Optimizing oil and xanthorrhizol extraction from *Curcuma xanthorrhiza* Roxb. rhizome by supercritical carbon dioxide

Rinaldi Salea · Edward Widjojokusumo ·
Bambang Veriansyah · Raymond R. Tjandrawinata

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Abstract Oil and xanthorrhizol extraction from *Curcuma xanthorrhiza* Roxb. rhizome by supercritical carbon dioxide was optimized using Taguchi method. The factors considered were pressure, temperature, carbon dioxide flowrate and time at levels ranging between 10–25 MPa, 35–60 °C, 10–25 g/min and 60–240 min respectively. The highest oil yield (8.0 %) was achieved at factor combination of 15 MPa, 50 °C, 20 g/min and 180 min whereas the highest xanthorrhizol content (128.3 mg/g oil) in *Curcuma xanthorrhiza* oil was achieved at a factor combination of 25 MPa, 50 °C, 15 g/min and 60 min. Soxhlet extraction with n-hexane and percolation with ethanol gave oil yield of 5.88 %, 11.73 % and xanthorrhizol content of 42.6 mg/g oil, 75.5 mg/g oil, respectively. The experimental oil yield and xanthorrhizol content at optimum conditions agreed favourably with values predicted by computational process. The xanthorrhizol content extracted using supercritical carbon dioxide was higher than extracted using Soxhlet extraction and percolation process.

Keywords *Curcuma xanthorrhiza* Roxb. rhizome · Xanthorrhizol · Extraction · Supercritical carbon dioxide · Optimization

Abbreviations

Adj MS	Adjusted means of squares
Adj SS	Adjusted sums of squares
ANOVA	Analysis of variance
CO ₂	Carbon dioxide

DF	Degree of freedom
F	F-value
FID	Flame ionization detector
GC	Gas chromatography
HPLC	High performance liquid chromatography
<i>i</i>	Experiment number
<i>n</i>	Number trials for experiments <i>i</i>
P	P-value
Pa	Pascal
Pc	Critical pressure
SCFE	Supercritical fluid extraction
SCFE–CO ₂	Supercritical fluid carbon dioxide extraction
Seq SS	Sequential sum of squares
S/N ratio	Signal-to-noise ratio
Tc	Critical temperature
<i>Y</i>	Response

Introduction

Curcuma xanthorrhiza Roxb., a member of the ginger family (*Zingiberaceae*), is distributed in Southeast Asia region (Suksamram et al. 1994). It has been used to treat stomach diseases, liver disorders, constipation, bloody diarrhoea, dysentery, children's fevers, hypotriglyceridaemic, haemorrhoids and skin eruptions due to its antibacterial, antioxidative, anti-tumor, anti-inflammatory and hepatoprotective effects (Hwang et al. 2000; Lin et al. 1996; Masuda et al. 1992; Park et al. 2008; Ruslay et al. 2007; Yasni et al. 1994). The traditional benefits of *Curcuma xanthorrhiza* were further supported by isolation and identification of several active constituents, including xanthorrhizol, curcumin and few volatile substances. Xanthorrhizol has shown medical properties in treatment and prevention of various diseases (Choi et al. 2005; Devaraj et al. 2010a, b; Kang et al. 2009).

R. Salea · E. Widjojokusumo · B. Veriansyah ·
R. R. Tjandrawinata (✉)

Dexa Laboratories of Biomolecular Sciences, Advanced Technology Development, PT. Dexa Medica, Industri Selatan V, Block PP no. 7, Jababeka Industrial Estate II, Cikarang, West Java 17550, Indonesia
e-mail: raymond@dexa-medica.com

Pharmacologically active compounds in herbal plants are usually in low concentrations and a number of different effective and selective extraction methods have been developed for extraction of these compounds from raw material. The most widely used method is based on organic solvent extraction (Lang and Wai 2001; Tandrasasmita et al. 2010, 2011; Tjandrawinata et al. 2010). Organic solvent extraction methods have drawbacks such as usage of organic solvent, production of hazardous wastes and few adjustable parameters to control the selectivity of extraction process. Therefore, development of more reliable, simpler, less chemical-intensive and less expensive technique is amenable to commercial-scale production.

In recent years, supercritical fluid carbon dioxide extraction (SCFE-CO₂) have been widely been utilized for extraction of oil and bioactive compounds from plant materials (Azmir et al. 2013; Balachandran et al. 2006; Grosso et al. 2008; Huang et al. 2008; Lang and Wai 2001; Salea et al. 2013; Ziemons et al. 2007). SCFE-CO₂ offers many advantages in extraction process due to its non toxic nature, unique physicochemical properties including low viscosity, fast diffusion and tunable physical properties with temperature and pressure. The low critical temperature and pressure of carbon dioxide (CO₂) (T_c=31 °C and P_c=7.38 MPa) offers possibility to operate extraction process at low temperature (below 80 °C) and moderate pressure (10–45 MPa) which may be an ideal condition for thermo labile compound extraction (Azmir et al. 2013; Lang and Wai 2001; Temelli and Guclu-Ustundag 2005). Despite the high potential use of SCFE-CO₂ for extraction of oil and bioactive compounds, various parameters of SCFE-CO₂ (i.e. temperature, pressure, CO₂ flowrate and time of extraction) have been become major obstacle in finding the optimum extraction condition for each plant material (Azmir et al. 2013; Reverchon and Marco 2006; Temelli and Guclu-Ustundag 2005).

Recently, we reported a comparative study of full factorial design with taguchi method for SCFE-CO₂ of *Nigella sativa* seeds oil (Salea et al. 2013). It was shown that taguchi method was able to simplify experimental procedure and maintain experimental cost at minimum level without affecting quality of result. In the other hand, difference between full factorial design and the taguchi methods is insignificant in oil yield (±0.1 %). In this present study, the optimization process for SCFE-CO₂ of rhizomes *Curcuma xanthorrhiza* Roxb. was conducted using the taguchi method. Effect of pressure, temperature, CO₂ flowrate and dynamic extraction time will be described as determined parameters to obtain the optimum condition in the SCFE-CO₂ process. The experimental *Curcuma xanthorrhiza* oil yield and xanthorrhizol content at optimum condition were compared with predicted computational results

and also compared to conventional extraction methods such as Soxhlet extraction and percolation process.

Material and method

Materials

Dried rhizomes of *Curcuma xanthorrhiza* Roxb. were supplied by Mitra Keluarga (Cianjur, Indonesia). The dried rhizomes were grounded in milling machine (FFC-15, China) with 2 mm round stainless steel filter. Moisture content was 11.91 % and loss on drying was 17.87 %. Xanthorrhizol standard was purchased from Chromadex (Irvine, CA). Methanol (HPLC grade) and ethanol (HPLC grade) were purchased from J.T. Baker (Phillipsburg, NJ). n-Hexane (ChromAR) was obtained from Merck (Germany). Ethanol (technical grade) was purchased from Brataco (Cikarang, Indonesia). Hydrogen (purity of 99.9 %), air (purity of 99.99 %) and liquid carbon dioxide (food grade) were purchased from PT Inter Gas Mandiri (Cikarang, Indonesia).

Apparatus and procedure

Supercritical fluid extraction

The supercritical fluid carbon dioxide extraction (SCFE-CO₂) experiments were conducted using a custom-build SCFE-CO₂ apparatus. Figure 1 shows a schematic diagram of the system. Details of apparatus and experimental procedures were described in the previous publication (Salea et al. 2013). Extractor vessel was loaded with 100 g grounded material for each experimental condition. Extraction pressure was varied from 10 to 25 MPa and temperature was varied from 35 to 60 °C. Carbon dioxide (CO₂) flow rate was varied from 10 to 25 g/min and static extraction time was fixed to 60 min followed by dynamic extraction time (60–240 min). A Taguchi L-16 orthogonal arrays design was used to investigate optimal conditions and select the most influencing parameters in SCFE-CO₂ process, by using four parameters and four levels. The parameters and levels are listed in Table 1 whereas structure of Taguchi's orthogonal array design is shown in Table 2.

Soxhlet extraction

Soxhlet extraction was carried out using stainless steel soxhlet apparatus (KIST, Korea). Fifty gram of dried material and 600 mL of hexane were used. The extraction was carried out at the normal pressure of hexane for 6 h. After extraction, hexane was removed with evaporation at reduced pressure

Fig. 1 Schematic diagram of supercritical CO₂ extraction system. Note: 1. CO₂ cylinder. 2. Level cell. 3. CO₂ Feed tank. 4. Filter. 5. Condenser. 6. CO₂ pump. 7. CO₂ pre-heater. 8. Extractor. 9. Rupture. 10. Back pressure regulator. 11. Separator. 12. Absorber. 13. Circulator (chiller). 14. Circulator (heater)

using Rotavapor R-215 (Buchi, Switzerland). The amount of remaining extract was determined as yield of experiment.

Percolation

Percolation was carried out by using 2,400 mL custom built stainless steel percolator. About 150 g of dried *Curcuma xanthorrhiza* rhizomes were loaded into a percolator. Ethanol (96 %-v) with total volume of 2,600 ml was used as solvent. A HKS-12000 Pump (Korea) was used to continuously deliver solvent through the system with rate 180 ml/min. After 4 h extraction time, solvent then removed with evaporation

at reduced pressure using Rotavapor R-215 (Buchi, Switzerland). The amount of remaining extract was determined as yield of experiment.

Table 1 Parameters and levels used in experimental design

Level	Parameters			
	Pressure (MPa)	Temperature (°C)	CO ₂ flowrate (gr/min)	Dynamic time (min)
	A	B	C	D
1	10	35	10	60
2	15	40	15	120
3	20	50	20	180
4	25	60	25	240

Table 2 Standard L₁₆ orthogonal arrays

Exp. no.	Independent variables			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Analytical methods

Moisture content in the raw material was measured using a V30 compact volumetric Karl Fischer titrator (Mettler Toledo, OH). Loss on drying was measured using a HR83 halogen moisture analyzer (Mettler Toledo, OH). Xanthorrhizol content was quantified using Perkin-Elmer Gas chromatography model Clarus 680 equipped with a flame ionization detector (FID) and Elite-5 column (30 m×ID 0.25 mm, 0.25 µm film thickness). Initial column temperature was 160 °C, followed by ramping up to 230 °C with a rate of 5 °C/min. Temperature of detector and injector was maintained at 240 °C. The carrier gas was nitrogen at a flow rate of 1.0 mL/min. Samples were prepared by dissolving oil with concentration of 500 ppm. Methanol and ethanol was used as solvent with 1:1 ratio. The injection volume was 1 µL with a split ratio of 10:1.

Statistical analysis

Data obtained from SCFE-CO₂ were subjected to analysis of variance (ANOVA) and signal-to-noise (S/N) ratio calculation. ANOVA was used to determine the significant differences among extractions yields. P-value less than 0.05 were considered significant. The S/N ratio calculation is an evaluation of output performance stability which measures level of performance and effect of noise parameters on performance with three different target values: “larger is better”, “smaller is better” or “nominal is better” (Nuruddin and Bayuaji 2009). In this study, target values of ‘larger is better’ was used since the purpose of this study was the highest oil yield and xanthorrhizol content. The larger difference (Δ) value in parameter indicated a significant effect on the process since changes in signal cause a larger effect on the output factor being measured. The S/N ratio is calculated using the following Eq. (1):

$$S/N = -10 * \log_{10} \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{Y_i^2} \right) \quad (1)$$

where, n is the number trials for experiments i , i is the experiment number and Y is the response. All statistical analysis were performed using MINITAB v.15 (Minitab Inc., USA) statistical software package.

Result and discussion

Summary of supercritical fluid carbon dioxide extraction (SCFE-CO₂) experiments using Taguchi method are listed in Table 3. The results show that *Curcuma* oil yield vary from 4.7 to 7.6 % with xanthorrhizol content 75.7–125.9 mg/g oil.

Table 3 Experiment results for SCFE-CO₂ process of *Curcuma xanthorrhiza* with Taguchi Method

Run	Pressure (MPa)	Temperature (°C)	CO ₂ flowrate (gr/min)	Dynamic time (min)	Yield oil (%)	Xanthorrhizol (mg/g oil)
1	10	35	10	60	4.7	92.6
2	10	40	15	120	6.8	90.1
3	10	50	20	180	6.6	82.6
4	10	60	25	240	5.4	75.7
5	15	35	15	180	7.0	94.7
6	15	40	10	240	7.2	96.0
7	15	50	25	60	7.6	115.7
8	15	60	20	120	6.9	105.8
9	20	35	20	240	7.3	100.9
10	20	40	25	180	6.6	117.1
11	20	50	10	120	5.9	106.8
12	20	60	15	60	6.0	103.1
13	25	35	25	120	6.2	99.4
14	25	40	20	60	6.4	124.4
15	25	50	15	240	7.3	125.9
16	25	60	10	180	7.5	107.1

Pressure effect

Figure 2a shows effect of extraction pressure on oil yield and xanthorrhizol content. The amount of xanthorrhizol extracted from *Curcuma xanthorrhiza* material increased as the extraction pressure increased within the selected range of pressure. Generally, by using higher pressure at isothermal conditions resulted in increasing solvent density and subsequently solvent power and solubility of compounds. As the density increased, distance between molecules decreased and interaction between compounds and CO₂ increased, which led to greater solubility of compounds in CO₂ and higher solvent strength of supercritical CO₂. Therefore, increase in density of CO₂ will also accelerate mass transfer of analytes and solvent in supercritical extractor vessel system and improve extraction rate (Reverchon and Marco 2006). Effect of the extraction pressure on oil yield showed no particular trend. Since the difference of oil yield on pressures higher than 15 MPa was not significant, it was concluded that the optimum pressure for extraction of *Curcuma xanthorrhiza* oil is 15 MPa.

Temperature effect

Figure 2b shows that oil yield and xanthorrhizol content are not strongly dependent on extraction temperature. As the extraction temperature increased, two competing factors

Fig. 2 Main effects plot for oil yield and xanthorrhizol content: **a** pressure effect; **b** temperature effect; **c** CO₂ flowrate effect; **d** dynamic extraction time effect

namely solvent density and solid vapor pressure are influenced. Increase in temperature reduces the density of supercritical CO₂ thus reducing solvent power of the supercritical solvent; but it increases vapor pressure of the compounds to be extracted (Danh et al. 2009). As result, there is a high possibility that density and solid vapor effects negate each other and give insignificant trend.

CO₂ flowrate effect

Effect of CO₂ flowrate were investigated at rate 10–25 g/min. As shown in Fig. 2c, both oil yield and xanthorrhizol content relatively constant on CO₂ flowrate variation. CO₂ flowrate is a relevant parameter only if the process is controlled by an external mass transfer resistance or by equilibrium: the amount of supercritical solvent feed to the extraction vessel, in this case, determines the extraction rate. In this study, extraction process probably controlled by internal mass transfer that related to particle size. Particle size plays a determining role in extraction processes that control by internal mass transfer resistances since a smaller mean particle size reduces the length of diffusion of the solvent (Reverchon and Marco 2006).

Dynamic extraction time effect

Figure 2d shows that *Curcuma* oil yield increased with increasing time up to 180 min and did not vary with further increase in the extraction time. Most parts of xanthorrhizol was extracted in the first (rapid) stage of extraction during static time. Xanthorrhizol is volatile compound and easily extracted at rapid extraction stage. Less volatile and more

polar compounds were extracted later and diluted xanthorrhizol in the *Curcuma* oil. Yonei et al. (1995) and Sonsuzer et al. (2004) found similar results for observed volatile compound extraction from ginger and *Thymbra spicata*.

Optimum condition

The signal-to-noise (S/N) ratio calculation result in terms of oil yield and xanthorrhizol content are shown in Tables 4 and 5. The S/N values indicated the effect of oil yield and xanthorrhizol content when level of factor in parameters is changed. Based on the S/N ratio calculation, the most influencing parameters in this process is extraction pressure. Influencing parameters decreased in the order: extraction pressure > dynamic extraction time > extraction temperature > carbon dioxide flowrate. Similar phenomena were observed by Sonsuzer et al. (2004) for SCFE-CO₂ of *Thymbra spicata*

Table 4 S/N value calculated for each parameters and level in terms of oil yield

Level	Pressure	Temperature	CO ₂ flowrate	Dynamic time
1	15.28	15.86	15.88	15.69
2	17.11	16.58	16.60	16.17
3	16.16	16.67	16.64	16.80
4	16.68	16.12	16.13	16.58
Δ (max-min)	1.83	0.81	0.76	1.11
Rank	1	3	4	2

Table 5 S/N value calculated for each parameter and level in terms xanthorrhizol content

Level	Pressure	Temperature	CO ₂ flowrate	Dynamic time
1	38.59	39.72	40.04	40.69
2	40.23	40.50	40.22	40.03
3	40.57	40.54	40.20	39.96
4	41.11	39.73	40.04	39.83
Δ (max-min)	2.52	0.82	0.19	0.86
Rank	1	3	4	2

oil and Danh et al. (2009) for SCFE-CO₂ of *Vetiveria zizanioides*.

Tables 6 and 7 listed analysis of variance (ANOVA) of four parameters for SCFE-CO₂ of *Curcuma xanthorrhiza* Roxb. with 95 % confidence. Results showed that different level of parameters had no significant effect on extraction result ($P>0.05$). However, it was shown that extraction pressure as a main factor effect on extraction process and was in a good agreement with S/N ratio calculation results.

Based on the taguchi method, it was established that the conditions (pressure, temperature, carbon dioxide flow rate and time) for optimum oil yield from *Curcuma xanthorrhiza* Roxb. rhizome were 15 MPa, 50 °C, 20 g/min and 180 min; and for extraction of xanthorrhizol from *Curcuma xanthorrhiza* Roxb. oil were 25 MPa, 50 °C, 15 g/min and 60 min respectively. These data were subjected to Minitab v.15 statistical software package to predict the oil yield and xanthorrhizol content at proposed optimum conditions. The predicted oil yield was 7.9875 % at proposed optimum conditions for oil yield whereas the predicted xanthorrhizol content was 127.2 mg/g oil at these optimum conditions for xanthorrhizol content as mentioned above. The experimental oil yield was 8.0 % (xanthorrhizol content 94.0 mg/g oil) whereas the experimental xanthorrhizol content was 128.3 mg/g oil (oil yield 5.5 %) at optimum condition as mentioned above. Experimental results have

Table 6 Analysis of variance (ANOVA) for oil yield

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	3	7.437	7.437	2.4789	1.42	0.390
Temperature	3	1.748	1.748	0.5826	0.33	0.804
CO ₂ flowrate	3	1.647	1.647	0.5489	0.31	0.816
Dynamic time	3	2.873	2.837	0.9576	0.55	0.683
Residual error	3	5.240	5.240	1.7467		
Total	15	18.944				

Table 7 Analysis of variance (ANOVA) for xanthorrhizol content

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	3	14.1858	14.1858	4.72862	4.14	0.137
Temperature	3	2.5386	2.5386	0.84621	0.74	0.594
CO ₂ flowrate	3	0.1197	0.1197	0.03990	0.03	0.990
Dynamic time	3	1.7844	1.7844	0.59480	0.52	0.697
Residual error	3	3.4233	3.4233	1.14111		
Total	15	22.0519				

similar value with the predicted results. The application taguchi method in SCFE-CO₂ of *Curcuma xanthorrhiza* Roxb. provides an alternative way to simplify experimental design required to optimize oil yield and xanthorrhizol content. This method can significantly reduce the number of experiments from 256 (4⁴) experiment trials when using full factorial design, to those of only 16 using L₁₆ arrays, without influencing the quality of results. These results proved an example of how an experimental design could be beneficial for a comprehensive determination of the best experimental conditions as in the case of SCFE-CO₂ of *Curcuma xanthorrhiza* Roxb.

Comparison SCFE-CO₂ and conventional methods

Table 8 shows experimental results for three different extraction techniques in order to compare extraction methods for *Curcuma xanthorrhiza*. SCFE-CO₂ has the highest xanthorrhizol content compared to both conventional extraction methods. However, for oil yield, SCFE-CO₂ have lower value compared to percolation. This result suggests *Curcuma xanthorrhiza* has high content of ethanol soluble compound. As result, extraction yield from percolation is higher and xanthorrhizol is diluted with other compound. This comparison study shows the ability of SCFE-CO₂ to specifically extract volatile compound.

Table 8 Results from SCFE-CO₂, Soxhlet extraction and percolation

Methods	Yield (%)	Xanthorrhizol (mg/g oil)
Conventional methods:		
Soxhlet extraction with n-hexane	5.88	42.6
Percolation with ethanol (96 %)	11.73	75.5
SCFE-CO ₂ :		
Optimum oil	8.0	94.0
Optimum xanthorrhizol	5.5	128.3

Conclusion

Optimization process for oil yield and xanthorrhizol content from SCFE-CO₂ of rhizomes *Curcuma xanthorrhiza* Roxb. was successfully performed using L-16 orthogonal arrays design of taguchi method. Optimum conditions of oil yield (8.0 %) was achieved at extraction pressure of 15 MPa, extraction temperature of 50 °C, carbon dioxide flowrate of 20 g/min and dynamic extraction time of 180 min. Optimum conditions of xanthorrhizol content (128.3 mg/g oil) was achieved at extraction pressure of 25 MPa, extraction temperature of 50 °C, carbon dioxide flowrate of 15 g/min and dynamic extraction time of 60 min. The experimental oil yield and xanthorrhizol content at optimum conditions was in good agreement with the predicted computational results. The S/N ratio calculation and ANOVA identified pressure as a main factor that has the largest effect on SFCE-CO₂ of *Curcuma xanthorrhiza* Roxb. SCFE-CO₂ has the highest xanthorrhizol content compare to soxhlet and percolation extraction system.

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