Ultrasound-assisted extraction of polyphenols from potato peels: Profiling and kinetic modelling[†]

Author list

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Abstract

Ultrasound-assisted extraction (UAE) at 33 kHz and 42 kHz have been investigated in the extraction of polyphenols from peels of two potato varieties, cream-skinned Lady-Claire (LC) and pink-skinned Lady-Rosetta (LR), commonly used in snack-food production. Extraction efficacy between the UAE-untreated (control) and the UAE-treated extracts was assessed on the total phenolic content and antioxidant capacities (DPPH and FRAP). Application of UAE showed significantly higher recovery of phenolic compounds compared to solid-liquid extraction process alone. Lower ultrasonic frequency (33 kHz) was more effective in recovering polyphenols compared to 42 kHz ultrasonic treatment. The liquid chromatography-tandem mass spectrometry revealed that chlorogenic acid and caffeic acid were the most prevalent phenolics in LR peels, whereas caffeic acid was dominant in LC peels. Peleg's equation showed a good correlation ($R^2 > 0.92$) between the experimental values and the predicted values on the kinetics of UAE of phenolic compounds.

Keywords: Ultrasound-assisted extraction (UAE), potato peel, antioxidant activity (DPPH and FRAP), phenolic acids, UHPLC-MS/MS, Peleg's kinetics modelling

1. Introduction

Every year, tens of thousands tonnes of potato peels are generated by the snack-food industries worldwide and the peels are either used as cattle feed or disposed of in landfills that could cause environmental damage and disposal costs to the processors. However, potato peels have potential to be reutilised by exploiting them as sustainable source for high value food additives such as natural antioxidants (Rehman *et al.*, 2004), dietary fibre (Toma *et al.*, 1979) and anti-microbial agent (De Sotillo *et al.*, 1998). In particular, extracts from potato peel have exhibited potential as antioxidants in food systems (Kanatt *et al.*, 2005) due to their high content of polyphenols. Friedman (1997) reported that the polyphenols in potato peel, which accounted for approximately 50% of all polyphenols in potato tuber, are ten times higher than in the pulp. These polyphenols exhibit natural antioxidant capacities by scavenging reactive oxygen species (ROS) i.e. free radicals (through electron or hydrogen atom transfers) thus inhibiting oxidative damages to the cell components. However, in food application (mainly for stability of lipids and fats) they stabilise the free radicals through resonance delocalisation instead of terminating peroxy free radicals by donating hydrogen atom as done by commercial antioxidants (Tiwari *et al.*, 2013). They could be a potential replacement of synthetic antioxidants such as butylated hydroxyanisole and butylated hydroxytoluene and tertiary butylhydroquinone (have shown some evidence of toxic and carcinogenic properties (Branen, 1975)), in food preservation as well as food fortification.

In recent years, a number of improved novel extraction methodologies including ultrasound-assisted extraction (UAE) have emerged as efficient extraction alternatives to conventional extraction techniques. Advantages of UAE include simplicity, flexibility, versatile, easy to use, requiring relatively low capital investment and scalable for commercial uses (Patist and Bates, 2008). Essentially, the ultrasonic treatment amplifies extraction efficiency by accelerating diffusion, improving solvent penetration and increased mass transfer. UAE has been reported to be efficient for the recovery of diverse range of valuable compounds such as polysaccharides, pectin, hemicellulose, proteins, unsaturated fatty acids, glycoalkaloids and phenolic compounds (Chen *et al.*, 2011, Samaram *et al.*, 2015, Tabaraki and Nateghi, 2011, Karki *et al.*, 2010, Fu *et al.*, 2006). In addition studies investigating the ability of UAE to enhance yields of polyphenols from food waste published to date

have used HPLC or TLC to characterise phenolic compounds (Wijngaard *et al.*, 2012, Onyeneho and Hettiarachchy, 1993), which suffer from specificity and low sensitivity in detecting target molecules. On contrary, employing ultra-high performance liquid chromatography tandem mass spectrometry (UHPLC-MS/MS) will confer a greater specificity, sensitivity and speed to polyphenol analysis. In addition the modelling of extraction kinetics helps in predicting the optimum extraction parameters to recover maximum target molecules from plant matrices. Peleg's model of sorption kinetics (Peleg, 1988) has been applied for various UAE kinetic studies like chicory by-products (Pradal *et al.*, 2016), bioactives from brown seaweed (Kadam *et al.*, 2015), however this approach has not been adopted from the UAE recovery of polyphenols from potatoes. In present study, we have investigated the effect of UAE on the kinetic of extraction of phenolic compounds from potato peel of two different potato varieties collected from snack-food manufacturing industries followed by UHPLC-MS/MS characterisation.

2. Material and methods

2.1 Materials and reagents

Phenolic standards chlorogenic acid, caffeic acid, trans-cinnamic acid, gallic acid, ferulic acid, isoferulic acid, rutin, protocatechuic acid, luteolin-7-*O*-glucoside and p-coumaric acid, all other chemicals and HPLC-grade organic reagents were purchased from Sigma-Aldrich (Wicklow, Ireland). The enzymes α-amylase, protease and amyloglucosidase were purchased from Megazyme (Wicklow, Ireland).

2.2 Sample preparation

Potato peels slurry arising from two potato varieties namely Lady-Claire (LC) and Lady-Rosetta (LR) were provided by Largo Foods Limited (Meath, Ireland). Freeze-drying was carried out for the stability of the raw material on the frozen peel in FD 80 GP "LEANNE" freeze drier model (CUDDON Limited, New Zealand) at a temperature of -50 ºC and a pressure of 0.01 mbar for 24 h. Freeze dried samples were immediately powdered, vacuum packed and kept in -20 ºC for further analysis.

2.3 Proximate analysis of potato peel powder

The protein content was measured using a nitrogen analyser (FP-628 Leco Instrument, USA) based on the Dumas principle (N x 6.25), total fat using acid hydrolysis method (AOAC 954.02), ash content by AOAC 923.03 method (AOAC., 2000) and total carbohydrate was calculated by difference i.e. [100- (g protein + g fat + g ash)]. Total dietary fibre analysis of LC potato peel was conducted by ANKOM automated dietary fibre analyser in accordance with the AOAC (1990) method 991.43.

2.4 Generation of crude phenolic extracts

2.4.1 Solid-liquid extraction (SLE)

A preliminary solid-liquid extraction was carried out on peels from LR variety using different solvent combinations, i.e. 1) 100% distilled water, 2) 100% methanol, 3) 80% methanol-water and 4) 50% methanol-water (v/v) to select the best solvent combination for extraction of phenolic compounds from potato peel. The polyphenol content from SLE was used to benchmark the effect of UAE on various parameters of the extracts in addition to potato varietal comparison. Briefly, dried and ground potato peel samples (2 g) were extracted with 20 mL of solvents at room temperature (~23 ºC) for overnight (15 h) in a tube shaker at 1500 rpm (Multi Reax, Heidolph, UK). The resulting slurries were then centrifuged for 10 min at 4000g. The supernatant was immediately filtered using a 0.45 µm PTFE syringe filter and stored at -20 ºC until further analysis. Two replicate extractions were carried out per sample.

2.4.2 Ultrasound-assisted extraction (UAE)

Freeze dried potato peel powders (1 g) mixed with 80% methanol at a fixed ratio of 1:10 (w/v) were subjected to UAE for 30, 60, 180, 360, and 900 min in separate tubes. Ultrasonic treatment was carried out by submerging the tubes (four tubes per treatment time) in ultrasonic bath BRANSON 3510 with operating frequency of 42 kHz (45 W). Another ultrasonic bath JENCONS S1000 operating at 33 kHz (100 W) was used only with LC variety to understand the effect of ultrasonic frequency/power on the extraction of phenolic compounds of potato peel. The temperature of the samples during sonication treatment was monitored using thermocouples (Radionics, Ireland), which ranged from (30 to 45) ºC. The extracts were collected and stored at -20 ºC until further analysis.

2.5 Phenolic content and antioxidant activity

The total phenolic content (TPC) and two antioxidant assays, namely DPPH radical scavenging and FRAP reducing power capacity, were determined by colourimetric assays. The TPC of extracts was estimated by using the Folin-Ciocalteu reagent as described by Singleton and Rossi (1965); Gallic acid solutions of different concentrations (10-100 µg/mL) were used to prepare calibration curve and the results were expressed as milligram of gallic acid equivalent per gram dry weight basis (mg GAE/gdb). The 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was performed using a modified version of the method proposed by Goupy *et al.* (1999); Various Trolox concentrations (1-8 µg/mL) were used for standard curve and the activity was expressed as milligram equivalents of Trolox per gdb (mg TE/gdb). FRAP activities were carried out based on the procedure of Stratil *et al.* (2006); Calibration curve consisting of different Trolox concentrations (25-150 µg/mL) was prepared and the results were also expressed as mg TE/gdb. All the experiments were performed in duplicate and the results were expressed as mean ± standard deviation (SD).

2.6 UHPLC-MS/MS analysis of polyphenols

Mass spectrometry analysis of the potato peel polyphenols was performed as described by Gangopadhyay *et al.* (2016) with some modifications. The filtered methanolic extracts of potato peels were first screened against 55 known polyphenols from an 'in-house' database using an Acquity ultra-high performance liquid chromatography tandem mass spectrometry (UHPLC-MS/MS) (Waters Corp., MA, USA). Following the identification against authentic standards, the multiple reaction monitoring (MRM) transitions of the detected polyphenols were used for quantification purpose (Supplementary Table S1). Separation of the analytes was achieved on a HSS T3 (C18 column, 2.1 x 100 mm, 1.8 µm) using the solvents 0.1% formic acid in water (solvent A) and 0.1% formic acid in acetonitrile (solvent B) with following gradient: 0-1 min, 2% B; 1-2.5 min, 10% B; 2.5-6 min, 15% B; 6-7.5 min, 50% B; 7.5-9.5 min, 98% B and 9.5-10 min, 2% B at a rate of 0.5 mL/min. The UHPLC-MS/MS data were acquired using electrospray ionisation in negative ion mode with following ionisation conditions: capillary voltage 3 kV, cone voltage 30 V, extractor voltage 3 V, source temperature 120 °C, and desolvation temperature 250 °C. Calibration curves were prepared using 0.1 to 1 µg/mL concentration range for each phenolic compound except for chlorogenic acid and caffeic acid. Chlorogenic acid standards were prepared in the range of 0.1-15 µg/mL whereas caffeic acid

152 standards were between 1-10 µg/mL. The concentration of each phenolic compound in the sample
153 was quantified using the TargetLynx software (Waters Corp., MA, USA).

154 **2.7 Extraction kinetics and statistical analysis**

155 A two-parameter, non-exponential Peleg's sorption kinetic model was employed to describe the
156 extraction kinetics of total phenolic concentration and individual phenolic components (chlorogenic
157 acid and caffeic acid) as a function of potato peel variety and ultrasonic frequency:

158

$$C(t) = C_0 + \frac{t}{K_1 + K_2 \cdot t} \quad (1)$$

159 Where, *C* (t) is the concentration/bioactivity of targeted compound at time t (min), C_0 is the initial
160 concentration/activity at time t = 0 (mg /gdb), K_1 is Peleg's rate constant and K_2 is Peleg's capacity
161 constant. Since C_0 in all experimental case was zero, so equation (1) was modified as follows (Eq. 2)
162 for experimental data approximation i.e. predicted values.

$$C(t) = \frac{t}{K_1 + K_2 \cdot t} \quad (2)$$

163

164 The Peleg's rate constant K_1 relates to the extraction rate (B_0) at the start ($t = t_0$).

$$B_0(\mathrm{mg/g_{db}}) = \frac{1}{K_1} \quad (3)$$

165 The Peleg's capacity constant K_2 relates to the extraction extent (Ce) at equilibrium (t = ∞)

$$C_e(\mathrm{mg/g_{db}}) = \frac{1}{K_2} \quad (4)$$

166 Analysis of variance was carried out using SAS, USA Version 9.3 statistical software. Nonlinear
167 regression was used to determine the two parameters of Peleg's model i.e. constant K_1 and K_2 using
168 non-linear regression (Gauss-Newton method). Model fitting was judged based on regression
169 coefficient (R^2).

170 **3. Results and discussion**

171 **3.1 Proximate composition**

The proximate composition results of peels from two potato cultivars (Table 1) were broadly within the range of previously reported values for potato peels (Amado *et al.*, 2014, Camire *et al.*, 1997) except for the fat content, where these authors have observed slightly lower levels (0-1.07%) with respect to our data, i.e. 1.27-2.09% fat. These variations in potato peel composition may be attributed to various factors including varietal differences, peeling techniques, agronomic and other environmental factors (Burlingame *et al.*, 2009, Camire *et al.*, 1997). The protein and carbohydrate content were significantly higher ($p < 0.05$) in Lady Claire (LC) peels compared to the Lady Rosetta (LR) peels. The LC variety contained ~ 51% total dietary fibre presenting it as an attractive and sustainable source of dietary fibre.

3.2. Extraction efficacy of solvent combination for polyphenols

Several studies have used methanol to extract polyphenolic compounds from potato peels (Mohdaly *et al.*, 2010, Singh *et al.*, 2011, Singh and Saldaña, 2011). However a combination of water and alcohol (ethanol, methanol) has shown better extraction efficiency compared to organic solvents alone. For example, Turkmen *et al.* (2006) have reported the lowest total polyphenols (23.5 mg GAE/gdb) with absolute methanol, however the highest level of polyphenol (82.3 mg GAE/gdb) was noted with 50% methanol in black tea. Similarly Zhou and Yu (2004) on using 70% ethanol led to higher recovery of total phenols compered to ethanol alone from wheat bran. Yu *et al.* (2005), also observed that 80% methanol and 80% ethanol resulted in approximately 60% higher TPC from peanut skins when compared to water alone. Lapornik *et al.* (2005), on the other hand, used 70% alcohol (methanol or ethanol) and observed 2-4 fold increase in polyphenols and anthocyanins recovery after 12 h of extraction from red-current and black-current by-products compared to water alone. Hence various combinations of water-methanol for the extraction of potato peel polyphenols were investigated (Supplementary Table S2). Examination of the data revealed that use of an 80% methanol-water resulted in significantly higher ($p < 0.05$) level of TPC and antioxidant activity compared to other combinations examined. Findings by other authors and this study clearly suggested that the polyphenols extraction is improved using methanol-water combination, and therefore the 80% methanol was used as extractant to examine the effect of ultrasound treatment on phenolic yield in the peels.

3.3 Antioxidant activities and phenolic content of potato peel SLE extracts

As shown in Table 2, levels of total phenolic content (2.17-3.28 mg GAE/gdb) are within the range of those reported previously by other authors [Al-Weshahy and Venket Rao (2009) (1.51-3.33 mg GAE/gdb, Mohdaly *et al.* (2010) (2.91 mg GAE/gdb)]. It is also evident that LR peel possesses significantly higher ($p < 0.05$) amount of total phenolics and antioxidant activities compared to LC variety. One possible reason for a higher level of phenolics in LR peels is probably due to its pigmented skin as studies have shown that coloured potatoes have higher phenolic contents compared to white or brown-skinned potatoes (Lachman *et al.*, 2008, Al-Weshahy and Venket Rao, 2009). The high antioxidant activity from LR peels is supported by the fact that total phenolic content (TPC) and antioxidant activity (DPPH and FRAP) exhibited significantly high correlation for both the activities ($r > 0.99$, $p < 0.05$). This is further supported by the UHPLC-MS/MS data where the total phenolic acids (sum of chlorogenic acid and caffeic acid) in LR and LC were 322.4 μg/gdb and 70.4 μg/gdb, respectively (Table 2). This shows that antioxidant activity is influenced by the amount of phenolics extracted vis-a-vis varieties employed for extraction. Similar correlations haven been observed by Amado *et al.* (2014) in the phenolic compounds and antioxidant activities of 'Agria' potato peel.

As identified and quantified using UHPLC-MS/MS (Supplementary Figure S1), chlorogenic acid (23.7 mg/100gdb) and caffeic acid (8.5 mg/100gdb) were the two predominant phenolic acids in LR peel whereas caffeic acid (6.8 mg/100gdb) was the prevalent phenolic acid in LC (Table 2). Minor peaks of ferulic acid, p-coumaric acid, vanillic acid and rutin were also identified, however these compounds were present at levels below the limit of quantification for the method applied. Wijngaard *et al.* (2012) have also shown that the caffeic acid is the predominant phenolic acid in LC peel, however the maximum content reported was 65.1 mg/100gdb. This significant variation may be attributed to the choice of peels, method of extraction and analysis, agronomical or environmental factors. The relative abundance of chlorogenic acid is in line with previous studies as the most prevalent phenolic acid in potato peel (Onyeneho and Hettiarachchy, 1993, Nara *et al.*, 2006, Singh *et al.*, 2011, Singh and Saldaña, 2011). Al-Weshahy and Venket Rao (2009) found that chlorogenic acid (2.79 mg/gdb) in red colour potato peel from siècle variety was the highest among all the other five

varieties used in their study followed by caffeic acid (0.26 to 0.72 mg/gdb). In another study, Nara *et al.* (2006) identified two major peaks of chlorogenic acid and caffeic acid in potato peel extracts as free polyphenols and reported low levels of ferulic acid (0.37 µmol/gdb) in bound extracts. The type of polyphenols detected and their amounts measured in the present study varied from the above referred studies demonstrating the natural variation of polyphenols content due to different agronomic factors, varietal differences or different processing practices**.**

3.4 Effect of ultrasonic treatment on phenolic components of potato peels

The total phenolic content (TPC), antioxidant activity and individual phenolic acids in ultrasound treated potato peel extracts were significantly higher ($p < 0.05$) than in SLE extracts alone (Table 2). The TPC levels in SLE extracts increased from 3.28 mg GAE/gdb to 7.67 mg GAE/gdb in the LR variety whereas for LC variety the TPC increased from 2.17 mg GAE/gdb to 4.24 mg GAE/gdb following ultrasonication treatments. Similarly, UAE extracts had almost doubled the DPPH radical scavenging activity and a 3.5 fold higher FRAP capacity compared to SLE extracts for these two potato peel varieties. These findings are similar to other studies where the potentials of UAE for the extraction of phenolics and antioxidants from agro-industrial wastes have been explored. Khan *et al.* (2010) have demonstrated that UAE extraction of total phenols from orange peel was approximately 3 times faster with 35–40% increase in TPC compared to conventional solvent extraction. They have also reported considerably higher recovery of naringin (70.3 mg/100g of fresh weight) and hesperidin (205.2 mg/100g of fresh weight) from UAE than those obtained from conventional extraction (50.9 and 144.7 mg/100 g fresh weight, respectively) from orange peels. Another study by Ma *et al.* (2009) have demonstrated improved extraction efficiency of phenolic compounds such as caffeic and p-coumaric acid (4 fold), ferulic acid (6 fold), sinapic acid (5 fold), p-hydroxybenzoic acid and vanillic acid (2 fold) from citrus peel using UAE in contrast to a conventional maceration extraction technique using the same extraction time (1 h) and temperature (40 ºC). The greater efficiency of UAE may be attributed to the mechanical effects arising from cavitational phenomenon and strong micro-streaming currents development due to ultrasound wave (Soria and Villamiel, 2010). Acoustic cavitation followed by cavitational dislodgment together with micro-jetting and micro-streaming effects, causes disintegration of solid materials, disruption of cell walls and greater penetration of

255 solvents leading to increased diffusion rate and thereby accelerating the mass transfer (Vinatoru *et al.*,
256 1997).
257 In addition, the effect of ultrasonic frequency/power on the recovery of phenolic compounds and
258 corresponding antioxidant activity were studied using the LC variety peel. As can be seen in Table 2,
259 using the lower frequency (higher output power) of 33 kHz (100 W) as compared to the higher
260 frequency (lower output power) of 42 kHz (45 W) resulted in the total phenolic content, chlorogenic
261 acid concentration and DPPH antioxidant activity increasing significantly ($p < 0.05$) from 3.8 to 4.24
262 mg GAE/gdb, 5.98 to 8.69 mg/gdb and 3.16 to 3.66 mg TE/gdb, respectively. However, no significant
263 differences were observed for caffeic acid concentration and FRAP antioxidant activity. The reason
264 for this is unclear. However results for other indices of extraction efficiency clearly exhibited that
265 lower ultrasonic frequency was more effective compared to higher frequency. Similar findings were
266 reported for polyphenol recovery using ultrasonication from spinach (Altemimi *et al.*, 2015), where
267 the ultrasonic bath operating at 37 kHz was more effective than 80 kHz at temperature-power-time
268 combination of 40 ºC, 50% and 30 min, with regard to extraction yield, total phenols and % DPPH
269 inhibition. Furthermore, higher intensity/power ultrasound effectiveness over lower intensity/power
270 has also been testified for recovery of protein from soy flakes (Karki *et al.*, 2010) and glycoalkaloids
271 from potato peel (Hossain *et al.*, 2014).
272 Higher phenolic yield and antioxidant activity at a lower frequency may be associated with increased
273 intensity of acoustic cavitation in the solvent medium as cavitation intensity is inversely related to
274 ultrasonic frequency. It is also evident from literature that ultrasonic frequency is one of the
275 significant factors affecting acoustic cavitation (Tiwari, 2015). Improved extraction efficiency at
276 lower frequency may be linked to the generation of larger but relatively fewer cavitational bubbles
277 which implode with higher energy level thus resulting in a greater degree of cell disruption (Wu *et al.*,
278 2013).
279 **3.5 UAE kinetics of potato peel and Peleg's model**
280 Figures 1a to 1c show the kinetic profile of phenolic extraction for each UAE treatment fitted by
281 Peleg's model. The path of extraction curves indicate similarity with sorption process kinetics
282 described by Peleg's model. It can be observed that time has significant positive effect on the extent

283 of bioactive extraction. The rate of extraction was higher at the start of the extraction which plateaus
284 towards the end of treatment time.
285 The obtained constants of Peleg's model (rate constant K_1, capacity constant K_2) and calculated
286 parameters, i.e. regression coefficient (R^2), initial extraction rate (B_0) and extraction extent (C_e), are
287 shown in Table 3. The high regression coefficients (R^2> 0.921) in all the studied conditions and
288 corresponding graphs indicate good agreement between experimental values and predicted values
289 calculated using Peleg's equation proving well fit of this model. This implies that the Peleg's equation
290 can be used to predict the phenolic extraction under different ultrasonic frequencies at a given time.
291 Jokić *et al.* (2010) have applied the Peleg's model to describe the kinetics of solid-liquid extraction
292 process of total polyphenols from soybeans. The authors reported that all the experimental data well
293 fitted with the model's calculated data with correlation coefficient (r) ranging between 0.985-0.994
294 indicating the suitability of Peleg's model for the purpose of optimising the solid-liquid extraction
295 process for polyphenols. Galván D'Alessandro *et al.* (2014) have confirmed the kinetic model for
296 optimised UAE of anthocyanin from black chokeberry wastes with good agreement between
297 experimental data and the predicted data.

298 **4. Conclusions**

299 The potato peel slurry from two different potato varieties, Lady-Claire (LC) and Lady-Rosetta (LR),
300 produced as by-products of industrial processing could be a sustainable source of antioxidant
301 polyphenolic compounds namely chlorogenic acid and caffeic acid. Chlorogenic acid is the dominant
302 phenolic in LR peel whilst caffeic acid is the principal phenolic acid in LC peel. An 80% aqueous
303 methanol is the most suitable solvent for extraction of phenolics from potato peels. The use of UAE
304 significantly improves the recovery of antioxidant rich polyphenolic extract compared to conventional
305 extraction methods alone. Lower ultrasonic frequency (33 kHz) treatment was more efficient in
306 extraction than the higher frequency treatment (42 kHz). LR potato peel extracts had higher phenolic
307 content (7.67 mg GAE/gdb) and higher antioxidant activity (DPPH value 5.86 mg TE/gdb, FRAP
308 22.21 mg TE/gdb) compared to LC peel and therefore would be a preferred choice of natural
309 antioxidants for food preservation and/or functional food ingredient applications. The use of Peleg's

model of diffusion ($R^2 > 0.92$) served valuable tool for understanding the kinetics of ultrasound aided extraction to predict the phenolic yield of the extracts under varied range of extraction time.

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6. Competing interests

The authors declare that they have no competing interests.

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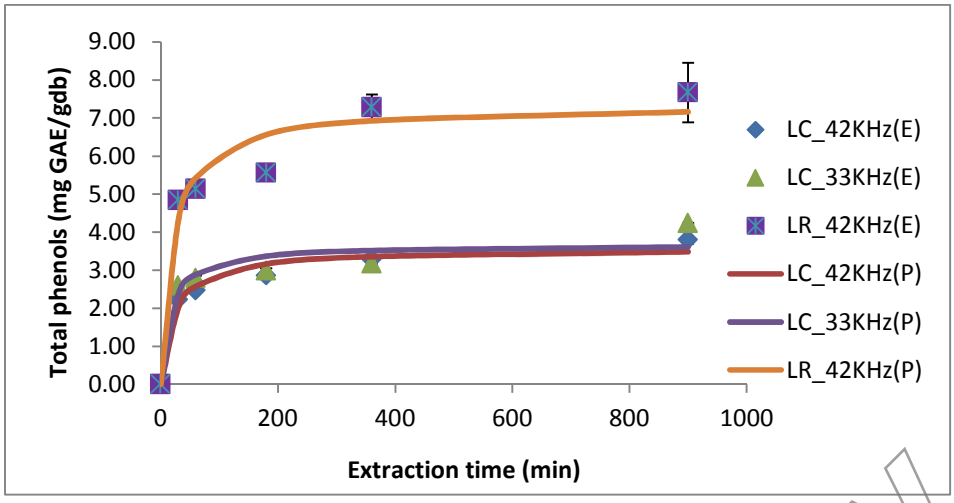
Legends to Figures

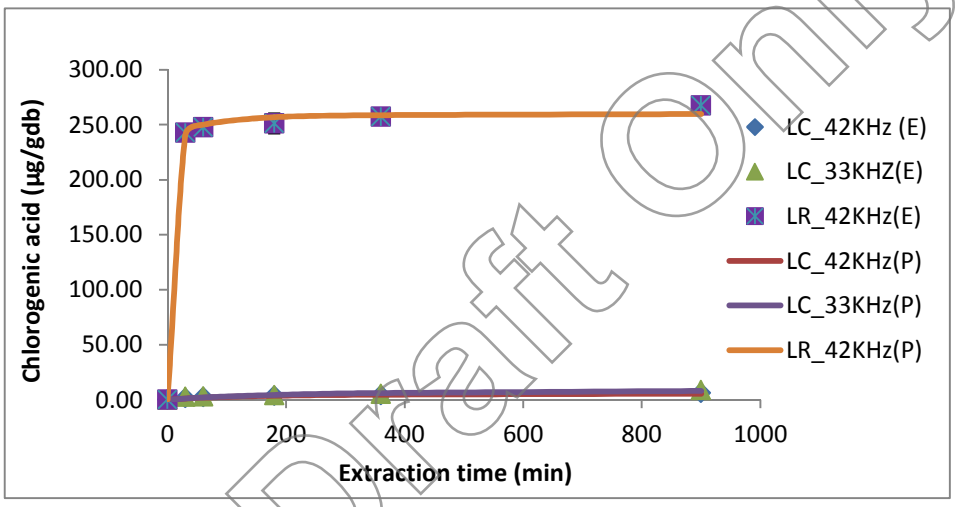
Figure 1. Experimental (E) and predicted (P) extraction kinetics of potato peels fitted by Peleg's model for polyphenols: (a) total phenolics; (b) chlorogenic acid; and (c) caffeic acid.

igure 1

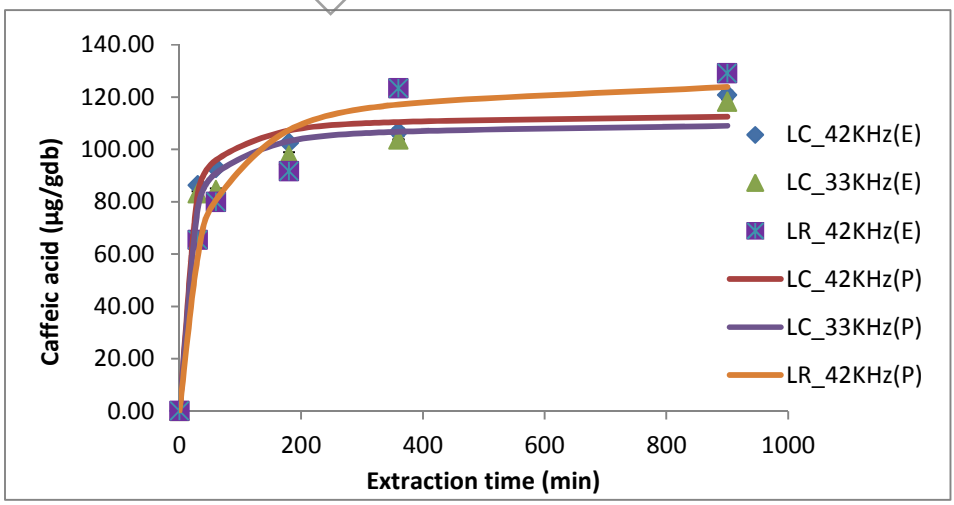
a)



b)



c)



450 **Table 1.** Proximate composition of potato peel powder in Lady Rosetta (LR) and Lady Claire (LC)

451 cultivars

Parameters	% dry wt. (LR)	% dry wt. (LC)
Crude fat	2.09 ± 0.01^{a}	1.27 ± 0.38^{a}
Crude protein	11.17 ± 0.03^{b}	12.44 ± 0.09^{a}
Ash	7.24 ± 0.02^{a}	4.83 ± 0.13^{b}
Moisture	6.98 ± 0.05^{a}	4.08 ± 0.04^{b}
Total Carbohydrate	72.53 ± 0.08^{b}	77.38 ± 0.65^{a}

452 Each value is expressed as mean ± standard deviation (n=2)

453 Means with different letters within a row are significantly different (p <0.05)

454 **Table 2.** Phenolic composition of 80% methanolic extracts from potato peel derived from two

455 varieties of potato

Extraction condition	Potato peel variety	Total Phenol (mg GAE/gdb)	DPPH activity (mg TE/gdb)	FRAP activity (mg TE/gdb)	Chlorogenic acid (µg/gdb)	Caffeic acid (µg/gdb)
SLE	LR	$3.28 \pm 0.07^{*,\$}$	$3.51 \pm 0.00^{*,\$}$	$6.27 \pm 0.06^{*,\$}$	$237.36 \pm 6.15^{*,\$}$	$85.08 \pm 0.47^{*,\$}$
	LC	$2.17 \pm 0.02^{*,a}$	$1.75 \pm 0.05^{*,a}$	$3.45 \pm 0.10^{*,a}$	$2.16 \pm 0.20^{*,a}$	$68.19 \pm 0.52^{*,a}$
UAE/ 42 kHz	LR	$7.67 \pm 0.79^{\$}$	$5.86 \pm 0.09^{\$}$	$22.21 \pm 0.24^{\$}$	$267.4 \pm 6.97^{\$}$	$129.05 \pm 0.97^{\$}$
	LC	3.80 ± 0.09^{b}	3.16 ± 0.05^{b}	5.85 ± 0.11^{b}	5.98 ± 0.27^{b}	120.83 ± 1.63^{b}
UAE/ 33 kHz	LC	4.24 ± 0.01^{c}	3.66 ± 0.00^{c}	5.64 ± 0.05^{b}	8.69 ± 0.38^{c}	118.28 ± 0.97^{b}

456 *denotes significant difference ($p < 0.05$) within a column, relative to SLE treatment between the variety

457 $^{\$}$denotes significant difference ($p < 0.05$) within a column, relative to LR variety between extraction conditions

458 ^{abc} letters followed by different alphabet within a column are significantly different ($p < 0.05$), relative to LC

459 variety among extraction conditions

460 **Table 3. Peleg's model constants (K_1 and K_2), initial extraction rate (B_0) and extraction extent**

461 **(C_e) for UAE extracts with regression coefficients**

Bioactives	UAE variable	K_1 (min. gdb/mg or µg)	K_2 (gdb/mg or µg)	B_0 (mg or µg/gdb)	C_e (mg or µg/gdb)	R^2 (Regression coefficient)
Chlorogenic acid (µg/gdb)	LC_33 kHz	22.853	0.100	0.044	10.030	0.921
	LC_42 kHz	22.241	0.155	0.045	6.460	0.969
	LR_42 kHz	0.010	0.004	104.004	260.417	0.998
Caffeic acid (µg/gdb)	LC_33 kHz	0.117	0.009	8.514	110.619	0.977
	LC_42 kHz	0.099	0.009	10.106	113.960	0.986
	LR_42 kHz	0.278	0.008	3.594	128.866	0.968
TPC (mg GAE/gdb)	LC_33 kHz	4.476	0.272	0.223	3.677	0.930
	LC_42 kHz	6.507	0.280	0.154	3.573	0.972
	LR_42 kHz	2.840	0.137	0.352	7.310	0.954

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