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Optimization Process Production Sorbitol Through MnCuFe2O4 Photonanocatalysis

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Abstract

Indonesia have a lot of biomassa is rice straw. The largest content rice straw is cellulose. Cellulose can be converted into sorbitol. The sorbitol produced is useful for various industries are chemical industry, textiles, cleaning, dust control, packaging, agriculture and fuel. In this study, we produced sorbitol from rice straw using multistage is NaOH hydrolysis followed by MnCuFe2O4 photonanocatalysis. The aim this study is maximize yield sorbitol, with the novelty of using photonanocatalysts MnCuFe2O4. This study provides results that by using multistage is NaOH hydrolysis followed by MnCuFe2O4 photonanocatalysis, sorbitol was successfully obtained from rice straw. The yield sorbitol model in this process is in the form of 2FI (two interaction factors). Optimization using RSM (Response Surface Methodology), genetic algorithm and PSO methods. The optimum yield sorbitol is at UV light power = 125 W and exposure time of 60 minutes. Morphological characterization by scanning electron microscope (SEM) shows granular sorbitol. FTIR shows that sorbitol has characteristics of alcohol (-OH) and alkyl (-CH) functional groups. X-ray diffraction (XRD) give the resulting sorbitol is amorphous sorbitol. Thermogravimetric analysis (TGA) shows that the weight % degrades with increasing temperature, where sorbitol begins to degrade at a temperature of 200°C and a maximum at a temperature of 357°C.

Keywords: *Rice Straw, Sorbitol, Photonanocatalysis, Multistage, Mncufe2o4.*

Introduction

The largest biomass in Indonesia is rice straw (Outlook Energi 2021). Rice straw in its use does not affect the food chain, because rice straw is inedible (Londoño-Pulgarin et al. 2021). The main content of rice straw is cellulose (Ramos et al. 2023). Rice straw consists of cellulose (40–50%), hemicellulose (20–30%) and lignin (10–18%) (Guo et al. 2020), cellulose is trapped in the hemicellulose-lignin matrix, which makes its separation very difficult (Rocha et al. 2020)(Guo et al. 2020).

Cellulose can be converted into sorbitol (Zhang, Zhang, and Chen 2023). The resulting sorbitol is useful for various industries. In the chemical industry, sorbitol is used as a solvent in various chemical industry applications (Dias et al. 2022). In the textile industry, sorbitol can be used in textile manufacturing as a binding agent or lubricant in the dyeing process (Sravan and Spandana 2021). In the cleaning industry, sorbitol is used in household cleaners (Deshmukh, Gogte, and Yenkie 2014). In the dust control industry, Sorbitol is used as a dust binding agent. With its moisture-attracting properties, sorbitol helps to keep dust down and out of the air (Kusnierek, Woznicki, and Treu 2024). In the packaging industry, sorbitol is used to coat packaging materials or as an additive in packaging of moisture-sensitive products, due to its ability to retain moisture and protect the product from drying out (Paudel, Regmi, and Janaswamy 2023). In agriculture, sorbitol is used in fertilizer or pesticide formulations to help stabilize the active ingredient mixture and facilitate application of the product to crops (Production 2008). Sorbitol can also be used as a raw material in the production of biofuels (Torres-Mayanga et al. 2019).

Conversion of cellulose into sugar alcohol can be done by UV *light photocatalysis* using TiO_2 catalyst (Yu et al. 2017), $NiCuFe_2O_4$ catalyst (Rumondang 2017), $NiZnFe_2O_4$ (Safitri 2018), $LaCrO_3$ catalyst (Situmeang et al. 2019), $Ni/LaFeO_3$ catalyst (Iervolino et al. 2021) and ZnO catalyst (Cumba et al. 2022). Photocatalysis has the advantages of being environmentally friendly (Kumari et al. 2023), recyclable (Kumari et al. 2023), stable (Tahir et al. 2020), easy to separate (Tahir et al. 2020)and many other advantages.

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Mn can be used as a photocatalyst in several photocatalytic reactions, Mn-based photocatalytic catalysts have advantages over expensive metal-based catalysts such as titanium or platinum due to their lower cost and high stability. Manganese is more affordable and naturally abundant compared to platinum or gold, making it more economical. Some manganese compounds show good stability under harsh photocatalytic reaction conditions, which allows them to be used in organic pollutant degradation reactions or water splitting to produce hydrogen.

In the sorbitol production process, many variables need to be analyzed. These variables are not few and varied. Direct experiments for all these variables are expensive. The experiment also takes a lot of time and is difficult. These things are what cause the need for an accurate model. Many alternative parameter values in the sorbitol production process require the best solution, which can be obtained by the optimization method.

Therefore, this study conducted the production of sorbitol from rice straw with a multistage process, is NaOH hydrolysis followed by $MnCuFe_2O_4$ photonanocatalysis. The novelty of this study is the use of $MnCuFe_2O_4$ photonanocatalysis to convert cellulose into sorbitol. To obtain process conditions with optimum sorbitol yield , this study also carried out modeling and optimization.

Methodology

Material

In this study, biomass used rice straw. This rice straw came from Rambutan District, Banyuasin Regency. South Sumatra Indonesia. NaOH used is NaOH ≥ 99.0% (E-Merck). H_2SO_4 used for cellulose content testing is H_2SO_4 98 % (E-Merck). $NaClO_2$ used for bleaching stage is $NaClO_2$ 80 % Sigma-Aldrich. Mn $(NO_3)_2.4H_2O$ used is Mn $(NO_3)_2.4H_2O$ 98 % (E - Merck). Cu $(NO_3)_2.3H_2O$ used Cu $(NO_3)_2.3H_2O$ 99 % (E - Merck). Fe $(NO_3)_3.9H_2O$ used is Fe $(NO_3)_3.9H_2O$ 98 % (Pallav). The glycerol used is 99 % glycerol (E-Merck).

Preparation of Cellulose from Rice Straw

Preparation of cellulose from rice straw through 2 stages, is pre-treatment and delignification. In the pre-treatment stage, rice straw is mechanically crushed at 5000 rpm, then soaked in water for 6 hours, then mixed with 7 % wt NaOH, then refluxed at 80°C for 5 hours. This is done to remove lignin and hemicellulose from rice straw and to purify cellulose.

The next stage is delignification. The delignification stage is the results of the pre-treatment stage being filtered and the residue being washed with hot water, then the residue being dried in an oven, then 5,25% $NaClO_2$ solution being added, then refluxed at 110°C for 4 hours. The results were left to cool to room temperature, then filtered and the residue was washed with water until a white cellulose solid was obtained.

Preparation of $MnCuFe_2O_4$ catalyst

$MnCuFe_2O_4$ nanocatalyst was made using the sol gel method. The advantage of this sol gel method is that it produces catalysts with nano size and higher purity. The stages of making $MnCuFe_2O_4$ nanocatalyst are:

Mixing Mn $(NO_3)_2.4H_2O$ in water, Cu $(NO_3)_2.3H_2O$ in water, Fe $(NO_3)_3.9H_2O$ in water and glycerol. The solution is stirred with a magnetic stirrer until homogeneous.

The mixture is heated at a temperature of 80 °C until it forms a gel.

The gel formed is dried to remove water or other solvents. This process produces xerogel which is a porous material.

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Xerogel was ground until smooth and then calcined at a temperature of 600 ◦ C. The initial calcination temperature was at 30 ◦ C, then the temperature was raised by 2 ◦ C/minute to 120 ◦ C, the temperature was held for 2 hours and then heated to 350 ◦ C. The temperature of 350 ◦ C was held for 2 hours, then the temperature was raised again to 600 ◦ C, the temperature was held for 2 hours. Then it was stopped and left to stand until room temperature.

Problem Formulation

The problem formulation in this study is objective function, constraints and optimization variables. The objective function in this study is the maximum yield sorbitol. The constraints in this study is the UV light power of 0-125 watts and the UV light exposure time is 0-60 minutes. Optimization variables in this study is the UV light power and the irradiation time.

Experimental Design

In this study, the factors that affect the yield sorbitol is UV light power and irradiation time. The UV light power factor has 2 levels, is 60 and 125 watts. The irradiation time factor has 3 levels, is 30 minutes, 45 minutes and 60 minutes. The experimental design in this study used the Taguchi method. Taguchi uses an orthogonal array (OA). The appropriate orthogonal array is L6. L6 (2^1 x 3^1) means that there are 6 experiments. The Taguchi experimental design with L6 can be seen in Table 1. Each run was carried out 3 replicates.

Table 1. DOE

Run	UV *light* power (watt)	Exposure time (minutes)
1	60	30
2	60	45
3	60	60
4	125	30
5	125	45
6	125	60

Photonanocatalytic Activity Test

Conversion Cellulose to Sorbitol

Photonanocatalytic activity test on $MnCuFe_2O_4$ nanocatalyst was conducted on the conversion of cellulose to sorbitol. 10 grams cellulose was mixed into 100 mL distilled water, then 1 gram of $MnCuFe_2O_4$ nanocatalyst was added and hydrogen gas was flowed at a rate 10 mL/minute. After that, a UV lamp was installed, where the position of the UV lamp was at a distance of 10-15 cm to the surface of the reactor. The variable power of the UV lamp energy used was 60 W and 125 W. The variable time of the UV irradiation process on the conversion of cellulose to sorbitol was 30, 45 and 60 minutes. The resulting samples were analyzed using an HPLC instrument.

Analysis of Sorbitol By HPLC

From the results of point 2.6.1, an analysis was carried out to determine the sorbitol content contained with an HPLC instrument. The HPLC instrument used has a CLC-NH2 column (4.6 x 250 mm), RID-20A detector, a flow rate of 1 mL/min with a column temperature of 80 ◦ C. The working procedure in HPLC uses a standard sorbitol solution to determine the comparison of retention time with the sample being analyzed. 20 µL of a 2 gram/L sorbitol standard solution was injected into the column. The solution was left until the standard solution components came out of the column and the retention time was recorded. The mobile phase used was distilled water.

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Yield Sorbitol

Yield in production is the ratio between the amount of production output and production input that describes the value of production efficiency. The production output in this study is sorbitol. The production input for this second stage is cellulose. The results of HPLC analysis can be used to calculate the yield of sorbitol. The yield of sorbitol can be calculated using Equation 1.

$$\text{Yield sorbitol} = \frac{\text{mol sorbitol}}{\text{mol cellulose}} \text{ X } 100\ \% \quad [1]$$

Modeling

A mathematical model describing sorbitol yield is needed to follow the effect of UV light power and irradiation time on the sorbitol production process from cellulose. The unavailability of rice straw properties in batches, lack of understanding of the effect of UV light power and irradiation time on yield sorbitol, lack of understanding of $MnCuFe_2O_4$ nanocatalysts, lack of understanding of photonanocatalysis causes the need for an empirical model. An empirical model involving a number of parameters can be made with experimental data. The empirical model uses dependent variables, is yield sorbitol. The empirical model has 2 independent variables, is UV light power and irradiation time.

Optimization

Optimization yield sorbitol in the sorbitol production process from cellulose obtained from rice straw contains 2 types of factors, is UV light power and irradiation time. In this study, optimization was carried out using 3 methods, is RSM, GA and PSO. RSM is a statistical instrument for experimental design, empirical modeling, and factor impact assessment. RSM can reduce the number of experimental tests needed to assess various parameters and their interactions (Thakur et al. 2020). The two factors of this study were examined through a central composite design. The UV light power factor varied at two levels, is 60 W and 125 W. The irradiation time factor had 3 levels, is 30, 45 and 60 minutes. The design produced 6 experiments (Table 1). By using the reaction surface model and point prediction from specialist design software, the ideal expected values of the variables can be obtained. Validation of the study was carried out in 3 replicas. The measured reaction was given with the predicted response to validate the corresponding values.

Genetic Algorithm (GA) is a promising technique for solving nonlinear and complex problems, and has been used for optimization of several chemical engineering problems well (Biyanto 2013). In general, GA is the most efficient optimization technique in terms of function evaluation. Solving nonlinear problems using GA has been proven to be a valid approach, where computation time is not the most important thing (L. Costa dan P. Oliveira 2001). In this study, the population generation and parameters are as follows:

Nvar = 2; % number of optimized design variables (factors)

Nbit = 20; % number of bits

Npop = 100; % population (Population x Generation)

Maxit = 200; % iterations, generations

Pc = 0.85; % crossover probability

Pm = 0.005; % mutation probability

El = 0.05; % elitism

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Particle Swarm Optimization (PSO) (Biyanto 2013)(Sateria, Dwi Saputra, and Dharta 2018)is an optimization method that can be used to determine process parameters that produce optimum response values. PSO imitates the social behavior of a flock of birds or fish in a natural habitat. Each individual or particle behaves by using its own intelligence and is also influenced by the behavior of its collective group. When one particle or a bird finds the right or shortest path to a food source, the rest of the group will also be able to immediately follow the path even though their location is far from the group. Each individual or particle is treated like a point in a certain spatial dimension. There are two factors that characterize the particle status in the search space, namely the particle position and the particle velocity. The following is a mathematical formulation that describes the position and velocity of particles in a certain spatial dimension:

$$X_j(i) = X_1(1), X_2(1), \ldots, X_{jN}(i)$$

$$V_j(i) = V_1(1), V_2(1), \ldots, V_{jN}(i) \quad [2]$$

With:

T = position of particle

R = particle velocity

E = Eth iteration

F = particle index

0 = number of particles

The equation for the particle state update mechanism is as follows:

$$V_j(i) = V_j(i-1) + c_1 r_1 (P_{best,j} - X_j(i-1)) + c_2 r_2 (G_{best,j} - X_j(i-1))$$

$$X_j(i) = V_j(i) + X_j(i-1) \quad [3]$$

With

J = 1,2, …, N represents the number of particles.

Obj_i = response from experiment

$P_{best,j}$ = personal best of the jth particle

$G_{best,j}$ = global best of the whole flock

c_1, c_2 = learning factor

Equation 3 is used to calculate the new particle velocity based on the previous velocity, the distance between the current position and the best particle position (personal best) and the distance between the current position and the best position of the swarm (global best). The particle then moves to the new position. This PSO algorithm is run with a certain number of iterations until it reaches the stopping criteria, so that a

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solution will be obtained that lies in the global best. This equation will be simulated in a space with a certain dimension with a number of iterations, so that in each iteration the particle position will increasingly lead to the intended target (minimization or maximization of the function value). This is done until the maximum iteration is reached or another stopping criterion is reached.

Characterization

After obtaining the optimal process parameters, the resulting sorbitol product was subjected to characteristic analysis using SEM, FTIR, XRD and TGA.

*Scanning Electron Microscopy (Sem***)**

SEM-EDX was used to examine the microscopic structure and surface morphology of sorbitol fibers. SEM was performed at an acceleration voltage of 20kV (Fischer et al. 2014). Gold coating was performed before scanning.

Fourier Transform Infrared (FTIR) Spectroscopy

FT-IR was used to determine functional groups (Kunusa et al. 2018). FT-IR was performed on a spectrometer operating at a transmission range of 500–4000 cm $^{-1}$ (Khan et al. 2020). FT-IR test was conducted to see the presence of sorbitol content. FTIR spectra for all test objects were recorded in several parts of the wave band ranging from 500–4000 cm $^{-1}$ using the ATR method (Lei et al. 2018).

X-Ray Diffraction (XRD)

X-ray Diffraction (XRD) analysis aims to determine the percentage of crystal and amorphous content in sorbitol. High crystallinity was obtained using an X-ray diffractometer equipped with Cu Kα (α=0.154nm) in the 2θ range between 5–90, (battery energy settings: 40kV and 30mA). An empirical method was used to obtain the crystallinity index, Xc of the sample as shown in Equation 4 (Teixeira et al. 2011)

$$Xc = \frac{I_{002} - I_{am}}{I_{002}} X\ 100 \qquad [4]$$

where I_{002} and I_{am} are the peak intensities of crystalline and amorphous materials respectively. Equation 5, is the Scherrer equation, is used to calculate the crystallite size.

$$\tau = \frac{K\lambda}{\beta \cos\theta} \qquad [5]$$

Where,

τ is the crystal dimension perpendicular to the diffraction plane with Miller index hkl

λ is the wavelength of X-ray radiation (λ=0.154Å)

β is the full width at half maximum (FWHM) of the diffraction peak (Bhattacharya, Germinario, and Winter 2008)

Thermo Gravimetric Analysis (TGA)

TGA measurements of sorbitol samples were carried out at a heating rate of 10°C min^{-1} under N_2 atmosphere (20 ml min^{-1}) using TGA. The weight of the sample was taken as 6.0688 mg and stored in a desiccator until weighed. TGA was carried out to observe the degradation characteristics of the sorbitol

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samples. The samples were held for 1 min at 40 °C and then heated at a rate of 10 °C min $^{-1}$ from 40 °C to 1000 ⁰ C. During the heating period, the weight fraction and temperature difference were recorded as a function of temperature.

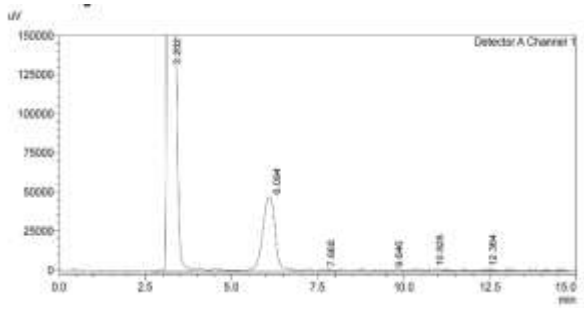
Results and Discussion

Experimental Results

The results of HPLC analysis with UV light power of 60 W and exposure time of 60 minutes can be seen in Figure 1. Figure 1 shows that there are 2 peaks. The peak at a retention time of 3.202 minutes is water and the peak at a retention time of 6.094 minutes is sorbitol. The effect of UV light power on sorbitol yield can be seen in Figure 2. Figure 2 shows that with increasing UV light power to 125 W, the sorbitol yield increases. This is because higher UV light intensity is able to provide more energy to the system. This can accelerate chemical reactions that depend on UV photons to break or form chemical bonds. In addition, higher UV intensity can increase the production of reactive species which are often needed to increase the reaction rate. With more energy from UV light available, more target molecules can be involved in the reaction, thereby increasing the yield of the desired product. The Pareto chart for sorbitol yield can be seen in Figure 3. The UV light power is above the Bonferroni red line, indicating that UV light power is a factor that has a significant effect on yield sorbitol. Based on the Pareto chart, UV light power has a positive effect. This means that the higher the UV light power, the higher the yield sorbitol. This is in accordance with the research of Reiß et al. that the greater the UV light power , the greater the yield obtained (Reiß et al. 2021) (Molinari, Lavorato, and Argurio 2020)(Kowalska, Rau, and Ohtani 2012)(Kuipers 2014)(Yu et al. 2017). In this study, ANOVA analysis was also performed. ANOVA analysis for yield sorbitol can be seen in Figure 4. From the ANOVA analysis, UV light power has a p-value <0.0001. This shows that UV light power is a factor that has a significant effect on yield sorbitol.

Figure 1 also shows that the longer the exposure to UV light up to 60 minutes, the higher yield sorbitol. This is because the longer exposure (the right exposure time) can provide enough energy to accelerate or activate chemical reactions. With longer exposure (the right exposure time), it has high photon energy that can break chemical bonds or promote molecules to an excited state, so that these molecules are more reactive. This can accelerate the reaction rate, increase product formation which has an impact on increasing yield. Based on Figure 2, the duration of UV light exposure is above the Bonferroni red line, indicating that the duration of UV light exposure is a factor that has a significant effect on yield sorbitol. This is in accordance with the research of Hassaan et al. (Sorathiya et al. 2016)(Situmeang et al. 2019)(Hassaan et al. 2023). Based on the Pareto chart, the duration of UV light exposure has a positive effect. This means that the longer exposure, the higher yield sorbitol. From the ANOVA analysis, the exposure time has a p-value of 0.0006. This shows that the exposure time is a factor that has a significant effect on yield sorbitol.

Based on the Pareto chart, the T-value of the UV light power factor has a higher value than the exposure time. The T-value of the UV light power factor is 6.17. The T-value of the UV light exposure time factor is 4.24. This shows that UV light power is a more significant factor than the UV light exposure time in providing yield sorbitol.



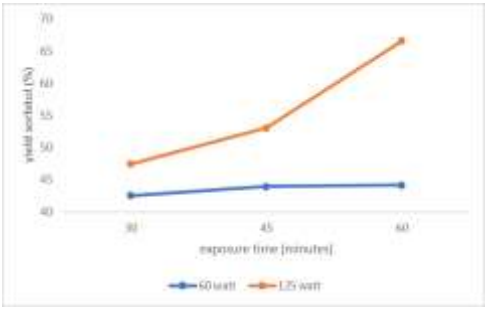


Figure 1. HPLC Analysis at 60 W for 60 Minute Figure 2. Experimental Data

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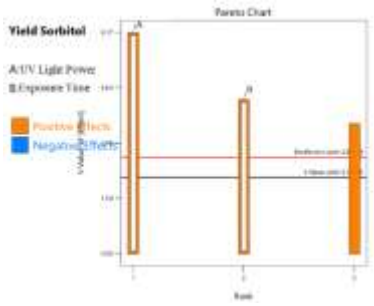

ANOVA for selected factorial model

Response 1 : Yield Sorbitol

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	986.05	2	493.02	28.24	< 0.0001	significant
A-UV light Power	664.06	1	664.06	38.03	< 0.0001	
B-Exposure time	321.99	1	321.99	18.44	0.0006	

Figure 3. Pareto Chart **Figure 4. ANOVA**

Modeling

Jones et al. put forward two main objectives of modeling, is first to gain a better understanding of the cause-effect relationships in a system, and to provide better qualitative and quantitative interpretations of the system. The second objective of modeling is more applied or problem-oriented, namely to gain better predictions of the behavior of the system that is used immediately in improving control or management of the system. (Jones and Palmer 1987). Modeling the production process sorbitol uses experimental data that has been explained in point 3.1 by drawing a causal relationship with the influence of UV light power. and exposure time which affects the yield sorbitol.

The response surface methodology using design center composites was used to determine the variables that affect the results. The relevant factors is UV light power and exposure time. This analysis aims to determine the mathematical model that will be used to describe the phenomenon of the research results. Determining the type of mathematical model to be used depends on the p-value of the model, so that the suggested model can be determined. There are mathematical model tests, is Sequential Sum of Summary and model summary statistics.

Sequential Sum of Summary analysis on the response states that the model is acceptable if p value has a value below 5% (0.05), which indicates that the value has a real influence on the response, while p value has a value of more than 5%, then the model has an inaccuracy or error exceeding 5%, and is considered inaccurate to the response. The 2FI model (2 factor interaction), shows a p value of < 0.001, so the 2FI model has an inaccuracy to the response of < 0.1%. In the Model Summary Statistics test, the parameters used in selecting the right model are the lowest standard deviation, the highest R-square (R^2), the highest Adjusted R^2, the highest Predicted R^2 and the lowest PRESS. R^2 is a coefficient of determination that shows the proportion or percentage of total variation in the dependent variable explained by the independent variable from the regression equation. The R^2 value between 0 and 1. The smaller R^2 value indicates the relationship between the variables is also lower and vice versa the larger R^2 (approaching 1), then the relationship of the variables is greater. In the R^2 test, a good model is a model has R^2 close to 1. The standard deviation in the 2FI model is 1.51. The R^2 in the 2FI model is 0.9743. The Adjusted R^2 in the 2FI model is 0.9688. The R^2 prediction in the 2FI model, is 0.9619. The Model Summary Statistics test also takes into account the PRESS (Prediction Error of Sum of Squares) value. The PRESS value is used to indicate the prediction sum of squares error of the model. The PRESS value on the 2FI model type is 47.53.

The conclusion of all types of mathematical model testing above, is Sequential Sum of Summary and Model Summary Statistics , explains the relationship between UV light power and exposure time.on yield sorbitol is the 2FI model. The results of the influence UV light power and exposure time, which results in yield sorbitol can be seen in Equation 6, which is an equation in the form of 2FI .

Yield sorbitol = 54.12111 – (0.217111 X UV light power) – (0.485111 X exposure time) + (0.008978 X UV light power X exposure time) [6]

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Model Verification

Model testing using Sequential Sum of Summary, Model Summary Statistics , Sum of Square test , normal plot of residual , residuals - predicted plot and residuals - order plot . The Sequential Sum of Summary test gives the result of Equation 6 has a p value < 0.001, which means the inaccuracy of the model shown is below the 5 %, so the model is appropriate.

Model Summary Statistics test gives an R^2 is 0.9743. R2 is close to 1. The smaller standard deviation, model better to predicting the response. This shows that the Equation 6 can be stated as appropriate.

In the Sum of Square test, a model is declared appropriate if the Adjusted R^2 and Predicted R^2 have a difference of less than 0.2. The Adjusted R^2 in this study is 0.9688 and the Predicted R^2 is 0.9619. This study has a difference Adjusted R^2 and Predicted R^2 less than 0.2, so the Equation 6 can be declared appropriate.

The normal plot of residuals in this study can be seen in Figure 5. Figure 5 shows that all points (experimental data) are around the red line and do not form a pattern, indicating that the residuals are normally distributed. Normally distributed residuals are needed to estimate accurate standard errors for model parameter estimates. A suitable model is one that has a normal or near-normal residual data distribution. This study has normally distributed residuals, so the Equation 6 can be stated as appropriate.

Residuals - predicted plot in this study can be seen in Figure 6. Figure 6 shows all residual data in the study are between the red lines. This indicates that there are no outliers. Outliers are observations that do not fit the model. With no outliers, the Equation 6 can be stated as appropriate.

The residuals - order plot of this study can be seen in Figure 7. The residuals - order plot provides an examination of hidden variables that may affect the response during the study. Figure 7 shows a random distribution and does not form a pattern. With this random distribution, the Equation 6 can be stated as appropriate.

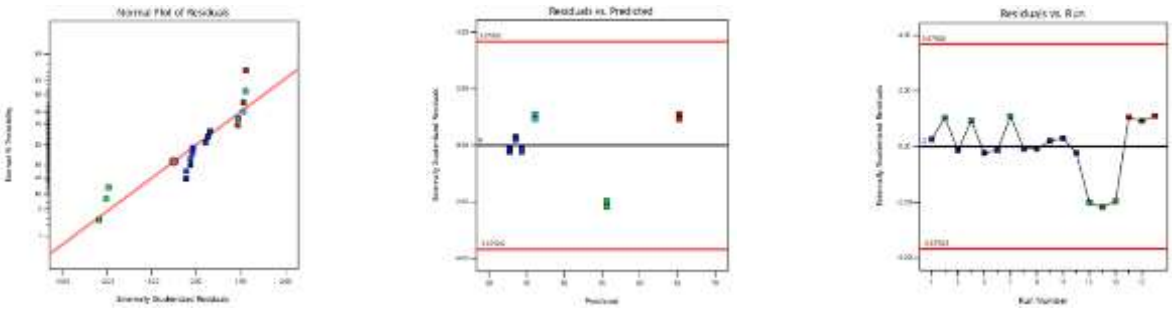

Figure 5. Normal Plot of Residuals Figure 6. Residuals - Predicted Plot Figure 7. Residuals - Order Plot

Model Validation

Error prediction to the actual for yield sorbitol was less than 5 %, both at 60 and 125 W UV light power with exposure times of 30, 45 and 60 minutes. Predictions for yield sorbitol can be seen in Table 2. Table 2 shows that the error in the predicted yield sorbitol compared to the actual yield was a maximum of 4.9 %.

ANOVA of yield sorbitol model has an F-value 28.24 and P-value < 0.01 %, which means the model is significant. The UV light power and exposure time have a significant effect on the response indicated by P-value of less than 0.05. If P-value is less than 0.05, then the parameters vary and the analysis results are statistically significant (Carvalho et al. 2021). R^2 value indicates the extent to which the model is able to predict the response. The coefficient of determination (R^2) yield sorbitol model is 0.9743. In this case, the data from the observed values with the predicted values indicate that the model is significant.

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Table 2. Validation of Research Model

No	UV Light Power (W)	Exposure Time (minutes)	Yield Sorbitol Actual (%)	Yield Sorbitol Prediction (%)	Error (%)
1	60	45	43,9	43,505055	0,899647
2	125	30	47,44	46,096405	2,832199
3	60	30	42,53	42,70152	-0,40329
4	125	30	47,3	46,096405	2,544598
5	60	30	42,4	42,70152	-0,71113
6	60	60	44,14	44,30859	-0,38194
7	125	30	47,5	46,096405	2,954937
8	60	60	44,2	44,30859	-0,24568
9	60	30	42,6	42,70152	-0,23831
10	60	45	43,81	43,505055	0,696063
11	60	45	43,95	43,505055	1,012389
12	60	60	44,01	44,30859	-0,67846
13	125	45	53,05	55,65349	-4,90762
14	125	45	53,04	55,65349	-4,92739
15	125	45	53,1	55,65349	-4,80883
16	125	60	66,56	65,210575	2,027381
17	125	60	66,4	65,210575	1,791303
18	125	60	66,62	65,210575	2,115618

For validation of models other than those explained above, this study also uses RMSE values. The RMSE value for sorbitol yield is 1.32. The normalized RMSE for sorbitol yield is 0.33. This shows that the smaller the level of prediction error, the more accurate the prediction results will be.

Optimization

Optimization is the process of finding one or more solutions related to the values of one or more objective functions in a problem so that an optimal value is obtained (Berlianty, I., & Arifin 2010). In general, optimization means finding the best value (minimum or maximum) of several functions given in a context. Optimization can also mean an effort to improve performance so that it has good quality and high work results. Mathematically, optimization is a way to get extreme prices, either maximum or minimum, of a particular function with its limiting factors. If the problem to be solved is to find the maximum value, then the decision is in the form of maxima (Sari 2014). Optimization is one of the disciplines in mathematics that focuses on systematically obtaining minimum or maximum values from a function, opportunity, or other value searches in various cases. Optimization can almost be used in various fields to achieve the effectiveness and efficiency of the desired target. One of the goals of optimization is to determine the minimum, so the goal in the mathematical model is minimization (Maharani 2015).

In this study, optimization was carried out to obtain maximum yield sorbitol with minimum UV light power and minimum exposure time. The objective function in this study was the maximum yield sorbitol. The decision variables were minimum UV light power and exposure time. Optimization was carried out using 3 types of optimization methods, is RSM (Response Surface Methodology), genetic algorithm and PSO method.

Based on the results of the response surface analysis, the 2FI model will be shown on the contour plot and surface plot of the magnitude of roughness surface. Each analysis result, surface plot surface roughness shown in Figure 8, while the contour plot is shown in Figure 9.

Yield sorbitol optimization with the RSM method can be seen in Figure 10 (a), yield sorbitol optimization with the genetic algorithm method can be seen in Figure 10 (b), yield sorbitol optimization with the PSO method can be seen in Figure 10 (c). Figure 10 shows that the maximum yield sorbitol with both the RSM, genetic algorithm and PSO method produced consistent results, is the maximum at 125 W UV light power and 60 minutes exposure time.

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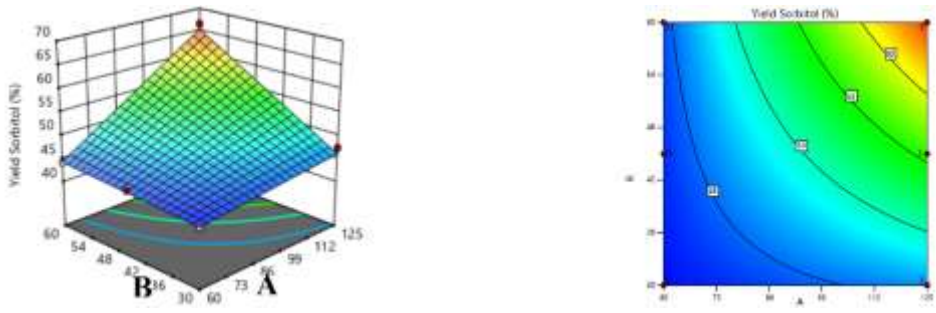

A : UV Light Power (W)

B : Exposure Time (minutes)

Figure 8. Surface Plot of Power and Exposure Time. Figure 9. Contour Plot of Power and Exposure Time

Number	UV Light Power (W)	Exposure Time (minutes)	Yield Sorbitol (%)	Desirability	
1	**125.000**	**60.000**	**65.209**	**0.942**	**Selected**

(a)

(b) (c)

Figure 10. Optimization of Yield Sorbitol Using the Method (a) RSM, (b) Genetic Algorithm, (c) PSO.

SEM Characteristic Results

Sorbitol obtained at optimum yield sorbitol, is at UV light power 125 W and exposure time 60 minutes, was analyzed by SEM. The results of SEM analysis is shown in Figure 11 (a). Figure 11 (a) shows the microscopic structure and surface morphology of sorbitol. Sorbitol is granular. This is in accordance with the results of Marushka's research (Marushka et al. 2022), where the SEM results of sorbitol in Marushka's study can be seen in Figure 11 (b).

FTIR Characteristic Results

FT-IR was used to determine functional groups (Kunusa et al. 2018). Sorbitol obtained at optimum yield sorbitol, is at UV light power 125 W and exposure time 60 minutes, was analyzed by FTIR. The results of the FTIR analysis is shown in Figure 12 (a). Figure 12 (a) shows, main peak of sorbitol is a typical absorption peak associated with alcohol (-OH) and alkyl (-CH) functional groups. The OH peak is located at around 3200–3600 cm^{-1}, indicating the upright vibration of the OH bond. CH stretching is at a peak around 2800–3000 cm^{-1} indicating the vibration of the CH bond. The peak at 1400-1450 cm^{-1} is associated with CH deformation. The peak at 1000-1200 cm^{-1} indicates the vibration of the C-O bond, which is important for identifying the presence of alcohol in the sorbitol molecule. This is in accordance with the results of Basu's

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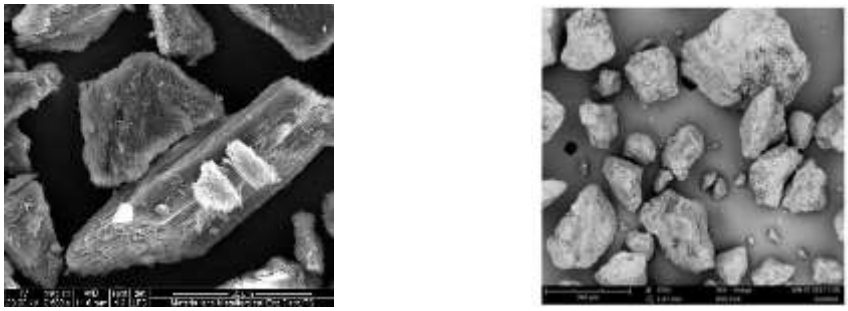
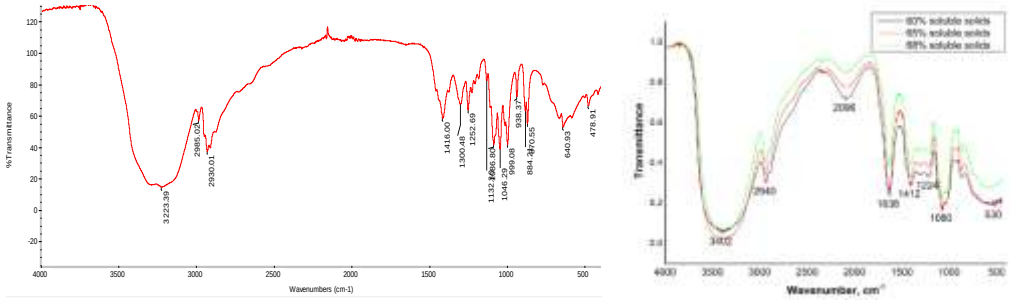
research (Basu et al. 2011), where the FTIR results of sorbitol in Basu's research can be seen in Figure 12 (b).



(a) (b)

Figure 11 (a). SEM Sorbitol Experiment at Optimum Conditions in this Study (b) SEM Sorbitol Marushka Research (Marushka et al. 2022)



(a) (b)

Figure 12 (a). FTIR Sorbitol Experiment at Optimum Conditions in this Study (b) FTIR Sorbitol Basu Research (Basu et al. 2011)

XRD Characteristic Results

Sorbitol obtained at optimum yield sorbitol, is at UV light power 125 W and exposure time 60 minutes, was subjected to XRD analysis. The results of XRD analysis are shown in Figure 13 (a). XRD is used to study the behavior of crystals and to evaluate the relationship between structure and crystal characteristics. Sorbitol in its molecular structure is amorphous, this means that the molecular structure of sorbitol is random. There is no regular arrangement of sorbitol molecules, which causes this structure to be called amorphous. Sorbitol molecules are randomly distributed and do not form a crystal lattice like in the crystalline form. In addition, the solubility of amorphous sorbitol is faster. Amorphous sorbitol tends to be more soluble in water than the crystalline. In addition, amorphous sorbitol absorbs moisture from the air more easily. From Figure 13 (a), the XRD diffraction pattern of sorbitol shows peaks that match the characteristic peaks of the sorbitol structure of DeJong's research (DeJong and Hartel 2021)

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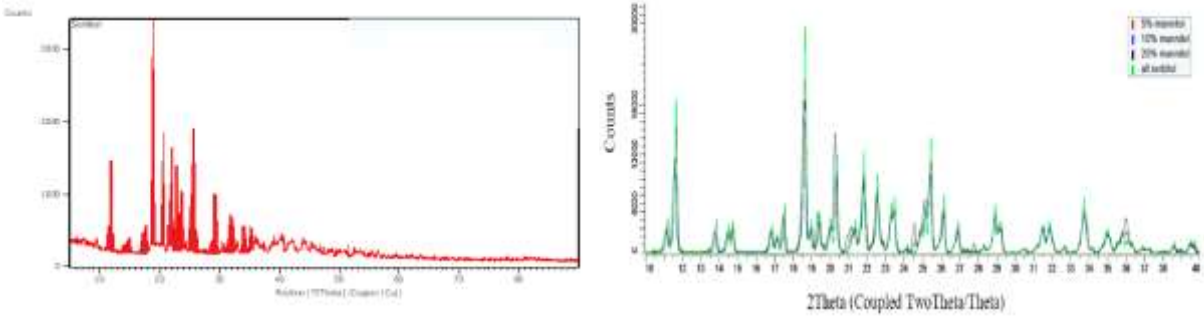
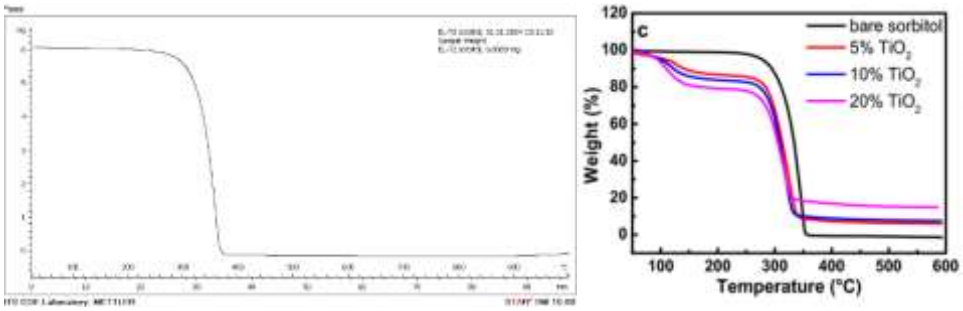


(a) (b)

Figure 13 (a). XRD Sorbitol Experiment at Optimum Conditions in this Study (b) XRD Sorbitol DeJong Research (DeJong and Hartel 2021)

TGA Characteristic Results

Sorbitol obtained at optimum yield sorbitol, is at UV light power 125 W and exposure time 60 minutes, was subjected to TGA analysis. The results of the TGA analysis are shown in Figure 14 (a). The TGA results for sorbitol in this study are in accordance with the TGA results for sorbitol in Jyoti's study (Jyoti Saroha, Sonali Mehra 2021) (Sokker et al. 2005)shown in Figure 14 (b). Figure 14 shows that % weight experiences degradation (mass reduction) along with increasing temperature. Figure 14 also shows that sorbitol begins to experience degradation at a temperature of 200^{o}C and a maximum at a temperature of 357^{o}C.



(a) (b)

Figure 14 (a). Experimental Sorbitol TGA at Optimum Conditions in this Research (b) Sorbitol TGA Jyoti Research (Jyoti Saroha, Sonali Mehra 2021).

Conclusion

The conclusion of this study is $MnCuFe_2O_4$ photonanocatalysis can be convert cellulose into sorbitol. Based on the results of SEM, FTIR, XRD and TGA showed that by using multistage, is NaOH hydrolysis followed by $MnCuFe_2O_4$ photonanocatalysis, sorbitol was produced from rice straw. The yield sorbitol model is in the form of 2FI. Optimization of yield sorbitol can be done by using RSM, genetic algorithm and PSO method. Optimum yield sorbitol at UV light power 125 W and exposure time 60 minutes.

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