Maximising recovery of phenolic compounds and antioxidant properties from banana peel using microwave assisted extraction and water

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Revised: 12 January 2019 / Accepted: 29 January 2019 / Published online: 19 February 2019
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Abstract Banana peel is rich in phenolic compounds and is generally considered as waste. This study aimed to maximise recovery of phenolics from banana peel using water via microwave assisted extraction. The impact of various parameters including pH of solvent, sample to solvent ratio, irradiation time with/without cooling periods, and irradiation power were investigated individually. Following this, extraction conditions were further optimised using Response Surface Methodology. The results revealed that the extraction efficiency can be significantly improved by reducing the pH of water, increasing microwave power and time. However, cooling time during irradiation did not affect the extraction efficiency. Optimal conditions were identified at pH of 1, ratio of 2:100 g/mL, 6 min irradiation, and microwave power of 960 W. Under these optimal conditions, approximately 50.55 mg phenolics could be recovered from 1 g dried peel. These conditions are recommended for recovery of phenolic compounds from banana peel for further utilisation.

Keywords Banana peel · Microwave assisted extraction · Phenolic · Antioxidant · Food waste · Response surface methodology

Introduction

Bananas are thought to originate from the tropical regions of Southern Asia, and are now cultivated throughout the world (Anhwange 2008). It is the most popular fruit worldwide with the production of 102 million tonnes annually (FAOSTAT. 2013). The fruit is either consumed fresh, cooked or processed into different products (Mohapatra et al. 2010). The fruit peel, which accounts for around 35% of fruit weight is generally considered as waste, creating an environmental problem from cultivation and production of bananas (Vu et al. 2016b). The peel has been utilised in traditional medicine for the treatment of a range of ailments including burns, anaemia, diarrhoea, ulcers, inflammation, and excessive menstruation (Kumar et al. 2012). Recent studies have reported various pharmacological properties of banana peel, such as inhibition against wide range of bacteria and fungi, reducing blood sugar, cholesterol and also inhibiting the development of some cancer cells (Pereira and Maraschin 2015; Sirajudin et al. 2014; Wu et al. 2015). In addition, banana peel exhibits strong antioxidant capacity (Singh et al. 2016). Further, individual bioactive compounds present in banana peel also possess number of health benefits and potential medical uses (Singh et al. 2016).

Banana peel is reportedly a rich source of phenolic compounds with total content up to 30 mg/g dried matter (DM) (Singh et al. 2016), and phenolic compounds were demonstrated to be the major antioxidants within the peel (Vu et al. 2016b). Several studies have attempted to

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-019-03610-2>) contains supplementary material, which is available to authorized users.

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recover phenolic compounds from banana peel, however most of these studies used organic solvents for extraction (Anal et al. 2012; González-Montelongo et al. 2010). Although water seems to be an ideal solvent to extract polar compounds, and is favoured due to being environmentally safe and available at low cost, it has been shown to be ineffective in extracting phenolic compounds from banana peel (Sulaiman et al. 2011).

Amongst the different extraction methods available, microwave assisted extraction (MAE) has gained tremendous research interest due to reduced extraction times and solvent consumption (Kala et al. 2016). In addition, microwave irradiation effectively liberates bound phenolic compounds from the peel during the drying process (Vu et al. 2016a). It is also well established that the antioxidant activity of banana peel is attributed to its polar substances (Dahham et al. 2015). Therefore, with the assistance from microwave irradiation, water may yet be an effective solvent system in extracting the polar bioactive compounds from banana peel.

It is important to optimise extraction techniques for improvement of the extraction efficiency of phenolic compounds. There are number of modelling techniques available to assist with this, such as Response Surface Methodology (RSM) and Artificial Neural Networks (Chen et al. 2006; Khayet et al. 2011). Amongst these, RSM is a popular method for determining the impact of different variables and their interactions on the desired responses, and to predict the optimal conditions for effective recovery of phenolic compounds and antioxidant capacity (Singh et al. 2017; Vu et al. 2016b). RSM has proven to be useful due to its high precision predictions and time efficiency (Chen et al. 2006).

Given the potential of microwave irradiation, this study aimed to determine the impact of different extraction parameters, including microwave irradiation time, cooling periods during irradiation, irradiation power, sample to solvent ratio, and pH of solvent on the extraction efficiency of phenolic compounds from banana peel using water, and to further optimise the extraction conditions using RSM.

Materials and methods

Plant material

Ripened bananas (*Musa cavendish*) were purchased from a local market, Central Coast, NSW, Australia. Peels were separated from the flesh and dried using a freeze dryer (Thomas Australia Pvt., Ltd., Seven Hills, NSW, Australia), with the drying chamber pressure of 2×10^{-1} mbar and cryo-temperature of -45°C .

Dried peels were then ground using a commercial blender (John Morris Scientific, Chatswood, NSW, Australia), sieved through a 1.4 mm steel mesh (EFL 2000; Endecotts Ltd., London, England), and kept in sealed containers at -18°C . The final moisture content of the dried banana peel was 6.9%.

Experimental design

In this study, two experimental processes were applied including (1) single-factor experimental design and (2) RSM. Single-factor experimental design was conducted to test the impact of individual parameters (irradiation time, cooling period during irradiation, sample to solvent ratio, solvent pH, and microwave power) on the extraction efficiency of phenolic compounds and antioxidant capacity to identify the most important factors for further optimisation in the second process. The optimal ranges of these important factors were also identified for the RSM optimisation process.

Single-factor experiments

Extraction conditions

Banana peels were extracted with deionised water using a household microwave (1200 W, Frequency 2450 MHz, Sharp Carousel, Japan). After completion of each described extraction process, the mixture was immediately cooled to room temperature by an ice-bath, then centrifuged at 4500 rpm for 20 min at 10°C (Beckman J2-MC Centrifuge and JA-14 rotor, Beckman Instruments Inc., Palo Alto, CA). The supernatant was collected and stored at -18°C for further analysis. All experiments were conducted in triplicate and results were then statistically analysed.

Irradiation time

In this study, irradiation time ranged from 0.5 to 6 min. The mixture of banana peel and solvent (deionised water) was microwaved until boiling. The boiling point was recorded, and irradiation time was calculated from the point the mixture reached its boiling point.

The extractions were conducted at the power level of 720 W, with an irradiation time of 10 s on, followed by 10 s off for cooling with the sample to solvent ratio of 2:100 g/mL.

Impact of cooling time

The cooling time is referred as the time when irradiation is off. As the duration of the cooling could affect the

extraction efficiency, this study investigated the impact of different cooling times (0 s; 10 s; 30 s; and 60 s) after every 10 s of microwave irradiation, on the extraction efficiency of phenolic compounds.

The extractions were conducted at the power level of 720 W, with a sample to solvent ratio of 2:100 g/mL, deionised water as the solvent with the irradiation time determined in the previous experiment.

Impact of sample to solvent ratio

Different sample to solvent ratios were tested in this study including 2; 4; 6; and 8 g banana peel in 100 mL of solvent. Extraction conditions were applied at the power level of 720 W, deionised water as solvent with the optimal irradiation time and cooling times determined in the preceding experiments.

Impact of solvent pH

As solvent pH could affect the extraction efficiency of phenolic compounds, the mixture of solvent and banana peel was adjusted to different pH levels (1; 2; 4; 6; 8; 11) using hydrochloric acid (0.1 M) or sodium hydroxide (0.1 M) before starting the extraction process.

Extraction conditions included a power level of 720 W, with the optimal irradiation time, cooling time and sample to solvent ratio as determined from the preceding experiments.

Impact of microwave power

Five irradiation power levels were evaluated in this study including 240; 480; 720; 960; and 1200 W. The remaining extraction conditions such as irradiation time, cooling time, sample to solvent ratio and solvent pH were based on the findings from all previous preliminary experiments outlined above.

Optimisation by response surface methodology

In this study, three variables were investigated including: sample to solvent ratio X_1 (2, 3, and 4 g/100 mL), with the solvent was adjusted to pH 1; continuous irradiation time X_2 (2, 4 and 6 min); and microwave power X_3 (60, 80% and 100% power capacity or 720, 960, and 1200 W). The range of each variable was selected based on the results from the preliminary experiments.

The experiments were designed using JMP-11 software with three levels, three factors, and central composite face-centred design with two central point replicates (Table 1). Of note, during response surface modelling, the real value of the three input variables were scaled to coded levels

which vary from (− 1) to (+1) that correspond to minimum and maximum levels, respectively (Khayet et al. 2011). The following equation was applied to transform a real value (Z_i) into a coded value (X_i) (Bezerra et al. 2008).

$$X_i = \frac{Z_i - Z_i^0}{\Delta Z_i}$$

where “i” refers to the number of variable (1 to 3), “ Z_i^0 ” is the real value in the central point of a variable, and ΔZ_i is the distance between the real values of the central point and the maximum (or minimum) levels of a variable.

Three responses (Y) were investigated including Y_1 : total phenolic content (TPC), Y_2 : ferric reducing antioxidant power (FRAP), and Y_3 : 1,1-diphenyl-2-picrylhydrazyl radical scavenging capacity (DPPH). Each response was presented as a function of the three variables through a second order polynomial equation (Vu et al. 2016b)

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2$$

where Y denotes the predicted response; X_1 , X_2 , X_3 , refer to the coded levels of the input variables; β_0 , β_1 , β_2 , β_3 ; β_{12} , β_{13} , β_{23} ; and β_{11} , β_{22} , β_{33} are regression coefficients for intercept; linear; interaction and quadratic terms, respectively.

Total phenolic content

Recovery of phenolic compounds was determined using the Folin–Ciocalteu method described by Vuong et al. (2013) with some modifications. Briefly, 2.5 mL of freshly made 10% v/v Folin–Ciocalteu reagent in water was added to 0.5 mL of the diluted extract or water (as the control). The mixture was settled for 8 min, then 2 mL of 7.5% (w/v) Na_2CO_3 was added, followed by 1 h incubation in the dark at room temperature (26 °C). Absorbance was measured at 765 nm using a UV–VIS spectrophotometer (Cary 50 Bio Varian, Australia). Gallic acid was used to make a standard curve. The results were expressed as mg gallic acid equivalent (GAE)/g DM.

Antioxidant properties

Two antioxidant assays were used to evaluate the antioxidant properties of banana peel extracts including the DPPH radical scavenging and Ferric reducing antioxidant power assays, as detailed below.

DPPH radical scavenging activity

1,1-diphenyl-2-picrylhydrazyl radical scavenging (DPPH) ability of the banana extracts were evaluated using a spectrophotometric method as described by Vuong et al.

Table 1 Central composite face-centred design and response values

Pattern*	Ratio (g/100 mL)	Irradiation time (min)	Power (W)	TPC (mg GAE/g DM)	FRAP (mg TE/g DM)	DPPH (mg TE/g DM)
— — —	2	2	720	37.81	58.14	81.44
— — +	2	2	1200	35.99	53.95	78.79
a00	2	4	960	48.95	84.32	91.97
— + —	2	6	720	53.27	92.56	92.93
— ++	2	6	1200	53.14	93.74	96.76
0a0	3	2	960	34.31	53.58	74.67
00a	3	4	720	42.13	67.66	83.30
000	3	4	960	42.86	70.16	82.11
000	3	4	960	40.25	67.42	80.74
00A	3	4	1200	40.88	67.87	81.53
0A0	3	6	960	47.01	82.22	89.00
+ — —	4	2	720	29.14	42.79	66.29
+ — +	4	2	1200	29.28	42.18	65.37
A00	4	4	960	37.44	56.50	72.04
++ —	4	6	720	43.75	71.15	81.94
+++	4	6	1200	46.80	79.68	87.37

*Pattern identifies the coding of the input variable levels: with “+” for high, “—” for low factor, “a” and “A” for low and high axial values, and “0” for midrange

(2013). Briefly, stock solution was made by dissolving 0.024 g 1,1-diphenyl-2-picrylhydrazyl in 100 mL methanol (0.024% w/v). The working solution was freshly prepared by diluting 1.0 mL of stock solution with 45 mL of methanol, then adjusted to the absorbance of 1.1 ± 0.02 at 515 nm by adding small amounts of methanol or stock solution. Then, 2.85 mL of the working solution was added to 0.15 mL of the diluted extract. The mixture was incubated in the dark at room temperature (26 °C) for 3 h and the absorbance was measured at 515 nm using a UV–VIS spectrophotometer (Cary 50 Bio Varian, Australia). Water and Trolox were used as the control and standard, respectively. The results were expressed in mg Trolox equivalents (TE) per gram of dry matter.

Ferric reducing antioxidant power

The ferric reducing antioxidant power (FRAP) was evaluated using the colorimetric method as described by Thaipong et al. (2006). Briefly, three reagents were prepared, including (1) 300 mM acetate buffer (pH 3.6); (2) 10 mM tripyridyl triazine (TPTZ) in 40 mM HCl; and (3) 20 mM FeCl₃·6H₂O. The working solution was made daily by mixing reagents 1, 2, and 3 at the ratio of 10:1:1. For the FRAP reaction, 2.85 mL of the working solution was added into 0.15 mL of the diluted extract. The mixture was set for 30 min before measuring the absorbance at 593 nm using a UV–VIS spectrophotometer (Cary 50 Bio Varian, Australia). Water and trolox were used as the control and

standard, respectively. The results were expressed in mg TE/g DM.

Data analysis

All experiments were conducted in triplicate. Differences between means were determined by performing one-way Analysis of variance (ANOVA) and Tukey’s post hoc test (using SPSS statistical software version 23, IBM Corp., NY). The differences were taken at the significance level (p) of $p < 0.05$. JMP software (Version 11, SAS, Cary, NC, USA) was used for RSM modelling and plotting the 3D and 2D contour plots of the responses and further, predicting the optimum values of the explanatory variables and responses. The adequacy of RSM models were evaluated based on the statistical indices including coefficient of determination (R^2), p value and lack of fit of the model (Bezerra et al. 2008).

Results and discussion

Influence of microwave irradiation time on recovery of phenolic compounds and antioxidant properties of banana peel

Timing is critical in every extraction. In microwave assisted extraction, timing is even more important due to its association with solvent temperature and evaporation

(Zhang et al. 2011). Unlike the conventional extraction techniques, which may take from 10 min to several days, a typical microwave extraction only takes a very short period of time (usually, 3–30 min) (Sparr Eskilsson and Björklund 2000). However, heat generated by microwaves may affect the extraction efficiency of phenolic compounds (Palma et al. 2001). Therefore, it is important to determine the optimal irradiation time for maximum extraction of phenolic compounds. The impact of irradiation time on the extraction efficiency of phenolic compounds from banana peel is shown in Fig. 1a. Results indicate that the recovery of phenolic compounds increases steadily with the extraction time. In particular, the majority of the phenolic compounds (~ 75%) were recovered during the heating period (approximate 2 min) till the boiling point. In this experiment, 13.36 mg phenolics were recovered from 1 g of banana peel when the mixture reached the boiling point. However, the phenolics recovery increased by only 25% when the extraction time was prolonged for a further 4 min. Beyond this, the recovery of phenolic compounds starts to decrease. Similar behaviour was observed for antioxidant properties.

Our findings were in agreement with previous studies on tea, *Myrtus communis* leaves, and sweet potato leaves (Dahmoune et al. 2015; Pan et al. 2003; Song et al. 2011) where longer microwave irradiation times liberated more phenolic compounds. However, prolong extraction time was also found to be associated with decreasing of antioxidants in mung bean extract (Singh et al. 2017). Based on the results (Fig. 1a), irradiation time between 2 and 6 min is found to be ideal for further optimisation.

Influence of cooling time during the extraction process on recovery of phenolic compounds and antioxidant properties of banana peel

Cooling time allows the maintenance of the desired temperature, and prevents the sample from being overheated (Zhang et al. 2008). It is particularly important for heat sensitive compounds like polyphenols (Palma et al. 2001). Although the influence of cooling time on microwave irradiation has been investigated in the past (Pan et al. 2003; Zhang et al. 2008), it remains unclear on how it influences the extraction efficiency of the phenolic compounds in banana peel. Figure 1b shows the variation in cooling times on the levels of phenolic compounds and antioxidant capacity of the extracts. The figure indicates that the influence of cooling time is not significant. This suggests that the cooling is not essential for the extraction of phenolic compounds from banana peels. This phenomenon could be explained by the heat resistance of banana peel phenolics. Of note, many phenolic compounds are stable up to 100 °C, with some up to 125 °C (Liazid

et al. 2007). In addition, it has been shown that phenolic compounds which have fewer hydroxyl-type substituents in their structure are more stable under the extraction conditions than those which have more substituents (Liazid et al. 2007). As a result, continuous irradiation (cooling time = 0 s) was applied in our subsequent experiments.

Influence of sample to solvent ratio on recovery of phenolic compounds

Sample to solvent ratio is closely linked with the extraction efficiency of phenolic compounds. It is also associated with the volume of solvent used as well as energy required for solvent removal afterwards. It was observed that the extraction efficiency of banana peel dropped sharply when higher sample ratios were used (Fig. 1c). The phenolic content decreased almost by half as the sample to solvent ratio increased from 2:100 g/mL to 8:100 g/mL. Similar observations were recorded for antioxidant capacity from DPPH and FRAP assays. Past studies also reported similar results on peanut skins, *Myrtus communis* leaves, and sweet potato leaves (Ballard et al. 2010; Dahmoune et al. 2015; Song et al. 2011). This can be explained by the swelling of the plant material when a lower sample ratio is used, which increases the contact surface between the plant matrix and the solvent (Hayat et al. 2009). In contrast, published studies showed increasing the solvent volume may neither affect (Vu et al. 2016b) nor reduce the efficiency of the phenolic extraction (Zhang et al. 2011). This could particularly be attributed either to the solvent strength or the excessive swelling of plant materials potentially inducing the absorption of the target compounds without releasing them (Vetal et al. 2014). In this study, the sample to solvent ratio ranging from 2 g to 4 g/100 mL was selected for further optimisation.

Influence of pH of extraction solvent on recovery of phenolic compounds

pH is an important factor influencing the stability and solubility of phenolic compounds (Friedman and Jürgens 2000) which subsequently contributes to the extraction efficiency. A wide range of pH values were tested in this study. Figure 2a shows that strong acidic conditions (low pH) significantly enhanced the extraction efficiency than neutral or strong base conditions. At pH = 1 the highest amount of phenolics recovered from the peels is equivalent to 44.59 mg/g. This extraction yield was three times higher than that of neutral pH (pH = 6 or 8). This is most likely due to many phenolics being more stable in acidic conditions than in neutral conditions (Friedman and Jürgens 2000). It is also likely the cell wall is hydrolysed under acidic conditions, releasing the phenolics (Chirinos et al.

Fig. 1 Impact of microwave irradiation time, cooling time and sample to solvent ratio on phenolic compounds and antioxidant capacity. Values in the same category (either TPC, FRAP or DPPH) sharing a letter are not significantly different from each other ($p < 0.05$)

2007; Friedman and Jürgens 2000). Further, the use of acid in extraction was coupled not only with water but also with organic solvents in extracting phenolic compounds from plant materials (Chirinos et al. 2007; Vatai et al. 2009). In a majority of the cases, addition of acid improved extraction efficiency (Chirinos et al. 2007; Vatai et al. 2009).

Interestingly, the amount of extracted phenolic compounds increased slightly when extraction is performed in

base medium (pH of 11) but the antioxidant properties did not increase concomitantly. This could be due to the formation of salts from some phenolic compounds under basic conditions. Salt forms are more soluble but have limited antioxidant power. This explains the increase in total phenolic compounds but not in the DPPH radical scavenging activity or the ferric reducing power. Based on the

Fig. 2 Impact of pH and microwave power of extraction solvent on recovery of phenolic compounds. Values in the same category (either TPC, FRAP or DPPH) sharing a letter are not significantly different from each other ($p < 0.05$)

results obtained, a pH of 1 was used for the subsequent experiments.

Influence of microwave power on recovery of phenolic compounds

Microwave power levels are a major factor that affect the recovery of bioactive compounds. It has the ability to disrupt the dynamic structure of the sample, which in turn releases bioactive compounds. Conversely, microwave power can also be the cause of overheating, which degrades heat sensitive substances (Ballard et al. 2010). Figure 2b reveals that more phenolic compounds were obtained when the power increased from 240 W up to 720 W. Beyond this power level, extraction efficiency was not greatly enhanced and would also require higher energy inputs. Similar finding was reported while extracting phenolic compounds from the peanut skin (Ballard et al. 2010). This finding indicated that extraction at higher microwave power levels

does not always ensure better recovery compared to medium levels of power. This could be due to the generated higher localized temperature and pressure when a higher power is applied, resulting in more phenolic compounds being released into the solvent (Hayat et al. 2009). However, higher temperature could decrease recovery yield due to phenolic degradation (Singh et al. 2017). Therefore mid temperature is usually found as optimal extraction temperature than extended high temperature (Singh et al. 2017). In this study the power range between 720 to 1200 W was chosen for further optimisation.

Optimisation of aqueous microwave assisted extraction conditions using RSM

Model fitting

Based on the findings from earlier experiments in this study, three extraction factors including sample to solvent

ratio, irradiation time and power were further investigated using RSM modelling (model design and response values are presented in Table 1). The model allows optimisation of the variable conditions for maximum response, in this case, recovery of phenolic compounds and the antioxidant ability. The efficiency of the RSM model is explained by satisfactory model performance, measured using R^2 , p values and lack of fit indices during model prediction. The variance analysis results (Table 2) presents the predictive capacity of the RSM models. The R^2 of phenolic contents and antioxidant assays ranged from 0.97 to 0.98, meaning that the models can explain at least 97% of results variation. The p values for phenolic content and antioxidant assays were less than 0.001, indicating significance of the model at a 99.9% confidence level. In addition, lack of fit indices were much higher than 0.05 indicating their insignificance. Model performance, obtained based on the performance criteria, indicates that the predictive models are well suited for prediction.

Table 2 Analysis of variance for determination of model fit

	TPC	FRAP	DPPH
R^2	0.98	0.98	0.97
F ratio of Model	34.81	30.27	24.18
P model > F	0.0002	0.0003	0.0005
P lack of fit	0.69	0.35	0.29
RMSE*	1.59	3.70	2.32

*Root mean square error

The three RSM models are fitted into the following second-order polynomial formulas:

$$Y_{TPC} = 41.86 - 4.27X_1 + 7.74X_2 + 0.00X_3 \\ - 0.06X_1X_2 + 0.64X_1X_3 + 0.58X_2X_3 + 1.19X_1^2 \\ - 1.35X_2^2 - 0.50X_3^2$$

$$Y_{FRAP} = 69.26 - 9.04X_1 + 16.87X_2 + 0.51X_3 \\ - 1.04X_1X_2 + 1.37X_1X_3 + 1.81X_2X_3 + 0.91X_1^2 \\ - 1.60X_2^2 - 1.74X_3^2$$

$$Y_{DPPH} = 81.99 - 6.98X_1 + 8.14X_2 + 0.39X_3 \\ + 1.02X_1X_2 + 0.42X_1X_3 + 1.60X_2X_3 - 0.27X_1^2 \\ - 0.43X_2^2 + 0.15X_3^2$$

where Y_{TPC} , Y_{FRAP} , and Y_{DPPH} are recovery yield of TPC, FRAP and DPPH, respectively.

Optimal model conditions and validation

In the context of RSM, the regression coefficient represents the influential strength of each factor while the p value is a useful tool to check the significance of the coefficients (Song et al. 2011). The bigger the regression coefficient, the stronger the effect of the parameter on the dependent response. The smaller the value of p , the more significant the corresponding coefficient is (Song et al. 2011). Based on this, sample to solvent ratio has the strongest influence, followed by irradiation time, with power having the least

Table 3 Analysis of variance for model coefficients

Term	TPC		FRAP		DPPH	
	Estimate	Prob > t	Estimate	Prob > t	Estimate	Prob > t
β_0	41.86	< 0.0001*	69.26	< 0.0001*	81.99	< 0.0001*
β_1	- 4.27	0.0001*	- 9.04	0.0002*	- 6.89	< 0.0001*
β_2	7.74	< 0.0001*	16.87	< 0.0001*	8.14	< 0.0001*
β_3	0.00	1.00	0.51	0.68	0.39	0.61
β_{12}	- 0.06	0.92	- 1.04	0.46	1.02	0.26
β_{13}	0.64	0.30	1.37	0.34	0.42	0.63
β_{23}	0.58	0.35	1.81	0.22	1.60	0.10
β_{11}	1.19	0.27	0.91	0.71	- 0.27	0.86
β_{22}	- 1.35	0.22	- 1.60	0.51	- 0.43	0.77
β_{33}	- 0.50	0.63	- 1.74	0.48	0.15	0.92

*Significant different at $p < 0.05$; β_0 : intercept; β_1 , β_2 , and β_3 : linear regression coefficients for X_1 sample to solvent ratio, X_2 irradiation time and X_3 microwave power; β_{12} , β_{13} , and β_{23} : regression coefficients for interaction between $X_1 \times X_2$, $X_1 \times X_3$, and $X_2 \times X_3$; β_{11} , β_{22} , and β_{33} : quadratic regression coefficients of X_1^2 , X_2^2 , and X_3^2 .

Fig. 3 Impact of extraction parameters on extraction efficiency: 3D response surface profiler

impact on extraction efficiency of phenolic compounds and antioxidant capacity (Table 3). However, only the ratio of sample to solvent and irradiation time significantly affected extraction efficiency of phenolic compounds and antioxidant capacity within the tested ranges of these variables. Extraction efficiency of phenolic compounds and antioxidant capacity increased while decreasing sample to solvent ratio. Whereas, extraction efficiency of phenolic

compounds and antioxidant capacity decreased while increasing the irradiation time (Fig. 3). Interestingly, there was no significant impact ($p > 0.05$) of the interaction between the sample to solvent ratio and irradiation time, the sample to solvent ratio and power, or the irradiation time and power on extraction efficiency of phenolic compounds and antioxidant capacity (Table 3). This indicates that extraction efficiency of phenolic compounds and

antioxidant capacity were individually affected by sample to solvent ratio and irradiation time, not by their interaction.

Based on the prediction from the RSM models, the highest recovery yield of phenolic compounds and antioxidant capacity could be obtained under the extraction conditions of: sample to solvent ratio of 2 g/100 mL, irradiation time of 6 min, and microwave power of 960 W. At these conditions, the optimal values predicted for the phenolic compounds, FRAP and DPPH antioxidant properties were 53.76 mg GAE/g DM; 95.52 mg TE/g DM; and 95.29 mg TE/g DM, respectively. To validate model results, banana peels were extracted in triplicates and analysed for total phenolic compounds and antioxidant capacity, the values of the phenolic compounds, FRAP and DPPH were obtained as following 50.55 ± 1.06 mg GAE/g, 88.89 ± 1.21 mg TE/g, and $93.06 \text{ mg} \pm 1.21$ TE/g, respectively. These actual values fell within the prediction ranges (Fig. 3), indicating the adequacy of the models. Therefore, these optimal conditions should be applied for maximizing aqueous extraction of the phenolic compounds and antioxidant capacity from banana peels using microwave-assisted extraction.

Earlier studies reported phenolic compounds in banana peel in range from 9 to 30 mg/g DW (Singh et al. 2016). Clearly, more phenolics (50 mg GAE/g DM) could be extracted under our suggested optimal conditions in comparison with other reported conditions. The enhancement of the phenolic recovery by microwave extraction can be explained by the interior superheating that may cause liquid vaporisation within the cells, which may then rupture the cells. This theory is confirmed by Dahmoune et al. (2015) who used scanning electron microscopy to observe severe cell damages that were induced by microwave extraction. Furthermore, particle size of samples after microwave irradiation were found to be smaller than that of unprocessed samples or samples processed with conventional extraction techniques (Zhang et al. 2011). This means that microwave irradiation increases the surface area of the samples. In contrast, conventional extraction relies on permeation and solubilisation processes therefore demanding longer times and are therefore less efficient (Zhang et al. 2011). Additionally, extended extraction times, which enhance exposure of phenolics to light and oxygen, may contribute to low recovery yields and poor antioxidant power of extracts prepared by conventional methods (Hayat et al. 2009).

Apart from the above explained effectiveness between microwave extraction and conventional technique, microwave extraction requires less time and is more environmental friendly (Nkhili et al. 2009). This is largely beneficial for up-scaling to an industrial level.

Conclusion

This study showed that water, could be used to effectively recover phenolic compounds and antioxidants from banana peel using microwave assisted extraction. Results showed that the pH of the solvent, and sample to solvent ratio significantly affected the extraction efficiency of phenolic compounds and antioxidants from banana peel. Microwave irradiation time and power also significantly affected extraction efficiency of phenolic compounds and antioxidants from banana peel, however the cooling period is not an essential factor when extracting using microwave. The optimal conditions identified as solvent pH of 1, sample to solvent ratio of 2:100 g/mL, irradiation time of 6 min, and microwave power of 960 W.

Acknowledgements The authors would like to thank Dr Dipangkar Kundu (The University of Sydney) and Ms Rebecca Richmond (The University of Newcastle) for proof reading and insightful review, which has significantly contributed to the quality of the manuscript. We would also like to thank Dr Mark Tarleton and Assoc. Prof. Michael Bowyer for their advice concerning the chemistry in this project. The financial support for this study was from the Vietnamese Government through the Vietnam International Education Development-Ministry of Education and Training, and the University of Newcastle. The awarding of a VIED-TUIT scholarship to the first author is greatly acknowledged.

References

- Anal AK, Jaisanti S, Noomhorm A (2012) Enhanced yield of phenolic extracts from banana peels (*Musa acuminata* Colla AAA) and cinnamon barks (*Cinnamomum varum*) and their antioxidative potentials in fish oil. J Food Sci Technol 51:2632–2639. <https://doi.org/10.1007/s13197-012-0793-x>
- Anhwange BA (2008) Chemical composition of *Musa sapientum* (banana) Peels. J Food Technol 6:263–266
- Ballard TS, Mallikarjunan P, Zhou K, O'Keefe S (2010) Microwave-assisted extraction of phenolic antioxidant compounds from peanut skins. Food Chem 120:1185–1192. <https://doi.org/10.1016/j.foodchem.2009.11.063>
- Bezerra MA, Santelli RE, Oliveira EP, Villar LS, Escaleira LA (2008) Response surface methodology (RSM) as a tool for optimization in analytical chemistry. Talanta 76:965–977. <https://doi.org/10.1016/j.talanta.2008.05.019>
- Chen VCP, Tsui K-L, Barton RR, Meckesheimer M (2006) A review on design, modeling and applications of computer experiments. IIE Trans 38:273–291. <https://doi.org/10.1080/07408170500232495>
- Chirinos R, Rogez H, Campos D, Pedreschi R, Larondelle Y (2007) Optimization of extraction conditions of antioxidant phenolic compounds from mashua (*Tropaeolum tuberosum* Ruiz & Pavón) tubers. Sep Purif Technol 55:217–225. <https://doi.org/10.1016/j.seppur.2006.12.005>
- Dahham SS, Mohamad T, Tabana YM, Majid A (2015) Antioxidant activities and anticancer screening of extracts from banana fruit (*Musa sapientum*). Acad J Cancer Res 8:28–34
- Dahmoune F, Nayak B, Moussi K, Remini H, Madani K (2015) Optimization of microwave-assisted extraction of polyphenols

- from *Myrtus communis* L. leaves. Food Chem 166:585–595. <https://doi.org/10.1016/j.foodchem.2014.06.066>
- FAOSTAT (2013) FAO statistical database (FAOSTAT). <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>. Accessed 17 May 2016
- Friedman M, Jürgens HS (2000) Effect of pH on the stability of plant phenolic compounds. J Agric Food Chem 48:2101–2110. <https://doi.org/10.1021/jf990489j>
- González-Montelongo R, Gloria Lobo M, González M (2010) Antioxidant activity in banana peel extracts: testing extraction conditions and related bioactive compounds. Food Chem 119:1030–1039. <https://doi.org/10.1016/j.foodchem.2009.08.012>
- Hayat K et al (2009) Optimized microwave-assisted extraction of phenolic acids from citrus mandarin peels and evaluation of antioxidant activity in vitro. Sep Purif Technol 70:63–70. <https://doi.org/10.1016/j.seppur.2009.08.012>
- Kala HK, Mehta R, Sen KK, Tandey R, Mandal V (2016) Critical analysis of research trends and issues in microwave assisted extraction of phenolics: have we really done enough. TrAC Trends Anal Chem 85:140–152. <https://doi.org/10.1016/j.trac.2016.09.007>
- Khayet M, Cocjocar C, Essalhi M (2011) Artificial neural network modeling and response surface methodology of desalination by reverse osmosis. J Membr Sci 368:202–214. <https://doi.org/10.1016/j.memsci.2010.11.030>
- Kumar KPS, Bhowmik D, Duraivel S, Umadevi M (2012) Traditional and medicinal uses of banana. J Pharmacogn Phytochem 1:53–63
- Liaizid A, Palma M, Brigui J, Barroso CG (2007) Investigation on phenolic compounds stability during microwave-assisted extraction. J Chromatogr A 1140:29–34. <https://doi.org/10.1016/j.chroma.2006.11.040>
- Mohapatra D, Mishra S, Sutar N (2010) Banana and its by product utilisation. J Sci Ind Res 69:323–329
- Nkhili E, Tomao V, El Hajji H, El Boustani ES, Chemat F, Dangles O (2009) Microwave-assisted water extraction of green tea polyphenols. Phytochem Anal 20:408–415. <https://doi.org/10.1002/pca.1141>
- Palma M, Piñeiro Z, Barroso CG (2001) Stability of phenolic compounds during extraction with superheated solvents. J Chromatogr A 921:169–174. [https://doi.org/10.1016/S0021-9673\(01\)00882-2](https://doi.org/10.1016/S0021-9673(01)00882-2)
- Pan X, Niu G, Liu H (2003) Microwave-assisted extraction of tea polyphenols and tea caffeine from green tea leaves. Chem Eng Process 42:129–133. [https://doi.org/10.1016/S0255-2701\(02\)00037-5](https://doi.org/10.1016/S0255-2701(02)00037-5)
- Pereira A, Maraschin M (2015) Banana (*Musa* spp) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. J Ethnopharmacol 160:149–163. <https://doi.org/10.1016/j.jep.2014.11.008>
- Singh B, Singh JP, Kaur A, Singh N (2016) Bioactive compounds in banana and their associated health benefits—a review. Food Chem 206:1–11. <https://doi.org/10.1016/j.foodchem.2016.03.033>
- Singh B, Singh N, Thakur S, Kaur A (2017) Ultrasound assisted extraction of polyphenols and their distribution in whole mung bean, hull and cotyledon. J Food Sci Technol 54:921–932. <https://doi.org/10.1007/s13197-016-2356-z>
- Sirajudin ZNM, Ahmed QU, Chowdhury AJK, Kamarudin EZ, Khan AV, Uddin ABMH, Musa N (2014) Antimicrobial activity of banana (*Musa paradisiaca* L.) peels against food borne pathogenic microbes. J Pure Appl Microbio 8:3627–3639
- Song J, Li D, Liu C, Zhang Y (2011) Optimized microwave-assisted extraction of total phenolics (TP) from Ipomoea batatas leaves and its antioxidant activity. Innov Food Sci Emerg Technol 12:282–287. <https://doi.org/10.1016/j.ifset.2011.03.001>
- Sparr Eskilsson C, Björklund E (2000) Analytical-scale microwave-assisted extraction. J Chromatogr A 902:227–250. [https://doi.org/10.1016/S0021-9673\(00\)00921-3](https://doi.org/10.1016/S0021-9673(00)00921-3)
- Sulaiman SF, Yusoff NAM, Eldeen IM, Seow EM, Sajak AAB, Supriatno Ooi KL (2011) Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (*Musa* sp.). J Food Compos Anal 24:1–10. <https://doi.org/10.1016/j.jfca.2010.04.005>
- Thaipong K, Boonprakob U, Crosby K, Cisneros-Zevallos L, Byrne DH (2006) Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts. J Food Compos Anal 19:669–675. <https://doi.org/10.1016/j.jfca.2006.01.003>
- Vatai T, Škerget M, Knez Ž (2009) Extraction of phenolic compounds from elder berry and different grape marc varieties using organic solvents and/or supercritical carbon dioxide. J Food Eng 90:246–254. <https://doi.org/10.1016/j.jfoodeng.2008.06.028>
- Vetal MD, Chavan RS, Rathod VK (2014) Microwave assisted extraction of ursolic acid and oleanolic acid from *Ocimum sanctum*. Biotechnol Bioprocess Eng 19:720–726. <https://doi.org/10.1007/s12257-013-0798-y>
- Vu HT, Scarlett CJ, Vuong QV (2016a) Effects of drying conditions on physicochemical and antioxidant properties of banana (*Musa cavendish*) Peels. Drying Technol 35(9):1141–1151. <https://doi.org/10.1080/07373937.2016.1233884>
- Vu HT, Scarlett CJ, Vuong QV (2016b) Optimization of ultrasound-assisted extraction conditions for recovery of phenolic compounds and antioxidant capacity from banana (*Musa cavendish*) peel. J Food Process Preserv 41:e13148. <https://doi.org/10.1111/jfpp.13148>
- Vuong QV, Hirun S, Roach PD, Bowyer MC, Phillips PA, Scarlett CJ (2013) Effect of extraction conditions on total phenolic compounds and antioxidant activities of Carica papaya leaf aqueous extracts. J Herb Med 3:104–111. <https://doi.org/10.1016/j.hermed.2013.04.004>
- Wu H, Xu FH, Hao J, Yang Y, Wang X (2015) Antihyperglycemic activity of banana (*Musa nana* Lour.) peel and its active ingredients in alloxan-Induced diabetic mice. In 3rd International conference on material, mechanical and manufacturing engineering, pp 231–238
- Zhang B, Yang R, Liu C-Z (2008) Microwave-assisted extraction of chlorogenic acid from flower buds of *Lonicera japonica* Thunb. Sep Purif Technol 62:480–483. <https://doi.org/10.1016/j.seppur.2008.02.013>
- Zhang H-F, Yang X-H, Wang Y (2011) Microwave assisted extraction of secondary metabolites from plants: current status and future directions. Trends Food Sci Technol 22:672–688. <https://doi.org/10.1016/j.tifs.2011.07.003>

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