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Optimization of Red Ginger (*Zingiber officinale* var. Rubrum) Extraction Using Microwave Assisted Hydrodistillation Method

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ABSTRACT

Red ginger is a spice plant that has high economic and social value. One of the uses of red ginger is to process it into a product, namely essential oil. This study aims to determine the optimization of the extraction process conditions on solvent volume, time, and extraction power that can produce optimum yield and residual content of red ginger essential oil solvent. The extraction was carried out with the help of microwaves. The research method is experimental design and optimization process with Response Surface Methodology (RSM) type Box-Behnken Design (BBD). The results showed that the optimum yield was at 700 mL solvent volume, 1 min extraction time, and 10% power (69.9 watts) with the equation Y = 0.2076 + 0.0262A – 0.0300B – 0.0013C and the concentration conditions the optimum remaining solvent with the equation Y = 4.98 – 1.0000A + 4.56B + 5.44C. The optimal yield of red ginger essential oil was 0.205%, with a residual solvent content of 3.8%, specific gravity 0.885, acid number 1.399, refractive index 1.485. The results of the optimum residual solvent content of -6.023%. Based on the results obtained, the yield value with the help of microwaves is higher than that without the help of microwaves.

1. INTRODUCTION

Indonesia possesses highly fertile land, making it suitable for the growth of various plants. One of the successfully cultivated plants in Indonesia is ginger. According to data from the Central Bureau of Statistics in 2020, ginger is classified as a medicinal plant (*biofarmaka*) with increased production. The demand for ginger in Indonesia reached 183.52 thousand ton in 2020, compared to 174.38 thousand ton in 2019 (BPS, 2020).

Ginger grown in Indonesia consist of three main types: red ginger, *emprit* or small ginger, and elephant ginger. The oil content varies, with red ginger ranging from 2.58% to 3.90% (dry weight), *emprit* ginger from 1.7% to 3.8%, and elephant ginger from 0.18% to 1.66% (Setyaningrum & Saparinto, 2013). This data indicates that red ginger contains a higher amount of essential oil compared to the other types, making it the most commonly used variety. Red ginger is widely utilized as a source of essential oil, which is known for its distinct aroma and volatile nature (Pairul, 2017).

The success of essential oil extraction and the quality of the oil produced are determined by several factors, including the extraction method, the condition of the raw material, and the extraction process conditions (Hanif *et al.*, 2020). Commonly used extraction methods include percolation, maceration, Soxhlet extraction, and hydrodistillation. These conventional methods often require a significant amount of time to obtain essential oils. Furthermore, the results obtained from hydrodistillation processes are generally inconsistent and have low efficiency in terms of both quality and quantity of essential oil produced (Argo *et al*., 2021). An alternative solution to these issues is to combine conventional extraction methods with modern techniques, resulting in a two-step process. In the first step, the raw material undergoes initial treatment using Microwave Assisted Extraction (MAE), followed by the hydrodistillation process. Factors influencing extraction using MAE include solvent volume, time, power, temperature, and the characteristics of the material. Due to the numerous factors affecting the MAE extraction process, optimization is conducted to determine the optimal conditions for extracting red ginger essential oil (*Zingiber officinale var. Roscoe*) using the Response Surface Methodology (RSM).

The objective of this research is to determine the optimum conditions for extracting red ginger using Microwave Assisted Extraction technology, with variations in solvent volume, time, and extraction power, utilizing the Response Surface Methodology.

2. MATERIALS AND METHODS

2.1. Equipment and Materials

The equipment utilized in this study includes a Microwave Oven, Rotary Vacuum Evaporator, biuret, ABBE Refractometer, distillation apparatus, convection oven, analytical balance, and thermometer. The raw material for this research is dried red ginger powder with a moisture content of 14.6%, obtained from the Simalungun region, Medan.

2.2. Research Method

The research method employed is experimental, utilizing the Box-Behnken Design response surface methodology in the Design Expert application version 13. This study involves three treatment factors: solvent volume, time, and microwave power. The constraints and variable levels using RSM for process optimization are presented in Table 1.

Table 1. Constraints and variable levels using RSM for process optimization

Independent Variable	Constraints and Levels		
	-1	0	1
Solvent-to-Material Ratio (g/mL)	1 : 6	1 : 8	1 : 10
Extraction Time (minutes)	1	3	5
Power (%)	10	30	50

Based on the table, the number of experiments in the study resulted in 17 samples (runs) (Table 2). In this research, each experimental unit used a sample of 70 g, requiring volumes of 420 mL, 560 mL, and 700 mL for solvent-to-material ratios of 1:6, 1:8, and 1:10, respectively. The research stages consist of four phases: preparation of raw materials, extraction of red ginger with MAE assistance, distillation of red ginger essential oil using hydrodistillation, and analysis of characteristics based on SNI. The research stages diagram is presented in Figure 1.

2.3. Analysis Procedure

2.3.1. Red Ginger Essential Oil Yield

Partial Yield

Partial yield calculations are conducted at each process stage. In this study, partial yield calculations include extraction yield, hydrodistillation yield, and filtration yield. Extraction yield is the ratio of the mass of the extracted product to the mass before the extraction process. Hydrodistillation yield is the ratio of the mass after extraction to the mass of the distillate, while filtration yield is the ratio of the mass after filtration to the mass before filtration or the mass of the distillate. Partial yield calculation employs the following equation:

$$R_{Partial}\ (\%) = \frac{Mb}{Ma} \times 100\% \quad (1)$$

where Ma is the initial mass of material before process, and Mb is mass obtained from each process.

Table 2. Total run executed to evaluated the treatment effects based on Box-Behnken design

Run No.	Factor 1: Solvent Volume (mL)	Factor 2: Time (Min)	Factor 3: Power (%)
1	420	1	30
2	420	3	10
3	420	3	50
4	420	5	30
5	560	1	10
6	560	1	50
7	560	3	30
8	560	3	30
9	560	3	30
10	560	3	30
11	560	3	30
12	560	5	10
13	560	5	50
14	700	1	30
15	700	3	10
16	700	3	50
17	700	5	30

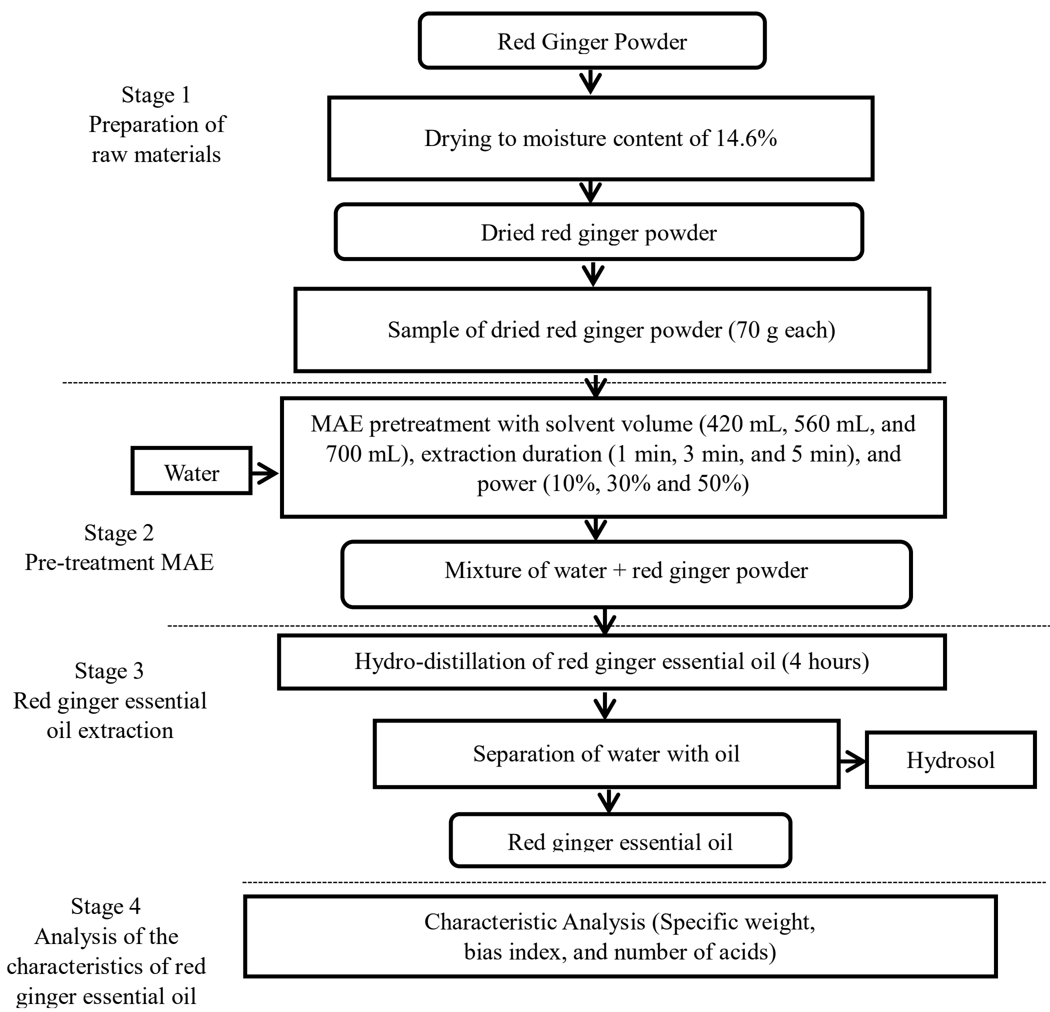

Figure 1. Flow diagram of research stage

Total Yield

Total yield is the ratio of the mass of red ginger essential oil produced to the mass of the raw material (red ginger powder) extracted. Total yield calculation utilizes the following equation:

$$R_{Total}\ (\%) = \frac{m1 - (m1 \text{ x } m2)}{m} \times 100\% \tag{2}$$

where *m* is the initial mass of red ginger powder, m_1 is mass of essential oil, and m_2 is the residual solvent content.

2.3.2. Residual Solvent Content

The residual solvent in the extract was calculated based on the weight of the solvent evaporated using a rotary vacuum evaporator. Residual solvent content is calculated using the following equation:

$$\text{Residual Solvent Content}\ (\%) = \frac{b - c}{b - a} \tag{3}$$

where *a* is empty evaporator flask mass (g), *b* is initial mass of red ginger essential oil (g), and *c* is evaporator flask mass after 1 hour of evaporation (g).

2.3.3. Specific Gravity

The specific gravity value of red ginger essential oil at 25°C is interpreted as a comparison between the weight of oil at 25°C and the weight of water of equal volume at 25°C. Specific gravity value was calculated as the following:

$$\text{Specific Gravity} = \frac{m_2 - m}{m_1 - m} \text{ x } 100\% \tag{4}$$

where *m* is empty pycnometer weight (g), m_1 is pycnometer plus water weight (g), m_2 is pycnometer plus red ginger extract weight (g). Specific gravity measurements were performed using a 1 mL pycnometer, measured in duplicate.

2.3.4. Refractive Index

The refractive index is a degree of deviation from the light passing through a bright medium. The refractive index can detect the purity of essential oil and identify its components. Calculating the refractive index value utilizes the following conditions:

$+ \Delta t \text{ x } 0.0003$ if the reading temperature < 25ºC.

$- \Delta t \text{ x } 0.0003$ if the reading temperature > 25ºC.

2.3.5. Acid Value

The acid value principle involves neutralizing free acids using standard base solutions volumetrically (BSN, 1998). The composition of essential oil, when in contact with air, undergoes oxidation reactions catalyzed by light, forming free acid compounds. The measurement of the acid value of red ginger essential oil is as follows:

$$\text{Acid Value} = \frac{56{,}1 \, x \, V \, x \, N}{m} \tag{5}$$

where 56.1 is relative mass of KOH, *V* is volume of KOH solution (mL), *N* is normality of KOH solution, and *m* is mass of red ginger essential oil used (g).

3. RESULTS AND DISCUSSION

3.1. Total Yield and Residual Solvent Content of Red Ginger Essential Oil

Total yield is the ratio between the mass value of red ginger essential oil produced and the mass of the raw material, which is dried red ginger powder. The total yield obtained is used as a response variable in RSM using Design Expert

13 application. The total yield and residual solvent content in this study are comprehensively presented in Table 3. Based on the table, the total yield values for each treatment varied significantly. The total yield of red ginger essential oil ranged from 0.14% to 0.28%. This yield value is influenced by the mass of essential oil obtained from filtration and the residual solvent content. Treatment run number 14 had the highest total yield at 0.28%, influenced by a solvent volume of 700 mL, extraction time of 1 minute, and 30% power. The low application of extraction time and power combined with a high solvent volume resulted in a shorter heating process, and a residual solvent content of 0%, thus achieving a high total yield. According to Kristian *et al*. (2016), a lower residual solvent content indicates better quality extract, and if a high extract yield is accompanied by a high residual solvent content, it suggests a significant amount of solvent remains in the extract.

Table 3. Total yield and residual solvent content

Run No.	Factor 1: Solvent Volume (mL)	Factor 2: Time (Min)	Factor 3: Power (%)	Total Yield (%)	Residual Solvent Content (%)
1	420	1	30	0.23	0
2	420	3	10	0.16	0
3	420	3	50	0.22	12
4	420	5	30	0.14	4
5	560	1	10	0.25	0
6	560	1	50	0.15	8
7	560	3	30	0.20	3.7
8	560	3	30	0.21	4
9	560	3	30	0.22	3.8
10	560	3	30	0.26	0
11	560	3	30	0.22	8.6
12	560	5	10	0.15	4.5
13	560	5	50	0.16	28
14	700	1	30	0.28	0
15	700	3	10	0.22	0
16	700	3	50	0.24	0
17	700	5	30	0.22	8

The lowest total yield was observed in treatment run number 5 at 0.14%, with the lowest solvent volume of 420 mL, extraction time of 5 minutes, and 30% power. Extraction time is one of the factors affecting yield value. Longer extraction times lead to higher temperatures, resulting in faster heating (Kristanti *et al*, 2019). The use of a low solvent volume led to a low yield value with a residual solvent content of 4%. This is supported by the statement of Rifai *et al*. (2018) that a higher volume of extraction solvent leads to a higher extraction yield.

Table 4. Optimization solutions for yield and residual solvent content provided by RSM

No	Solvent Volume	Time	Power	Yield	Desirability	Remarks
1	700.000	1.000	10.004	0.265	0.945	*Selected*
2	699.999	1.000	10.349	0.265	0.945	
3	699.999	1.000	10.629	0.265	0.945	
4	699.997	1.000	10.821	0.265	0.945	
5	699.999	1.003	10.167	0.265	0.945	

3.2. Optimization of Response Using RSM

The optimization process using RSM method with Design Expert 13 application was conducted to achieve a response with high desirability. There were 65 solutions provided by RSM with different desirability values. The highest desirability value was 0.945. A desirability value approaching one indicates a more suitable optimization process for that response variable. The factors with the highest desirability value recommended had a solvent volume of 700 mL, extraction time of 1 minute, and 10% power (Table 4).

3.3. Optimization of Red Ginger Essential Oil Yield

The total yield of red ginger essential oil obtained in this study was used for optimization using RSM. The equation used in the RSM model of this research is a linear equation. This model is recommended by the application with a p-value of 0.0422, lack of fit of 0.1671, adjusted R^2 of 0.3305, and predicted R^2 of -0.0313. The application suggests a linear model because it can provide significance in ANOVA and non-significance in lack of fit. The suggested model results for the response of red ginger essential oil yield are presented in Table 5.

Table 5. Recommended model for red ginger essential oil yield by the application

Source	p-value	Lack of fit	adjusted R^2	Predicted R^2	Remarks
Linier	0.0422	0.1671	0.3305	-0.0313	*Suggested*
2FI	0.4107	0.1515	0.3389	-0.6762	
Quadratic	0.2288	0.1723	0.4713	-1.6249	
Cubic	0.1723		0.7019		*Aliased*

Based on the table, the model recommended by the application is the linear model because the p-value for the linear model is less than 0.05. The values for the other three models do not meet the requirement as they have p-values greater than 0.05. The cubic model is stated as "Aliased," indicating a warning that the model cannot be used as it may cause errors or deviations in the data. The suggested linear model is significant because the p-value is less than 0.05, and the Lack of Fit p-value is greater than 0.05, making the Lack of Fit value non-significant. Lack of Fit represents deviation or inaccuracy in the model. Lack of fit value is a requirement for a good model because it indicates the conformity of the yield response data with the model (Rahmawaty, 2019). The results of the linear model analysis in ANOVA are presented more comprehensively in Table 6.

Table 6. ANOVA (analysis of variance) for yield response

Source	Sum of Squares	df	Mean Square	F-value	P-value	Remarks
Model	0.0127	3	0.0042	3.63	0.0422	Significant
A-Solvent Volume	0.0055	1	0.0055	4.72	0.0489	
B- Time	0.0072	1	0.0072	6.17	0.0275	
C- Power	0.0000	1	0.0000	0.0107	0.9192	
Residual	0.0152	13	0.0012			
Lack of fit	0.0131	9	0.0015	2.80	0.1671	Not Significant
Pure Error	0.0021	4	0.0015			
Total Correlation	0.0279	16				

The p-value obtained from ANOVA analysis using the linear model is 0.0422, which is less than 0.05, indicating significance in ANOVA. The p-value for the lack of fit is 0.1671, which is greater than 0.05, indicating that the response is not significant. Solvent volume and time factors influence the yield of red ginger essential oil, while the power factor does not. This is demonstrated in Figure 2.

Table 7. Fit statistic values for yield response

R^2	0.4560
***Adjusted* R^2**	0.3305
***Predicted* R^2**	-0.0313
***Adeq Precision* R^2**	6.7869

Based on Table 7, it is shown that the obtained R^2 value is not yet close to one, only at 0.4560. As the R^2 value approaches one, the obtained model becomes better. This R^2 value indicates the magnitude of the combination of independent variables affecting the response value. The difference between Adjusted R^2 and Predicted R^2 values is more than 0.2. This indicates that there is a problem with the data. The cause of this data deviation is due to the presence of an insignificant independent variable, which is the power variable, limiting the capability of these independent variables and resulting in a small R^2 value. Another cause is the narrow range between the upper and lower limits of the power variable used, which does not significantly affect the yield of red ginger essential oil obtained. The Adeq Precision value is a comparison between the predicted value at each design point and the average prediction error. The obtained Adeq Precision value is 6.7869, indicating that the model can be used and accepted because the obtained ratio is greater than four.

Based on Figure 2, it shows the visualization of contour plots on the yield response. The higher the yield value, the more red the contour color, and the lower the yield value, the more blue the contour color. Conditions with higher solvent volume and lower time show higher yield response results. The larger the ratio of solvent volume to the extracted material, the larger the yield obtained (Harfendi, 2020; Yunisa, 2017).

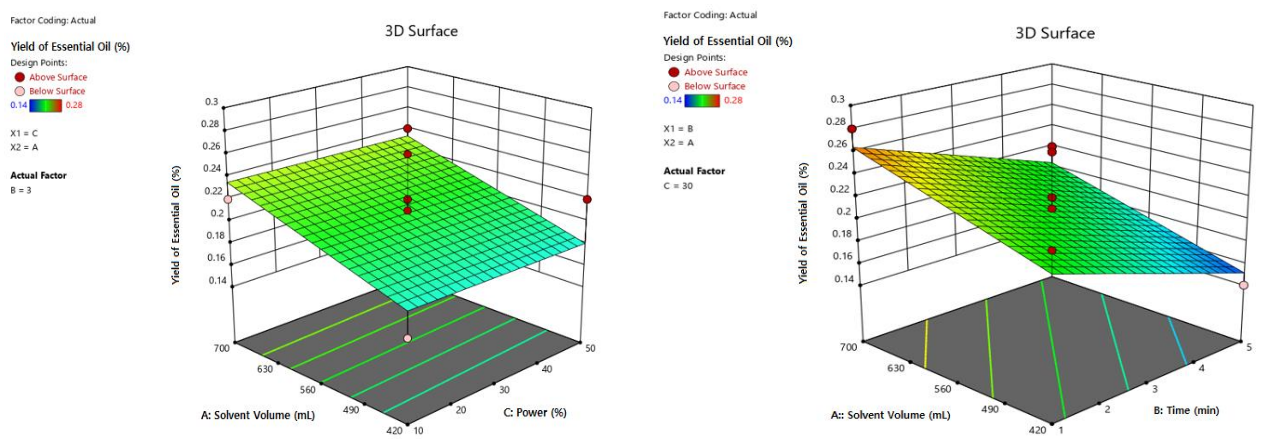

Figure 2. Three-dimensional plot of the yield response: (left) influence of solvent volume and time; and (right) influence of solvent volume and power

Based on Figure 3, it can be seen that the relationship between solvent volume and power factors on the yield results in a contour plot with green and yellow shading. The highest yield is indicated by the area with green to yellowish shading conditions, with higher solvent volume and lower power. The increased solvent amount will enhance the contact area between the material and the solvent, thus improving the solvent's ability to bind the extracted components, resulting in increased yield (Faadhilah, 2019; Sukardi *et al*., 2019; Dobreva *et al*., 2011).

The relationship between the three factors forms the equation model generated by RSM. The linear equation to produce optimization of yield as a response (Y), with solvent volume (A), time (B), and power (C) factors, is modeled in the following equation.

$$Y = 0.2076 + 0.0262A - 0.0300B - 0.0013C \quad (6)$$

3.2.1.1. Analysis of Optimal Yield Validation Results

The optimal solution obtained from the RSM analysis is a combination of solvent volume of 700 mL, extraction time of 1 minute, and power of 10%. This treatment was validated to determine whether the model could predict the response value accurately. The yield obtained from the validation results was 0.205%. This validated yield value is not far from the predicted yield by the Design Expert application, which is 0.265% (Table 8).

Table 8. Validation Results of Yield Response

Response	Predicted Value	Actual Value	Lowest Prediction (95% PI low)	Highest Prediction (95% PI high)	Std. Dev
Yield	0.265147	0.205	0.176747	0.353547	0.03

The validation result of 0.205 is within the range of 95% PI low and 95% PI high values, indicating that the test result falls within the prediction range. The validation percentage calculated is 77.35%, which is not close to 100%, indicating that the response value is not optimal even though the actual result falls within the predicted result. This discrepancy might be due to the adjusted R^2 and Predicted R^2 values differing by more than 0.2, indicating data issues. The validation percentage can be calculated using Equation 7.

$$\text{\% Validation} = \frac{Actual\ total\ yield}{Predicted\ total\ yield}\ x\ 100\% \quad (7)$$

3.3.1. Optimization of Red Ginger Essential Oil Residue Solvent Content

The residual solvent content of red ginger essential oil is also used as a response variable for optimization using RSM. The suggested model by the application has a p-value of 0.0195, lack of fit of 0.0950, adjusted R^2 of 0.4102, and predicted R^2 of 0.0480. The application suggests a linear model because it can provide significance in ANOVA and non-significance in lack of fit. The suggested model for the residual solvent content of red ginger essential oil is presented in Table 9. The recommended linear model is significant as the p-value is less than 0.05 and the Lack of Fit p-value is greater than 0.05, indicating non-significance. A more detailed analysis of the linear model in ANOVA is presented in Table 10.

Table 9. Recommended application model for red ginger essential oil residue solvent content

Source	P-value	Lack of fit	adjusted R^2	Prediction R^2	Remarks
Linier	0.0195	0.0950	0.4102	0.0480	Suggested
2FI	0.3595	0.0895	0.4361	-0.5982	
Quadratic	0.1506	0.1267	0.6052	-1.0818	
Cubic	0.1267		0.8110		Aliased

Table 10. ANOVA (analysis of variance) of residual solvent content response

Source	Sum of Squares	DF	Mean Square	F-value	P-value	Remarks
Model	411.06	3	137.02	4.71	0.0195	Significant
A-Solvent Volume	8.00	1	8.00	0.2749	0.6089	
B- Time	166.53	1	166.53	5.72	0.0325	
C- Power	236.53	1	236.53	8.13	0.0136	
Residual	378.27	13	29.10			
Source	**Sum of Squares**	**DF**	**Mean Square**	**F-value**	**P-value**	**Remarks**
Lack of fit	340.98	9	37.89	4.06	0.0950	Not Significant
Pure Error	37.29	4	9.32			
Cor Total	789.33	16				

The p-value obtained from the ANOVA analysis using the linear model is 0.0195, indicating significance in ANOVA. The p-value of the Lack of Fit obtained is 0.0950, which is greater than 0.05, indicating non-significance in response. The p-value for factor A (volume of solvent) is 0.608, for factor B (Time) is 0.0325, and for factor C (Power) is 0.0136. Time and Power have p-values less than 0.05, making these factors significant. Meanwhile, factor A (Volume of Solvent) has a p-value greater than 0.05, indicating insignificance and its potential impact on the response of red ginger essential oil residue solvent content.

Based on Table 11, the obtained R^2 value is not close to one, namely 0.5208. The difference between Adjusted R^2 and Predicted R^2 is 0.362, which is greater than 0.2, indicating a problem with the data. The reason for this deviation is due to an insignificant independent variable, which is the volume of solvent, limiting the capabilities of the independent variables and resulting in a small R^2 value. The Adeq Precision value obtained is 7.6436, indicating that the model can be used and accepted because the ratio obtained is greater than four.

Based on Figure 4, it shows the visualization of contour plots against solvent residue content. Conditions with higher time and lower solvent volume show higher solvent residue content. The lower the ratio of solvent volume to the extracted material, the higher the solvent residue content produced. A low solvent residue value is desirable because it indicates the amount of water still contained in the essential oil.

Table 11. Fit statistic values for residual solvent content response

R^2	0.5208
***Adjusted* R^2**	0.4102
***Predicted* R^2**	0.0480
***Adeq Precision* R^2**	7.6436

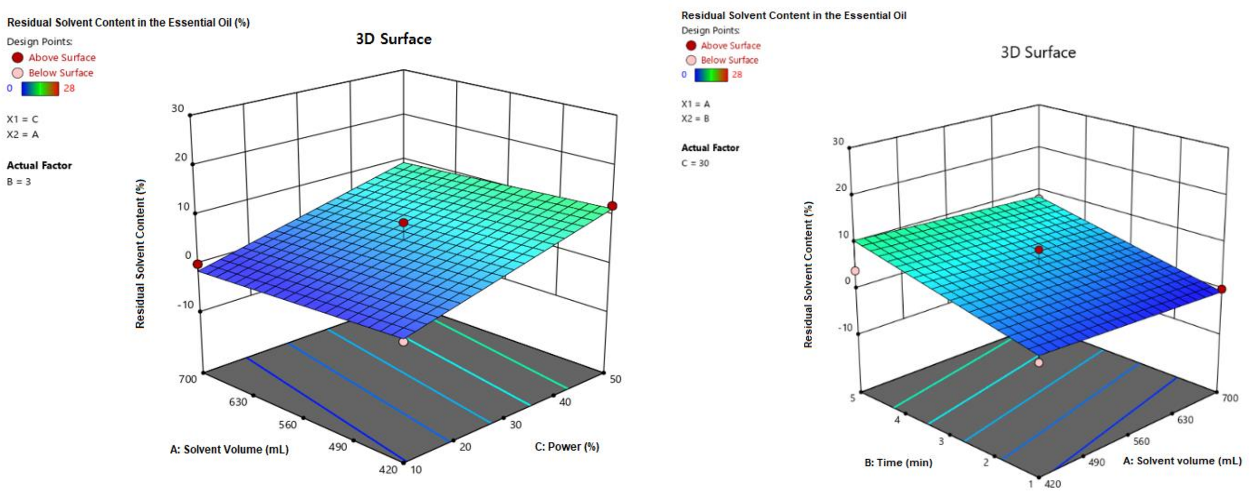

Figure 3. Three-dimensional plot of solvent residue content response: (left) influence of solvent volume and time; and (right) influence of solvent volume and power

Based on Figure 5, it demonstrates a three-dimensional plot of solvent residue content against solvent volume and power. Conditions with lower solvent volume indicate higher solvent residue content. Thus, increasing the solvent volume ratio leads to better solvent residue content. Optimal power conditions for solvent residue response are at low power because lower power values indicate lower solvent residue content. The relationship among the three factors forms the equation model generated by RSM. The linear equation for optimizing solvent residue content as a response (Y), with solvent volume (A), time (B), and power (C) factors, is modeled in Equation 8:

$$Y = 4.98 - 1.0000A + 4.56B - 5.44C \quad (8)$$

3.2.2.1 Analysis of Optimum Solvent Residue Content Validation Results

The optimum solution obtained from the RSM analysis is a combination of 700 mL solvent volume, 1 min extraction time, and 10% power. The solvent residue content obtained from the validation results is 3.8%. This value differs significantly from the predicted solvent residue content of -6.02336% by the Design Expert application, although it still falls within the prediction range (-19.9775 to 7.93007%). The validation results are presented in Table 12.

Table 12. Validation results of solvent residue content response

Response	Predicted Value	Actual Value	Lowest Prediction (95% PI low)	Highest Prediction (95% PI high)	Std. Dev
Solvent Residue Content	-6.02336	3.8	-19.9775	7.93077	5.39

Based on the obtained validation results, the value of 3.8 falls within the range of 95% PI low and 95% PI high. These test results still fall within the predicted range. The calculated validation percentage is -63.12%. This result is far from approaching 100%, indicating a poor response value, although the actual results obtained are still within the predicted results. The reason for this is that in the fit statistic of the yield response, one of the factors does not meet the requirements, namely, the difference between the Adjusted R^2 and Predicted R^2 values is greater than 0.2, indicating a problem with the data. The validation percentage can be calculated using the following equation:

$$\% \text{ Validation} = \frac{\textit{Total Actual Solvent Residue Content}}{\textit{Total Predicted Solvent Residue Content}}\ x\ 100\% \quad (9)$$

3.2.2.2. Control Treatment Analysis

Control treatment is conducted to compare the total yield of essential oil obtained from the MAE pretreatment process with and without MAE pretreatment. The control treatment uses the optimum process conditions recommended by RSM, which is using a solvent volume of 700 mL. The yield obtained from the control treatment is 0.169%, and the resulting solvent residue content is 0%. The total yield obtained from the control treatment is lower compared to the validation results obtained, which is 0.205%. This indicates that the essential oil yield obtained from the MAE pretreatment process is more effective than without the MAE pretreatment. This statement is supported by Syafutri *et al*. (2019) that microwave radiation can help accelerate extraction through efficient and rapid solvent heating.

3.4. Characteristics of Red Ginger Essential Oil

3.4.1. Specific Gravity

One of the methods to determine the quality of produced essential oils is through specific gravity measurement. This measurement is conducted to ascertain the ratio of the weight of the essential oil to the weight of water under the same volume and temperature conditions. The density value increases as the weight fraction contained within the oil increases. The larger the obtained specific gravity value, the greater the number of components contained within the substance (Argo *et al.,* 2021). The average specific gravity values are presented in Table 13.

Table 13. Average specific gravity values of red ginger essential oil

Condition	Factor 1: Solvent Volume (mL)	Factor 2: Time (Minutes)	Factor 3: Power (%)	Specific Gravity
Lower Limit	420	1	10	0.889 ± 0.011
Optimum Point	700	1	10	0.885 ± 0.008
Upper Limit	700	5	50	0.868 ± 0.002

The specific gravity measurements were compared with the Indonesian National Standard (SNI). According to the SNI standard, the specific gravity value for ginger oil ranges from 0.8720 to 0.8890. The specific gravity measurement results obtained from the three conditions: the lower limit condition with a solvent volume of 420 mL, extraction time of 1 minute, and power of 10%, comply with the SNI standard. Similarly, the optimum point condition with a solvent volume of 700 mL, extraction time of 1 minute, and power of 10% also meets the SNI standard. However, the upper limit condition with a solvent volume of 700 mL, extraction time of 5 minutes, and power of 50% does not meet the SNI standard. This is attributed to the use of a microwave with longer duration and higher power, resulting in thermal degradation that reduces the amount of compounds and density, thus causing a decrease in specific gravity. The decrease in specific gravity value can be due to excessive heating (Rosadhani, 2019).

3.4.2. Acid Value

The acid value is one of the parameters for determining the quality of essential oils. It indicates the amount of free acids present in the oil. Essential oils with low acid content are considered of higher quality because acids are prone to oxidation reactions from air, leading to changes in the oil's aroma (Balai Penelitian Tanaman Obat dan Aromatik, 2006). The average acid values are presented in Table 14.

According to the Indonesian National Standard, good quality ginger oil should have a maximum acid value of 2. Based on the three conditions, the acid values obtained range from 1.399 to 2.513. The condition that does not meet the SNI standard is the upper limit condition with a solvent volume of 700 mL, extraction time of 5 minutes, and power of 50%. Argo *et al.* (2021) states that the acid value increases with higher temperatures and longer distillation times (Nasruddin *et al*., 2005). The increase in acid value is caused by higher temperatures and longer distillation times facilitating oxidation reactions, leading to the formation of acid components in the material. This aligns with the

Table 14. Average acid values of red ginger essential oil

Condition	Factor 1: Solvent Volume (mL)	Factor 2: Time (Min)	Factor 3: Power	Acid Value
Lower Limit	420	1	10	1.955 ± 0.388
Optimum Point	700	1	10	1.399 ± 0.396
Upper Limit	700	5	50	2.513 ± 0.385

condition at the upper limit using high power, resulting in a high temperature and consequently a high acid value compared to the other two conditions. The condition with the lowest acid value is the optimum point condition with a solvent volume of 700 mL, extraction time of 1 minute, and 10% power, at 1.399, indicating a lower amount of acid compared to the other two conditions.

3.4.3. Refractive Index

Refractive index measurement serves to determine the purity of a substance contained in the oil. The refractive index decreases as the water content in the essential oil increases (Sani *et al*., 2012). This is because water has the property of refracting incoming light. Essential oils with a higher refractive index will have better quality compared to those with a lower refractive index (Widiyanto, 2014). The average refractive index values are presented in Table 14.

Table 14. Refractive index of red ginger essential oil

Condition	Factor 1: Solvent Volume (mL)	Factor 2: Time (Min)	Factor 3: Power	Refractive Index
Lower Limit	420	1	10	1.489 ± 0.001
Optimum Point	700	1	10	1.485 ± 0.000
Upper Limit	700	5	50	1.490 ± 0.001

Based on the Indonesian National Standard, the refractive index value for ginger oil ranges from 1.4853 to 1.4920. The refractive index measurement values from the three conditions show that the produced essential oil still falls within the standard range according to SNI. The largest refractive index value is in the upper limit condition, which is 1.490, indicating that the essential oil in that condition has better quality compared to the other two conditions.

4. CONCLUSIONS

Extraction of red ginger essential oil using microwave-assisted extraction can enhance the yield of the produced oil. The yield is influenced by the solvent volume and extraction time, while the residual solvent content is affected by the power and extraction time. The linear model for yield is Y = 0.2076 + 0.0262A – 0.0300B – 0.0013C, and the optimal residual solvent content condition is presented as Y = 4.98 – 1.0000A + 4.56B + 5.44C, where solvent volume (A), time (B), and power (C) are represented. The optimum yield value of red ginger essential oil obtained after validation process is 0.205%, while the optimum residual solvent content value is 3.8%. Furthermore, the characteristics of red ginger essential oil obtained from testing at the optimum point yield a specific gravity value of 0.885, an acid value of 1.399, and a refractive index of 1.485. These characteristics from the optimum point testing meet the Indonesian National Standard 06-1312-1998 for Ginger Oil.

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