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Optimization for ultrasound-assisted extraction of polysaccharides with antioxidant activity *in vitro* from the aerial root of *Ficus microcarpa*

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ABSTRACT

In this study, optimization of ultrasound-assisted extraction and antioxidant activity of polysaccharides from the aerial root of *Ficus microcarpa* (FMPS) were investigated. The optimal conditions for extraction of FMPS were determined as followings: ultrasound power 200 W, ultrasound temperature 70 °C, extraction temperature 74 °C, liquid–solid ratio 35, extraction time 238 min, ultrasound time 49 min. The experimental yield of FMPS (3.44%) obtained under these conditions was well agreement with the value predicted by the model. In addition, Fourier transform-infrared spectroscopy and antioxidant activity assays revealed that FMPS were acidic polysaccharides and had strong Fe^{2+} chelating activity and moderate hydrogen peroxide scavenging effect. Further work on the purification, structure characterization and antioxidant activity *in vivo* of FMPS is in progress.

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1. Introduction

Ficus microcarpa L. fil. (Chinese banyan tree, Moraceae) is a popular ornamental tree grown widely in many tropical regions of the world. It is native from Ceylon to India, Southern China, Ryukyu Islands, Australia and New Caledonia. The aerial root of *F. microcarpa* has been used as folk herbs for perspiration, deintoxication, alleviating fever, relieving pain, dispelling wind and clearing heat in China, Vietnam and Okinawa Islands (Ya, Lu, Chen, & Tan, 2010). It has been demonstrated that the aerial root of *F. microcarpa* is a rich source of triterpenoids, polyphenols, organic acids, alkaloids and polysaccharides that may contribute to the biological functions such as antibacterial, antithrombotic, antioxidation and anticancer activities (Wang, Liu, & Xu, 2009; Wang et al., 2009). However, to the best of our knowledge, there is limited literature on the extraction, structures and biological activities of polysaccharides from the aerial root of *F. microcarpa* compared with those of some other pharmacological components (Ao, Deba, Tako, & Tawata, 2009; Chiang, Chang, Kuo, Chang, & Kuo, 2005; Chiang & Kuo, 2002, 2003).

Conventional heat solvent extraction (HSE) is the most commonly used method to extract polysaccharides. Although HSE is simple and safe, However, the requirement for high temperatures and extended extraction times has some disadvantages (Hromadkova, Ebringerova, & Valachovič, 2002; Li, Ding, & Ding, 2007; Wang, Liu, & Xu, 2009; Wang et al., 2009). The high temperature and long extraction time of HSE lead to the degradation of polysaccharides and the decrease of the pharmacological activity of polysaccharides. Thus, developing an optimized novel extraction technology is very important in pharmaceutical, food and cosmetic industries. Recently, ultrasound-assisted extraction has been developed as a novel technique for the extraction of bioactive substances from plants. It has been proved to be a desirable method of extraction with many advantages, such as less extraction time, low extraction temperature and high extraction quotiety. Therefore, in this present study, the ultrasound-assisted method was performed for the extraction of FMPS. And the extraction variables were optimized for maximum polysaccharides yield. In addition, FMPS was preliminarily characterized by Fourier transform-infrared spectroscopy (FT-IR). Its antioxidant activity

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in vitro was also investigated by determining Fe^{2+} chelating and hydrogen peroxide scavenging abilities.

2. Materials and methods

2.1. Materials and equipments

The fresh aerial root of *F. microcarpa* was purchased from the traditional Chinese medicine market (Nanyang, China). The sample was washed with distilled water, dried and ground into powder using a high speed disintegrator, and the material that passed through a 60-mesh sieve was then kept in sealed polyethylene bags until use. All other reagents were of analytical grade. The ultrasound extraction was performed in an ultrasound extraction device (SY-1000, Shanghai Ultrasound Co., Ltd., China) working at a frequency of 40 kHz and a ultrasound input power of 100–250 W.

2.2. Preparation of FMPS

The extraction of FMPS was performed according to the reported method with some modifications (Zhao, Dong, Chen, & Hu, 2010). Briefly, the powder of dried aerial roots was refluxed with absolute ethyl alcohol at 75 °C for 2 h. The extract was removed, and the resulting pretreated powder was dried and used for the extraction of FMPS. For ultrasound treatment, a sample (1 g) was put into a triangular flask (1 L), diluted with deionized water at a liquid–solid ratio varying from 10: 1 to 50: 1, v/w, and sonicated at an ultrasound input power ranging from 100 to 250 W at 50–80 °C for 20–60 min. After the ultrasound treatment, the triangular flask was removed to another thermostat-controlled water-bath (55–95 °C) and kept for extraction for 150–270 min. The extraction mixture was centrifuged at 5000 rpm for 15 min, and the insoluble residue was retreated as mentioned above for 2 times. The supernatants were collected, concentrated by a rotary evaporator under reduced pressure to an appropriate volume, mixed with three times of absolute ethanol and kept overnight at 4 °C. The resulting precipitates were collected by centrifugation at 5000 rpm for 20 min, washed sequentially with anhydrous ethanol and acetone, and dried to afford crude FMPS. The extraction yield (%) was calculated with the formula below:

$$Y(\%) = 100\% \times \frac{w_1}{w_0}$$

where Y was the yield of polysaccharides, w_1 was the polysaccharides of extraction (g), and w_0 represented dried sample weight (g).

2.3. Experimental design of RSM

Based on the results of single-factor experiments, a five-level CCD with four factors was applied to determine the optimal levels for extraction temperature (X_1), liquid–solid ratio (X_2), extraction time (X_3) and ultrasound time (X_4). The whole design consisted of 26 experimental points carried out in random order (Table 1). Two replicates at the center of the design were used to allow for estimation of a pure error sum of squares. The response value in each trial was average of duplicates.

2.4. FT-IR spectrometric analysis

The FT-IR spectrum was recorded with a Nicolet 5700 FT-IR spectrometer (Thermo Electron, Madison, WI, USA) using KBr disks method. The dried FMPS was grinded with potassium bromide powder and pressed into pellet for spectrometric measurement in the frequency range of 4000–500 cm^{-1}.

2.5. Antioxidant activity in vitro of FMPS

2.5.1. Assay of H_2O_2 scavenging activity

The H_2O_2 scavenging activity of FMPS was determined according to the method reported by Liu et al. (2010) with some modifications. One milliliter of sample with different concentration (0.4–3.6 mg/ml) was mixed with 2.4 ml of phosphate buffer (0.1 M, pH 7.4) and 0.6 ml of H_2O_2 solution (40 mM). The mixture was shaken vigorously and incubated at room temperature for 10 min. Then, the absorbance of the reaction mixture was determined at 230 nm. The H_2O_2 scavenging activity was calculated according to the formula below:

$$H_2O_2 \quad \text{scavenging activity}(\%) = 100 \times \frac{A_0 - A_1 + A_2}{A_0}$$

where A_0 is the absorbance of control sample (water instead of sample), A_1 is the absorbance in the presence of tested sample, and A_2 is the absorbance of the sample only (water instead of H_2O_2 solution). The ascorbic acid was used as positive control.

2.5.2. Assay of Fe^{2+} chelating activity

The Fe^{2+} chelating activity of FMPS was determined according to the reported method (Liu, Wang, Xu, & Wang, 2007). One milliliter polysaccharide sample at different concentration (0.4–3.6 mg/ml) was added to 0.05 ml of ferrous chloride ($FeCl_2$) solution (2 mM), 0.2 ml of ferrozine solution (5 mM) and 2.75 ml of water. The mixture was shaken well and incubated for 10 min at room temperature, and then the absorbance of the mixture was determined at 562 nm. The Fe^{2+} chelating activity was calculated by the following formula:

$$Fe^{2+} \quad \text{chelating activity}(\%) = 100 \times \frac{A_0 - A_1 + A_2}{A_0}$$

where A_0 is the absorbance of control sample (water instead of sample), A_1 is the absorbance in the presence of tested sample, and A_2 is the absorbance of the sample only (water instead of $FeCl_2$ solution). Ethylenediaminetetraacetic acid disodium salt (EDTA-2Na) was used as positive control in the present study.

2.6. Statistical analysis

Analysis of the experimental design and data was carried out using Design Expert software of version 7.0 (Stat-Ease Inc., Minneapolis, USA). Analysis of variance (ANOVA) was carried out and the fitness of the polynomial model equation was expressed as the coefficient of determination R^2. The significances of the regression coefficients were tested by *F*-test. One-way ANOVA was performed using the SPSS 13.0 for windows (SPSS, Chicago, IL, USA). *P*-Values of less than 0.05 were regarded as significant.

3. Results and discussion

3.1. Effect of ultrasound power on the yield of FMPS

Preliminary studies were performed in order to determine the required ultrasound power for the extraction yield of polysaccharides from the aerial root of *F. microcarpa*. As shown in Fig. 1a, the yield of polysaccharides increased from 2.0 to 3.2% as ultrasound power increased from 100 to 200 W. And when the ultrasound power exceeded 200 W, the extraction yield of FMPS no longer changed. The result was in accordance with other reports for polysaccharides extraction (Zou, Chen, Yang, & Liu, 2011). Taking it into consideration that higher ultrasound power would result in degradation of polysaccharides (Zhou & Ma, 2006), 200 W was chosen as the optimal ultrasound power for producing polysaccharides.

Table 1
Experimental design with the respective codified factors, variation levels and the response values (yield of FMPS).

Run	Factors				Variation levels				Yield (%)
	x_1	x_2	x_3	x_4	X_1	X_2	X_3	X_4	
1	1	1	−1	−1	80	40	180	30	2.70
2	1	1	1	1	80	40	240	50	3.38
3	−1	−1	−1	1	70	20	180	50	2.03
4	0	2	0	0	75	50	210	40	2.98
5	1	−1	1	−1	80	20	240	30	1.98
6	1	1	−1	1	80	40	180	50	2.66
7	−1	1	1	1	70	40	240	50	3.35
8	−1	−1	1	−1	70	20	240	30	2.17
9	0	0	0	0	75	30	210	40	3.49
10	0	0	0	2	75	30	210	60	3.48
11	−1	1	−1	−1	70	40	180	30	2.11
12	1	−1	1	1	80	20	240	50	2.65
13	0	0	−2	0	75	30	150	40	2.04
14	0	−2	0	0	75	10	210	40	2.17
15	−2	0	0	0	65	30	210	40	2.36
16	−1	−1	−1	−1	70	20	180	30	2.28
17	1	1	1	−1	80	40	240	30	2.84
18	1	−1	−1	1	80	20	180	50	2.51
19	−1	1	−1	1	70	40	180	50	2.40
20	2	0	0	0	85	30	210	40	2.84
21	−1	−1	1	1	70	20	240	50	2.40
22	0	0	2	0	75	30	270	40	2.53
23	0	0	0	0	75	30	210	40	3.41
24	0	0	0	−2	75	30	210	20	2.86
25	1	−1	−1	−1	80	20	180	30	2.62
26	−1	1	1	−1	70	40	240	30	2.68

3.2. Effect of ultrasound temperature on the yield of FMPS

Previous research has shown that increasing the ultrasound temperature decreases the liquid viscosity and increases the cavitations within the tissues so that the area of contact between the particles and separating medium is maximized. Therefore, increasing the ultrasound temperature leads to an increase in the extraction yield (Hemwimol, Pavasant, & Shotipruk, 2006; Zhang,

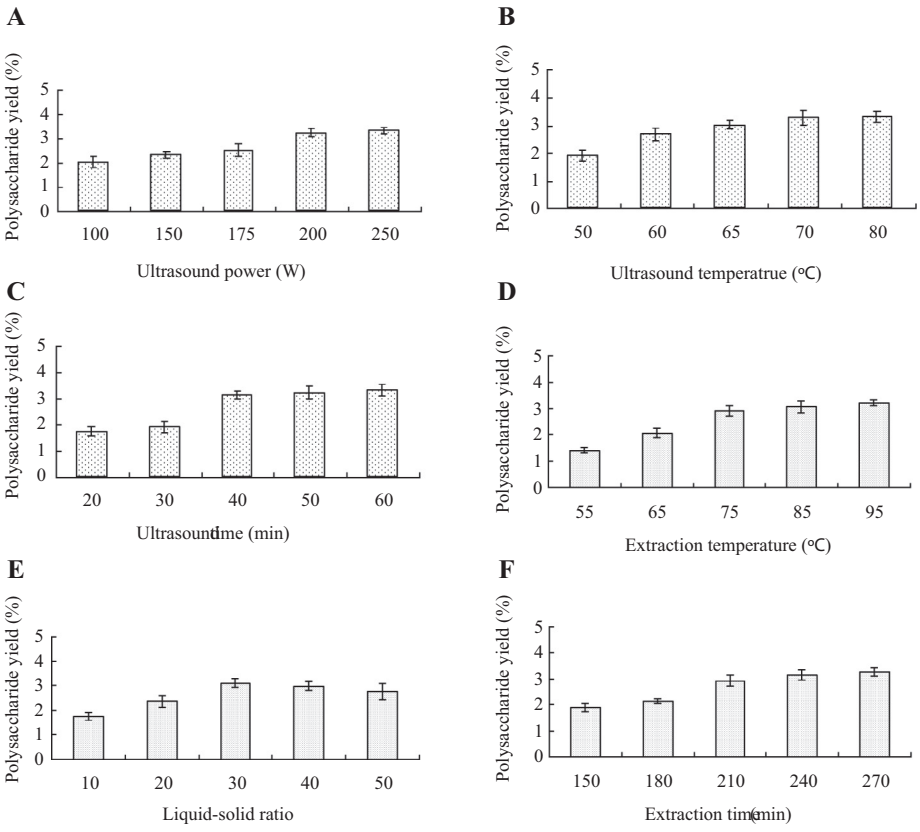

Fig. 1. Effects of ultrasound power (A), ultrasound temperature (B), ultrasound time (C), extraction temperature (D), liquid–solid ratio (E), extraction time (F) on the yield of FMPS.

Zhou, Chen, Cao, & Tan, 2011). As shown in Fig. 1b, the yield of polysaccharides increased with the increase of the ultrasound temperature. When ultrasound temperature varied from 50 to 70 °C, the extraction yield increase rapidly. The polysaccharide production reached a maximum at 70 °C, and then no longer changed as the extraction proceeded. This indicated that the ultrasound temperature of 70 °C was sufficient to obtain the polysaccharide production.

3.3. Effect of ultrasound time on the yield of FMPS

Ultrasound time is an important factor that affects the efficiency of polysaccharide extraction (Wang et al., 2012). As shown in Fig. 1c, the yield of polysaccharides increased from 1.70 to 3.10% as ultrasound time increased from 20 to 40 min. And when the ultrasound time continued to increase, the extraction yield no longer changed. Therefore ultrasound time of 40 min was selected as the center point for further experiment.

3.4. Effect of extraction temperature on the yield of FMPS

The increase of the polysaccharides diffusion coefficient and the enhanced solubility of the polysaccharides in the extracting solvent at higher temperatures caused the increase of the polysaccharides mass going out from the cells into the solution (Cao & Lin, 2006). The extraction coefficient increased with increasing the extraction temperature due to the increase of the polysaccharide solubility (Braga, Moreschi, & Meireles, 2006). As shown in Fig. 1d, the extraction yield of polysaccharides increased when extraction temperature increased from 55 to 95 °C. The maximum yield (3.2%) of polysaccharides was observed when extraction temperature was 95 °C. This tendency is in agreement with other reports in extracting polysaccharides (Ray, 2006). Taking it into consideration that there were no significant differences among the treatments of 75, 85 and 95 °C ($P > 0.05$), extraction temperature range of 75 °C was selected as the center point for CCD experiment.

3.5. Effect of liquid–solid ratio on the yield of FMPS

Liquid–solid ratio significantly affects the extraction yield of polysaccharides (Govender et al., 2005). If liquid–solid ratio is too small, polysaccharides in raw material cannot be completely extracted up. If liquid–solid ratio is too big, this will cause high process cost. Therefore, suitable liquid–solid ratio should be selected for extraction of targeted polysaccharides. As shown in Fig. 1e, the polysaccharides yield increased with increasing liquid–solid ratio, and reached highest value (3.1%) when the ratio was 30. However, when the ratio was higher than 30, the polysaccharides yield was decreased. This might be due to the reason that polysaccharides could be excessively dissolved in lower concentration solvent, making big loss during production collection. Therefore, liquid–solid ratio 30 was adopted in the following CCD experiment.

3.6. Effect of extraction time on the yield of FMPS

Extraction time is another factor influencing the extraction efficiency and selectivity of the fluid. It has been reported that a long extraction time favors the production of polysaccharides. While the excessive lengthening of extraction time may induce the change of polysaccharides molecule structure (Cai, Gu, & Tang, 2008). In this study, the yield of the polysaccharides increased with the increase of extraction time (Fig. 1f). The polysaccharides achieved a maximum percentage of 3.07% when the extraction time was 210 min. After this point, the yield of the polysaccharides started to maintain a dynamic equilibrium with increasing the extraction time. Therefore, a 210-min extraction time was selected as the center point for CCD experiment.

Table 2
Variance analysis of response surface quadratic model for the extraction of polysaccharides from the aerial root of *F. microcarpa*.

Source	Sum of squares	DF	Mean square	*F*-value	*P*-value
Model	5.4024	14	0.3859	25.9196	0.0001[a]
Lack of fit	0.1606	10	0.0161	5.0178	0.3352[b]
Pure error	0.0032	1	0.0032		
Corrected total	5.5700	25			
X_1	0.3456	1	0.3456	23.2133	0.0005[a]
X_2	1.0872	1	1.0872	73.0219	0.0001[a]
X_3	0.4056	1	0.4056	27.2434	0.0003[a]
X_4	0.4374	1	0.4374	29.3793	0.0002[a]
X_1X_2	0.0016	1	0.0016	0.1075	0.7492[b]
X_1X_3	0.1260	1	0.1260	8.4649	0.0142[a]
X_1X_4	0.0009	1	0.0009	0.06045	0.8103[b]
X_2X_3	0.4290	1	0.4290	28.8168	0.0002[a]
X_2X_3	0.0529	1	0.0529	3.5532	0.0861[b]
X_3X_4	0.3080	1	0.3080	20.6894	0.0008[a]
X_1^2	0.9294	1	0.9294	62.4245	0.0001[a]
X_2^2	0.9845	1	0.9845	66.1300	0.0001[a]
X_3^2	1.6719	1	1.6720	112.3033	0.0001[a]
X_4^2	0.1359	1	0.1359	9.1306	0.0116[a]

$R^2 = 0.9706$, Adjusted $R^2 = 0.9331$.
[a] 5% significance level.
[b] Not significant relative to the pure error.

3.7. Predicted model and statistical analysis

RSM optimization is more advantageous than the traditional single parameter optimization in that it saves time, space and raw material. The application of RSM offers, based on parameter estimates, an empirical relationship between the response variable (extraction yield of polysaccharides) and the test variables. The design matrix and the corresponding results of RSM experiments to determine the effects of the four independent variables are shown in Table 1. By applying multiple regression analysis on the experimental data, the response variable and the test variables are related by the following second-order polynomial equation:

$$Y = 3.45 + 0.12x_1 + 0.21x_2 + 0.13x_3 + 0.13x_4 + 0.01x_1x_2 - 0.09x_1x_3 + 0.01x_1x_4 + 0.16x_2x_3 + 0.06x_2x_4 + 0.14x_3x_4 - 0.23x_1^2 - 0.24x_2^2 - 0.31x_3^2 - 0.09x_4^2$$

where Y represents the yield of FMPS, x_1, x_2, x_3 and x_4 are the coded values of the test variables for extraction temperature, liquid–solid ratio, extraction time and ultrasound time, respectively.

The statistical significance of the second-order polynomial equation was checked by *F*-test, and the analysis of variance (ANOVA) for response surface quadratic polynomial model was performed by software Design-Expert. As shown in Table 2, the quadratic regression model had a high *F*-value ($F = 25.920$) and a very low *P*-value ($P < 0.0001$), indicating that the fitness of the model was highly significant. The lack of fit measures the failure of the model to represent the data in the experimental domain at points which are not included in the regression. If the model does not represent the data well, the lack of fit *F*-statistic will be significant (Ghafari, Aziz, Isa, & Zinatizadeh, 2009). In the present study, the lack of fit showed a low *F*-value ($F = 5.018$) and a very high *P*-value ($P = 0.3352$), implying that the lack of fit *F*-statistic was insignificant. The result indicated that the model equation was adequate for predicting the yield of FMPS under any combination of values of the variables. The goodness of the model can be checked by the determination coefficients (R^2). The R^2 coefficient gives the proportion of the total variation in the response predicted by the model, indicating ratio of sum of squares due to regression to total

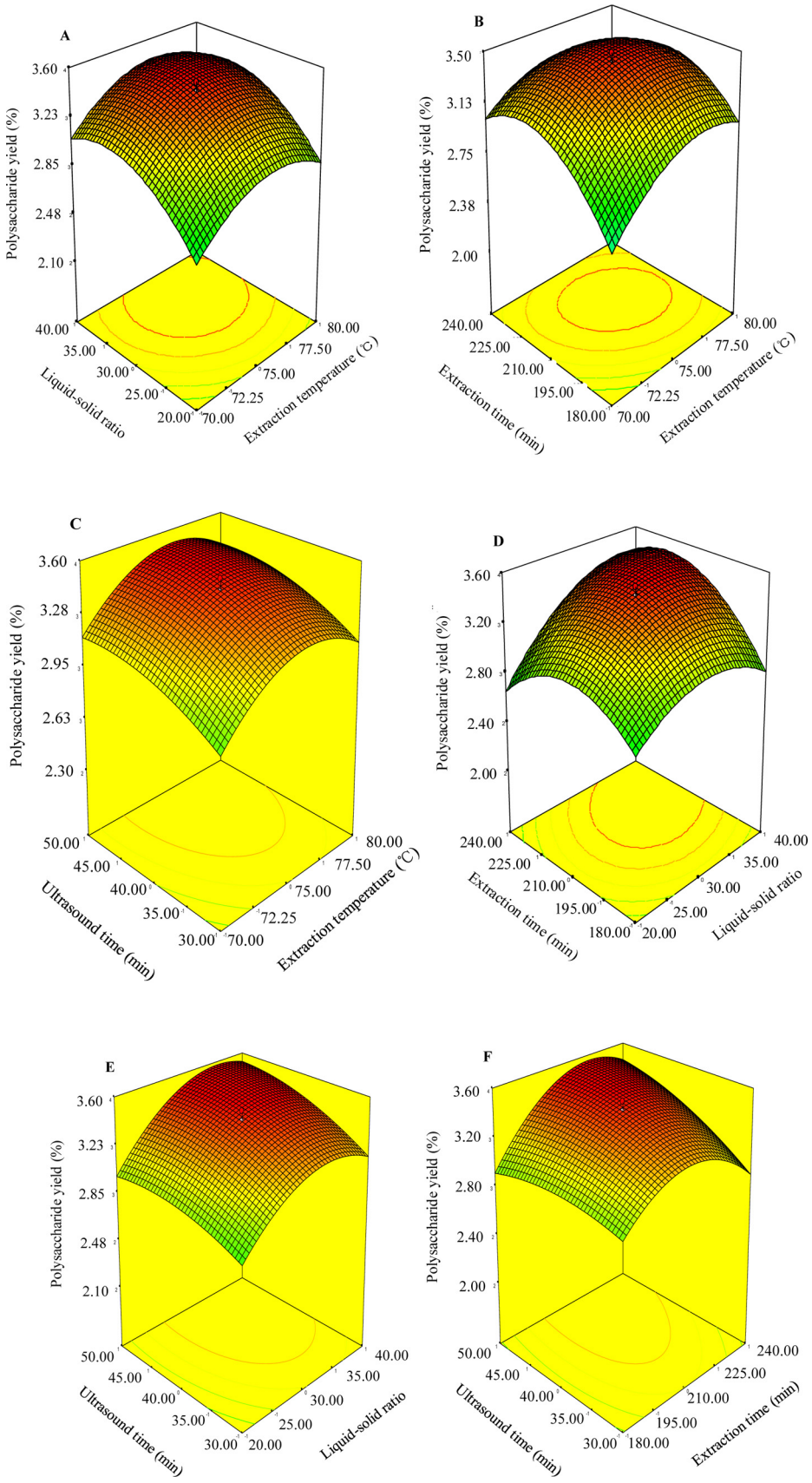

Fig. 2. Response surface plots (A, B, C, D, E and F) showing the effects of extraction temperature, liquid–solid ratio, extraction time, ultrasound time and their mutual effects on extraction yield of FMPS.

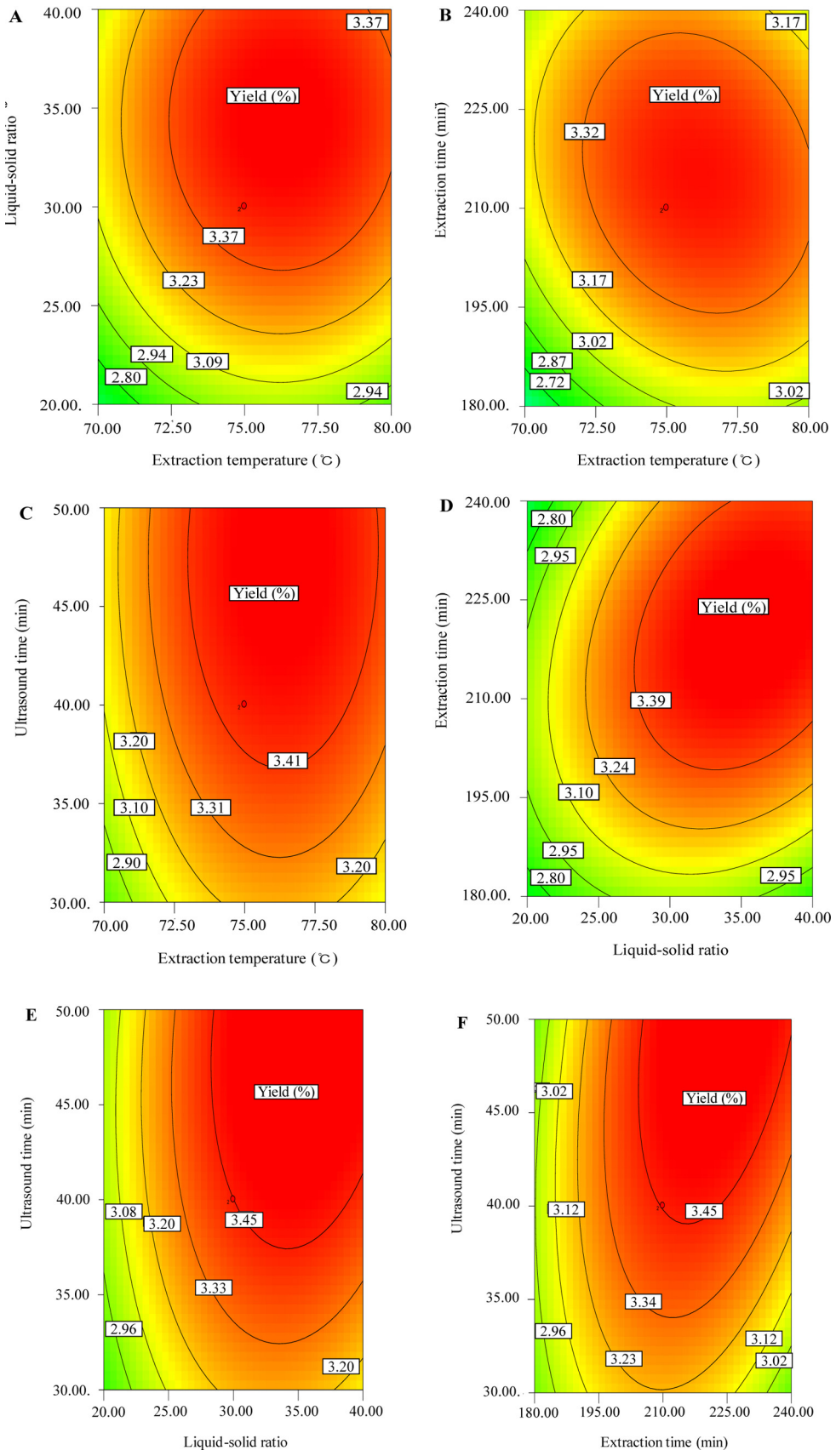

Fig. 3. Contour plots (A, B, C, D, E and F) showing the effects of extraction temperature, liquid–solid ratio, extraction time, ultrasound time and their mutual effects on extraction yield of FMPS.

sum of squares. A high R^2 coefficient ensures a satisfactory adjustment of the quadratic model to the experimental data. As shown in Table 2, the value of R^2 (0.9706) indicated good agreement between the experimental and predicted values of the yield of FMPS. The value of adj-R^2 (0.9331) suggested that the total variation of 93% for the yield of FMPS was attributed to the independent variables.

The significance of each coefficient was checked using *P*-value in Table 2. The *P* value is used as a tool to check the significance of each coefficient. The corresponding variable will be more significant if the *P*-value becomes smaller (Chen et al., 2010). In this case, the linear coefficients (X_1, X_2, X_3, X_4), quadratic term coefficients (X_1^2, X_2^2, X_3^2, X_4^2) and cross product coefficients (X_1X_3, X_2X_3, X_3X_4), with very small *P*-values ($P < 0.05$), are significant model terms. The result indicated extraction temperature, ultrasound time, extraction time and liquid–solid ratio were significant single parameters influencing the extraction yield of FMPS.

3.8. Response surface plot and contour plot

The 3D response surface and 2D contour plots are the graphical representations of regression equation. They provide a method to visualize the relationship between responses and experimental levels of each variable and the type of interactions between two test variables. The shapes of the contour plots, circular or elliptical, indicate whether the mutual interactions between the variables are significant or not. Circular contour plot indicates that the interactions between the corresponding variables are negligible, while elliptical contour plot indicates that the interactions between the corresponding variables are significant (Muralidhar, Chirumamila, Marchant, & Nigam, 2001). In the present study, the tri-dimensional surface plots obtained by plotting the response on the *Z*-axis against any two variables while keeping other variables at their zero level are presented in Figs. 2 and 3. It is clear that the interactions between extraction temperature and extraction time, liquid–solid ratio and extraction time, ultrasound time and extraction time were significant. However, interactions between extraction temperature and liquid–solid ratio, extraction temperature and ultrasound time, ultrasound time and liquid–solid ratio were not significant. Furthermore, the optimal values of the tested variables for obtaining FMPS of approximate 3.5% were located in the following ranges: extracting temperature 72.5–77.5 °C (Fig. 3a–c), liquid–solid ratio 30–40 (Fig. 3a, e and f), extracting time 210–240 min (Fig. 3b, d and f), and ultrasound time 40–50 min (Fig. 3c, e and f).

3.9. Optimization of extracting parameters and validation of the model

By employing the software Design-Expert, the solved optimum values of the tested variables were extraction temperature 73.65 °C, liquid–solid ratio 34.75, extracting time 237.92 min, ultrasound time 49.37 min. Under the optimal conditions, the maximum predicted yield of FMPS was 3.59%. Taking account of the operating convenience, the optimal parameters were determined as following: extraction temperature 74 °C, liquid–solid ratio 35, extraction time 238 min, ultrasound time 49 min. To ensure the predicted result was not biased toward the practical value, experimental rechecking was performed using this deduced optimal condition. A mean value of 3.44 ± 0.19% ($n = 3$), obtained from real experiments, demonstrated the validation of the RSM model. The good correlation between experimental and predicted values confirmed that the response model was accurate and adequate for the extraction of FMPS.

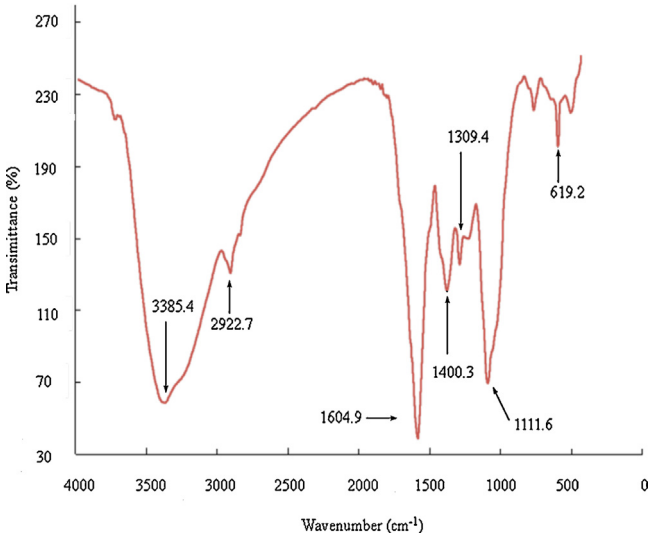

Fig. 4. FT-IR spectra of FMPS.

3.10. FT-IR spectrometric characterization of FMPS

FMPS were characterized by FT-IR spectroscopy as shown in Fig. 4. A strong and broad absorption peak at 3385.4 cm^{-1} for O—H stretching vibrations, a peak at 2922.7 cm^{-1} for C—H stretching vibrations, and a strong extensive absorption in the region of 900–1200 cm^{-1} for coupled C—O and C—C stretching and C—OH bending vibrations were observed in FMPS, indicating the characteristic absorptions of polysaccharides (Liu et al., 2008). Two absorption peaks at 1309.4 and 1111.6 cm^{-1} for the asymmetric and symmetric stretching vibrations of S=O, respectively, confirmed FMPS were sulfated polysaccharides (Gan, Ma, Jiang, Xu, & Zeng, 2011). Furthermore, two strong peaks at 1604.9 and 1400.3 cm^{-1} were assigned to the absorbance of the deprotonated carboxylic group (COO^-), indicating FMPS be acidic polysaccharides (Zhao et al., 2010).

3.11. Antioxidant activities in vitro of FMPS

3.11.1. Scavenging activity on hydrogen peroxide of FMPS

Hydrogen peroxide can induce the oxidative degradation of most biological macromolecules such as lipids, proteins or enzymes, carbohydrates and nucleic acids through generation of hydroxyl radicals. Thus, removing hydrogen peroxide is very important for life being away from damage. As shown in Fig. 5a, the scavenging effect of FMPS on hydrogen peroxide was increased with the increase of concentration up to 3.6 mg/ml. At a concentration of 3.6 mg/ml, the hydrogen peroxide scavenging activity of FMPS was 50.6% and was lower than that of ascorbic acid at 3.6 mg/ml. The result demonstrated that FMPS possessed moderate hydrogen peroxide scavenging effect.

3.11.2. Fe^{2+} chelating activity of FMPS

The chelating activity of the antioxidants are assayed by inhibiting the formation of red-colored ferrozine-Fe^{2+} complex (Liu et al., 2010). As shown in Fig. 5b, the Fe^{2+} chelating activity of FMPS and EDTA-2Na was evident at all of the tested concentrations. At a concentration of 3.6 mg/ml, the Fe^{2+} chelating activity of FMPS and EDTA-2Na was 81.3 and 91.2%, respectively. The results indicated that FMPS had significant Fe^{2+} chelating activity. It has been reported that compounds with metal ion chelating activities usually contain two or more of the following functional groups: —OH, —SH, —COOH, $—PO_3H_2$, CO, $—NR_2$, —S— and —O— (Yuan, Bone, &

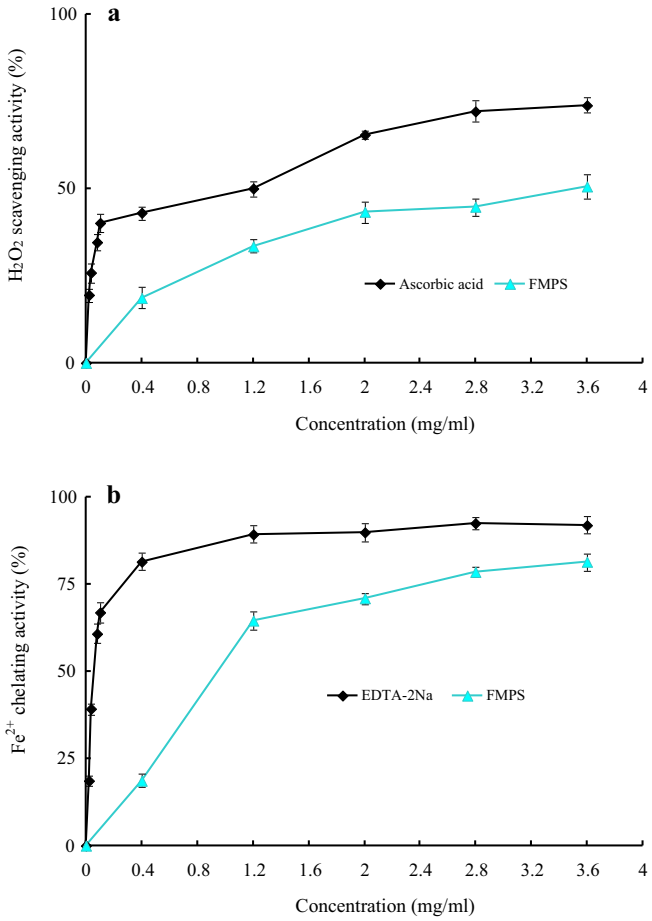

Fig. 5. The hydrogen peroxide scavenging activity (a) and Fe^{2+} chelating activity (b) of FMPS.

Carrington, 2005). The chelating effect of FMPS might be partly due to the strong Fe^{2+} chelating groups in the structure.

4. Conclusions

In this study, ultrasound technology was firstly performed for the polysaccharides extraction from the aerial root of *F. microcarpa*. The maximum yield of FMPS (3.59%) was obtained under the following conditions: ultrasound power 200 W, ultrasound temperature 70 °C, extraction temperature 74 °C, liquid–solid ratio 35, extraction time 238 min, ultrasound time 49 min, an actual experimental yield of 3.44 ± 0.19% was obtained. The results of variance analysis suggested that the regression model was accurate and adequate for the extraction of FMPS. Then, FMPS was characterized by FT-IR and found to be acidic polysaccharides. Finally, the results of antioxidant activity assays demonstrated that FMPS had strong Fe^{2+} chelating activity and moderate hydrogen peroxide scavenging effect. Further work on the purification, structure characterization and antioxidant activity *in vivo* of FMPS is in progress.

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