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Microwave-Assisted Hydrolysis of Robusta Coffee Parchment as a Reducing Sugar Feedstock

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Abstract. The hydrolysis process is a process of breaking down substances by reacting using water, the aim is to break down the substance. This research focuses on the hydrolysis process to determine the reducing sugar content of coffee parchment. The method used is microwave-assisted hydrolysis. This method can increase lignin release more effectively than conventional methods in the process of cellulose and hemicellulose hydrolysis. The most commonly used hydrolysis to hydrolyze cellulose is acid hydrolysis. This research uses coffee parchment raw material (horn skin) which contains cellulose and hemicellulose with HCl solvent. Hydrolysis with acid concentration is (1, 2, and 3%), microwave power (150, 300, and 450 W), and time (20, 25, and 30 minutes). In this study, the optimal reducing sugar yield was 8,054 g/mL under the operating conditions of 25 minutes, 3% HCl concentration, and 450 W microwave power.

Keywords: *Hydrolysis, coffee parchment, microwave-assisted hydrolysis, and reducing sugar.*

1. Introduction

Over time the need for fuel has increased, requiring alternative fuels. Fossil fuel reserves are dwindling, even though people's needs are increasing. In addition, as fuel oil becomes increasingly expensive, there is a growing need for alternative fuel sources such as biomass. Currently, Indonesia's petroleum reserves are only 1% of the world's oil reserves, therefore there is a need for other alternatives to replace the use of kerosene and LPG gas which are currently still widely used by the community [1]. Second-generation bioethanol with cellulose raw materials derived from various biomass materials is one form of alternative energy. The potential of cellulose waste from wood and non-wood materials is the most abundant natural resource, one of which is coffee parchment [2].

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Based on data from the Central Statistics Agency (BPS), coffee availability in Indonesia in 2020 reached 99.33% when combined with state-owned and private plantations. This shows the amount of coffee production that is exported both domestically and abroad. The availability of 45% coffee parchment in East Java, especially in the area around Bondowoso [3]. Coffee parchment as raw material can produce bioethanol with 38.68% content after going through hydrolysis and fermentation processes. The advantage of cellulose conversion into various products can also reduce environmental pollution problems due to the accumulation of agricultural biomass waste that is not optimally utilized [4]. Bioethanol is an organic fuel derived from plant materials through the natural process. However, there are various methods for producing bioethanol, such as the fermentation process involving microorganisms [5]. Bioethanol includes wood waste, agricultural waste, plantations, forest products, and organic components from industry and households [6].

As one of the alternative fuel sources processed from plants, bioethanol has the advantage of being able to reduce CO_2 emissions [7]. According to Wusnah et al, 2019 [8], sources of bioethanol are starch-containing plants (such as cassava, oil palm, tengkawang, coconut, kapok, jatropha, rambutan, soursop, malapari, and nyamplung), sugary (such as molasses, palm sap, sugarcane sap, and sweet sorghum sap) and cellulose fibers (such as sorghum stems, banana stems, straw, wood, and bagasse) [9]. Bioethanol has advantages compared to fuel, including having a higher oxygen content of about (35%) so that it burns more completely, a higher octane value (118), and is more environmentally friendly because it has a lower CO gas emission content of 19-25% [10]. One example of bioethanol raw material is coffee parchment, the availability of coffee parchment is quite large, in coffee processing will produce 65% coffee beans and 35% coffee parchment [11]. The structure of the coffee fruit can be seen in Figure 1 and the constituent content of robusta coffee can be seen in Table 1.

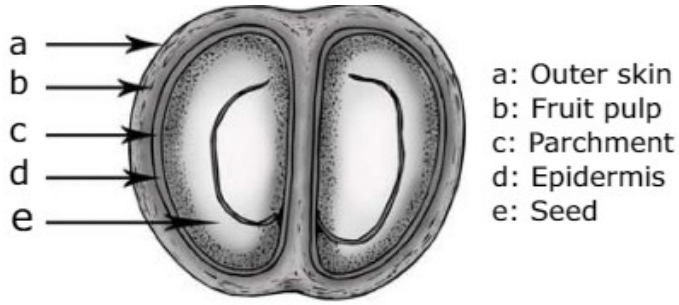

Figure 1. Structure of Coffee Fruit

Parchment has a fairly high cellulose content, making it possible to produce more glucose. According to Wardana et al, 2019 [4] the cellulose and hemicellulose content in Robusta coffee parchment after dry method treatment was found to be 27.26% cellulose and 11.65% hemicellulose, where the highest levels in the Bondowoso region were greater than other regions. The advantage of using Robusta coffee parchment as a raw material is that the fruit is widely grown around the Bondowoso district and has a high enough cellulose content so it can produce high glucose.

Table 1. Ingredients of Robusta Coffee

Outer skin	**Fruit pulp**	**Parchment**	**Epidermis**	**Seed**
Crude protein (91.7%)	Pectin (38.70%)	Crude protein (2.20%)	Chlorogenic acid (7.21%)	Crude fiber (27.2%)
Fat (2%)	Total sugar (45.80%)	Crude fiber (60.24%)	Fat (10.19%)	fat (10.6-12.6%)
Fiber (27.65%)	water (15.15%)	Cellulose (63%)		Crude protein (3-13.5%)
Reducing sugar (12.4%)		Hemicellulose (7.58%)		Reducing sugar (6-10%)
Non-reducing sugar (2.02%)		Ash (3.30%)		Non-reducing sugar (0.32-1.08%)
Tannin (7.47%)				Carbohydrates (4.47%)
Total pectin (6.52%)				Ash (3.38%)
Ash (3.36%)				Caffeine (9%)
N free (57.85%)				Chlorogenic acid (6-10%)

Based on Table 1, coffee skin contains 63% cellulose and 7.58% hemicellulose. Coffee parchment is an abundant agro-industrial cellulosic and lignocellulosic material that can be used to produce reducing sugars. The composition of coffee parchment consists of cellulose, hemicellulose, and lignin. However, the high lignin content requires pretreatment [12]. With its considerable cellulose content, the utilization of coffee skin as a raw material for reducing sugar with the application of bioethanol can be an opportunity for non-conventional fuels.

Bioethanol can be made from various agricultural materials, including materials containing sugar derivatives (saccharin), starch-containing materials, and cellulose-containing materials such as wood, and some other agricultural waste [10]. Materials containing saccharin can be directly fermented, but materials containing starch and cellulose must first be hydrolyzed into simple components, although they can be fermented directly using enzymes, currently the fermentation industry still utilizes microorganisms, because this method is much easier and cheaper, microbes that are widely used in the fermentation process are yeasts, molds, and bacteria [13]. The hydrolysis process is a process of breaking down substances by reacting using water, the aim is to break down these substances [12]. The purpose of this study is to optimize the hydrolysis process of coffee parchment using a microwave to determine the highest level of reducing sugar. Box–Behnken design (BBD) and response surface methodology (RSM) are employed to obtain statistical models for glucose stability optimization and identification of their stability regions. Factors including the HCL concentrations, hydrolysis time, and power microwave are subjected to sensitivity analyses, highlighting their ascendancy and interactional effect on the formulation stability.

The novelty carried out in this study is to vary the time, acid concentration, and power in the hydrolysis process of parchment, it is expected to obtain more optimal reducing sugar to produce the best bioethanol. According to Maryanti et al, 2019 [14], the most used hydrolysis to hydrolyze cellulose is acid hydrolysis. Some acids commonly used for acid hydrolysis include sulfuric acid (H_2SO_4), perchloric acid ($HClO_4$), and hydrochloric acid (HCl). The use of concentrated acid in the cellulose hydrolysis process is carried out at a lower temperature than dilute acid. The concentration of concentrated acid used is 1-3%. The reaction temperature is 100˚C and requires a reaction time between 20-40 minutes [15].

Microwaves are electromagnetic waves that have frequencies from 0.3 to 300 GHz. Lignin can be broken into smaller particles and detached from cellulose at 200ºC, pretreatment using microwave can be achieved within 60 minutes [16]. The use of microwaves enhances the release of protein bodies from starch more effectively than traditional methods, not only in the pretreatment process but also in the cellulose and hemicellulose hydrolysis process. In the hydrolysis process of these two materials in an acidic solution using the microwave method, starch is directly converted into simple sugars in a relatively short time. Compared with traditional heating, the reaction rate of starch hydrolysis to glucose is increased by 50-100 times [5]. The advantage of using this acid is that it contains sugar conversion up to 90% conversion

[17]. The initial moisture content of robusta coffee itself is around 48.7% and according to SNI, the maximum moisture content of dried coffee bean skin is 12.5% [18]. The results of glucose hydrolysis of robusta coffee obtained 6.73% and the results of glucose fermentation of robusta coffee skin for 7 days obtained a bioethanol content of 60%. The conversion process of glucose to produce bioethanol occurs maximally [19]. Previous research data can be seen in Table 2.

Some of the research results in the table obtained the highest reducing sugar yield of 42 g/mL using the acid hydrolysis method. The novelty of this research is that it uses the parameters of hydrolysis time, HCl concentration, and microwave power so that it influences the results of reducing sugar levels.

Table 2. Previous Research Data of Bioethanol Reducing Sugar Hydrolysis

Raw Material	Hydrolysis Method	Operating Conditions and Result	Reference
Robusta coffee parchment	Acid hydrolysis	The results of reducing water content obtained optimal results for 2 hours with water content lost by 12.056%, with a ratio of 8% hydrolysis starter obtained the highest reducing sugar of 673.765 mg/100 mL.	[10]
Water hyacinth	Acid hydrolysis	The best water hyacinth hydrolysis process conditions obtained were the use of 1 NH_2SO_4 catalyst and 600 W microwave power with a final reducing sugar content of 486 mg/L.	[16]
Rice straw	Acid hydrolysis using hydrolysis flask	Under optimal conditions, the highest reducing sugar yield from hydrolysis for 25 hours with 40% enzyme concentration was obtained at 8.75 mg.	[20]
Coffee skin	Acid hydrolysis	The highest reducing sugar content was obtained at 42.6 g/mL.	[13]
Arabica coffee parchment	Acid hydrolysis	Based on the 42% cellulose yield, the highest reducing sugar was obtained from the hydrolysis with 10% H_2SO_4 at 100°C by 8%.	[21]
Corn cob	Enzymatic hydrolysis with autoclave heating	Hydrolysis with cellulase enzyme, in alkaline treatment and repetition of 3 times obtained reducing sugar content of 9.96%.	[22]
Sorghum dregs	Microwave aqueous acid hydrolysis	By varying the concentration for 30 and 40 minutes, it was found that the reducing sugar content increased with increasing acid concentration at 30 minutes of hydrolysis time, namely 2.0-8.5 mg/L and experienced a significant increase when extending the hydrolysis time to 40 minutes, namely 19.1-42.7 mg/L. The largest reducing sugar concentration for ethanol production using 150˚C temperature with 2% acid concentration at 40 minutes hydrolysis time is 34.3 mg/L.	[5]
Sorghum Dregs	Acid hydrolysis using autoclave and microwave	The highest glucose level from the hydrolysis process using autoclaving obtained the highest reducing sugar of 30.86 g/L, with hydrolysis using microwave obtained reducing sugar of 44.97 g/L.	[23]
Cassava peel	Acid hydrolysis	From the hydrolysis process, the reducing sugar content was 9.9%.	[24]
Pineapple peel	Acid hydrolysis with stirring rate	From the results of this study, the optimal conditions of hydrolysis obtained the highest glucose occurred from the addition of HCl at 2 M and 300 RPM at 12.6%.	[9]

Raw Material	Hydrolysis Method	Operating Conditions and Result	Reference
Seaweed	Acid Hydrolysis using microwave	The highest reducing sugar content was 33.43 mg/L with an optimum temperature of 150°C, 2% acid concentration at an optimum hydrolysis time of 30 minutes.	[25]

2. Materials and Methods

2.1 Materials

The materials used in this study were robusta coffee parchment obtained from Sumber Wringin Village, Bondowoso District, East Java, distilled water, HCl 32%, NaOH 48%, anhydrous glucose, KNa tartrate, and 3.5-Dinitrosalicylic Acid.

2.2 Equipment

Blender (Miyako), 100 mesh sieve (RSL stainless steel 304), microwave (Samsung MS23K3515AS/SE), water bath (Prio WB-2-6), UV-Vis spectrophotometer (Tungsten 6mm).

2.3 Method

In this study, it was determined that: The control variable is the mass of coffee parchment of 100 grams with a size of 100 mesh [11]. The dependent variable is the reduced sugar content in the hydrolysis process. The independent variables used are hydrolysis time (20, 25, and 30 minutes) [15], acid concentration (1, 2, and 3%) [5], and Microwave power (150, 300, and 450 W) [26]. The analytical method used in this research is Box-Behnken Design (BBD) and response surface methodology (RSM) to obtain a statistical model for optimizing glucose stability and identifying areas of stability.

2.3.1 Raw Material Preparation

Robusta coffee parchment was cleaned first and then dried using an oven at 100˚C for 15 minutes and obtained a sample with a moisture content of 9.998%. Then, the coffee skin is pulverized using a blender so that the results are obtained in powder form. Furthermore, the coffee skin powder is sieved using a sieve with a size of 100 mesh [11].

2.3.2 Hydrolysis of Parchment

The coffee powder material weighed as much as 10 g with HCl catalyst concentration (1, 2, and 3%) as much as 100 mL then put into the flask to be hydrolyzed using microwave heating for (20, 25, and 30 minutes) with microwave power (150, 300, and 450 W) and then allowed to stand until the temperature of the hydrolysis results dropped to room temperature (25). This study carried out data analysis using Design Expert 11 Version Software with

Response Surface Methodology (RSM) BBD (Box Behnken Design) model 17 times shown in Table 3, then analyzed the reducing sugar content by DNS method.

Table 3. Variation of Box-Behnken Design (BBD) Acid Hydrolysis with 3 Variables Data

Run	Time (minutes)	Concentration (g/mL)	Power (W)
1	20	2	450
2	30	2	450
3	25	2	300
4	30	1	300
5	20	1	300
6	25	2	300
7	25	3	450
8	25	2	300
9	20	2	150
10	25	1	150
11	25	1	450
12	20	3	300
13	25	3	150
14	30	2	150
15	25	2	300
16	30	3	300
17	25	2	300

2.3.3 Reducing Sugar Analysis

Analysis of reducing sugars based on preliminary research on analyzing glucose levels using a UV-Vis Spectrophotometer using DNS reagents conducted by Kolo [5], Wardani [27], and Santi [28].

2.3.4 Preparation of DNSA Reagent

A total of 1 g of 3.5-Dinitrosalisilic was added to 20 mL of NaOH and homogenized. Separately dissolved KNa Tartrate (KNa $C_4H_4O_6.4H_2O$) as much as 30 g using distilled water and homogenized both solutions. Then put into a 100 mL volumetric flask, added distilled water until it reached the limit, homogenized, and transferred into a bottle [23].

2.3.5 Glucose Standard Curve Preparation

Standard glucose solutions were made with concentrations of 200, 400, 600, 800, and 1000 ppm, respectively. The preparation begins with making a glucose mother solution by dissolving 100 mg of anhydrous glucose and adding 100 mL of distilled water. Each standard glucose solution was taken 1 mL and placed in each test tube. Then added 1 mL of 3.5-Dinitrosalicylic Acid reagent and 1 mL of distilled water, then homogenized and heated in a water bath with boiling water for 5 minutes. Next, the solution was cooled to room temperature and added distilled water to a volume of 5 mL, and homogenized again. Absorbance was

measured using a UV-Vis Spectrophotometer with a wavelength of 540 nm. Absorbance is the ratio of the intensity of the light fired to the intensity of the absorbed light, the absorbance value will increase with the results obtained. Absorbance measurements were taken at each concentration of glucose solution and then a standard curve plot was made with glucose content (mg) abscissa (x) and absorbance as ordinate (y) [29].

2.3.6 Determination of Reducing Sugar

1 mL of sample was taken to the test tube, 0.5 mL of DNSA reagent was added, 2 mL of distilled water was homogenized, and the sample solution was heated in a water bath for 5 minutes. Then, the solution was cooled to room temperature, and added distilled water until the final volume of 5 mL, then tested using a UV-Vis spectrophotometer with a wavelength of 540 nm.

3. Result and Discussion

3.1 Analysis of Reducing Sugar Content

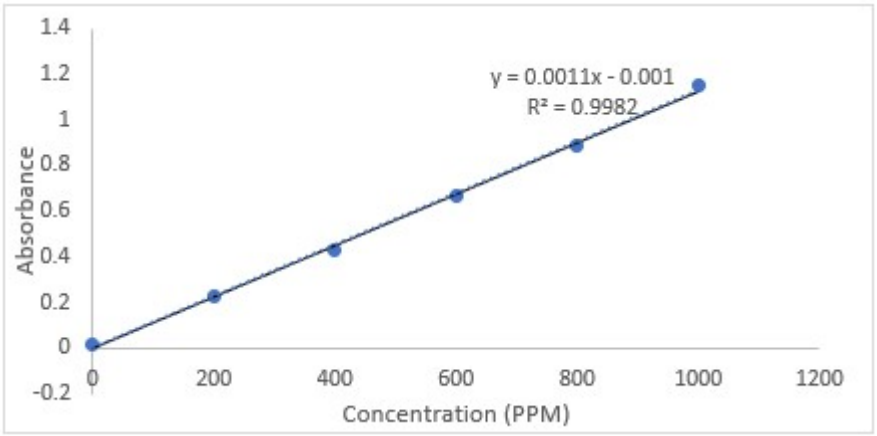

Figure 2. Glucose Standard of Solution Curve

The determination of reducing sugar content in this study was carried out first by determining the glucose standard curve to determine the linear regression equation. This curve was used to determine the concentration of reducing sugar in the samples. The glucose standard curve was obtained by measuring the absorbance of glucose standard solution with various concentrations of 200, 400, 600, 800, and 1000 ppm. Figure 2 shows that the curve is obtained from the linear regression equation at y = 0.0011x - 0.001, with an R^2 value of 0.9982. The results of reducing sugar can be seen in Table 4.

Table 4. Results of reducing sugar content of robusta parchment

Run	A Time (minutes)	B Concentration (%)	C Power (W)	Reduced Sugar Content (g/mL)
1	20	2	450	4.554
2	30	2	450	7.059
3	25	2	300	6.436
4	30	1	300	4.190
5	20	1	300	4.050
6	25	2	300	6.927
7	25	3	450	8.054
8	25	2	300	7.286
9	20	2	150	3.950
10	25	1	150	3.731
11	25	1	450	3.977
12	20	3	300	5.095
13	25	3	150	4.840
14	30	2	150	5.004
15	25	2	300	6.150
16	30	3	300	7.254
17	25	2	300	7.163

Based on Table 4, measured using a UV-Vis spectrophotometer, the highest reducing sugar content was 8.054 g/mL in the operating conditions of 25 minutes, 3% HCl concentration, and 450 W microwave power. Research with the microwave hydrolysis method conducted by Putera et al, 2019 [10], had lower results than this study, which amounted to 6.737 g/mL with an HCl concentration of 20% within 2 hours with an absorbance range of 3.22%.

3.2 *Analysis of Variance* (ANOVA)

The ANOVA result for this study can be seen in Table 5.

Table 5. Analysis of Variance (ANOVA) Results

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	33.08	9	3.68	18.88	0.0004	significant
A-Time	4.29	1	4.29	22.04	0.0022	
B-Concentration	10.80	1	10.80	55.48	0.0001	
C-Power	4.68	1	4.68	24.04	0.0017	
AB	1.02	1	1.02	5.23	0.0560	
AC	0.5256	1	0.5256	2.70	0.1443	
BC	2.20	1	2.20	11.31	0.0120	

Source	Sum of Squares	df	Mean Square	F-value	p-value	
A^2	2.88	1	2.88	14.79	0.0063	
B^2	2.82	1	2.82	14.47	0.0067	
C^2	2.86	1	2.86	14.67	0.0065	
Residual	1.36	7	0.1947	0.6007	0.6479	
Lack of Fit	0.4232	3	0.1411	0.6007	0.6479	not significant
Pure Error	0.9394	4	0.2349			
Cor Total	34.44	16				

Analysis of variance (ANOVA) is to determine whether these factors have a significant effect on variables with a form of statistical hypothesis testing where conclusions are made based on data or inferential statistical groups [30]. Based on Table 5, the variables of time (A), concentration (B), and power (C) used in this study have a significant effect on reducing sugar. This can be seen from the p-value (probability value) for time 0.0022, HCl concentration 0.0001, and power 0.0017 showing that the results of the analysis are smaller than the probability value which is <0.05 (5%).

Based on Table 5, the lack of fit value at the p-value is 0.6479, which represents that the ANOVA model produced passes the principle of fit. The lack of fit value is insignificant, lack of fit can be used if the value is ≥ 0.05. Lack of fit is a deviation or inaccuracy of independent variables against a model [31]. Fit statistics for this study can be seen in Table 6.

Table 6. *Fit Statistic*

R^2	Adjusted R^2	Predicted R^2	Adeq Precision
0.9604	0.9096	0.7608	12.0036

The values of R^2, adj-$R^{2,}$ and pred-R^2 are important to note. These values provide an expectation of the accuracy of an independent variable in the model. A good model has a minimum R^2 value of 0.8 or 80%. The value of R^2 is closer to 1, the better the resulting model [33]. Based on Table 6, the Fit Statistic data was obtained in this study. It is known that the value of R^2 is 0.9604, this indicates that hydrolysis time, HCl concentration, and microwave power have an influence of 0.9604 or 96.04% on reducing sugar. The adjusted R^2 value (adjusted) is 0.9096, then the predicted R^2 value is 0.7608 so that it can be accepted as appropriate because it has a difference < 0.2 [32]

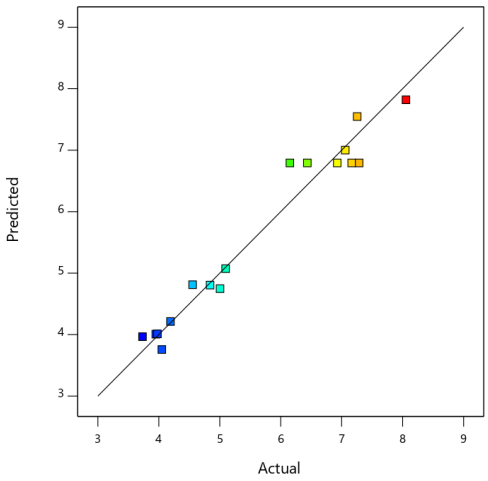

Figure 3. Comparison Chart of Model Data (Predicted) with Experiment (Actual)

Figure 3 shows the fit of the model data to the experimental data can be depicted on the pority plot graph. The straight line on the graph is the prediction data, while the actual data for each experimental data is depicted as a point on the graph. It can be seen from the resulting graph that there are some actual data obtained close to the predicted data.

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. The mathematical equation between the independent variable and the dependent variable to determine the reducing sugar content is shown in equation (2). The positive value in the equation is the response of reducing sugar content will increase directly proportional to the heating time with HCl concentration, the interaction between heating time and microwave power, the interaction between concentration and microwave power, and vice versa. The response of reducing sugar content will decrease as the HCl concentration decreases, this is indicated by the negative coefficient of the equation.

$$y = 1.4537A + 0.4269B + 0.005C + 0.1009AB + 0.00048AC + 0.00049BC - 0.3308A^2 - 0.8179B^2 - 0.000037C^2 \quad (2)$$

where,

Y = Reducing sugar content (g/mL)

A = Heating time (minutes)

B = HCl concentration (%)

C = Microwave power (W)

3.3 Effect of Hydrolysis Variables on Reducing Sugar Content

3.3.1 The effect of the relationship between time and HCl concentration on reducing sugar content response.

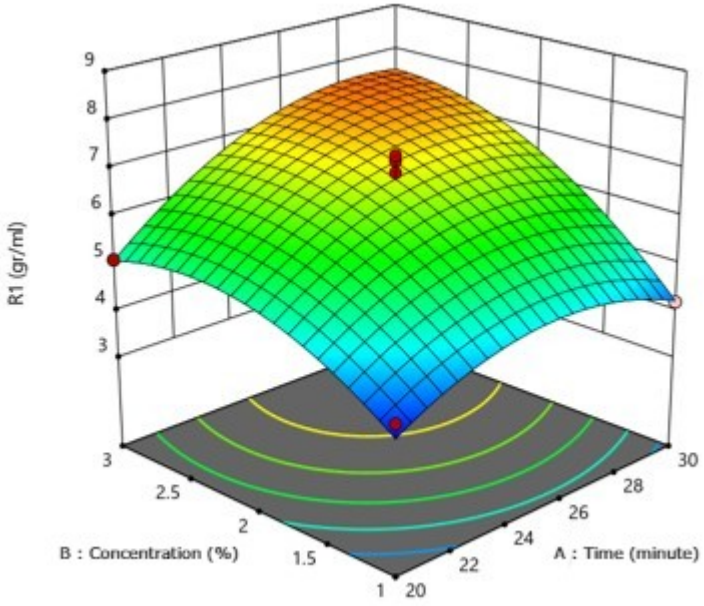

Figure 4. Effect of Hydrolysis Time (A) on HCl Concentration (B)

Figure 4 shows the reduced sugar content as affected by time (A) and HCl concentration (B). The reduced sugar content influenced by hydrolysis time is shown in Table 4. At a hydrolysis time of 20 minutes with 1% HCl concentration and 300 W of power, the reducing sugar content was 4.05 g/mL. If the time is increased to 25 minutes with 2% HCl concentration and 300 W of power, the result of reducing sugar is 7.16364 g/mL. the longer the hydrolysis time, the reduced sugar content. However, if it exceeds the optimum time, the reducing sugar content will also decrease due to inhibitors usually formed by hydroxymethylfurfural (HMF) compounds, too much acid concentration or too high hydrolysis temperature can increase the amount of inhibitors formed during the process so that it can inhibit glucose formation [10]. This is following with the research of Rifa'I et al, 2019 [6], so the time and HCl concentration variation has a significant effect on the response of reducing sugar content

3.3.2 The effect of the relationship between time and microwave power on reducing sugar content response

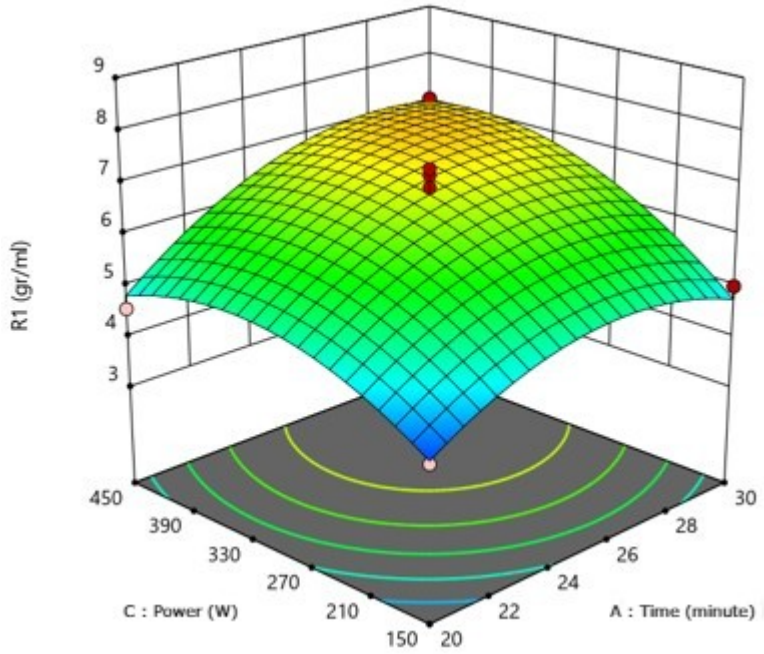

Figure 5. Effect of Hydrolysis Time (A) and Microwave Power (C)

Figure 5 shows the graph of the relationship between time (A) and power (C) to the response of reducing sugar content, optimal condition was obtained in the 7th experiment. It is known that at a time of 20 minutes and a concentration of 2% HCl with 150 W of power, the result of reducing sugar is 3.95 g/mL. when increased to 25 minutes and a concentration of 2% HCl with 300 W of power, the result of reducing sugar is 7.28636 g/mL. In this case, as the microwave power increases, the reduced sugar content will also increase. So, it can be said that if the time variable is increased with the experiment, it also accelerates the hydrolysis time in accordance with previous research conducted by Amini et al, 2022 [3].

3.3.3 The effect of the relationship between HCl concentration and microwave power on reducing sugar content response.

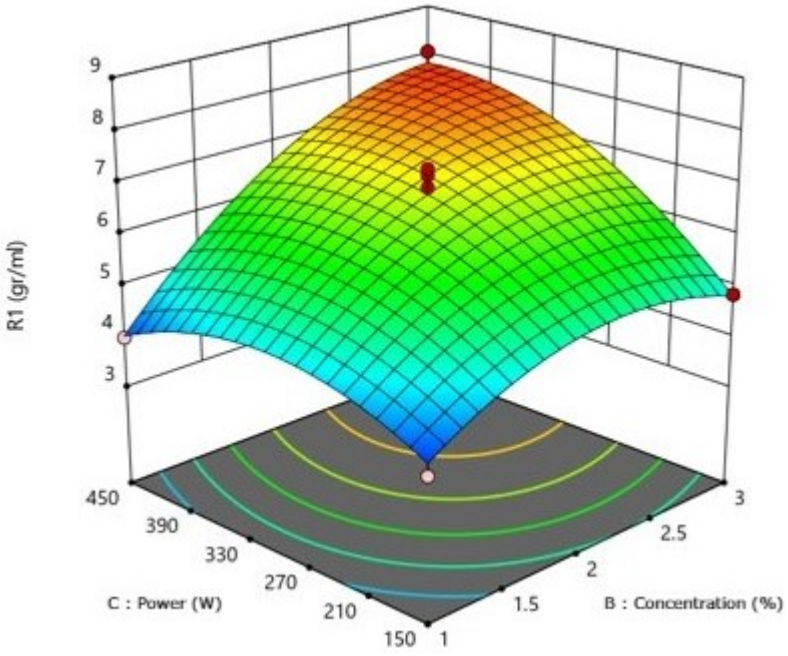

Figure 6. Effect of HCl Concentration (B) and Microwave Power (C)

Figure 6 shows the graph of the effect of the relationship between HCl concentration (B) and microwave power (B) to reducing sugar, obtained optimal results that occurred in the 7th experiment with a reducing sugar yield of 8.05455 g/mL. At a time of 25 minutes and a concentration of 1% HCl with a microwave power of 150 W, the reducing sugar was obtained at 3.73182 g/mL. If the HCl concentration is enlarged in the 25-minute experiment and 2% HCl concentration with 300 W of microwave power, the result of reducing sugar is 7.28636 g/mL, from these results it can be concluded that the addition of HCl has a significant effect on the increase in reducing sugar. This is comparable to the statement of Ahmad et al, 2020 [34]. It is known that the variation in HCl concentration has a linear effect along with the increase in H^+ ions on the glucose content produced. However, if the addition of acid concentration is increased beyond the optimum point, it will undergo decomposition into HMF compounds [33].

Based on Table 7, the optimal result on the response of one experiment on reducing sugar content is 8.021 g/mL when the hydrolysis time is 29.4, HCl concentration is 2.6%, microwave power is 370.8 W and also the desirability value reaches 1.000. The suitability of the model to the optimization value is obtained if the desirability value is close to one [34].

Table 7. Maximum optimization of reducing sugar content design expert

Hydrolysis Time	HCL Concentration	Microwave Power	Reduced Sugar Contet	Desirability
29.4	2.6	370.8	8.021	1.000

3.4 Comparison of Reducing Sugar with Previous Research

The following Table 8 provides data on the results of previous studies as a reference for comparison with this study.

Table 8. Comparison of Reducing Sugar Levels with Previous Studies

No.	Material	Methods	Reduced Sugar Content Result	Reference
1.	Robusta coffee	HCl, Agitation	6.73 g/mL	[10]
2.	Arabica coffee	H_2SO_4, Hot Plate	4.86 g/mL	[21]
3.	Robusta coffee	HCl, *Water Bath Shaker*	20.85 g/mL	[4]
4.	Robusta coffee	Kapang Pestalotiopsis sp. VM 9, Inokulasi	3.92 g/mL	[35]
5.	Kopi Robusta	HCl, *Microwave-Assisted hydrolysis*	8.05 g/mL	This study

4. Conclusions

Based on the results of the study, it can be concluded that the highest reducing sugar content of 8.054 g/mL is in the 7th run with 3% HCl concentration, 25 minutes hydrolysis time, and 450 W microwave power. Determination analysis using Analysis of variance (ANOVA) obtained the results that a significant effect occurred on all variables, namely hydrolysis time, HCl concentration, and microwave power with an R-value of 0.9096 where the value is close to 1, the better the experimental results. If the hydrolysis process passes the optimal conditions, the increase in reducing sugar will decrease because other compounds are formed, namely HMF.

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