EFFICIENT EXTRACTION OF CURCUMIN FROM TURMERIC WITH PHARMACEUTICAL SOLVENTS AND OPTIMIZATION USING RESPONSE SURFACE METHODOLOGY

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***Abstract*— The aim of the study was to find out a novel, effective, safe, and eco-friendly method for the extraction of curcumin from turmeric. A pharmaceutically safe solvent isopropyl alcohol was selected based on preliminary screening. Three methods, microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and maceration were explored, and optimization of each method was performed using Box-Behnken design with RSM. Yield (mg/g) ranged from 1.35-12.53, 1.43-5.59, and 0.23-7.06 (mg/g) in MAE, UAE, and maceration, respectively. For MAE, optimum conditions were 30 mL/g solvent-to-solid ratio (SSR), 240 W microwave power, and 40 s extraction time. The optimum UAE conditions were 40 °C, 10 min and 50 mL/g SSR. The optimum conditions for maceration were 60 °C, 90 min and 10 mL/g SSR. Based on the results, MAE was the most robust technique for extraction of curcumin from turmeric and the protocol may be developed for industrial application.**

***Keywords*— Curcumin extraction; microwave; ultrasound; response surface methodology; pharmaceutically safe solvent**

I. INTRODUCTION

Turmeric (*Curcuma longa* L.) is a medicinal herb that is the main source of the bioactive compound curcumin (Araújo and Leon, 2001). Curcumin has great medicinal importance; it shows anti-aging, anti-cancerous, photoprotective, antioxidant, anti-venom, anti-HIV, and anti-obesity effects (Johnson and Mukhtar, 2007; Teiten *et al.*, 2010; Kotha and Luthria, 2019). Its extraction has been increasingly popular in recent years as more people become aware of the health benefits.

Many organic solvents, such as methanol, ethanol, and acetone, have been widely utilized for the extraction of curcumin (Braga *et al.*, 2003), however, these solvents are not environmentally safe. Safer alternatives are the pharmaceutically safe solvents commonly used in pharmaceutical products or process. They may prove to be efficient for the extraction of curcumin as these are favored in the extraction of a drug products or excipients (Grodowska and Parczewski, 2010). In addition, the traditional extraction methods are being replaced with the present-day extraction techniques as the former methods require more energy, solvent and time, which is both environmentally and economically less favorable. Microwave- and ultrasound-assisted extraction (MAE and UAE) are two of the most common green extraction technologies. These novel extraction techniques are highly preferred because of their cost-effectiveness and environment friendly nature (Sahne *et al.*, 2017). The UAE requires low temperature for extraction and hence, less energy is consumed. It also requires less time compared to many conventional extraction techniques (Aydar, 2018b; Jiskani *et al.*, 2021). The MAE is also a very efficient method requiring less human effort, cheap equipment and less time, solvent, and energy (Aydar, 2021). Therefore, the extraction of curcumin using modern methods and pharmaceutical safe solvent would prove to be a novel extraction which would be both efficient as well as environment friendly. The extraction yield depends on the extraction parameters (such as temperature, time, power, speed, solvent ratio) (Aydar, 2019). As a result, improving the parameters impacting yield would be required to attain large yields of curcumin.

Response surface methodology (RSM) is a method for optimizing processes that combines measurable and numerical procedures (Aydar, 2018b). The extraction factors (temperature, time, power, speed, solvent ratio, particle size, amplitude, and the type of solvent) and their independent, interaction and quadratic effects greatly influence the extraction studies (Jiskani *et al.*, 2021). RSM is utilized to determine the impact of various factors on reaction. It generates a number of experiments giving different combination treatments of the independent variable with different levels, to evaluate their effect on the dependent variable. It also allows studying the linear and interaction effects of the extraction parameters on the response (Kurapati *et al.*, 2018). Several methods have been reported for the isolation of curcumin by HPLC (Wichitnithad and Rojsitthisak, 2009; Xu *et al.*, 2015; Sahne *et al.*, 2017). However, the quantification of curcumin using isopropyl alcohol that is pharmaceutically safe solvent has not yet been reported. Because extraction yield is influenced by extraction parameters (temperature, duration, power, speed, solvent ratio, and so on) (Roselló-Soto *et al.*, 2015), upgrading the variables that influence extraction yield is required to obtain curcumin in high yield. The main objectives of this study were: (1) to determine the optimum conditions for the extraction of curcumin from turmeric with various extraction strategies; (2) to compare novel extraction methods (MAE and

UAE), with the conventional method (maceration) using a pharmaceutical safe solvent, and (3) optimization of extraction conditions suitable for large scale production of curcumin for medicinal and industrial applications.

II. METHODS

A. Materials

Propylene glycol, glycerol, isopropyl alcohol, acetonitrile, and methanol were used as analytical grade solvents in this work and were purchased from Sigma-Aldrich Chemicals (St. Louis, US). Standard curcumin was obtained from Sigma-Aldrich (Steinheim, Germany).

B. Collection of Plant Material

A sample of turmeric *(Curcuma longa*) rhizomes was collected from an agricultural farm of Kasur, Punjab, Pakistan. The rhizomes were placed at room temperature to dry. The dried rhizomes were ground into a powder, which was screened through a 100-mesh sieve and utilized in the research.

C. Preliminary screening of pharmaceutical safe solvents

A preliminary study for the extraction of curcumin was carried out with three different pharmaceutical solvents: isopropyl alcohol (IPA), propylene glycol (PG), and glycerol (Glyc). The outcomes showed that the maximum extraction yield of curcumin was in the following order: IPA > PG >Glyc. Thus, IPA was selected for this study. The levels of the parameters used extraction techniques were selected on the basis of previous work (Ceyhan and Erdem, 2020; Wang *et al*., 2021; Aydar, 2021).

D. Microwave-assisted extraction (MAE)

The sample (1 g) was dissolved in the selected solvent (isopropyl alcohol) according to each experiment condition in (Table 1). The solvent-to-solid ratios were 1: 10, 1: 20 and 1: 30 g/ mL. The sample was set down in the microwave oven for the given time (s) while the power (W) was adjusted according to the given experimental conditions in Table 1. The samples were treated at different powers (240, 480, 720 W) and time (20, 40, 60 s). After irradiation, the sample was taken out of the microwave oven and was cooled at room temperature. After filtration, the sample (10 µL) was diluted with 20 mL of mobile phase. The samples were then quantified by HPLC. Experiments were done in triplicate.

E. Ultrasound-assisted extraction (UAE)

The sample (1 g) was dissolved in the selected solvent (isopropyl alcohol) according to the given solid-to-solvent ratios in Table 1. The samples were placed in the ultrasonic bath, where the probe and the ultrasonic processor were immersed into the sample, which was connected to the monitoring device. UAE was done using ultrasonic device by (Hielscher UP 200-SP). The ultrasonic probe was used to detect the signals. The power (W) and amplitude (kHz) were kept constant (50%). The temperature of each sample was controlled during the extraction, following the conditions applied. Initially, the samples were kept at room temperature, and during the sonication, the temperature was controlled using an ice bath and on and off button so that the temperature would not raise the given experimental temperature. The samples were treated under different temperatures (30, 35, 40 °C), and at different times (5, 10, 15 min) according to the treatment combinations in Table 1. After irradiation of ultrasound waves, the samples were further filtered and were kept at room temperature before use. The sample (10 µL) was diluted with 20 mL of mobile phase. The samples were then quantified by HPLC. Each experiment was performed in triplicate.

Table 1. Factors and levels of the parameters for MAE, UAE and Maceration extraction of curcumin from turmeric.

	Factors	Levels		
		-1	**0**	**+1**
MAE	Solvent-to-solid ratio (mL/g)	10	20	30
	Power (W)	240	480	720
	Time (s)	20	40	60
UAE	Time (min)	5	10	15
	Temperature (°C)	30	35	40
	Solvent-to-solid ratio (mL/g)	30	40	50
Maceration	Solvent-to-solid ratio (mL/g)	10	20	30
	Time (min)	60	90	120
	Temperature (°C)	20	40	60

F. Maceration extraction

The sample (1 g) was dissolved in the selected solvent (isopropyl alcohol) according to the experimental order (Table 1). The sample was placed in a shaking incubator, where temperature (°C) was adjusted according to the applied conditions and the time was noted. The samples were treated under different temperatures (20, 40, 60 °C) according to the treatment combinations given in Table 1 and 2. After shaking, the solution was filtered at room temperature. 10 µL of each sample was taken and diluted in 20 mL mobile phase. The sample was then quantified by HPLC. Experiments were done in triplicate.

G. Experimental design

The impacts of the selected factors on the yield were studied by response surface method followed by the Box-Behnken design (BBD). The regression coefficients were examined which showed the effects of the selected parameters on extraction and their interaction effects. A quadratic equation was used to evaluate the influence of different parameters on the response. The general form of the equation is as follows:

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

In the equation, Y is the dependent variable (response), β_0 is the constant term, β_i, β_{ii} and β_{ij} show the linear, quadratic and interaction effects, the independent variables are given as X_i and X_j. The coefficient of determination (R^2) adjusted determination coefficient (Adj-R^2) and adequate precision were used to check the model adequacies; the appropriate model was chosen when its P value < 0.05, lack of fit P value > 0.05, R^2were highest and AdeqPrecision >4 (Aydar, 2018b). The response surface and level plots of the study were also created and examined.

Table 2. Experimental design and results of yield for all extraction methods

	MAE				UAE				Maceration			
Run	A: Solvent (mL/g)	B: Power (W)	C: Time (s)	Yield (mg/g)	A: Time (min)	B: Temp. (°C)	C: Solvent (mL/g)	Yield (mg/g)	A: Solvent (mL/g)	B: Time (min)	C: Temp (°C)	Yield (mg/g)
1	0	1	-1	4.19	0	0	1	5.41	-1	0	1	7.06
2	1	0	1	2.92	-1	-1	-1	3.37	0	1	0	2.08
3	1	-1	0	12.53	-1	1	0	4.25	0	-1	0	1.64
4	-1	-1	0	3.46	0	1	1	5.59	-1	0	0	2.84
5	1	0	-1	5.42	0	0	-1	2.33	1	0	0	3.29
6	0	1	1	3.89	0	-1	0	3.47	0	0	-1	0.97
7	0	0	0	9.15	1	1	0	3.13	0	1	0	1.58
8	1	1	0	4.55	1	-1	-1	1.43	-1	0	0	1.63
9	0	-1	1	4.99	1	-1	1	5.28	0	0	1	2.13
10	0	-1	-1	11.47	0	-1	0	3.46	0	0	0	2.45
11	0	0	0	9.09	-1	-1	1	4.96	0	0	0	2.33
12	-1	0	-1	1.35	0	-1	0	3.42	-1	-1	0	0.23

Response surface model for maceration

The temperature (°C), time (min) and solvent-to-solid ratio (mL/g) were three independent factors that were selected and 20, 40, 60 (°C), 60, 90,120 (min), and 10, 20, 30 (mL/g) were three levels selected for each factor.

Response surface model for MAE

The power (W), time (s) and solvent-to-solid ratio (mL/g) were three factors selected for the experiments. The values or levels for each factor ranged from low to high (-1 to +1). 240, 480, 720 (W), 20, 40, 60 (s), and 10, 20, 30 (mL/g) were three levels each selected for power (W), time (s), and solvent-to-solid ratio (mL/g), respectively.

Response surface model for UAE

Temperature (°C), time (min), and solvent-to-solid-ratio (mL/g) were three factors selected for the experiments. The values for each factor and levels ranged from low to high (-1 to +1). 30, 35, 40 (°C), 5, 10, 15 (min), and 30, 40, 50 (mL/g) were three levels each selected for temperature, time, and solvent-to-solid ratio, respectively.

H. Quantification of curcumin

UV-visible Spectrophotometry

Standard curcumin showed the absorbance at the λmax. 421 nm using Ultraviolet–visible spectrophotometer (Labomed, Inc. USA).

Quantification with HPLC

To quantify curcumin, HPLC was performed using Shimadzu, SPD-6AV-HPLC (Kyoto, Japan). Mobile phase used for extraction consisted of methanol and acetonitrile (50% each). The wavelength was set on to be 421nm. The Mobile phase flow was constant (0.7 mL/ min).

I. Statistical analysis

All experiments were generated using Minitab software (version 7.0) and regression analysis with p-value<0.05 showed that the data was significant. The coefficient of determination (R^2) adjusted determination coefficient (Adj-R^2) and adequate precision were used to check the model adequacies.

III. RESULTS

A. Solvent selection

The dielectric constant for IPA (18.2) < PG (32.0) <Glyc (46.5), demonstrate that yield decreases as dielectric constant increases and the compounds with a high dielectric constant are strongly polar and vice versa. Therefore, curcumin showed a maximum yield in IPA compared to the other solvents. Besides, this may be because the chemical compounds having a high value of dielectric constant chemically break down more rapidly in contrast to the solvents with low dielectric constant. Thus, the solvent with a low dielectric constant may have shown high extraction efficiency (Lewis, 1996). In literature most commonly used solvent for extraction antioxidant compounds was alcoholic solvents including methanol, isopropyl alcohol and ethanol (Braga *et al.*, 2003; Paulucci *et al.*, 2013; Akinola *et al.*, 2014) The effect of different solvent extraction including methanol, ethanol, cold water and hot water on the phenolic content and antioxidant activity of turmeric (*C. longa*) and it was found that ethanol was the best solvent for phenolic antioxidant from turmeric compared to methanol and water (Array *et al.*, 2019). In the same study warm water was more efficient than cold water in extraction of antioxidant compounds from turmeric. Moreover, the yield of curcumin decreased as the number of hydroxyl groups increased, affecting the polarity and yield. This may be due to the intramolecular H-bonding between two –OH groups of propylene glycol or glycerol. Also, the presence of two or more electronegative atoms might have weakened the H-bonding. Besides, due to the low viscosity, IPA showed high permeability to dissolve curcumin. Therefore, isopropyl alcohol was selected for the extraction using different extraction techniques.

B. Optimization of maceration extraction

In maceration, curcumin yield ranged from 0.23 mg/ g to 7.06 mg/ g and the highest curcumin yield was obtained at solvent-to-solid ratio (10 mL/g) after time of 90 min at temperature 60 °C (Table 2). The maceration extraction parameter: solvent-to-solid ratio (A) was significant ($p < 0.05$) for curcumin yield (Table 3).

The interaction effect of the parameters; solvent and time (AB) was also significant ($p < 0.05$). The lack of fit was insignificant ($p>0.05$) and the model was significant ($p<0.05$) which confirmed the correctness of the model. Fig 1 shows the response surface plots for maceration which reveals the solvent-to-solid ratio have positive effect on the response as compared to the factors, time and temperature. The results revealed that the higher yield

Table 3. ANOVA table for maceration

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	32.99	6	5.50	3.81	0.0108	significant
A-Solvent	13.53	1	13.53	9.37	0.0062	
B-Time	1.14	1	1.14	0.7927	0.3839	
C-Temp.	0.2187	1	0.2187	0.1515	0.7012	
AB	13.32	1	13.32	9.23	0.0065	
AC	4.77	1	4.77	3.31	0.0840	
BC	0.0030	1	0.0030	0.0021	0.9639	
Residual	28.88	20	1.44			
Lack of Fit	23.03	12	1.92	2.63	0.0889	nonsignificant
R^2	0.5332					
Adj- R^2	0.3932					

was obtained by the maceration extraction at lower solvent-to-solid ratios (Table 2). The following quadratic polynomial equation for significant values was used to determine the response:

$$Yield_{Maceration} = +2.20 - 1.06A - 1.82\,AB$$

where A is solvent-to-solid ratio (mL/g), B is time (min). Previous research has also found that keeping the temperature high during maceration increases the yield (Monton and Luprasong, 2019). During maceration, increasing the temperature and time has a positive effect on the yield (Vergara-Salinas *et al.*, 2012). However, degradation of the sample occurs after an optimum value of time is reached during maceration extraction as maximum time of extraction(Chew *et al.*, 2011) drive to the decomposition of the chemical constituents present in the sample (Liu *et al.*, 2015). When compared to MAE and UAE models, which had considerably higher R2 (>0.99) and Adj-R2 (>0.99), the maceration model's lower R2 (0.5332) and Adj-R2 (0.3932) revealed that yield would be less predictable in the maceration extraction process (Table 3). Maceration is simple yet efficient conventional method for the extraction of organic compounds (Ćujić *et al.*, 2016). It requires long period for extraction compared to other modern extraction methods and has been previously carried out for the isolation of curcumin (Paulucci *et al.*, 2013), as well as other bioactive compounds from different natural plants (He *et al.*, 2016; Monton and Luprasong, 2019).

C. Optimization of MAE

In MAE, curcumin yield ranged from 1.35 mg/ g to 12.53 mg/ g. The highest yield (12.53 mg/g) was obtained at the combination treatment of solvent (30 mL/g), power (240 W), and time (40s) (Table 2). The MAE factors: solvent-to-solid ratio, power and time were found significant ($p < 0.05$). The quadratic and interaction effects for the extraction parameters on the response were also significant (Table 4).

The lack of fit was insignificant ($p>0.05$) and the model was significant ($p<0.05$) which confirmed the authenticity of the model. Figure 2 shows the response surface plots for microwave assisted extraction of curcumin that show the positive effect of the extraction factors on the response. The coefficient of determination, R2 is 0.99 explaining that 99 % variance in the yield could be explained through this model. Following quadratic formula for significant values was used to determine the response:

$$Yield_{MAE} = 9.12000 + 2.56000A - 2.06833B - 1.72167C - 1.94833AB + 0.498333AC + 1.54500BC - 3.83250A2 + 0.665833B2 - 3.65083C2$$

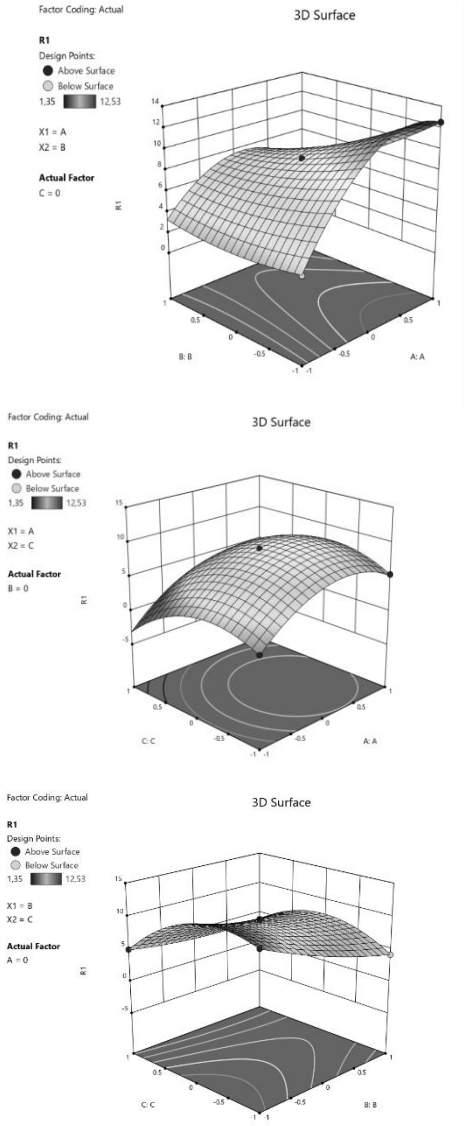

Figure 1. Response surface plots of yield from maceration based on A (Solvent) B (Time) and C (Temperature)

Table 4. ANOVA table for MAE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	140.68	9	15.63	1656.96	0.0006	significant
A-Solvent	17.48	1	17.48	1852.61	0.0005	
B-Power	20.53	1	20.53	2176.79	0.0005	
C-Time	14.23	1	14.23	1508.25	0.0007	
AB	6.51	1	6.51	689.83	0.0014	
AC	0.4257	1	0.4257	45.13	0.0214	
BC	9.55	1	9.55	1012.17	0.0010	
A^2	26.11	1	26.11	2768.07	0.0004	
B^2	1.12	1	1.12	118.73	0.0083	
C^2	33.67	1	33.67	3569.49	0.0003	
Residual	0.0189	2	0.0094			
Lack of Fit	0.0171	1	0.0171	9.48	0.1999	not significant
R2	0.9999					
Adj-R2	0.9993					

where A: solvent-to-solid ratio (mL/g), B: power (W), C: time (s).The results obtained from the experimentation show that the solvent ratio had a positive effect on the yield of curcumin. Quiroz *et al.* (2019) considered the extraction of bioactive compounds from annatto seeds via MAE, which showed a positive response of solvent on the yield. Time and microwave power (W) had a positive influence on the extraction of curcumin. However, degradation of the sample occurred after a particular time. This was due to thermal instability and solvent vaporization (Paulucci *et al.,* 2013). At the high power levels of the microwave, the sample is thermally degraded as there is direct contact of the sample with the electromagnetic waves during microwave irradiation (Laokuldilok *et al.*, 2015). Microwave-assisted extraction was previously carried out for curcumin extraction (Bener *et al.,* 2016), and as well as other organic compounds from different plants (Chen *et al.*, 2010; İşçimen, 2021). MAE show many advantages compared to other techniques with high extraction yield and shorter extraction times (Laokuldilok *et al.*, 2015).

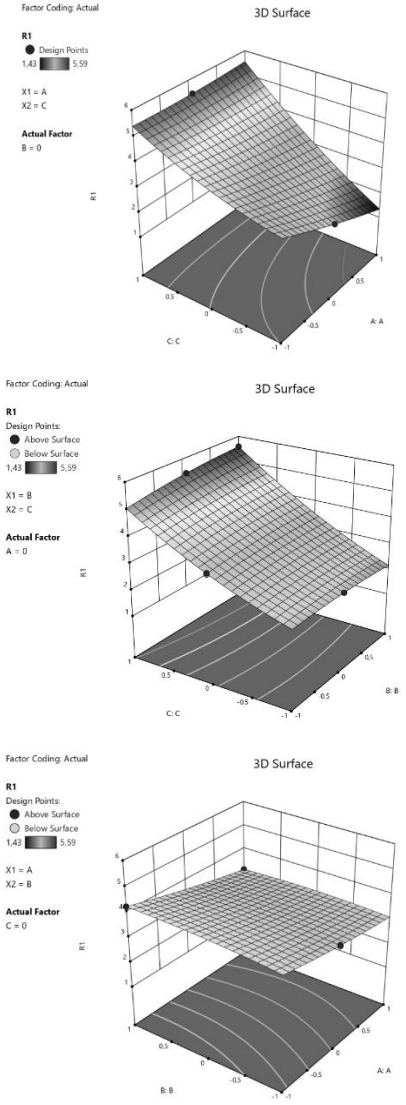

Figure 2. Response surface plots of yield from MAE based on A (Solvent) B (Power) and C (Time).

Table 5. ANOVA table for UAE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18.29	9	2.03	2903.65	0.0003	significant
A-Time	1.24	1	1.24	1773.76	0.0006	
B-Temp.	0.0283	1	0.0283	40.38	0.0239	
C-Solvent	4.74	1	4.74	6776.00	0.0001	
AB	0.0320	1	0.0320	45.76	0.0212	
AC	1.28	1	1.28	1824.14	0.0005	
BC	0.0432	1	0.0432	61.71	0.0158	
A^2	0.0039	1	0.0039	5.57	0.1422	
B^2	0.0032	1	0.0032	4.57	0.1661	
C^2	0.0554	1	0.0554	79.15	0.0124	
Residual	0.0014	2	0.0007			
Lack of Fit	0.2351	3	0.0784	111.97	0.0089	nonsignificant
R2	0.9999					
Adj-R2	0.9996					

D. Optimization of UAE

Ultrasound-assisted extraction was previously carried out in the extraction of curcumin (Xu *et al.*, 2015; Chhouk *et al.*, 2017; Şahin, 2018), and as well as other natural compounds from different plants (Vilkhu *et al.*, 2008; Jerman Klen and Mozetič Vodopivec, 2012; Kadam *et al.*, 2015), because of its advantages, which include an increase in extraction yield or rate, as well as an improvement in aqueous extraction procedures and quality without the use of solvents (Goula, 2013). In UAE, curcumin yield ranged from 1.43 mg/ g to 5.59 mg/ g under the given UAE conditions. The highest curcumin yield of 5.59 mg/g was acquired with the combination treatment of solvent (50 mL/g), time (10 min), and temperature (40 °C) (Table 2). The UAE factors: time, temperature and solvent-to-solid ratio showed significant results ($p<0.05$). The quadratic effects of the parameters on the response were also significant ($p<0.05$). The interaction effect of solvent-to-solid ratio (mL/g) was also significant (Table 5).

The lack of fit was insignificant ($p > 0.05$) and the model was significant ($p < 0.05$) which confirmed the correctness of the model. Fig 3.shows the response surface plots for UAE of curcumin, which shows that the extraction parameters and the response have a linear relationship. R^2 was 0.99 explaining that 99 % variance in the yield could be explained by the model.

The following quadratic formula for significant values was used to determine the response:

$$Yield_{UAE} = +3.63 - 0.4825A + 0.0875B + 1.54C - 0.0775AB + 0.5650AC + 0.180000BC + 0.2450C^2$$

where A: time (min), B: temperature (°C), C: solvent-to-solid ratio (mL/g).

A significantly high R^2 (>0.9) indicated that the ultrasonic extraction variables had a significant impact on curcumin extraction yield. The experimental data demonstrate that the curcumin yield was enhanced by increasing the temperature. The extraction rate was high at 40 °C along with the other conditions applied. A similar trend was noticed during the UAE of Swietenia Mahagoni, which showed the enhanced yield at increased temperatures due to the presence of cavitation bubbles in the sample. This could be explained by the fact that ultrasonic

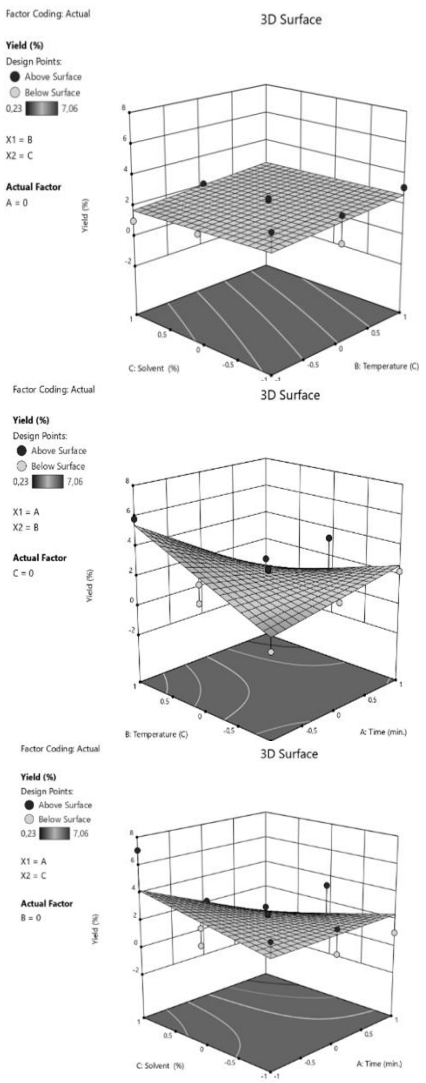

Figure 3. Response surface plots of yield from UAE based on A (Time) B (Temperature) and C (Solvent).

extraction at high temperatures facilitates the release of bioactive chemicals from plant cells into warm medium (Aydar, 2018a). The optimum temperature of 45°C was obtained during the UAE of phycocyanin from microalgae Spirulina sp (Hadiyanto *et al.*, 2015). Şahin (2018) also studied antioxidant activities from turmeric via UAE and revealed the positive impact of temperature and concentration on the extraction yield. The present results also evaluated the significant effect of solvent on the extraction. This may be because the desired compound effectively dissolves in a high solvent ratio (Jiskani *et al.*, 2021). As the temperature increased rapidly with time and the sample decomposes at a high temperature, therefore, high yield was obtained at the optimum time of 10 min (Chuyen *et al*., 2017a; Chuyen *et al.*, 2017b).

V. CONCLUSIONS

The present study investigated the effects of different extraction variables (such as, time, temperature, microwave power, and solvent-to-solid ratio) on the extraction yield of curcumin from turmeric obtained by different extraction methods. For MAE, optimized conditions were 30 mL/g solvent-to-solid ratio, 240 W microwave power, and 40 s extraction time. Optimum conditions of UAE were 50 mL/g solvent-to-solid ratio, 10 min sonication time, and 40 °C temperature. The optimum conditions for maceration were found as 60 °C, 10 mL/g and 90 min for temperature, solvent-to-solid ratio, and time, respectively. According to the experimental results, MAE and UAE extracted curcumin efficiently, and their models were more accurate in predicting extraction yield than maceration. The MAE yielded the highest amount of curcumin (12.53%), whereas the maceration extraction yielded the lowest amount (0.97%). Thus, MAE came out to be a very efficient green technique for extraction of curcumin form turmeric. Further studies could focus on the large-scale extraction of curcumin using the current experimental data.

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