

Research Article

Optimal Extraction of Gallic Acid from *Suaeda glauca* Bge. Leaves and Enhanced Efficiency by Ionic Liquids

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The ultrasound-assisted extraction (UAE) was initially applied to extract gallic acid from *Suaeda glauca* Bge. using 70% ethanol as extraction solvent. Temperature, liquid-solid ratio, and extraction time were optimized by response surface methodology (RSM), obtaining maximum levels of gallic acid ($6.30 \text{ mg}\cdot\text{g}^{-1}$) at 51°C , $19.52 \text{ mL}\cdot\text{g}^{-1}$, and 42.68 min, respectively. The obtained model was statistically significant ($p < 0.0001$). The verification experiments at the optimum conditions yielded gallic acid for $6.21 \text{ mg}\cdot\text{g}^{-1}$. Subsequently, under optimal conditions, four ionic liquids were used to extract gallic acid from *Suaeda glauca* Bge. The results indicated that the presence of 1-hexyl-3-methylimidazolium chloride allowed increasing the EE of gallic acid up to $8.90 \text{ mg}\cdot\text{g}^{-1}$. This might be interpreted in terms of the molecular interaction between ionic liquid and gallic acid. The use of ionic liquids involves a stronger gallic acid extraction capacity than conventional organic volatile solvents. A promising alternative process is proposed for the extraction of gallic acid of *Suaeda glauca* Bge.

1. Introduction

In recent years, phenolic compounds have been a hot research topic due to their relevant properties in the health and nutrition fields [1, 2]. Their advantages are characterized by high antioxidant activity and free radical scavenging capacities produced in metabolic processes, thus to protect against cancer, cardiovascular diseases, chronic diseases, and so forth [3, 4]. Some phenolic compounds such as flavonoids [5, 6], polysaccharides [7], and phenolic acids [8–10], especially gallic acid [11], are widely used in beverages, cosmetics, food, and medicine as functional products. Usually, the extraction of these compounds from natural sources is preferred compared with the synthetic routes as they usually entail higher toxicity [12]. Of course, there is no denying of the fact of toxicity of some phenolic components. Progress has been made in the research on the toxicity of small molecule phenols in wastewater treatment [13].

Gallic acid has been early reported with anti-inflammatory, antimutagenic, antioxidative, anti-free radical, and other bioactive properties [14, 15]; and gallic acid has

antitumor effect of inhibiting metastasis of mast cell tumors, thereby prolonging the survival period [16], and is a relatively suitable trypanocidal drug candidate [17] and has a protective effect on the liver [18]. Gallic acid is a naturally polyphenolic compound widely present in grapes, tea, and other plants. Gallic acid is mainly produced by the following methods such as acid hydrolysis, alkaline hydrolysis, fermentation, and enzymatic hydrolysis, but these methods have their different drawbacks, for example, severe acid corrosion of the equipment, complex process, long reaction period, and incomplete hydrolysis. So, to find friendly and green solvents and processes is an important task.

At present, the most novel sample extraction methods including ultrasonic-assisted extraction (UAE) [19], microwave-assisted extraction (MAE) [20], reflux extraction (RE) [21], enzymatic extraction (EE) [22], and supercritical fluid extraction (SCFE) [23] have been applied to extract the active compounds from the natural plants. Among several extraction techniques, UAE has recently become a very popular technique in sample preparation and extraction of active components since it has the significant advantages

of high efficiency, fast effect, energy-saving, and minimum solvent consumption [19, 24]. Response surface methodology (RSM) is currently widely applied in the food industry to optimize processing parameters for more advantageous complete parametric statistical analysis, image rendering, model establishing, and so on. It can not only reduce the run times of experimental trials, but also evaluate several variables and their interactions [25].

Additionally, ionic liquids (ILs) have been reported to present higher extraction performances than the conventional solvents [26, 27]. The reported results suggest that a proper choice of the chemical structure of the IL can provide tailored and optimized extraction of the target compound [27]. Apart from their inherent ionic character, such as a negligible vapor pressure, null flammability, high ionic conductivity, and high thermal and electrochemical stabilities, as well as negligible volatility and nonflammability, one of the main advantages of ionic liquids is their tunability, which allows the existence of trillions of possible combinations of a large asymmetric organic cation and either an organic or inorganic anion [28]. Much wider hydrophilic or lipophilic ILs allowing for more extensive selection have been intensively investigated in the last decade for the extraction of the most diverse compounds, where results up to complete extraction efficiency up to several times, even dozens of times, were achieved [29]. IL interacts with analytes through anion exchange, hydrogen bonding, and hydrophobic interaction [30].

Suaeda glauca Bge. belongs to *Suaeda salsa* family which is regarded as being a species well adapted to saline soil on the seashore [31, 32]. More than 100 kinds of *Suaeda salsa* are widely distributed in India, Southern China, and Australia. It has been demonstrated that *Suaeda salsa* is a green food and is edible as a good vegetable for human and animal feed [31]. Besides, it has been reported that *Suaeda glauca* Bge. leaves have a wide application as a traditional medicinal herb in treating diarrhea, fevers, bad digestion, and so forth [33]. Many studies revealed that *Suaeda glauca* Bge. possesses many active compounds [10, 34]. In many cases, pharmacological effects may be determined by the composition and contents of active components. So, an urgent process was needed to investigate extraction of active components from target plants.

Extraction of gallic acid from *Suaeda glauca* Bge. leaves using ILs as solvent has not yet been reported, which was compared with reference extraction approaches as well. The single factor experiments were initially performed, and influence parameters of UAE method were optimized by response surface methodology (RSM) [25, 35]. Under optimal conditions, ionic liquid was applied in the extraction process to examine extraction efficiency (EE) of ionic liquids [36, 37]. This work is to study the development of *Suaeda glauca* Bge. and put forward the process of extraction of gallic acid and further application of ionic liquids.

2. Materials and Methods

2.1. Material. Gallic acid standard was purchased from Beijing Yingze New Chemical Technology Research

Institute (Beijing, China). 1-Ethyl-3-methylimidazolium chloride ([Emim]Cl), 1-butyl-3-methylimidazolium chloride ([Bmim]Cl), 1-hexyl-3-methylimidazolium chloride ([Hmim]Cl), and 1-octyl-3-methylimidazolium chloride ([Omim]Cl) (purity > 99%) were provided by Lanzhou Greenchem ILS, LICP, China. These ILs were distilled for 4 h to remove any residual volatile compounds and water in a rotary evaporator and dried at 398.5 K under vacuum for 48 h prior to use. HPLC grade acetonitrile was obtained from Tedia (Tedia, USA). All other chemicals were of analytical grade and were obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

Suaeda glauca Bge. leaves were picked from the seawall in Dafeng city (Yancheng, Jiangsu, China) in March 2013. They were cleaned and dried at 60°C to constant weight. And they were pulverized by the Joyoung soybean machine (DJ13B-D18D, Shandong, China) into powder and sealed for further use after 60-mesh sieving.

2.2. Ultrasound-Assisted Extraction. An ultrasonic cleaner (KQ-300E, Kunshan Instruments Co., Ltd., Jiangsu, China) was used for extraction of gallic acid, which has the rectangular bath (27.5 cm × 18.5 cm × 20.2 cm). Samples accurately weighed (3.00 g) were placed in a 50 mL flask and mixed with a certain liquid-solid ratio (Table 1) of 70% aqueous ethanol and then immersed in a water bath. The temperature and time of extraction process were set by adjusting the knobs on the panel according to Table 1. The working power and frequency were fixed at 300 W and 40 kHz, respectively. After ultrasonic extraction, the final solutions were centrifuged by high speed centrifugation (800, Shanghai, China) and the insoluble residue was removed by the filtration through 0.22 μm organic membrane (Guangfu, Tianjin, China) by three times for further HPLC analysis.

2.3. HPLC System. Chromatographic instrumentation was carried out with Waters 2695, USA, equipped with Symmetry C18 (4.6 mm × 250 mm, 5 μm) column, alliance-2695 autosampler, and Waters 2489 UV detector. System control and data analysis were carried out using Empower 3 software. Chromatographic column (Sunfire-C18, 3.9 × 150 mm) was used. The mobile phase was composed of acetonitrile (A) and 0.1% phosphoric acid (B) in gradient elution mode. Gradient elution was performed as follows: 0–4 min, 92% B; 4–8 min, 90–86% B; 8–25 min, 86–83% B; 25–30 min, 83–80% B; 30–35 min, 80–79% B; 35–40 min, 79–76% B; 40–50 min, 76–71% B; 50–60 min, 76–67% B; 60–70 min, 67–64% B. The flow rate of the mobile phase was kept at 1.0 mL min⁻¹, using 320 nm as the preferred wavelength. The temperature of the column was kept at 30°C and the sample injection volume was 10 μL.

Gallic acid in the extract was identified by comparison of retention times with standards. The calibration curve of gallic acid was plotted by the peak area and concentrations of gallic acid by HPLC determination results. The curve equations were $y(\mu\text{g}\cdot\text{mL}^{-1}) = 0.0011x + 0.2161$ and $R^2 = 0.9964$, where y is the concentration of gallic acid ($\mu\text{g}\cdot\text{mL}^{-1}$) and x is the peak area.

TABLE 1: Design and results by RSM for gallic acid extraction from *Suaeda glauca* Bge. leaves.

Number	A	B	C	EE of gallic acid ($\text{mg}\cdot\text{g}^{-1}$)	
	Temperature ($^{\circ}\text{C}$)	Liquid-solid ratio ($\text{mL}\cdot\text{g}^{-1}$)	Extraction time (min)	Actual value	Predicted value
1	30	10	50	5.19	5.32
2	70	10	50	5.60	5.52
3	30	30	50	5.34	5.42
4	70	30	50	5.30	5.17
5	30	20	30	5.75	5.61
6	70	20	30	5.87	5.95
7	30	20	70	5.78	5.70
8	70	20	70	5.18	5.32
9	50	10	30	5.66	5.67
10	50	30	30	5.73	5.8
11	50	10	70	5.71	5.65
12	50	30	70	5.26	5.26
13	50	20	50	6.44	6.21
14	50	20	50	6.16	6.21
15	50	20	50	6.15	6.21
16	50	20	50	6.28	6.21
17	50	20	50	6.04	6.21

2.4. Extraction Efficiency of Gallic Acid. The mass of gallic acid in extracts was calculated by the calibration equation. The mass ratio of gallic acid in extracts to the weight of the sample studied was considered as the extraction efficiency. Indeed, the following formula was used for calculating extraction efficiency (EE):

$$\text{EE} (\text{mg} \cdot \text{g}^{-1}) = (0.0011x + 0.2161) \times \frac{V}{1000} \quad (1)$$

× sample mass,

where the unit of V is mL and the unit of sample mass is gram.

2.5. RSM Design. The optimization experiment according to Box-Behnken Design (BBD) [19] was employed to study the interaction between the factors because the effects of parameters on each other are always ignored. The bounds of the three factors were extraction temperature of 30–70 $^{\circ}\text{C}$, extraction time of 40–60 min, and liquid-solid ratio of 10–30 $\text{mL}\cdot\text{g}^{-1}$. The arrangements of factors and their levels are shown in Table 1. The complete design consisted of twelve factorial experiments and five repeated experiments. Regression model was built on the actual data of response variables using Design-Expert v7.1.6 software. Next, a validation test should be performed to verify the repeatability of the regression model obtained from the systematic study of different extraction parameters. Three samples of the same weight (3.00 g) were extracted under the optimal conditions.

2.6. Enhanced Extraction of Gallic Acid by Ionic Liquids. Based on regression equation, extraction solvents were changed as the mixture of four kinds of ionic liquids and 70% aqueous ethanol, respectively. Ionic liquids of the

same concentration (0.5 $\text{mol}\cdot\text{L}^{-1}$) examined were [Emim]Cl, [Bmim]Cl, [Hmim]Cl, and [Omim]Cl, respectively. Extractions were conducted under the optimal conditions.

2.7. Statistical Analysis. The multiple regression equation was established on the basis of the experimental data as follows:

$$Y = k_0 + k_1X_1 + k_2X_2 + k_3X_3 + k_{12}X_1X_2 + k_{13}X_1X_3 + k_{23}X_2X_3 + k_{11}X_1X_1 + k_{22}X_2X_2 + k_{33}X_3X_3, \quad (2)$$

where Y represents the predicted value, k_0 is the model intercept, $k_1, k_2, k_3, k_{11}, k_{22},$ and k_{33} and $k_{12}, k_{13},$ and k_{23} are linear quadratic and interaction coefficients, respectively, and $X_1, X_2,$ and X_3 are the independent variables.

The analysis of variance (ANOVA) was carried out using Fisher's F -test at 95% confidence level to investigate the statistical significance of the regression coefficients, which are expressed as surface plots to visualize the relationship between response and experimental results of each factor.

3. Results and Discussion

3.1. Single Factor Extraction Test. In this study, many parameters extensively affect the extraction efficiency of gallic acid, which were the concentration and type of solvents, extraction temperature, instrument power, extraction time, liquid-solid ratio, and so forth. The most significant factors were filtered out by single factor experiments.

3.1.1. Effect of Extraction Temperature. Investigation of different temperatures on the EE of gallic acid was performed at 30, 40, 50, 60, and 70 $^{\circ}\text{C}$ with liquid-solid ratio of 20 $\text{mL}\cdot\text{g}^{-1}$ and extraction time of 40 min. At higher temperature, more

of the solvent could permeate into cells and dissolve more target compounds to achieve higher EE of gallic acid. From the results (Figure 1(a)), it is observed that the EE of gallic acid was increased and reached the maximum ($6.19 \text{ mg}\cdot\text{g}^{-1}$) until 50°C and then declined [38]. This similar phenomenon was also found in other research [39]. So, in order to ensure the maximum extraction of gallic acid, the range of temperature from 30 to 70°C was selected.

3.1.2. Effect of Liquid-Solid Ratio. Liquid-solid ratio is an important factor in influencing EE of target compound as it concerns the contact area between raw material and solvent. As shown in Figure 1(b), the liquid-solid ratio for $20 \text{ mL}\cdot\text{g}^{-1}$ was distinguished by the highest level EE of gallic acid for $6.21 \text{ mg}\cdot\text{g}^{-1}$. The lower or higher liquid-solid ratio showed lower EE of gallic acid. The decrease of EE of gallic acid with the increase of solvent quantity does not seem to be in accordance with mass transfer principles since the higher the concentration gradient, the higher the diffusion degree of solute. Considering that larger liquid-to-raw ratio will result in more unnecessary wasting [40], liquid-solid ratio from 10 to $30 \text{ mL}\cdot\text{g}^{-1}$ needed to be further optimized.

3.1.3. Effect of Extraction Time. With an analogous trend to extraction temperature, the extraction time at 50 min produced the extreme EE of gallic acid (Figure 1(c)). The results indicated that ultrasonic time up to 50 min may loosen the cell matrix faster than other conventional extraction methods [8, 41]. By increasing EE at 30 – 50 min , the decrease of EE of gallic acid was observed after 50 min . This implied that dissolution and diffusion of soluble components of the plant matrix occur to the equilibrium concentration of active components in 50 min [35]. It is generally known that ultrasound treatment for longer extraction time might lead to degradation of the extracts and the increasing viscosity of solvent resulting in the slow diffusion [42]. However, time is also required from the economical point of view. Consequently, the time range of 30 – 70 min was an optimum.

3.2. Optimization Experiment by RSM. The main impact factors were determined as extraction temperature, liquid-solid ratio, and extraction time, but the interaction among the three factors might lead to the combination effects of the optimum conditions of each factor. This may not be consistent with the optimum extraction conditions of every factor determined in single factor test. Therefore, RSM was adopted to optimize the operating conditions to further study the interaction between the factors. The three-factor, three-level BBD was selected for processing data.

3.2.1. Fitting the Regression Model. Based on single factor test, BBD method with three variables was employed for further optimization with respect to three factors. Actual values of EE of gallic acid (Table 1) were obtained by the experiments according to 17 runs (see Figure S1 in the Supplementary Material available online at <http://dx.doi.org/10.1155/2016/5217802>) and compared with the predicted value calculated according to the regression model.

The multiple second-order polynomial equation was fitted based on the experimental data as follows:

$$\begin{aligned} \text{EE} (\text{mg} \cdot \text{g}^{-1}) = & -1014.18 + 133.5A + 236.66B \\ & + 71.07C - 0.56AB - 0.45AC \\ & - 0.65BC - A^2 - 4.56B^2 - 0.42C^2. \end{aligned} \quad (3)$$

The analysis of variance (ANOVA) was used to evaluate the significance of the quadratic polynomial models. For each term, a large F value or a small p value would imply a more significant effect on each factor. From Table 2, the F value (59.10) and p value (<0.0001) of the model indicated that the model is significant [5]. In this case, the linear terms of liquid-solid ratio (B) and extraction time (C), the interaction term of AB , AC , and BC , and the square term of extraction temperature (A^2), liquid-solid ratio (B^2), and extraction time (C^2) are important terms ($p < 0.05$) on the EE of gallic acid, whereas the linear term of extraction temperature (A) was only insignificant ($p > 0.05$). In addition, the lack of fit is not significant relative to the pure error ($p > 0.05$). Pred. R^2 of 0.8597 is in reasonable agreement with adj. R^2 of 0.9730 . This implied that the model is valid and can be used to predict the extraction efficiency of gallic acid.

The 3D response surface presented the effects of influence factors on the EE of gallic acid based on the regression equation (Figure 2) and the interaction between the factors. First of all, Figure 2(a) described interaction between temperature and liquid-solid ratio. The EE increased by increasing temperature and liquid-solid ratio when extraction time was kept at 50 min . However, with further increase in temperature and liquid-solid ratio, the EE reached a maximum value at the average values of extraction conditions. Figure 2(b) shows the response of surface plots of the interactive effects of temperature and time on the EE of gallic acid. At longer time of extraction, the EE of gallic acid declined by the increasing of temperature at a fixed liquid-solid ratio. Figure 2(c) showed interaction between liquid-solid ratio and time. It presented the same trend compared to Figures 2(a) and 2(b).

3.2.2. Optimization of Extraction Parameters and Verification Experiments. The UAE extraction process of gallic acid was optimized by RSM. The optimal condition was found as temperature of 51.06°C , liquid-solid ratio of $19.52 \text{ mL}\cdot\text{g}^{-1}$, and extraction time of 41.68 min , providing the highest theoretical EE of gallic acid of $6.26 \text{ mg}\cdot\text{g}^{-1}$.

In order to facilitate the actual operation, the verification experiments were performed three times under the optimal conditions modified as integer, 51°C extraction temperature, $20 \text{ mL}\cdot\text{g}^{-1}$ liquid-solid ratio, and 42 min extraction time. HPLC diagram of verification experiments was shown in Figure S2 (in Supplementary Material).

3.3. Enhanced Extraction of Gallic Acid by Ionic Liquids. Ionic liquids, as environmentally friendly solvents, have many excellent properties, in which favorable solvating property for a range of polar and nonpolar compounds has been observed [36, 37]. The structure of ionic liquids has significant influence on target compounds [43]. Many properties

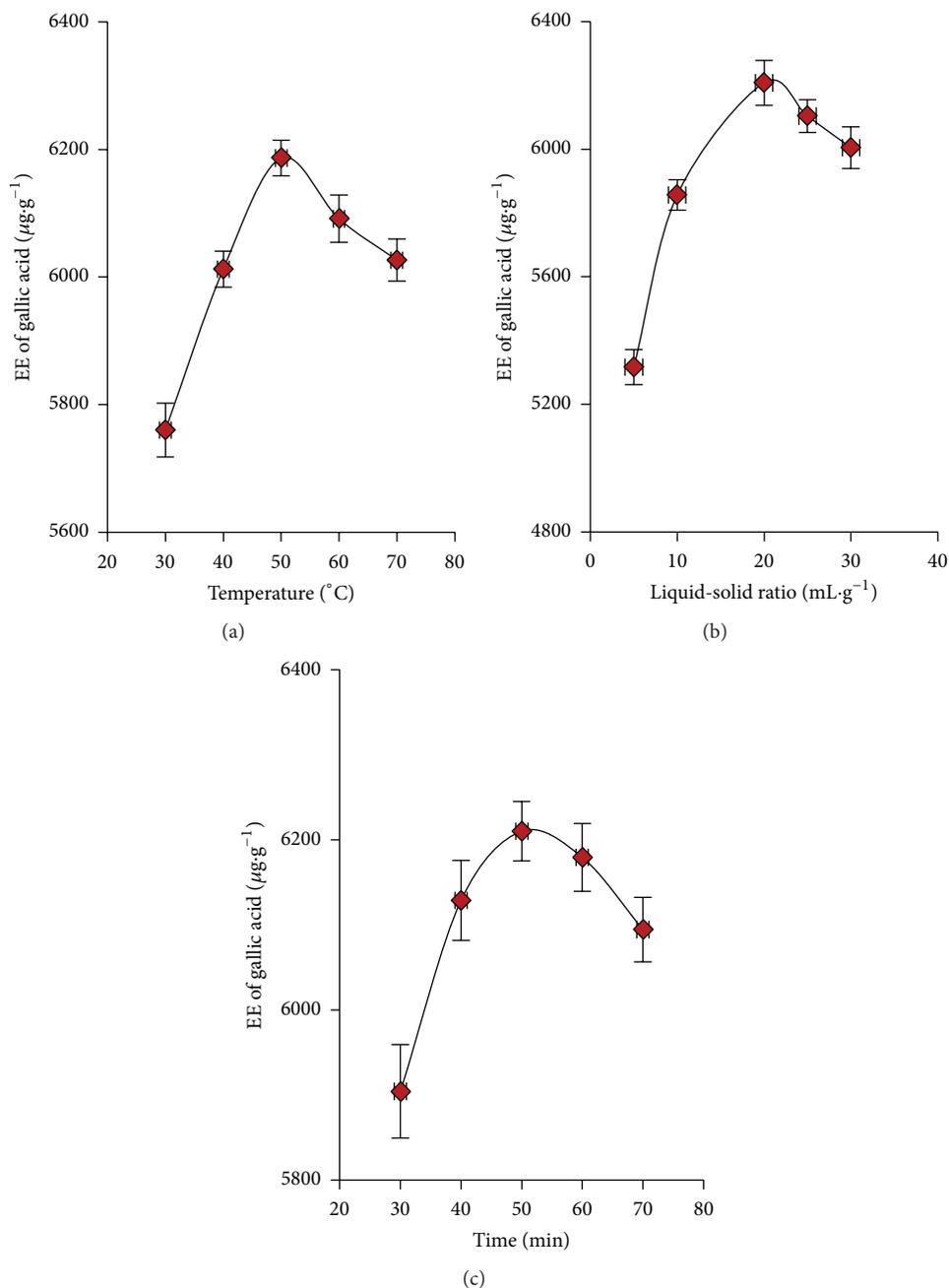


FIGURE 1: Effect of temperature (a), liquid-solid ratio (b), and time (c) on the extraction efficiency of gallic acid with 70% ethanol as solvent. Extraction efficiency is expressed as measured values of sample mass.

of the ionic liquid are dependent on their anions, such as NO_3^- , BF_4^- , Cl^- , Br^- , SO_4^{2-} , SCN^- , HSO_3^- , and Cl^- [11, 44, 45]. Cl^- , as a strong hydrogen-bond acceptor, is potent on generating hydrogen bonds with the target compound, which is more beneficial to dissolution and extraction of compounds studied. In this study, four kinds of ionic liquids with Cl^- anions were selected to extract gallic acid from *Suaeda glauca* Bge. leaves. The extraction results (shown in Figure S3 in Supplementary Material) were observed to enhance the EE of gallic acid under optimal conditions (Table 3).

Additionally, the viscosity of many ILs declined at higher temperature unless thermal decomposition and separation selectivity of components are not encountered. Hence, in this work, a mixture of ILs and water was used instead of pure ILs. The mixtures of ILs and water as the extraction solvent could significantly reduce the viscosity of extraction system and improve the transfer process in IL-mediated extraction. Moreover, the effect of the alkyl chain length was prominent in extraction. EE gradually increased, up to C6, but subsequently decreased in case of C8. This phenomenon

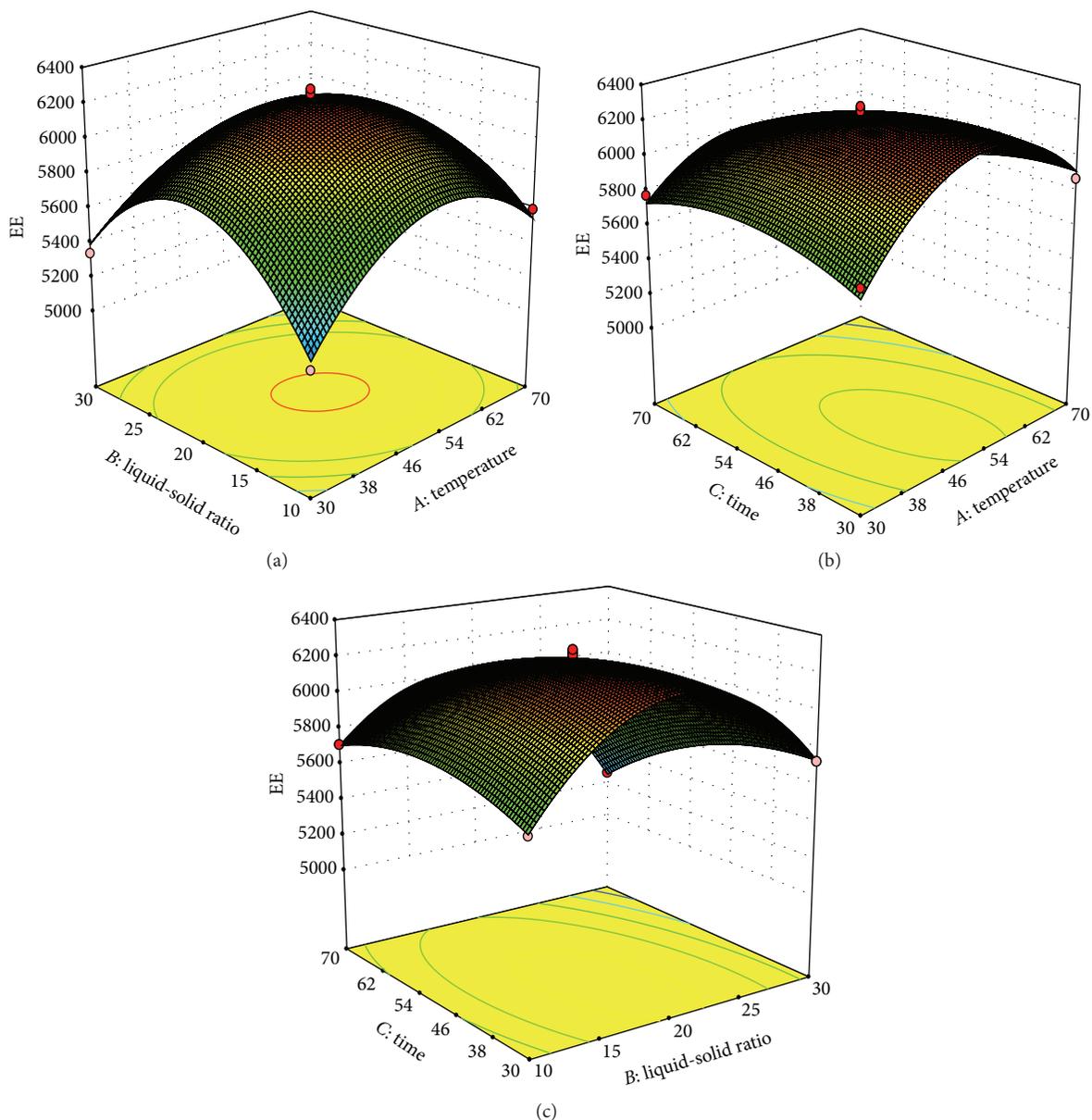


FIGURE 2: 3D response surface presenting the effect of influence factors on the EE of gallic acid. Interaction between temperature and liquid-solid ratio (a). Interaction between temperature and time (b). Interaction between liquid-solid ratio and time (c).

could be attributed to the fact that the lipophilicity of these ILs increases with increasing alkyl chain length. The concentration of gallic acid in the extract was analyzed by HPLC. Figure 3 showed the chromatogram of using [Hmim]Cl as solvent under the optimal conditions.

3.4. Comparison with the Reference Method. The comparison experiments were performed according to the following factors: solvents, extraction technique, and experimental conditions. Several different methods were performed on the optimized conditions, and the corresponding experimental results were shown in Table 3. The ILs-based UAE was compared to organic solvent-based UAE, MAE, and HRE. The extraction method using ethanol concentration of 70%

revealed higher EE ($6.21 \text{ mg}\cdot\text{g}^{-1}$) of gallic acid than methanol using UAE technique ($5.65 \text{ mg}\cdot\text{g}^{-1}$) and also higher values than the ones using MAE ($6.02 \text{ mg}\cdot\text{g}^{-1}$) and HRE method ($6.11 \text{ mg}\cdot\text{g}^{-1}$). However, the extraction results indicated that the extraction efficiency of ethanol as solvent was statistically lower than that of ILs at the same UAE conditions. The difference in efficiency could be caused by ILs, as ILs can form stronger binding energy with gallic acid than ethanol. Meanwhile, water is generally used as a swelling agent, whereas ethanol can disrupt the bonding of the plant matrices and solutes to enable solvent to penetrate the plant matrix. Furthermore, the ultrasonic power was a driving force for the complete dispersion and access of ILs into herbal materials. Therefore, ILs-based ultrasonic extraction technique is an

TABLE 2: Variance analysis of experimental results of RSM.

Source	Sum of squares	Df	Mean square	F value	p value
Model	2437377	9	270819.7	59.10	<0.0001
A	2745.035	1	2745.035	0.60	0.4643
B	73400.05	1	73400.05	16.02	0.0052
C	97271.37	1	97271.37	21.23	0.0025
AB	93434.15	1	93434.15	20.39	0.0027
AC	68840.64	1	68840.64	15.02	0.0061
BC	68620.42	1	68620.42	14.97	0.0061
A ²	693906.1	1	693906.1	151.42	<0.0001
B ²	1098205	1	1098205	239.64	<0.0001
C ²	74879.82	1	74879.82	16.34	0.0049
Residual	32079.38	7	4582.769		
Lack of fit	20532.69	3	6844.231	2.37	0.2115
Pure error	11546.69	4	2886.673		
Cor. total	2469456	16			
Std. dev.	67.70		R ²	0.9870	
Pred. R ²	0.8597		Adj. R ²	0.9730	

Note. The result in Table 2 was obtained with Design-Expert v7.1.6 software. A is extraction temperature (°C), B is liquid-solid ratio (mL·g⁻¹), and C is extraction time (min).

TABLE 3: Results of extraction of gallic acid by different solvents.

Solvents	Extraction technique	Conditions ^c	EE of gallic acid (mg·g ⁻¹)
[Emim]Cl ^a	UAE ^b	51°C, 20 mL·g ⁻¹ , 42 min	8.40
[Bmim]Cl ^a	UAE	51°C, 20 mL·g ⁻¹ , 42 min	8.51
[Hmim]Cl ^a	UAE	51°C, 20 mL·g ⁻¹ , 42 min	8.90
[Omim]Cl ^a	UAE	51°C, 20 mL·g ⁻¹ , 42 min	7.90
0% ethanol	UAE	51°C, 20 mL·g ⁻¹ , 42 min	3.47
40% ethanol	UAE	51°C, 20 mL·g ⁻¹ , 42 min	4.98
70% ethanol	UAE	51°C, 20 mL·g ⁻¹ , 42 min	6.21
100% ethanol	UAE	51°C, 20 mL·g ⁻¹ , 42 min	4.21
Methanol	UAE	51°C, 20 mL·g ⁻¹ , 42 min	5.65
70% ethanol	MAE ^b	51°C, 20 mL·g ⁻¹ , 10 min	6.02
70% ethanol	HRE ^b	20 mL·g ⁻¹ , 240 min	6.11

^a[Emim]Cl is 1-ethyl-3-methylimidazolium chloride; [Bmim]Cl is 1-butyl-3-methylimidazolium chloride; [Hmim]Cl is 1-hexyl-3-methylimidazolium chloride; [Omim]Cl is 1-octyl-3-methylimidazolium chloride; their concentrations were all 0.5 mol·L⁻¹ in extraction process.

^bUAE represents ultrasound-assisted extraction; MAE represents microwave-assisted extraction; HRE is hot reflux extraction.

^cExtraction conditions involved extraction temperature, liquid-solid ratio, and extraction time.

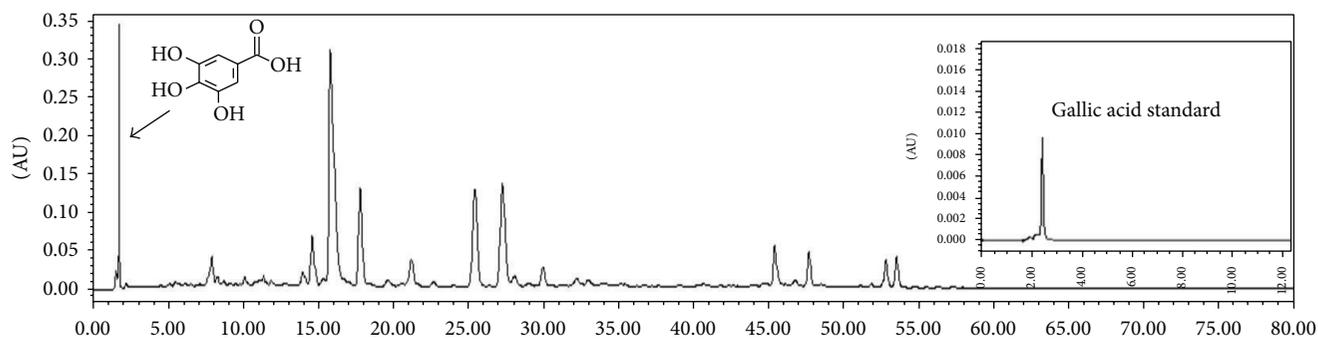


FIGURE 3: High performance liquid chromatography profile using 0.5 mol·L⁻¹ [Hmim]Cl as solvent under the operation conditions of 51°C extraction temperature, 20 mL·g⁻¹ liquid-solid ratio, and 42 min time.

effective method for extraction of gallic acid from *Suaeda glauca* Bge. leaves.

4. Conclusion

In this work, an efficient method has been established for extraction of gallic acid from *Suaeda glauca* Bge. The extraction process was optimized by RSM in order to obtain satisfactory extraction efficiency using UAE technique. The results proved that ionic liquids were possible alternative solvents for the extraction of gallic acid in the work. And 1-hexyl-3-methylimidazolium chloride possessed the highest extraction efficiency in selected ionic liquids under the extraction conditions: extraction temperature 51.06°C, liquid-solid ratio 19.52 mL·g⁻¹, and extraction time 41.68 min in 0.5 mol·L⁻¹ 70% ethanol solution using UAE technique. Compared to other reference approaches and solvents, the proposed method using ionic liquid as extraction solvent could present higher extraction efficiency, more useful energy-saving, and much shorter time consumption. The present results highlight the notion that the ILs-based UAE process can be used for the extraction of gallic acid of *Suaeda glauca* Bge.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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