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Effect of alkaline and high-pressure homogenization on the extraction of phenolic acids from potato peels

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ABSTRACT

Phenolic acids were extracted from potato peels with NaOH treatment and a high-pressure homogenization (HPH) process. Total phenolic content, total flavonoid content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity and extraction yield were determined with different treatment conditions. Significant improvement was observed after the alkaline and HPH treatments. HPLC analysis shows that the phenolic compounds contained gallic acid, sinapic acid, vanillic acid, syringic acid, protocatechuic acid, *p*-coumaric acid, chlorogenic acid, caffeic acid and ferulic acid. The yields of these specific phenolic acids varied with different treatments. Scanning electron microscope, nuclear magnetic resonance and particle size measurements suggest that changes in cellular structure may be the mechanisms for the improvement in extraction rendered by the HPH and NaOH treatments. In conclusion, the combined treatment of NaOH and HPH increased the extraction yield and functionality of the phenolic acids from the potato peel residues.

Industry relevance: High-pressure homogenization as a process method has been applied widely in food industry. It can help with emulsification and sterilization significantly. But the potential of High-pressure homogenization as an assist method to improve the yield of extraction from food and food waste has not been developed. The positive effect of phenolic and flavonoids has been proved and found in potato peels. However, the release of these bioactive components is a difficulty with traditional method. The High-pressure homogenization can reduce the particle size apparently and release the bioactive compound. For potato peels, the production can be added into bread, meat, beverage, etc. to increase the fiber and nutrition. For other sorts of similar material, the high-pressure homogenization can be a novel to improve the extraction process of bioactive component bound in cell wall instead of inside the cell. In this article, we developed a new method with high-pressure homogenization and alkaline treatment to improve the extraction process dramatically. Meanwhile, the process can be scale up to industry with minor modification and adjustment.

1. Introduction

Potatoes are a major crop in the world. In 2013, 376.45 million tons of potatoes were produced (FAOSTAT). One third of the production was consumed as a fresh product while the rest went into processing flow to meet the demands for convenience and fast food consumptions, which include frozen fries and wedges, crisps, starch and dried potatoes. During processing, most potatoes need to be peeled with various methods, resulting in a large amount of potato peel residues.

The potato peel residues from food processing contain starch, non-starch polysaccharide, protein, and fat. Therefore, it has been used as a carbon source in fermentation to produce lactic acid, biofuels (Arapoglou, Varzakas, Vlyssides, & Israilides, 2010), reducing sugars (Bhattacharyya, Chakraborty, Datta, Drioli, & Bhattacharjee, 2013), and cellulolytic enzymes (dos Santos, Gomes, Bonomo, & Franco, 2012). Phenolic compounds and glycoalkaloids are found in potatoes, especially in potato peels. Ferulic acid, gallic acid, sinapic acid, vanillic acid, caffeic acid, syringic acid, protocatechuic acid, *p*-coumaric and chlorogenic acid have been extracted and identified in potato peels (Friedman, 1997; Maldonado, Mudge, Ganzle, & Schieber, 2014). Higher quantities and stronger antioxidant activity of these acids were observed in potato peels than in potato flesh (Wu et al., 2012). These phenolic compounds have been proven to be a source of natural antioxidants, which can replace unhealthy anti-oxidant additives used in food products, such as butylated hydroxyanisole, butylated hydroxytoluene, tert-butyl hydroquinone (Rehman, Habib, & Shah, 2004). These natural antioxidants can retard the oxidation of proteins and lipids while exhibiting antimicrobial activity. They have been used in radiated

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lamb meat (Kanatt, Chander, Radhakrishna, & Sharma, 2005), chilled minced horse mackerel (Farvin, Grejsen, & Jacobsen, 2012), soy bean oil (Rehman et al., 2004), vegetables oil (A. A. A. Mohdaly, Sarhan, Mahmoud, Ramadan, & Smetanska, 2010), among other uses.

The phenolic acids may exist in free or bound form in potato peels. Most methods can isolate almost all of the free phenolic acids, but a smaller percentage of the bound phenolic acids. Most of ferulic acid and *p*-coumaric acid found in plants are bound to the cell wall polysaccharides through ester-bonds (Fry, 1986). The bound form phenolic acids can potentially offer strong antioxidant capacity if they are released from the cellular matrix (Nara, Miyoshi, Honma, & Koga, 2006). Alkaline treatments such as dilute sodium hydroxide solution have been shown to break the ester-bonds and release the bound form phenolic acids, resulting in a higher total yield of phenolic acids (Nara et al., 2006).

There have been many studies on the conventional methods for extraction of phenolic compounds from potato peels, using organic solvents such as methanol, acetone, ethanol, and ethyl acetate at high temperatures. It has been shown that methanol and ethanol can extract more phenolic acids from potato peels compared to acetone, hexane, diethyl ether and petroleum ether(Adel A. A. Mohdaly, Sarhan, Smetanska, & Mahmoud, 2010). In addition, a few new methods have been developed to extract the active components in potato peels and other crop residues. These include ultrasonic assisted extraction (Chen, Zhao, & Yu, 2015), subcritical water or pressurized liquid extraction at above 100 °C under high pressure (Alvarez, Cahyadi, Xu, & Saldana, 2014; P. P. Singh & Saldana, 2011), acidified water- and ethanol-based solvents (Maldonado et al., 2014), and microwave-assisted extraction (Singh et al., 2011).

High-pressure homogenization (HPH) has been reported to reduce particle size dramatically (Grau, Kayser, & Müller, 2000; Li et al., 2004), and is used for pharmaceuticals, food and other materials manufacturing industries. Homogenization is mainly a mechanical process that disrupts cellular structures; for example, it breaks cell walls and compartments, resulting in the direct release of cellular products and increased access of solvent to cellular materials. Microfluidization, the HPH technique used in this study, can generate 160 Mpa, whereas conventional homogenization techniques usually generate 30 Mpa. In the microfluidization technique, high velocity micro-streams are created as a fluid accelerates into chambers so that the high impact shear can damage the cell walls and reduce the particle size more significantly (McCrae, 1994).

However, there is no report on the use of a method combining HPH and alkaline treatment to extract phenolic acids from potato peels. This research seeks to compare a combined method to alkaline treatment and HPH methods used separately; to study the effect of alkaline treatment time and concentration on the yield of total phenolic acid, total flavonoids and radical scavenging capacity; and to determine the effect of the combined treatment process on the yield of individual major phenolic acids.

2. Materials and methods

2.1. Materials and chemicals

The potato peel residues were provided by Old Dutch Food Inc. (Roseville, MN, USA). HPLC-grade acetonitrile and water were purchased from Sigma-Aldrich (St. Louis, MO, USA). Phenolic standards of highest purity available were used. Ferulic acid (FER), gallic acid (GAR), sinapic acid (SIN), vanillic acid (VAN), caffeic acid (CAF), syringic acid (SYR), protocatechuic acid (PRO), *p*-coumaric acid (*p*-COU) and chlorogenic acid (CHL) were obtained from Sigma-Aldrich (St. Louis, MO, USA). All other chemicals were analytical grade ordered from Sigma-Aldrich (St. Louis, MO, USA).

2.2. Sample preparation, chemical analysis and experiment procedure

Potato peels were lyophilized and milled with a laboratory bench mill, and then screened by sieves. The samples with particle size between 125 μm and 355 μm were used for the extraction experiments. The chemical composition of potato peels was analyzed by the Minnesota Valley Testing Laboratories, Inc. (New Ulm, MN, USA). The moisture (AOAC 930.15), carbohydrate (calculated), fat (AOAC 2003.05), crude fiber (AOCS BA6A-05), protein (AOAC 990.03), starch (MVTL R&D) and ash (AOAC 942.05) were determined before the process. The extraction procedure is as follows: 4 g potato peel residue power was pretreated in ethanol with 100 mL NaOH of varying concentration (0–0.4 mol/L) at 40 °C for varying amounts of time (0–24 h). Table 2 shows the experimental conditions used for each sample. Sample Number 1 is the control sample that did not go through the NaOH pretreatment and HPH process. After that, the samples were neutralized with HCL in ethanol to pH 7.0 and passed through the High Pressure Homogenizer twice at 158.58 Mpa. All samples were diluted with ethanol to 200 mL and incubated at 40 °C for 1 h for extraction. In succession, the samples were centrifuged at 8000 rpm for 10 min and filtrated through a 0.45 μm membrane. The upper layer liquid (supernatant) was collected and stored in −20 °C for further testing.

2.3. Determination of total phenolic content

A modified Folin-Ciocalteu assay (Singleton, Orthofer, & Lamuela-Raventós, 1999) was employed to determine the total phenolic content of potato peel extracts. Gallic acid was used as a standard and a series of gallic acid solutions (0–100 mg/L) was prepared to establish the standard curve, which was a plot of gallic acid concentration vs. absorbance at 760 nm. For the analysis, 100 μL Folin-Ciocalteu Reagent was added to 1 mL sample or blank. After 5 min, 1 mL Na_2CO_3 solution (12%) was added, followed by addition of 5 mL distilled water. After incubation for 1 h at room temperature, the absorbance of samples was measured on a DR5000 Spectrophotometer (Hach Company, Germany) at 760 nm in a 1 mL cuvette. The results were expressed as mg gallic acid equivalent/g dry weight (mg GAE/g DW).

2.4. Determination of total flavonoid content (TFC)

The total flavonoid content was determined based on the method reported by (Zhishen, Mengcheng, & Jianming, 1999) with slight modification. A series of catechin solutions (0–100 mg/L) was prepared to establish the standard curve. Briefly, 1 mL sample or blank was diluted with 250 μL of distilled water, and then 75 μL $NaNO_2$ (5%) was added. After 5 min, 150 μL $AlCl_3$ (10%) was added. After another 5 min, 500 μL of 1 M NaOH was added and finally the solution was diluted with 2 mL distilled water. After incubation for 30 min at room temperature, the absorbance was read at 510 nm on the DR5000 Spectrophotometer (Hach Company, Germany). The total flavonoid content was calculated by comparing the readings against the standard curve and expressed as mg catechin equivalent/g dry weight (mg catechin/g DW).

Table 1
Proximate composition of potato peels residue.

Particle size	125–212 μm (%)	212–355 μm (%)
Moisture	6.00	5.55
Carbohydrate	72.57	72.21
Starch	49.40	45.60
Fiber, crude	6.58	9.09
Fat, ethyl ether	1.04	1.33
Protein N × 6.25	12.90	13.60
Ash	7.49	7.31