Optimization of Supercritical Carbon Dioxide Extraction of *Eucommia ulmoides* Seed Oil and Quality Evaluation of the Oil

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Abstract: Supercritical carbon dioxide extraction (SC-CO₂) technology was used to extract oil from *Eucommia ulmoides* seed. The optimum conditions and significant parameters in SC-CO₂ were obtained using response surface methodology (RSM). The qualities of the extracted oil were evaluated by physicochemical properties, fatty acid composition, vitamin E composition. It was found that the optimum extraction parameters were at pressure of 37 MPa, temperature of 40°C, extraction time of 125 min and CO₂ flow rate of 2.6 SL/min. Pressure, temperature and time were identified as significant parameter effecting on extraction yield. The importance of evaluated parameters decreased in the order of pressure > extraction time > temperature > CO₂ flow rate. GC analysis indicated that *E. ulmoides* seed oil contained about 61% of linolenic acid and its fatty acid composition was similar with that of flaxseed oil and perilla oil. The content and composition of vitamin E was determined using HPLC. The *E. ulmoides* seed oil was rich in vitamin E (190.72 mg/100 g), the predominant vitamin E isomers were γ -tocopherol and δ -tocopherol, which accounted for 70.87% and 24.81% of the total vitamin E, respectively. The high yield and good physicochemical properties of extracted oil support the notion that SC-CO₂ technology is an effective technique for extracting oil from *E. ulmoides* seed.

Key words: supercritical carbon dioxide, *Eucommia ulmoides* seed oil, extraction optimization, fatty acid composition, vitamin E composition

1 Introduction

Eucommia ulmoides Oliv., which is also called “Du-Zhong” in Chinese, is a unique medicinal plant in China. The bark and leaf of *E. ulmoides* has been used as a traditional Chinese medicine for thousands of years. Now, *E. ulmoides* is mainly cultivated in China, Japan, Taiwan and Korea, etc.¹⁾ In recent years, researches about *E. ulmoides* mainly focused on isolation of monomeric compounds, such as polysaccharide, chlorogenic acid, lignans, flavonoids and other trace elements from bark and leaves²⁻⁵⁾, as well as the analysis of pharmacological functions of the bioactive substances⁶⁾. However, as one of the most important byproducts of *E. ulmoides*, the seed of *E. ulmoides* have not got enough attention. *E. ulmoides* seed contains about 10%-15% oil. After peeling, the oil content can increase to 30%-40%.

It has been proven that supercritical carbon dioxide (SC-CO₂) extraction is a very effective method to extract a

variety of vegetable oils⁷⁻⁹⁾. Compared to conventional organic solvent, carbon dioxide as solvent have many advantages, such as non-toxic, non-flammable, easy to separate from the desired extract, no harmful solvent residues and no solvent disposal cost¹⁰⁾. Response surface methodology (RSM) which combines mathematics with statistics is often used to design experiments, build models, and evaluate the effect of factors. The main advantage of RSM is a small number of experimental trials needed to evaluate multiple parameters and their interaction. It has been successfully applied in various food processing operations¹¹⁻¹⁴⁾. However, to the best of our knowledge, the effect of SC-CO₂ extraction parameters on yield of *E. ulmoides* seed oil have not been investigated and its physicochemical properties, especially vitamin E composition were also rarely reported.

The main objective of this study was to determine the effects of pressure, temperature, extraction time and CO₂

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flow rate on yield of *E. ulmoides* seed oil, and to find the optimum processing conditions for SC-CO₂ extraction. In addition, the fatty acid composition, Vitamin E composition and physicochemical properties of *E. ulmoides* seed oil extracted at optimum conditions were evaluated.

2 Materials and methods

2.1 Materials

The *E. ulmoides* seed was purchased from the market in Zunyi city, Guizhou province, China. The seeds were cleaned and de-husked by hand, then stored in a self-sealing bag at 2–4°C. The seeds were ground in a FW-100 domestic grinder (Beijing ever light medical equipment Co., LTD, Beijing, China) before use.

The carbon dioxide (99.9%) was supplied by Yuanhua Gas Plant (Zhengzhou, China). Fatty acid methyl ester standards were purchased from Sigma Aldrich Corporation (Shanghai, China). Tocopherols (α -, β -, γ - and δ -) and tocotrienols (α -, β -, γ - and δ -) standards were purchased from Beijing Sunky Biological Technology Co., Ltd (Beijing, China). All chemicals used were of analytical or chromatographic grade.

2.2 SC-CO₂ extraction

The SC-CO₂ extraction of *E. ulmoides* seed oil was performed on a Helix system (Applied Separation, Allentown, PA, USA). The schematic flow diagram was shown in Fig. 1. Method were used as described by Kraujalis and Venskutonis¹⁵⁾ and with a slight modification. In each experiment, two hundred gram of *E. ulmoides* seed powder were put into a 1000 mL extraction vessel. The temperature of extraction vessel was controlled by the surrounding heating jacket. The flow rate of CO₂ in the system was controlled manually by the micro-metering valve. The volume of CO₂ was measured by a digital mass flow meter in standard liters per minute (SL/min) at a standard state ($P_{CO_2} = 100$ kPa, $T_{CO_2} = 20^\circ\text{C}$, $\rho_{CO_2} = 0.0018$ g/mL). The extracts were collected in glass bottles. The yield was determined gravimetrically and calculated using the following equation:

$$\text{Yield of oil (g/100 g seed powder)} = \frac{\text{Weight of extracted oil (g)}}{\text{Weight of } E. \text{ ulmoides seed powder (g)}} \times 100 \quad (1)$$

2.3 Experimental design

RSM based on a central composite design (CCD) was employed in this study. The extraction efficiency of SC-CO₂ relied on the pressure, temperature, extraction time, flow

Fig. 1 Schematic diagram of supercritical carbon dioxide extraction equipment.

Table 1 Uncoded and coded levels of independent variables used in the RSM design.

Independent variables	Symbols	Levels				
		−2	−1	0	1	2
Pressure (MPa)	X_1	20	25	30	35	40
Temperature (°C)	X_2	30	35	40	45	50
Extraction time (min)	X_3	30	60	90	120	150
CO ₂ flow rate (SL/min)	X_4	1	2	3	4	5

rate of CO₂, as well as moisture content and particle size of samples¹²⁾. Based on preliminary experiments, the studied variables and their ranges were selected and listed in **Table 1**. The experimental design consisted of 30 experiment runs, six replicate runs at the center point (0, 0, 0, 0) of the design were performed to allow the estimation of the pure error. All experiments were carried out three times in a randomized order and average experimental values were reported. The central composite design and experimental results are shown in **Table 2**.

A second-order polynomial regression model was used

for predicting responses of Y (oil yield). The generalized form of that regression model is shown as follows:

$$Y = \beta_0 + \sum_{i=1}^4 \beta_i X_i + \sum_{i=2}^4 \beta_{ii} X_i^2 + \sum_{i=1}^3 \sum_{j=i+1}^4 \beta_{ij} X_i X_j \quad (2)$$

where Y is the response, X_i and X_j are variables, β_0 is a constant and β_i , β_{ii} and β_{ij} are the linear, quadratic and interactive coefficients, respectively. Statistical analysis of the experimental data was performed using the software of Design Expert (Version 8.0.7.1, Stat-Ease Inc., Minneapolis, USA).

Table 2 Central composite design and data of SC-CO₂ extraction (n = 3).

Run number	X_1 : Pressure	X_2 : Temperature	X_3 : Time	X_4 : Flow rate	Oil yield (g/100 g seed)	
	(MPa)	(°C)	(min)	(SL/min)	Experimental	Predicted
1	25	35	60	2	17.81	18.23
2	35	35	60	2	25.05	24.52
3	25	45	60	2	22.31	22.56
4	35	45	60	2	23.91	24.30
5	25	35	120	2	20.79	19.98
6	35	35	120	2	26.86	26.61
7	25	45	120	2	25.79	25.97
8	35	45	120	2	27.80	28.05
9	25	35	60	4	22.81	22.21
10	35	35	60	4	26.63	26.77
11	25	45	60	4	22.02	22.59
12	35	45	60	4	22.13	22.59
13	25	35	120	4	22.91	22.84
14	35	35	120	4	28.33	27.73
15	25	45	120	4	24.71	24.89
16	35	45	120	4	25.32	25.22
17	20	40	90	3	21.07	21.00
18	40	40	90	3	27.54	27.64
19	30	30	90	3	20.32	21.46
20	30	50	90	3	24.39	23.28
21	30	40	30	3	23.48	22.92
22	30	40	150	3	26.70	27.30
23	30	40	90	1	23.85	23.89
24	30	40	90	5	25.05	25.04
25	30	40	90	3	28.16	27.28
26	30	40	90	3	27.59	27.28
27	30	40	90	3	26.05	27.28
28	30	40	90	3	27.24	27.28
29	30	40	90	3	26.27	27.28
30	30	40	90	3	28.37	27.28

2.4 Analysis of fatty acid composition

Fatty acid methyl esters (FAMES) were prepared according to the method described by Zhang *et al.*¹⁶⁾.

GC analysis was performed on an Agilent 7890B Gas Chromatograph (Agilent Technologies, USA), equipped with a flame ionization detector and a HP-Innowax capillary column (30 m × 0.32 mm i.d., film thickness 0.25 μm, Agilent Technologies, USA). The column was kept at 140°C for 5 min, and then raised to 240°C at 4°C/min. The injector and detector temperatures were 240°C and 280°C, respectively. Nitrogen was used as the carried gas at 1.0 mL/min and the split ratio was 1:50. The fatty acids peaks were identified by comparison of retention times with those of standards. Fatty acid methyl esters were quantified as percentages of the total methyl ester peak areas.

2.5 Analysis of vitamin E

Half a gram of *E. ulmoides* seed oil was dissolved in 10 mL of n-hexane, then filtered using a 0.45 μm PTFE filter for HPLC analysis. The analysis of tocopherols and tocotrienols were performed using a Waters e2695 HPLC system (Waters Corporation, Milford, USA) equipped with a Waters 2475 fluorescence detector (Waters Corporation, Milford, USA) and an Elite NH₂ column (250 mm × 4.6 mm × 5 μm, Dalian Elite Analytical Co., Ltd, Dalian, China). The column temperature was 40°C. The mobile phase was isopropanol: hexane (1:99, v/v), flow rate 0.8 mL/min. The excitation wavelength was 298 nm and the emission wavelength was 325 nm. The tocopherols and tocotrienols were identified by comparing their retention times with authentic standards and quantified based on the peak areas compared with the external standards.

2.6 Physicochemical analysis

AOCS Official Methods¹⁷⁾ were used to determine the acid value (Cd 3d-63), peroxide value (Cd 8-53), iodine value (Cd 1-25) and saponification value (Cd 3-25) of *E. ulmoides* seed oil. The color was determined by visual check. The specific gravity and refractive index were determined at a room temperature of 25°C using a specific gravity bottle and an Abbe refractometer, respectively. All experiments were repeated three times, and the average values were reported.

3 Results and discussion

3.1 Fitting the model

A second-order polynomial equation was fitted to the experimental data to develop a mathematical model, which will assist in predicting the extraction efficiency. The developed regression model obtained in terms of coded levels is given below:

$$Y = 27.28 + 1.66X_1 + 0.46X_2 + 1.09X_3 + 0.29X_4 - 1.14X_1X_2 + 0.08X_1X_3 - 0.44X_1X_4 + 0.42X_2X_3 - 0.99X_2X_4 - 0.28X_3X_4 - 0.74X_1^2 - 1.23X_2^2 - 0.54X_3^2 - 0.70X_4^2 \quad (3)$$

Higher model *F*-value (20.52) and lower *p*-value (*p* < 0.0001) demonstrated the significance of the developed model and implied that the model was suitable for the present experimental data. Meanwhile, “lack of fit” of this model was insignificant with the *p*-value being 0.7340. The coefficient of determination (*R*²) and adjusted coefficient of determination (Adj *R*²) were 0.9504 and 0.9041, respectively, which indicated that the accuracy and general availability of the polynomial model are adequate¹²⁾. In addition, lower value of coefficient of variation (C.V. = 3.40%) displayed the high degree of precision and good reliability of the conducted experiments⁸⁾. The adequate precision measures the signal to noise ratio and the ratio greater than 4 is desirable. In this study, the adequate precision was 16.52 which indicates an adequate signal and therefore the model can be used to navigate the design space.

The significance of each coefficient was also determined by the *F*-value and *p*-value. A value of *p* < 0.05 indicates that the equation term was significant. In this case, *X*₁, *X*₂, *X*₃, *X*₁*X*₂, *X*₂*X*₄, *X*₁², *X*₂², *X*₃² and *X*₄² were all significant equation terms. Besides, the larger magnitude of *F*-values and the smaller *p*-values mean a higher significance of the corresponding coefficient¹⁸⁾. The influence on the oil yield decreased in the order of pressure > extraction time > temperature > CO₂ flow rate.

The predicted value of *E. ulmoides* seed oil yield was calculated using the regression equation (Eq. 3) and compared with the experimental values in Table 2. The high linear correlation coefficient (*R* = 0.9748) between predicted and experimental values indicated the model was suitable. The residuals normal probability plot indicates that the residuals (difference between actual and predicted values) follow a normal distribution and form an approximately straight line.

3.2 Response surface analysis

The best way of expressing the effect of any parameter on the yield within the experimental range was to generate response surface plots of the model¹⁹⁾. Three-dimensional profiles of the regression model were used to depict the interactive effect of process variables for the oil yield (Figs. 2a-f).

3.2.1 Effect of extraction pressure

Pressure is one of the most important factors which effect the extraction efficiency of oil in SC-CO₂ extraction. Figures 2a, b and c show the interactive effect of pressure with each of three other factors on the oil yield. From the figures, it was observed that extraction pressure is more important than any other variables. The oil yield increased significantly with increasing pressure, particularly at lower

Fig. 2 Response surface plots showing the interactive effect of process variables on oil yield.

pressure. This is most likely due to that the rise of pressure results in an increase in the density, which in turn improved the solubility of *E. ulmoides* seed oil in SC-CO₂. However, once the pressure reached high levels, the oil yield increased slowly, even decreased. The likely reason was that the highly compressed CO₂ at high-pressure levels facilitates solute-solvent repulsion²⁰. These results are in agreement with the SC-CO₂ extraction of silkworm pupal

oil¹², *Mucuna* seed oil²¹ and almond oil²². Moreover, in view of safety and economic reasons, high pressure is not always recommended for SC-CO₂ extraction.

3.2.2 Effect of extraction temperature

Figures 2a, d and e show the interaction of temperature with pressure, extraction time and CO₂ flow rate, respectively. It can be seen that the oil yield increased with the increase of temperature in low temperature zone. However,

at higher temperature levels (above 40°C), the oil yield decreased with the further increasing of temperature. This is most likely due to the counter effect of temperature on the oil yield. On the one hand, temperature rise increased mass transfer speed and the vapor pressure of solute, which accelerated desorption of the oil from the seed matrix and elevated the solubility of oil in SC-CO₂¹⁹⁾. However, on the other hand, increasing temperature reduced the density of SC-CO₂, leading to the reduction in solvent power to dissolve the solute²¹⁾, which restrict the increase of oil yield. Therefore, the oil yield will tend to increase, remain constant, or decrease with increasing of temperature, which depend on whether the mass transfer speed and solute vapor pressure or the solvent density is predominant^{11, 14)}. Similar phenomena were also found in the SC-CO₂ extraction of other vegetable oils^{20, 22)}.

3.2.3 Effect of extraction time

Figures 2b, d and f show the interaction of extraction time with pressure, temperature and CO₂ flow rate, respectively. From the figures, it was observed that the oil yield increased dramatically with increasing of time and then leveled off after 110 min. Higher amount of oil recovery at initial extraction time may be due to the more oil contained in the surface of the samples. With the reducing of oil in the surface, SC-CO₂ had to spent more time to penetrate into the cell matrix, dissolve the oil and subsequently diffuse out from the materials. A longer extraction time had a positive effect on the oil yield. However, as shown in the figures, further increase in the extraction time from 110 min resulted in little change in the oil yield. Therefore, it is reasonable for *E. ulmoides* seed oil that the extraction time of SC-CO₂ extraction was about 110 min.

3.2.4 Effect of CO₂ flow rate

Figures 2c, e and f show the interaction of CO₂ flow rate with pressure, temperature and extraction time, respectively. As shown in the figures, the oil yield can be adjusted by changing the flow rate of CO₂ at the beginning of extraction period (constant extraction rate period). It can be explained by decrease of mass transfer resistance and increase in convection when high flow rate of solvent is used²³⁾. However, there is no significant difference in oil yield when the flow rate of CO₂ was beyond to 3.5 SL/min. This may be due to that the extraction was controlled mainly by diffusion of oil from the cell matrix, thus increasing the flow rate could not manipulate the rate of diffusion⁸⁾.

3.3 Optimization of extraction condition

Solving the regression equation (Eq. 3) with Software of Design Expert, the optimum levels of the test factors were extraction pressure at 36.89 MPa, extraction temperature at 39.49°C, extraction time at 125.13 min, and CO₂ flow rate at 2.62 SL/min. The maximum predicted oil yield was 28.99 g/100g seed. However, considering the operability in actual production, the optimal condition can be modified

as follows: extraction pressure at 37 MPa, extraction temperature at 40°C, extraction time at 125 min, and CO₂ flow rate at 2.6 SL/min. Under this condition, the mean value of practical oil yield was 28.75 g/100 g seed. The good correlation between predicted value and actual value confirmed that the response model was adequate to reflect the expected optimization. In addition, the oil yield of SC-CO₂ extraction at optimal condition were close to the total oil content (32.14 g/100 g seed) measured by Soxhlet method, which indicated SC-CO₂ was of high extraction efficiency for extracting oil from *E. ulmoides* seed.

3.4 Fatty acid composition

The fatty acid composition of *E. ulmoides* seed oil were determined using GC and listed in Table 3. It can be observed that five major fatty acids were present in the *E. ulmoides* seed oil, which were linolenic (about 61%), oleic (about 17%), linoleic (about 12%), palmitic (about 6.5%) and stearic (about 2%). This result was generally consistent with those reported by Zhang *et al.*²⁴⁾. It was worth noting that the fatty acid composition of *E. ulmoides* seed oil was similar with that of flaxseed oil²⁵⁾ and perilla oil²⁶⁾ as shown in Table 3. It can be inferred that *E. ulmoides* seed oil can be used as an alternative to flaxseed oil and perilla oil, and may have the same function and efficacy in preventing disorder such as cardiovascular disease, atherosclerosis, diabetes, cancer, and so on. But, the difference of these oils in triacylglycerol distribution need a further research.

3.5 Vitamin E composition

Vitamin E is a natural antioxidant that can stabilize vegetable oils. Vitamin E can be divided into two groups of tocopherols (TP) and tocotrienols (TT). Each of groups have four isomers, designated as α -, β -, γ -, δ -, which differ in number and position of methyl groups in the chromanol ring. As shown in Fig. 3, because of the difficulty involved in distinguishing the β - and γ - isomers of tocotrienols, the sum of these two isomers is shown throughout as ($\beta + \gamma$)-tocotrienols. From Table 4, γ - and δ -tocopherol were the main isomers of vitamin E in *E. ulmoides* seed oil, respectively, accounting for 70.87% and 24.81%. The total vitamin E content in *E. ulmoides* seed oil was 190.72 mg/100 g, which was higher than that of soybean oil (118.8 mg/100 g), sunflower oil (54.7 mg/100 g), and rapeseed oil (79.7 mg/100 g) as reported by Nagy *et al.*²⁷⁾. In addition, the concentration of vitamin E in oils was influenced by extraction pressure, temperature, solvent and method. Trentini *et al.* reported that the oil extracted with subcritical propane contained more vitamin E than that of soxhlet extraction²⁸⁾. It was suggested that higher temperatures and lower pressures will lead to higher levels of vitamin E in the oils extracted with supercritical fluid as reported by Santos *et al.*²⁹⁾. Some studies have reported that vitamin E

Table 3 Fatty acid composition of *E. ulmoides* seed oil.

Fatty acids	<i>E. ulmoides</i> seed oil	Flaxseed oil ^a	Perilla oil ^b
Saturated			
C8:0	—	—	0.68
C16:0	6.68 ± 0.11	5.22	4.11
C18:0	2.40 ± 0.05	4.12	1.87
C20:0	0.49 ± 0.08	0.20	0.18
C22:0	0.30 ± 0.01	0.15	0.08
C24:0	0.19 ± 0.00	0.13	0.07
Monounsaturated			
C16:1	0.09 ± 0.00	0.00	0.11
C18:1	17.32 ± 0.23	18.30	16.65
C20:1	0.06 ± 0.01	0.00	—
Polyunsaturated			
C18:2	12.06 ± 0.04	15.60	14.32
C18:3	60.51 ± 0.35	56.28	61.93
SFA	10.06	9.82	6.99
MUFA	17.47	18.30	16.76
PUFA	72.57	71.88	76.25
PUFA/SFA	7.21	7.32	10.91

^a The data was reported by Khattab and Zeitoun²⁵.^b The data was reported by Li *et al.*²⁶. Fig. 3 HPLC Chromatogram of Vitamin E of *E. ulmoides* seed oil.

has the ability to prevent chronic diseases, cardiovascular diseases, atherosclerosis and cancer³⁰. Therefore, it is inferred that *E. ulmoides* seed oil can be developed as a kind of functional healthy oil.

3.6 Physicochemical properties

The physical properties (refractive index and color) and chemical properties (acid value, iodine value, peroxide value and saponification value) of *E. ulmoides* seed oil ex-

tracted at optimum conditions of SC-CO₂ extraction were determined. At room temperature, *E. ulmoides* seed oil was primrose yellow and had a specific gravity of 0.921 ± 0.040 . The high refractive index (1.481 ± 0.003) and iodine value (194.25 ± 1.02 g I₂/100 g) indicated that *E. ulmoides* seed oil possess a high content of unsaturated fatty acid. The low acid value (0.91 ± 0.04 mg KOH/g) and peroxide value (4.43 ± 0.18 meq O₂/kg oil) proved that the oil has high antioxidant capacity and a long storage period²⁶. The high saponification value (186.47 ± 0.47 mg KOH/g) indicated that *E. ulmoides* seed oil have a high content of low molecular weight triacylglycerol. In summary, both physical and chemical properties of the oil demonstrated that *E. ulmoides* seed oil is a promising source of edible oil.

4 Conclusion

In this study, RSM was applied to optimize SC-CO₂ extraction parameters to obtain the highest yield of *E. ulmoides* seed oil. Results revealed that pressure, temperature and extraction time were significant, but CO₂ flow rate was not significant. The optimal conditions within the experimental ranges could be obtained at a pressure of 37 MPa, extraction temperature of 40°C, extraction time of 125 min, and CO₂ flow rate of 2.6 SL/min. GC analysis indi-

Table 4 Vitamin E composition of *E. ulmoides* seed oil.

Vitamin E isomer	<i>E. ulmoides</i> seed oil	Soybean oil ^a	Sunflower oil ^a	Rapeseed oil ^a
α -Tocopherol	2.66 $\pm$ 0.49	11.7 $\pm$ 4.0	46.5 $\pm$ 9.6	27.7 $\pm$ 7.7
β -Tocopherol	2.85 $\pm$ 0.24	1.7 $\pm$ 0.7	2.5 $\pm$ 0.8	0.4 $\pm$ 0.3
γ -Tocopherol	135.174 $\pm$ 2.06	73.3 $\pm$ 17.0	3.8 $\pm$ 6.5	50.0 $\pm$ 15.4
δ -Tocopherol	47.32 $\pm$ 0.39	31.7 $\pm$ 8.3	1.1 $\pm$ 2.4	1.2 $\pm$ 0.5
α -Tocotrienol	1.22 $\pm$ 0.42	0.1 $\pm$ 0.2	0.2 $\pm$ 0.2	0.1 $\pm$ 0.3
(β + γ)-Tocotrienol	0.28 $\pm$ 0.25	0.2 $\pm$ 0.4	0.5 $\pm$ 0.4	0.3 $\pm$ 0.9
δ -Tocotrienol	1.51 $\pm$ 0.32	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1	0.0 $\pm$ 0.2
Σ TP mg/100 g	188.00	118.40	53.96	79.30
Σ TT mg/100 g	2.73	0.4	0.8	0.4
Σ V _E mg/100 g	190.72	118.8	54.7	79.7

^a The data was reported by Nagy *et al.*²⁷⁾.

cated that main fatty acids in *E. ulmoides* seed oil were linolenic, oleic, linoleic, palmitic and stearic, which was similar with that of flaxseed oil and perilla oil. But the difference of these oils in triacylglycerol distribution need a further research. *E. ulmoides* seed oil was rich in vitamin E (190.72 mg/100 g), and the predominant vitamin E isomers were γ -tocopherol and δ -tocopherol. More content of linolenic acid and vitamin E suggested *E. ulmoides* seed oil was prone to oxidation and degradation at high temperature. The good physicochemical properties of extracted oil proven that SC-CO₂ extraction is suitable for *E. ulmoides* seed oil.

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