-products in terms of their general polyphenol contents is also difficult because the quantities present differ with the raw material used and the technological steps employed during processing. In red-fleshed and purple-fleshed potatoes, a high positive correlation between the antioxidant capacity and total phenolics and anthocyanin contents was found (Reyes *et al.* 2005).

Potato peels are a source of phenolic antioxidants and have also been demonstrated to significantly reduce plasma glucose levels in streptozotocin-induced diabetic rats and to ameliorate antioxidative stress (Singh *et al*. 2005a, 2005b). Freeze-dried aqueous potato peel extracts containing chlorogenic, caffeic, gallic and protocatechuic acids were investigated for their mutagenic and antimicrobial activities. While the extract was found not to be mutagenic in the *S. typhimurium – E. coli* microsome assay, antibacterial activity was observed only at high dosages (10^5 µg/mL extract) against *E. coli*, *B. cereus*, and *S. typhimurium* (Rodriguez de Sotillo *et al*. 1998).



Aglycone	R_1	R_2
Pelargonidin	H	H
Cyanidin	OH	H
Delphinidin	OH	OH
Peonidin	OCH_3	H
Petunidin	OCH_3	OH
Malvidin	OCH_3	OCH_3

Fig. 2 Structures of anthocyanidins commonly found in foods.

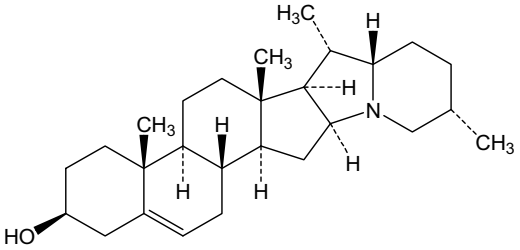


Fig. 3 Structure of solanidine.

POTATO GLYCOALKALOIDS

Glycoalkaloids are plant secondary metabolites that are toxic to microorganisms, viruses, insects, animals, and also humans. The major glycoalkaloids present in potatoes are α-chaconine and α-solanine, which share the same aglycone, solanidine (**Fig. 3**). Structurally, these compounds differ in the saccharide moiety in that α-solanine contains the trisaccharide solatriose, whereas in α-chaconine the aglycone is attached to chacotriose. Stepwise removal of a sugar moiety from the trisaccharides leads to the formation of β- and γ-glycoalkaloids and finally to solanidine, which display a lower toxicity compared to the parent compounds (Rayburn *et al*. 1994). The glycoalkaloid content of potato tubers can vary considerably and is influenced post-harvest by factors such as exposure to light, irradiation, mechanical injury, and conditions of storage. Total levels of solanine and chaconine between 6.4 and 3,526 µg/g in potato flesh, peel and whole potatoes have been reported. Other glycoalkaloids, α-tomatine and dehydrotomatine, are found also in tomatoes. In immature green tomatoes, tomatine may be present in quantities of up to 500 mg/kg. During ripening it is degraded to levels of approximately 5 mg/kg fresh weight (Friedman 2004). In the past decade excellent reviews on various aspects of potato alkaloids have been published, focusing in particular on their chemistry, analysis, safety, and their role in plant physiology (Friedman and McDonald 1997; Friedman 2004, 2006). Therefore, within this review only selected aspects will be addressed as outlined below. A selection of studies on the extraction of glycoalkaloids is given in **Table 4**.

Solanidine, the aglycone of the potato glycoalkaloids, is a hexacyclic tertiary amine, which can be released from the glycosylated parent compounds after either enzymatic or acid-catalyzed hydrolysis. Because of its steroid structure (rings A-D), solanidine represents an interesting educt for conversion to an intermediate for the synthesis of steroid hormones. The genus *Dioscorea*, also known as "yam", which includes more than 600 species widely distributed in the tropical and subtropical regions of Asia, Africa, and America, contains steroid saponins and also sapogenins such as diosgenin. Diosgenin is the starting material for the synthesis of numerous steroids and related products which are marketed as anti-inflammatory, androgenic, estrogenic, and contraceptive drugs (Sautour *et al*. 2007). However, because the supply chain of diosgenin has often been impaired by various factors, the search for alternatives has been a logical consequence of this lacking sustainability. In this context, waste streams from potato starch production, in particular the protein ("protamylasse") fraction containing also the glycoalkaloids (Wojnowska *et al.* 1981), have attracted intense interest. Vronen *et al*. (2004) described a reaction protocol comprising 9 steps to convert solanidine to dehydropregnenolone acetate with a 30% yield. Wijbenga *et al.* (1999) patented processes for the microbial and

Table 4 Selected studies on the extraction of glycoalkaloids from potatoes.

Potato part	Extraction solvent(s)	Compounds determined	Reference
Tubers	1 L water, 20 mL acetic acid, 5 g sodium bisulphite	α-solanine, α-chaconine	Machado *et al.* 2007
Tubers	4 g of 1-heptane sulfonic acid sodium salt in 1 L of distilled water containing 10 mL of acetic acid	α-solanine, α-chaconine	Abreu *et al.* 2007
Tubers	0.02 M sodium 1-heptanate-sulfonate in 0.17 M acetic acid	total glycoalkaloids	Tömösközi-Farkas *et al.* 2006
Tubers	5% acetic acid	α-solanine, α-chaconine	Sotelo and Serrano 2000
Peels	5% acetic acid	α-solanine, α-chaconine	Friedman *et al.* 2003
Peels	5% acetic acid	α-solanine, α-chaconine	Soule *et al.* 1997
Tubers, peels	Water/acetic acid/sodium bisulphite (95:5:0.5) (v/v/w)	α-solanine, α-chaconine	Eltayeb *et al.* 2003/4
Tubers, peels, sprout	Tetrahydrofuran/water/acetonitrile (50:30:20)	α-solanine, α-chaconine	Bushway *et al.* 1979

enzymatic conversion of solanaceous steroid glycoalkaloids to their aglycones and metabolites, aiming at detoxification and production of raw materials for hormone synthesis. Although the protamylasse fraction appears to be a good source of glycoalkaloids according to Friedman and McDonald (1997), the potential of potato peels for the recovery of α-chaconine and α-solanine should also be elucidated, especially since these compounds are predominantly located within the first millimetre from the outside of the tuber (Friedman 2006).

Apart from being promising intermediates in steroid drug synthesis, and beyond their undisputed detrimental effects, glycoalkaloids and their aglycones may also have beneficial properties, such as antiallergic, antipyretic, anti-inflammatory, hyperglycemic effects, and antibiotic activities against pathogenic bacteria, viruses, protozoa, and fungi (Friedman 2006). Furthermore, potato glycoalkaloids showed anticarcinogenic effects against a series of human cancer cells *in vitro* (Friedman *et al.* 2005). The effects were concentration dependent in the range of 0.1-10 µg/mL. Besides the potential pharmacological applications, α-solanine and α-chaconine have been shown to act synergistically in inhibiting snail feeding and might therefore be considered also for pest control (Smith *et al.* 2001).

From the above mentioned studies it becomes evident that with glycoalkaloids, in addition to phenolic compounds, potato peels contain another fraction of components which are interesting from various points of views. Investigations on the recovery of potato glycoalkaloids should include the development of economically feasible and environmentally friendly extraction and purification protocols. In a best case scenario, they should also allow other valuable components such as phenolic acids to be recovered from potato by-products. The nature of the peel waste largely depends on the type of peeling that has been applied. According to Charmley *et al.* (2006), the waste originating from steam peeling is a sticky product with the consistency of peanut butter. It can be expected that peels from abrasive peeling are a more suitable by-product to be used as a source of glycoalkaloids and phenolic compounds, respectively. In any case, extraction protocols need to be carefully adapted to the sample matrix in order to allow for high yields.

POTATO PEELS AS A SOURCE OF DIETARY FIBRE

The main portion of potato peels consists of alcohol-insoluble matter (Mahmood *et al.* 1998), with a dietary fibre content of approximately 40% (Camire and Flint 1991). The starch content of potato peels depends on the peeling process: while steam peels contained approximately 28% starch, abrasion peels had about twice as much starch (51%), since more potato flesh is removed during the abrasion process (Camire *et al.* 1997). Initial studies on the introduction of potato peels to bread date back to the 1970s and 1980s when concerns about low levels of dietary fibre in the American diet and related health risks emerged. The addition of peels obtained from various processes (abrasion, steam, caustic, and manual peeling) to wheat flours at levels of 5, 10 and 15% resulted in breads of acceptable sensory quality (Toma *et al.* 1979), but sensory evaluation of the products made with peels from caustic peeling revealed a musty aroma (Orr *et al.* 1982). Apart from the off-flavour described it is also questionable whether consumers would accept a product that contains lye peeled potato waste.

Later, comprehensive studies were conducted by Camire's group in the 1990 on the effects of extrusion cooking, a high-temperature short-time process that heats food under pressure, on the technological and functional properties of potato peels. Camire and Flint (1991) reported that extrusion of abrasion potato peels reduced the hydration capacity and increased non-starch polysaccharides. When potato peels originating from steam peeling were extruded at barrel temperatures of 104 and 143°C and various feed moistures, the application of high-temperature processing resulted in darker extrudates, probably caused by enzymatic and non-enzymatic browning reactions. Color was the parameter that was affected most by the extrusion process, as indicated by lower Hunter L values (Arora *et al.* 1993). Extruded peels bound more deoxycholic, cholic, and glycocholic acids that did non-extruded peels, but no effects of extrusion of potato peels on binding of taurocholic acid was observed (Camire *et al.* 1993). Unextruded steam peels were more efficient in binding benzo[a]pyrene than peels extruded at a barrel temperature of 110°C and feed moisture of 30%, and abrasion peels bound less of the carcinogen than steam peels (Camire *et al.* 1995). Extrusion cooking reduced the starch content and increased total dietary fibre of steam peels, whereas the total dietary fibre content of peels obtained from abrasion peeling was not affected by the extrusion process. An increased level of soluble non-starch polysaccharides was observed for both types of peels (Camire *et al*. 1997). As the starch present in potato peels increases the caloric value, which is undesirable if peels are to be used in low-caloric products, attempts have been made to remove starch from extruded and unextruded peels by enzymatic hydrolysis using α-amylase and/or amyloglucosidase. Comparable glucose yields were obtained from non-extruded peels treated with both enzymes and extruded peels treated with amyloglucosidase (Camire and Camire 1994).

MISCELLANEOUS USES OF POTATO PEELS

In addition to the above investigations, a number of other studies have been conducted in various fields on the utilization of potato peels. Tsao and Yang (2006) screened selected Canadian crops such as squash, pepper peel, spinach, kale, and potato for their lutein contents and also described a method for the recovery of lutein from marigold flowers by high-speed counter-current chromatography. While squash and pepper peels proved to be a good source of free lutein (between 18 and 42 mg/100 g fresh weight), the amounts found in potato peels were very low (0.4 mg/100 g fw). Thus, it appears that potato peels are not an economically important source of lutein. In a randomized study, boiled potato peels were compared to honey dressings in the treatment of burns. Although the subjective evidence of relief of pain was comparable, potato peels were inferior to honey with respect to wound healing time and antibacterial activity (Subrahmanyam 1996). Okeke and Frankenberger (2005) used potato peel waste in combination with starch as a substrate for amylolytic bacteria in the bioreduction of perchlorate (ClO_4^-). The rate of perchlorate reduction was dependent on the amount of potato peel, with over 90% removal being achieved in 4 days with 2% (w/v) peels.

CONCLUSIONS

Potato peels as a by-product from potato processing are available in large amounts and contain a wide variety of compounds that could be used in foods and also in non-food applications. Despite the numerous attempts that have been described in this review, so far no concept has been developed that holds promise for a complete utilization of potato peels. Other sectors of the food processing industry have already implemented strategies in this respect. For example, the pectin industry has long established processes for the exploitation of apple pomace as a source of pectin, dietary fibre, natural sweeteners, and apple seed oil, which lead to an almost complete utilization of pomace originating from juice production (Schieber *et al.* 2003). Similar strategies in the potato industry would add value to potato production and diversification and at the same time reduce the enormous amounts of waste generated. As discussed in this review, potato peels not only contain phenolic compounds and high molecular cell wall components but also glycoalkaloids, which may be used as intermediates in steroid synthesis. Thus, potato peels differ greatly from other agricultural by-products because of the presence of both nutriti-

onally and pharmaceutically interesting constituents. In order to be economically feasible, the above mentioned strategies, including separation and purification processes, need to be as cost-efficient as possible, and the technologies applied should be environmentally acceptable. In this context, supercritical fluid extraction using carbon dioxide may be a promising alternative to conventional techniques, since no solvent residues are left after recovery of the target compounds. The data very recently published by Saldaña *et al.* (2007) on the solubility of hydroxycinnamates also present in potato peels are essential for the design of efficient extraction methods. Apart from technical aspects, a market needs to be identified for the components obtained from potato by-products. However, in view of the increased trend towards natural compounds in various industry sectors, the perspectives should be promising.

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