INDUSTRIAL POTATO PEEL WASTE APPLICATION IN FOOD PRODUCTION: A REVIEW

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Abstract
Potato (*Solanum tuberosum* L.) is one of the most important agricultural crops for human consumption and high amount is produced worldwide every year. Potato peel waste is a zero value by-product, which occurs in big amounts after industrial potato processing and can range from 15 to 40% of initial product mass, depending on the peeling method. Food waste utilization causes great concern in food industry in Europe and many scientific works were written on this topic in the last years offering solutions and original approaches.
Present article aims to summarize the review of available literature on industrial potato peel waste application possibilities in food production industry. Scientific articles on food waste management, potato peel chemical composition and recycling methods have been studied. The main results show, that there is a big potential for potato peel extract as an antioxidant in food systems due to its high phenol content. In addition, potato peel powder could serve as a partial flour replacement in dough up to 10 g 100 g^{-1} of flour weight without causing significant changes in sensory properties. Potato peel waste can serve as a solid substrate for fermentation. Further investigations in the present field are needed in order to evaluate full potato peel waste application potential.
Key words: potato waste utilization, phenols, dietary fibre.

Introduction

Potatoes (*Solanum tuberosum* L.) are one of the most important agricultural crops for human consumption after wheat (*Triticum* L.), rice (*Oryza* L.) and maize (*Zea mays* subsp. *mays* L.), with 376 million tons produced in 2013 (Compare data…, 2013). In developed countries up to 69.5% (in 2012) of total produced potatoes are processed (U.S. per Capita…, s.a.). Potatoes are usually peeled during processing and production losses in a form of potato peel waste (PPW) can vary from 15 to 40%, depending on the peeling method (Arapoglou et al., 2009). Each year huge quantities of PPW as a by-product remain after industrial potato processing.

Abrasion peeling is typical for chips production, whereas steam peeling is used for dehydrated and frozen potato products (Schieber and Saldaña, 2009). Steam peelers are compact and generate less product losses, but require high investment and operation costs. Because of that, steam peeling is reasonable when high quantities of product (from 8 to 20 t h^{-1}) have to be peeled in limited space and appearance of brown ring (also known as heat ring, or cooking ring) does not cause problems for final product (Steam peeling…, s.a.). Brown ring occurs due to tissue damage and enzyme-catalyzed phenolic oxidation reaction (Bayindirli, 2010). It is reported, that chemical peeling using NaOH could replace steam peeling to avoid heat-ring (Garrote et al., 1993). Otherwise abrasion peeling is to be used.

PPW is not suitable for non-ruminants without further treatment because it is too fibrous to be digested (Birch et al., 1981), but as an inexpensive by-product it contains a large quantity of starch, non-starch polysaccharides, lignin, polyphenols, protein and small amount of lipids. This makes it a cheap and valuable base material for extraction of valuable products (such as natural antioxidants, dietary fibre, biopolymers, etc.) and fermentation processes (Arapoglou et al., 2009; Al-Weshahy and Rao, 2012; Wu et al., 2012).

Many studies were made and articles were written on PPW application possibilities in order to minimize industrial waste amount and find suitable application for PPW as a by-product. The aim of the present study is to summarize the available literature on possible industrial PPW utilization methods and highlight its application possibilities in food production.

Materials and Methods

Monographic method has been used for this study. Available literature on food waste management, PPW chemical composition and recycling methods have been studied with the aim to cover broad spectrum of methods developed for industrial potato waste application possibilities in order to produce new food products.

Results and Discussion

PPW chemical composition

Raw potato peels have high moisture and carbohydrate contents, but overall protein and lipid contents are generally low (Table 1). High content of starch (52 g 100 g^{-1} of dry weight) makes it a good basis for fermentation (Potatoes, raw, skin, s.a.; Arapoglou et al., 2009). In addition, potato peels (PP) contain a variety of valuable compounds, including phenols, dietary fibres, unsaturated fatty acids, amides, etc. (Schieber and Saldaña, 2009; Wu et al., 2012).

Table 1

Chemical composition of raw potato peel, g 100 g^{-1}

Compound	Minimum and maximum values	Average content	Source*
Water	83.3-85.1	84.2	Potatoes, raw, skin, s.a. Arapoglou et al., 2009
Protein	1.2-2.3	1.8	Arapoglou et al., 2009 Potatoes, raw, skin, s.a.
Total lipids	0.1-0.4	0.3	Potatoes, raw, skin, s.a. Arapoglou et al., 2009
Total carbohydrate	8.7-12.4	10.6	Arapoglou et al., 2009 Potatoes, raw, skin, s.a.
Starch	7.8		Arapoglou et al., 2009
Total dietary fibre	2.5		Potatoes, raw, skin, s.a.
Ash	0.9-1.6	1.3	Arapoglou et al., 2009 Potatoes, raw, skin, s.a.

* The first source refers to min value, the second – to max value.

PP contains high quantities of polyphenols which have a role in the defence mechanism against phytopathogens. Therefore almost 50% of phenolics are located in the peel and adjoining tissues and decrease toward the center of the tuber (Friedman, 1997). PP polyphenols can reach almost three times more antioxidant activity than the other plant tissues.

Total phenolic compound content in PPW differs between potato cultivars (Murniece et al., 2014) and it is very heterogeneous class that can be classified in phenolic acids and flavonoids. Phenolic acids are the main phenolic compounds in potatoes (Mäder et al., 2009; Schieber and Saldaña, 2009; Singh and Saldaña, 2011) and a major part of them make neochlorogenic, chlorogenic and caffeic acids (Sánchez Maldonado et al., 2014). Most common flavonoids are flavonols, flavan-3-ols, flavones, flavanones and anthocyanins (Schieber and Saldaña, 2009). Total phenolic content in freeze-dried PP extract can be in range from 1.5 to 3.3 mg of gallic acid equivalents per gram (GAE g^{-1}) (Rodriguez De Sotillo et al., 1994; Al-Weshahy and Rao, 2009). Some studies show up to 4.3 mg of GAE g^{-1} (Kähkönen et al., 1999). The highest phenolic content is obtained from red-colour PP extracts. This may be explained with high amount of anthocyanins which are pigments in red-colour varieties of potatoes (Im et al., 2008; Al-Weshahy and Rao, 2009), and in some coloured potato varieties anthocyanin content in peel can be up to 2.5 times higher than in flesh (Jansen and Flamme, 2006). Major phenolic compounds in PPW freeze-dried extracts are chlorogenic (50 g 100 g^{-1}), gallic (42 g 100 g^{-1}), protocatechic (8 g 100 g^{-1}), and caffeic (0.2 g 100 g^{-1}) acids (Rodriguez De Sotillo et al., 1994). Due to this fact, after potato processing the highest content of phenolic compounds is in peeling by-products (Mäder et al., 2009). Moreover, PP phenols both free and bound-form show higher radical scavenging activity than potato flesh phenols (Nara et al., 2006).

Phenolic compounds contribute to antioxidant activity and protect plants against various biotic and abiotic stresses. As a result, their presence in human diet prevents degenerative diseases (Pourcel et al., 2007; Im et al., 2008). There is a strong correlation between total phenol content in the extract and antioxidant properties, and losses are observed in total polyphenol amounts in PP during storage even at -20 ºC. In the freeze-dried samples moisture level is lower than 2 g 100 g^{-1} and it is still possible that some enzymes can still remain active (Al-Weshahy et al., 2013). Because of that, PP require proper storage conditions to maintain their antioxidant properties (Al-Weshahy and Rao, 2009; Al-Weshahy et al., 2013).

Glycoalkaloids are secondary plant metabolites and they are toxic to humans, animals, microorganisms, insects and viruses (Mäder et al., 2009; Schieber and Saldaña, 2009). The main glycoalkaloids found in PP are α-solanine, α-chaconine and solanidine, and they are suitable for utilization in pharmaceutical industry (Friedman, 2004; Sánchez Maldonado et al., 2014). Studies on rats show that extract derived from PP significantly offsets carbon tetrachloride induced liver injury (Singh et al., 2008). Total levels of solanine and chaconine in PP can range from 84 to 3526 mg kg^{-1} (with ratio of α-solanine to α-chaconine from 2.1 to 2.4) and it depends on variety of factors such as potato cultivars, light, irradiation, conditions of storage and mechanical injury (Friedman, 2004).

PPW is a good source of dietary fibre: primarily insoluble carbohydrates – cellulose, hemicellulose, lignin, pectin, gums, etc. (Al-Weshahy and Rao, 2012) with average content of 40 g 100 g^{-1} (Camire and Flint, 1991) and it depends on the peeling method. Abrasion peeling results in more starch and less dietary fibre (especially lignin) comparing to the steam peeling. In addition, higher amount of glucose can be recovered from the insoluble fibre fraction of steam peeled wastes, and this fact can be explained by formation of resistant starch (Camire et al., 1997).

Safety of PPW application

PP extracts results in mixtures of phenols and toxic glycoalkaloids and separation is needed prior to phenolic extract application in foods (Hossain et al., 2014; Sánchez Maldonado et al., 2014), where it has huge potential as antioxidant (Mansour and Khalil, 2000; Friedman, 2004; Zia-ur-Rehman et al., 2004; Arapoglou et al., 2009; Al-Weshahy and Rao, 2012). Moreover, at present moment there are no method for the simultaneous recovery and subsequent separation of phenols and glycoalkaloids (Sánchez Maldonado et al., 2014). It is reported, that a glycoalkaloid limit of 20 mg 100 g^{-1} is acceptable for human consumption (Papathanasiou et al., 1999).

Synthetic antioxidants are commonly used in food production, however, due to safety concerns, interest in natural antioxidants is high (Shahidi, 2000). It is reported, that synthetic antioxidants are toxic in high dosages (Ito et al., 1986; van Esch, 1986; Kahl and Kappus, 1993). From the other side, safety limits of natural antioxidants are mostly unknown and there is no guaranty that they are safer than synthetic analogue (Pokorný, 2007). Synthetic antioxidants butylhydroxyanisole (BHA) and butylhydroxytoluene (BHT) and natural vitamin E in high dosages induce impairment of blood clotting in animals (are antagonists to vitamin K), but in contrast to BHA and BHT, comparing carcinogenic effect of high dosages, vitamin E is not carcinogenic (Kahl and Kappus, 1993). Further studies on antioxidant toxicity are needed.

It has been reported that in terms of safety as natural antioxidant in foods, PPW phenolic extract is not mutagenic (Sotillo et al., 1998).

PPW application in food industry

Methanol, ethanol and water are the most commonly used solvents for phenolic compound extraction from PP (Singh and Rajini, 2004; Mohdaly et al., 2010; Amado et al., 2014; Sánchez Maldonado et al., 2014). Phenols extracted from PPW show potential in food industry as a natural antioxidant to prevent lipid oxidation (Singh and Rajini, 2004; Mohdaly et al., 2010). It is reported, that PPW extract is able to protect against oxidation of soybean oil (Onyeneho and Hettiarachchy, 1993; Zia-ur-Rehman et al., 2004; Amado et al., 2014) and fish-rapeseed oil mixture (Koduvayur Habeebullah et al., 2010). Soy bean oil samples, containing 1600 and 2400 mg kg^{-1} of PP petroleum ether extract after 60 day storage at 45 °C, showed lower peroxide values (10 and 9 meq kg^{-1}) and free fatty acids content (1.2 g kg^{-1} and 1.1 g kg^{-1}), than the control samples (59 meq kg^{-1} and 3.2 g kg^{-1}, respectively) (Zia-ur-Rehman et al., 2004). Positive results were gained on freeze-dried PPW extracts application in raw beef patties during cold storage at ~5 °C for 12 days. In this study, freeze-dried extract showed maximum antioxidant capacity at pH range 5-6 (Mansour and Khalil, 2000). Moreover, it is capable to retard lipid peroxidation of irradiated meat and antioxidant activity of PP extract was found to be comparable to BHT (Kanatt et al., 2005). It is very important aspect because during irradiation process meat can undergo oxidative changes that affect its quality (Formanek et al., 2003). Ethanol extracts were found to be very effective in retarding lipid and protein oxidation in mackerel mince (*Trachurus trachurus*). Samples of mackerel mince (with PPW ethanol extract concentrations 2.4 and 4.8 g kg^{-1}) were stored at 5 °C for 96 h. Antioxidant effect of the extract resulted in low levels of peroxide value and carbonyl compounds (Sabeena Farvin et al., 2012).

Studies show that potato dietary fibre is able to bind bile acids in-vitro and can be part of the mechanism that lowers plasma cholesterol (Camire et al., 1993). In addition, high intake of dietary fibre has a positive effect on blood glucose profile (Onyechi et al., 1998; Chandalia et al., 2000; Singh et al., 2005). Studies were made by adding dry PPW powder to baked products. The best results were achieved by replacing 10–15% of flour in dough. Prepared samples were darker and harder than control without differences between types of peels. Meanwhile, replacing up to 10% of flour did not make significant sensory changes comparing to control (Toma et al., 1979; Magied, 1991; Arora and Camire, 1994; Camire et al., 1995; Pasqualone et al., 2013).

PPW extract at high concentrations found to have species independent antibacterial and antifungal activities, especially significant compared to streptocycline (an effective antibiotic against bacterial plant pathogens) against *Pseudomonas aeruginosa* (Deviprasad and Pushpa, 2007). Conversely, other studies show that PPW extract is species dependent and is effective against gram negative and one gram positive bacteria and have only bacteriostatic effect – inhibits multiplication of bacteria (Sotillo et al., 1998).

Edible films, films produced from edible biopolymers and food grade additives (Han, 2014), can be produced from PPW (Kang and Min, 2010; Tammineni et al., 2013). H.J. Kang and S.C. Min (2010) developed edible film production method. In their studies, PPW powder was produced, mixed with water and pre-homogenized. To destruct biopolymers, homogenate was treated in three ways: by high-pressure homogenization (138 MPa), gamma irradiation (10-20 kGy) or ultrasound (24 kHz, 120 μm). Glycerol as plasticizer and soy lecithin as emulsifier were used. Film, prepared by high-pressure homogenisation, showed better moisture barrier, tensile and colour properties. Present results make good basis for further studies, because produced PPW-based film should be further improved to be applied to food products.

There are several potential compounds that can be manufactured from PPW by using fermentation reactions (Salvador et al., 2002), such as ethanol (Arapoglou et al., 2009, 2010; Kheyrandish et al., 2015), lactic acid (Zhang et al., 2006, 2007; Zhang, 2008; Liang et al., 2014), enzymes (Mahmood et al., 1998; Sachslehner et al., 2000; Asgher et al., 2007; Mabrouk and El-Ahwany, 2008).

PPW features a high potential for ethanol production that has a large potential market (Arapoglou et al., 2010; Kheyrandish et al., 2015). PPW contains sufficient quantities of starch, cellulose, and hemicellulose. However, fermentable reducing sugar content is very low, 0.6 g 100 g^{-1} of dry weight and because of this fact fermentation of raw material is not practical and an initial hydrolysis of carbohydrates is necessary. Sugars can be hydrolysed with various enzymes and/or acid, and fermented by *Saccharomyces cerevisiae* var. *bayanis* (Arapoglou et al., 2009, 2010). Studies show that sulphuric acid is an adequate acid to hydrolyse dried potato samples for further fermentation and it is more efficient than enzymatic hydrolysis (Guerra-Rodríguez et al., 2012).

Among different compounds, lactic acid can be produced during hydrolysed PPW fermentation process using *Rhizopus* fungus cultures (Zhang et al., 2007, 2008) and undefined mixed culture inoculated from wastewater treatment plant sluge (Liang et al., 2014). Concentration of 85.7 g L^{-1} was obtained by using *Rhizopus arrhizus* in association with the formation of coalesced loose small pellets (Zhang et al., 2008).

PPW starch can be used for enzyme production such as thermostable α-amylase, a starch hydrolysing enzyme that is widely used in different food industries. Positive results were achieved using *Bacillus subtilis* strains (Mahmood et al., 1998; Asgher et al., 2007) with maximum enzyme production after 48 h of cultivation at pH 7.0 and 50 °C. Enzymes had optimum activity at pH 8.0 and 70 °C, were stable for 1 h at 60 and 70 °C and had suitable characteristics for application in starch processing and food industries (Asgher et al., 2007). In addition, enzyme β-mannanase can be produced using *Bacillus amylolequifaciens* and it is reported that PPW found to be the most effective carbon source, comparing to peel samples of orange, apple, mango, as long as palm seed powder, corn cob and rice husk (Mabrouk and El-Ahwany, 2008). Currently β-mannanase is used in instant coffee processing for coffee mannan hydrolysis to significantly reduce the viscosity of coffee extracts (Sachslehner et al., 2000).

Conclusions

1. Potato peel waste (PPW) can serve as a basis for phenol extraction, ethanol, lactic acid and enzyme (α-amylase and β-mannanase) production through fermentation, and edible film production.
2. PPW extract has a high application potential as antioxidant in food systems. It can prevent lipid oxidation in oils and meat.
3. PPW has potential as a base for fermentation reactions because of high starch content, but due to its low fermentable reducing sugar content, requires initial hydrolysis of carbohydrates.
4. PPW can be used in healthy and functional food production as dietary fibre source. It can be used in bakery production and replace up to 10% of flour amount without changes in sensory quality.

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