

Optimization of Cellulose Acetate with Acetylation from Empty Fruit Bunch (EFB) using Respon Surface Methodology (RSM)

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Abstract. Empty fruit bunches (EFB) are a kind of biomass waste from the palm oil industry with a cellulose content of 45.95%. Cellulose can be modified into cellulose acetate through an acetylation process, resulting in a product that has the potential to be applied in various industrial fields. The study utilised Response Surface Methodology (RSM) as an optimisation technique by examining multiple process parameters to assess the impact of acetate anhydride ratio, reaction temperature, and reaction duration on the yield and degree of substitution (DS) of cellulose acetate produced from empty palm fruit bunches. This approach enables a systematic assessment of the impact and interplay between various process factors. The research variables used include the ratio of acetic anhydride to cellulose (2:1, 4:1, and 6:1), reaction temperature (30, 60, and 90°C), and reaction time (20–100 minutes). The research methods included the TKKS isolation process, the production of cellulose acetate through acetylation, and characterization based on yield and degree of substitution values. Experimental conditions determined through response surface methodology were met at a 6:1 acetic anhydride to cellulose ratio, a 60°C reaction temperature, and a 100-minute reaction duration. These conditions yielded a 96%, a degree of substitution (DS) of 1.1, and a desirability value of 0.975. Therefore, the optimization of this acetylation process demonstrates the potential of TKKS as a raw material for the production of value-added cellulose acetate that supports the development of environmentally friendly materials.

1 Introduction

Indonesia is the world's largest palm oil producer. According to the Central Statistics Agency, palm oil production in Indonesia is around 1,887,999–2,197,217 tons per year. Oil palm plantations produce increasing amounts of fruit bunches and generate solid waste in the form of TKKS. One ton of oil palm fruit bunches produces 23% or 230 kg of EFB waste[1]. In 2017, 31 million tons of EFB were produced, and this amount continues to increase in line with oil palm production. However, the EFB produced has not been

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optimally utilized[2]. If not managed properly, this waste can have serious environmental impacts [3]. EFB has added value potential because it contains 45.95% cellulose, 22.84% lignin, and 16.59% hemicellulose[4]. EFB has a high cellulose content. The cellulose produced can be used as a raw material for various environmentally friendly industries. This can reduce the impact of palm oil waste [5]. However, its use is limited due to the rigid nature of pure cellulose, which is insoluble in organic solvents and non-thermoplastic. Therefore, cellulose can be modified by acetylation. This process replaces hydroxyl groups with acetyl groups to produce cellulose acetate, which has more flexible characteristics, increased solubility, and heat resistance [6].

Cellulose acetate is mostly used in making plastics, paints, films, cigarettes, filters, textiles, and medicines [7]. Various studies have shown the success of the acetylation process using a variety of raw materials. One study conducted by Bello et.al, (2016) on the acetylation of cotton stems showed that the optimum conditions for the acetylation process were 2.76 hours using a 6.09% sulfuric acid catalyst at a temperature of 40°C with a ratio of glacial acetic acid to cellulose of 6:1 and a ratio of acetic anhydride to cellulose of 4.36:1. The FTIR and XRD results indicated that cellulose acetylation had been successful, characteristic by the presence of acetyl groups, a decrease in the number of OH groups, and a transformation in the cellulose structure from an initially rigid to a more irregular and flexible form.

Based on previous studies, cellulose has been modified into cellulose acetate from various biomass sources. However, studies focusing on cellulose acetate specifically produced from EFB are still limited, especially in terms of systematic process optimization that considers the combined effects of acetylation parameters such as the ratio of acetic anhydride to cellulose, reaction temperature, and reaction time. Furthermore, the relationship between yield and degree of substitution (DS), which is important for evaluating process efficiency and product characteristics, has not been discussed in depth for EFB-based cellulose acetate.

Therefore, this study focuses on optimizing the acetylation process of cellulose derived from EFB using the Response Surface Methodology (RSM). RSM provides an efficient statistical approach to evaluate the individual effects and interactions of various process variables simultaneously, enabling optimization of reaction conditions with fewer experiments. The application of RSM is expected to improve the efficiency of the acetylation process and strengthen the potential of cellulose acetate derived from EFB as an environmentally friendly raw material for various industrial applications.

2 Materials and Methods

2.1 Materials

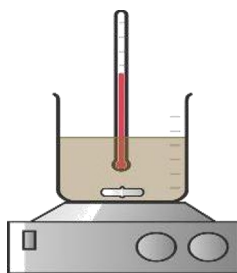


Fig. 1. Experimental setup for cellulose acetate preparation from EFB

The equipment used in this study included 500 ml beakers (Pyrex), magnetic stirrers, thermometers with a measurement range of 0–110 °C (Ludwig), and heating plates (Dlab MS-H280-Pro) with a maximum operating temperature of 300 °C, as shown in Figure 1. The main raw material used was cellulose obtained from empty fruit bunches (EFB) of oil palm obtained from PT. Sawit Arum Madani, Blitar, Indonesia. The chemicals used in this process included 10% by weight sodium hydroxide (NaOH, technical grade), 3% by weight hydrogen peroxide (H₂O₂, technical grade), and 1 N sulfuric acid (H₂SO₄, technical grade), all supplied by CV. Chemical Indonesia Multi Sentosa. Anhydrous acetic acid (pro analys grade) was purchased from Merck.

2.2 Methods

2.2.1 Preparation of raw materials

The EFB is washed with distilled water to remove dirt and dust, then dried until its weight stabilizes. The dried EFB is ground into powder and filtered using a 100-mesh sieve to obtain uniform particle size before the cellulose isolation process.

2.2.2 Isolation cellulose

25 g of EFB powder is mixed with 200 mL of 10% NaOH solution (technical grade) and heated at 90°C for 1 hour with continuous stirring to remove non-cellulose components. The resulting pulp is filtered and washed with distilled water until a neutral pH is achieved. The bleaching process was carried out using 100 mL of 3% H₂O₂ solution (technical grade) at 90°C for 1 hour with stirring. The bleached pulp was washed repeatedly with distilled water until a neutral pH was achieved and dried in an oven at 110°C until a constant weight was achieved.

2.2.3 Production of cellulose acetate

5 grams of cellulose were reacted with 50 ml of glacial acetic acid, stirred for 1 hour at a speed of 200 rpm at a temperature of 38°C. The solution was added with 0.8 ml of 1 N sulfuric acid, then added with acetic anhydride (ratios of 2:1, 4:1, 6:1) at temperatures (30, 60, 90°C) and reaction times (20, 40, 60, 80, 100 minutes). Then, 2 ml of distilled water was added to the solution and stirred for 30 minutes. The solution was filtered and washed with distilled water until neutral. The solution was dried in an oven at 110°C until dry, then ground and filtered. Thus, the product obtained was cellulose acetate.

2.2.4 Determination of cellulose acetate yield (%)

The yield of cellulose acetate is calculated based on the ratio between the final mass of dry cellulose acetate product obtained after the acetylation process and the initial mass of cellulose used. After the acetylation process is complete, the product is filtered, washed to a neutral pH, and dried in an oven at 110°C to a constant weight. Productivity (%) is calculated using the following equation:

$$\text{yield (\%)} = \left(\frac{\text{dry cellulose acetate mass}}{\text{initial cellulose mass}} \right) \times 100\% \quad (1)$$

2.2.5 Determination of degree of substitution (DS) of cellulose acetate

0.1 grams of cellulose acetate was dissolved in a mixture of 5 mL of 0.25 M NaOH solution and 5 mL of ethanol, then left to stand for 24 hours at room temperature. After that, 10 mL of 0.25 M HCl solution was added to the mixture and left to stand for 30 minutes. Next, the mixture was titrated using a 0.25 M NaOH standard solution with phenolphthalein indicator until a color change occurred. This procedure was performed in three replicates. The percentage of acetyl group (%AG) was calculated using the following formula [7]:

$$\%GA = \frac{\{(V_{bi}+V_{bt})\cdot\mu_b-(V_a\cdot\mu_a)\}\cdot M\cdot 100}{mac} \quad (2)$$

$$DS = \frac{386 \times \%GA}{10240 \times \%GA} \quad (3)$$

V_{bi} = volume of NaOH added to the system (L)

V_{bt} = volume of NaOH consumed in the titration (L) V_a = volume of HCl added to the system (L)

μ_a = HCl concentration (M)

μ_b = NaOH concentration (M)

M = molar weight of acetyl group (43 g mol^{-1}) Mac = weight of cellulose acetate sample (g)

Table 1. Determination of independent variables and treatment symbols in the research.

Independent variable	Symbol	Levels and range		
		-1	0	1
Ratio of acetic anhydride to cellulose	A	2 : 1	4:1	6 : 1
Reaction time	B	20	60	100
Reaction temperature	C	30	60	90

Table 2. yield response data and degree of substitution from the BBD design

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2
	A : Acetic anhydride to cellulose ratio (gram)	B : Reaction time (minutes)	C : Reaction Temperature	Yield (%)	DS
1	4	60	60	89	0.27
2	4	60	60	87	0.27
3	4	20	90	84	0.24
4	4	100	30	91	0.56
5	2	20	60	85	0.12
6	2	100	60	88	0.56
7	2	60	30	84	0.20
8	6	60	90	89	0.79
9	6	100	60	96	1.15
10	4	60	60	88	0.19
11	4	60	60	88	0.28
12	4	20	30	83	0.16
13	4	100	90	86	0.71

14	6	60	30	92	0.52
15	6	20	60	87	0.39
16	2	60	90	86	0.32
17	4	60	60	89	0.30

2.2.6 Experimental design for acetylation process optimization using Response Surface Methodology (RSM)

The cellulose acetylation process was optimized using Response Surface Methodology (RSM) with Box–Behnken Design (BBD) implemented in Design-Expert software. BBD was chosen because it is efficient in modeling quadratic response surfaces while requiring fewer experiments than full factorial designs. In addition, BBD avoids experimental combinations at extreme factor levels, which is beneficial for chemical reaction systems because it minimizes the risk of unwanted side reactions and material degradation.

This study used three independent variables, namely the ratio of acetic anhydride to cellulose (A), reaction time (B), and reaction temperature (C). The responses evaluated were the yield of cellulose acetate and the degree of substitution (DS). The levels of each independent variable are presented in Table 1, and the experimental matrix generated by BBD, consisting of 17 experimental runs, is shown in Table 2.

3 Result and Discussion

3.1 Model adequacy and statistical analysis (ANOVA Evaluation)

ANOVA analysis is used to analyze differences in mean values between factors. Only variables that show a statistically significant effect are used in modeling based on F and p values. In addition, the goodness-of-fit test in ANOVA shows that the model does not deviate significantly from the experimental data, so that the model is used statistically as a predictive model. The results of the analysis are shown in Tables 3 and 4, which show the parameters that significantly affect the response results.

Table 3. ANOVA model for yield response.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	162.51	9	18.06	27.78	0.0001	significant
A-Acetic anhydride : cellulose	55.13	1	55.13	84.81	< 0.0001	
B-temperature	3.12	1	3.12	4.81	0.0644	
C-times	60.50	1	60.50	93.08	< 0.0001	
AB	6.25	1	6.25	9.62	0.0173	
AC	9.00	1	9.00	13.85	0.0074	
BC	9.00	1	9.00	13.85	0.0074	
A ²	6.84	1	6.84	10.53	0.0142	
B ²	12.53	1	12.53	19.28	0.0032	
C ²	0.9500	1	0.9500	1.46	0.2659	
Residual	4.55	7	0.6500			
Lack of Fit	1.75	3	0.5833	0.8333	0.5413	not significant
Pure Error	2.80	4	0.7000			
Cor Total	167.06	16				

The analysis of variance (ANOVA) presented in Table 3 shows that the quadratic model developed for acetate cellulose production yields has high statistical significance, with an F value of 27.78 and a p value of 0.0001 ($p < 0.05$). These results confirm that the process variables studied collectively have a significant effect on the production yield response.

Table 4. Model fit statistical parameters

R²	0.9728
Adjusted R²	0.9377
Predicted R²	0.8062
Adeq Precision	21.8324

Among the main effects, the ratio of acetic anhydride to cellulose (A) and reaction time (C) were identified as the most influential factors on the results, both showing p-values below 0.0001. The high F-values associated with these parameters indicate that the availability of the acetylation agent and the duration of the reaction play a dominant role in determining the rate of acetate cellulose formation. On the other hand, reaction temperature (B) did not show a statistically significant linear effect on yield ($p = 0.0644$), suggesting that temperature variations within the studied range did not directly increase acetylation yield.

Significant interaction effects were found for AB, AC, and BC ($p < 0.05$), indicating that the influence of each main factor on the results was not independent. The significant AC interaction indicates that the effect of the acetic anhydride to cellulose ratio is highly dependent on reaction time, while the significance of the AB and BC interactions indicates that temperature becomes influential when combined with reagent ratio or reaction duration.

Regarding nonlinearity, the quadratic terms A² and B² were statistically significant ($p = 0.0142$ and 0.0032 , respectively), indicating a curvature effect of the acetic anhydride ratio and reaction temperature on the yield response. Conversely, the quadratic term C² is not significant ($p = 0.2659$), suggesting that the relationship between reaction time and yield remains predominantly linear within the experimental domain.

The goodness-of-fit test yielded an F value of 0.8333 with a p value of 0.5413, which is not statistically significant. These results confirm that the quadratic model adequately represents the experimental data and that there is no systematic deviation between the model predictions and the observed responses.

The adequacy of this model is further supported by the statistical parameters summarized in Table 4. The coefficient of determination (R²) value of 0.9728 indicates that 97.28% of the variation in crop yield can be explained by the model. The Adjusted R² value of 0.9377 confirms the model's robustness after taking into account the number of terms included. In addition, the Predicted R² value of 0.8062 shows good agreement with the Adjusted R², indicating that the model has adequate predictive power in the experimental design space.

The Adequate Precision value of 21.8324, which is explicitly reported in Table 4 and obtained from the Design-Expert software output, is much higher than the recommended minimum value of 4. This high signal-to-noise ratio confirms that the developed model is reliable and suitable for navigating the design space and optimizing acetate cellulose yields.

Overall, these results indicate that the production of cellulose acetate from empty palm fruit bunches is primarily influenced by the ratio of acetic anhydride to cellulose and the reaction time, while the reaction temperature plays a secondary role, with its influence becoming significant through interactions and nonlinear effects.

After confirming that the results model meets the feasibility criteria, the analysis was continued with a quadratic model for DS. The DS parameter is very important because it indicates the degree of cellulose acetylation that can affect the physicochemical properties of cellulose acetate products. The ANOVA data generated for DS are shown in Tables 5 and 6.

The results of the analysis of variance (ANOVA) presented in Table 5 show that the quadratic model developed for the yield response has very high statistical significance, with an F value of 36.79 and a p value < 0.0001 . This confirms that the selected process variables collectively have a significant effect on the acetate cellulose yield.

Among the linear terms, the ratio of acetic anhydride to cellulose (A) and reaction time (C) were identified as the most influential parameters, both showing very high F values (97.21 and 153.00, respectively) and p values below 0.0001. These results indicate that the availability of the acetylation agent and sufficient reaction duration are the dominant factors governing cellulose acetate formation. Reaction temperature (B) also showed a statistically significant linear effect on yield ($p = 0.0076$), although its influence was less pronounced compared to factors A and C.

Table 5. ANOVA model for yield response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.16	9	0.1288	36.79	< 0.0001	significant
A-Acetic anhydride : cellulose	0.3403	1	0.3403	97.21	< 0.0001	
B-temperature	0.0481	1	0.0481	13.73	0.0076	
C-times	0.5356	1	0.5356	153.00	< 0.0001	
AB	0.0056	1	0.0056	1.61	0.2455	
AC	0.0256	1	0.0256	7.31	0.0305	
BC	0.0012	1	0.0012	0.3499	0.5728	
A ²	0.1167	1	0.1167	33.34	0.0007	
B ²	0.0035	1	0.0035	1.01	0.3480	
C ²	0.0674	1	0.0674	19.25	0.0032	
Residual	0.0245	7	0.0035			
Lack of Fit	0.0174	3	0.0058	3.28	0.1405	not significant
Pure Error	0.0071	4	0.0018			
Cor Total	1.18	16				

Table 6. Model fit statistical parameters

R²	0.9793
Adjusted R²	0.9527
Predicted R²	0.7551
Adeq Precision	22.0642

Interaction effects showed a more selective contribution. The AC interaction was statistically significant ($p = 0.0305$), indicating that the effect of the acetic anhydride to cellulose ratio on the yield depends on the reaction time. Conversely, the AB and BC interactions were not significant ($p > 0.05$), suggesting that temperature does not significantly modify the effect of the reagent ratio or reaction time when considered collectively.

Related to nonlinear behavior, the quadratic terms A² and C² were found to be significant ($p = 0.0007$ and 0.0032 , respectively), indicating a curvature effect on the response surface for the ratio of acetic acid anhydride and reaction time. This suggests that excessive increases in these variables do not result in proportional increases in the results, and that there is an

optimal range. In contrast, the quadratic term B^2 was not significant ($p = 0.3480$), indicating that the effect of temperature on the results remained linear within the range studied. The goodness-of-fit test yielded an F value of 3.28 with a p value of 0.1405, which is not statistically significant. This confirms that the quadratic model adequately represents the experimental data and that the deviation between the predicted and observed responses is due to random error rather than model inadequacy.

The reliability of the model is further supported by the statistical parameters summarized in Table 6. The R^2 value of 0.9793 indicates that 97.93% of the variability in yield can be explained by the model. The Adjusted R^2 value of 0.9527 confirms the model's strong robustness after accounting for the number of model terms. Additionally, the Predicted R^2 value of 0.7551 shows reasonable agreement with the Adjusted R^2 , indicating that the model has acceptable predictive power within the experimental design space. The Adequate Precision value of 22.0642, which is explicitly reported in Table 6 and obtained from the Design-Expert software output, is well above the recommended minimum value of 4. This high signal-to-noise ratio confirms that the model is suitable for exploring the design space and can be reliably used for optimizing results.

Overall, these results indicate that the production of cellulose acetate is primarily influenced by the ratio of acetic anhydride to cellulose and the reaction time, with temperature playing a secondary but still significant role. The presence of a significant quadratic effect for factors A and C highlights the importance of process optimization over simple linear scaling. These findings support the hypothesis that precise control of reaction stoichiometry and reaction duration is essential for maximizing acetate cellulose production yields.

3.2 Response graph analysis

Graphical analysis is performed to provide an overview of the tendency of changes in production output values due to variations in the process factors used. Thus, the trend patterns of increases and decreases in production output can be observed more clearly than with numerical analysis alone. Therefore, graphs form the basis for assessing the effectiveness of process conditions and support the determination of optimum operating points. The graphical analysis of the resulting production output response can be seen in Figure 2.

Based on the three-dimensional response surface and contour graph, it can be observed that three process variables, namely the ratio of acetic anhydride to cellulose (A), reaction temperature (B), and reaction time (C), affect the cellulose acetate yield within the experimental range studied. Increasing the ratio of acetic anhydride to cellulose and reaction time generally produces higher yield values, as indicated by the upward trend on the response surface and the contour color gradient. The effect of temperature on yield is less pronounced and becomes more apparent when combined with other variables, especially at moderate to high levels. This is consistent with the principles of acetylation reaction kinetics, where the addition of heat energy, sufficient reaction duration, and increased availability of acetyl groups can increase the number of substituted cellulose $-OH$ groups [8]. The response surface does not show a sharp decrease in yield within the experimental domain studied, indicating that the optimum region lies at relatively higher values of acetic anhydride ratio and reaction time, with temperature acting as a supporting factor rather than a primary promoter.

Further interaction graphs show that the combined effect of process variables is very important in determining the response of the results. The interaction between the ratio of acetic anhydride to cellulose and reaction time shows a clear synergistic trend, while the interaction involving temperature shows a more gradual change in the results. These

graphical observations are consistent with the ANOVA results, which identify the ratio of acetic anhydride to cellulose and reaction time as the dominant factors influencing the results, while temperature contributes mainly through interaction effects.

Overall, response surface and contour analysis confirmed the suitability of the RSM-based optimization approach for evaluating the simultaneous effects of process variables in cellulose acetate synthesis and for identifying favorable operating regions that maximize yield.

In addition to yield, the acetylation process must also be evaluated based on the degree of substitution (DS). A DS contour plot was used to illustrate the variation in DS as a function of the ratio of acetic anhydride to cellulose (A), reaction time (B), and reaction temperature (C). This plot allows the distribution trends and interaction effects among the process variables to be visualized more clearly. The three-dimensional response surface and corresponding DS contour plot are presented in Figure 3.

Graph AB, which illustrates the interaction between the ratio of acetic anhydride to cellulose (A) and reaction time (B), shows a clear increase in the degree of substitution (DS) as the anhydride ratio increases, especially during medium to long reaction times. This trend indicates that the availability of the acetylation agent is a major factor driving the substitution of hydroxyl groups on cellulose [12]. An increase in DS with reaction time is also evident in graph AB, confirming that the acetylation reaction proceeds further as the contact time between cellulose and acetic anhydride increases, allowing the reaction to approach equilibrium conditions. The corresponding contour plot shows an optimum region at a high anhydride ratio combined with a medium to high reaction time, as indicated by the contour line curving to the upper right, showing a strong combined effect of these two variables on DS.

The AC plots showing the interaction between anhydride ratio (A) and reaction temperature (C) indicate that DS increases significantly with increasing anhydride ratio, while the effect of temperature is relatively weaker in the range studied. Temperature becomes a critical factor only when the temperature range is wide or when the reaction mechanism changes, such as with different catalysts or solvents, so it does not play a dominant role in a narrow range [13]. The response surface and contour patterns show that temperature contributes to the increase in DS, especially at higher anhydride ratios, but does not act as a dominant controlling factor. This behavior is consistent with previous reports showing that temperature becomes a critical parameter only when a wider temperature range is applied or when the reaction mechanism changes, such as through the use of different catalysts or solvent systems [13]. In the relatively narrow temperature range studied in this study, the acetylation reaction remains primarily controlled by reagent availability rather than thermal activation.

The BC plot illustrating the interaction between reaction time (B) and temperature (C) shows that an increase in reaction time generally results in higher DS values at almost all temperatures. However, the response surface tends to flatten out at longer reaction times and higher temperatures, indicating plateau behavior. This suggests a kinetic limitation or limited availability of acetic anhydride, which ultimately limits further replacement of cellulose hydroxyl groups. The BC contour plot shows that the optimal DS region occurs at long reaction times and moderate temperatures, rather than at the highest temperatures tested. These findings imply that excessive temperature increases do not always enhance DS when other factors, particularly reagent ratios, become limiting

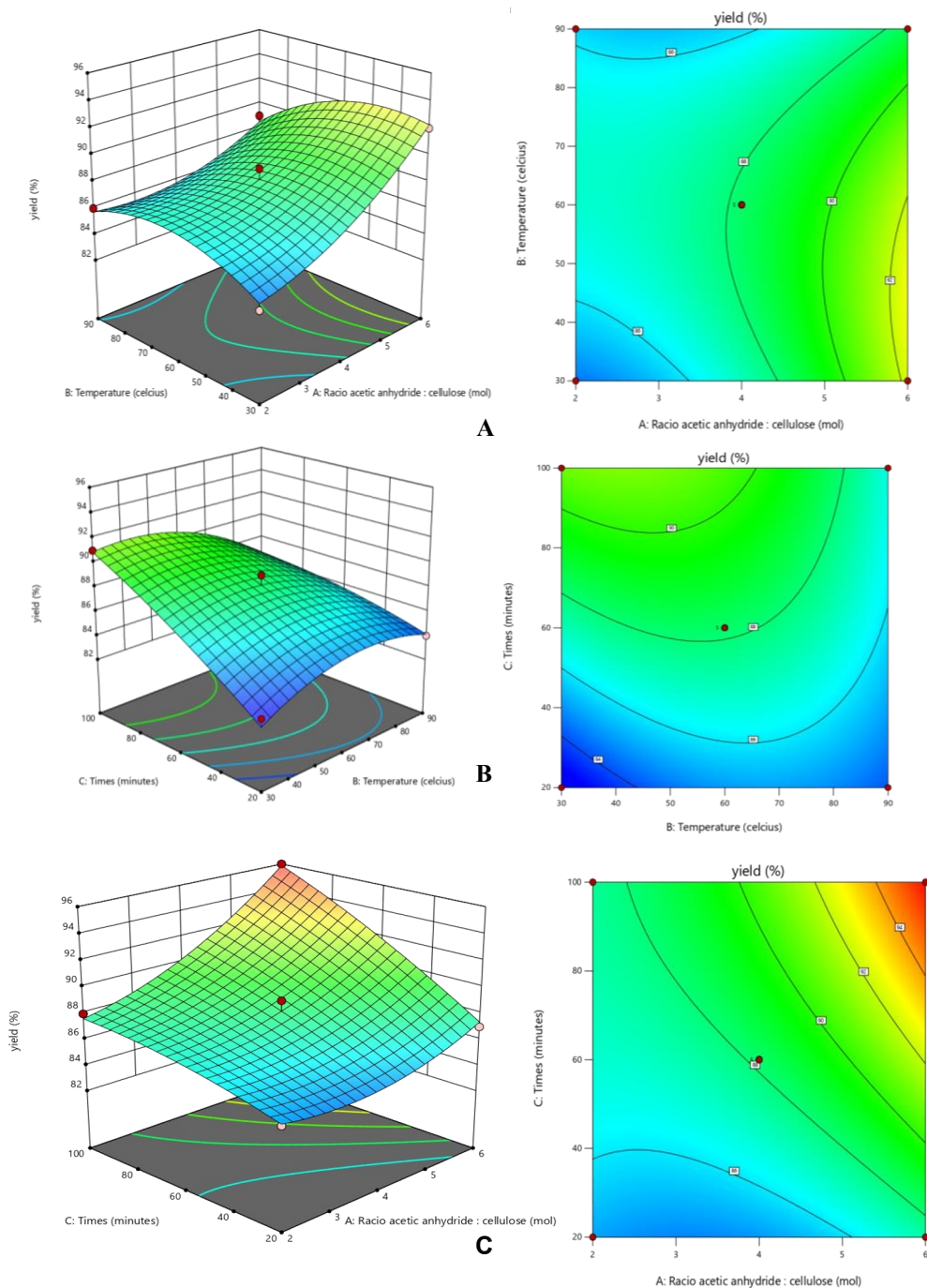


Fig. 2. 3D response surface and contour plots of the effect of process variables on acetate cellulose yield: (a) combination of acetate anhydride– cellulose ratio (A) and temperature (B), (b) the combination of reaction time (B) and reaction temperature (C), (c) the combination of acetate anhydride– cellulose ratio (A) and reaction time (C)

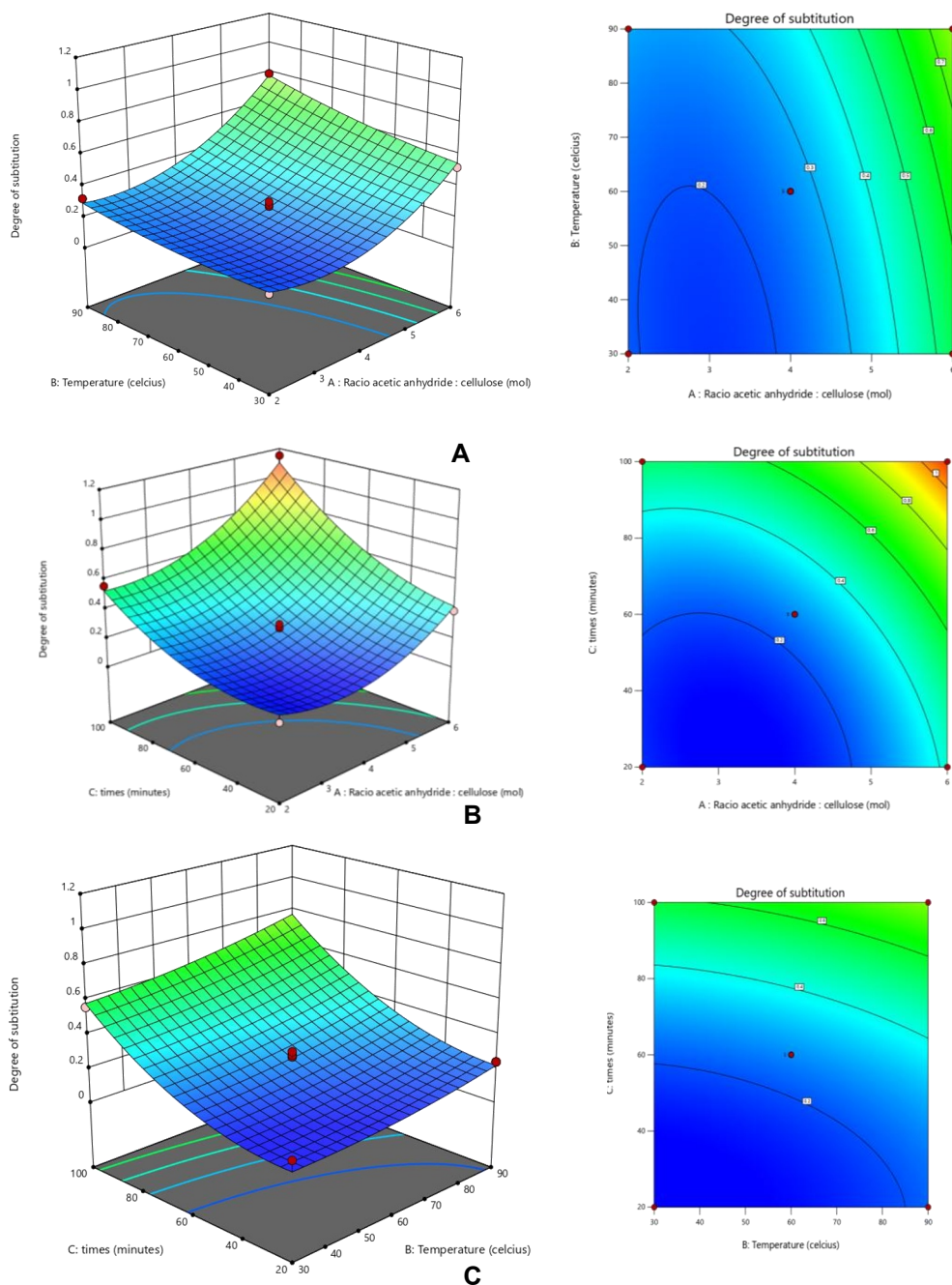


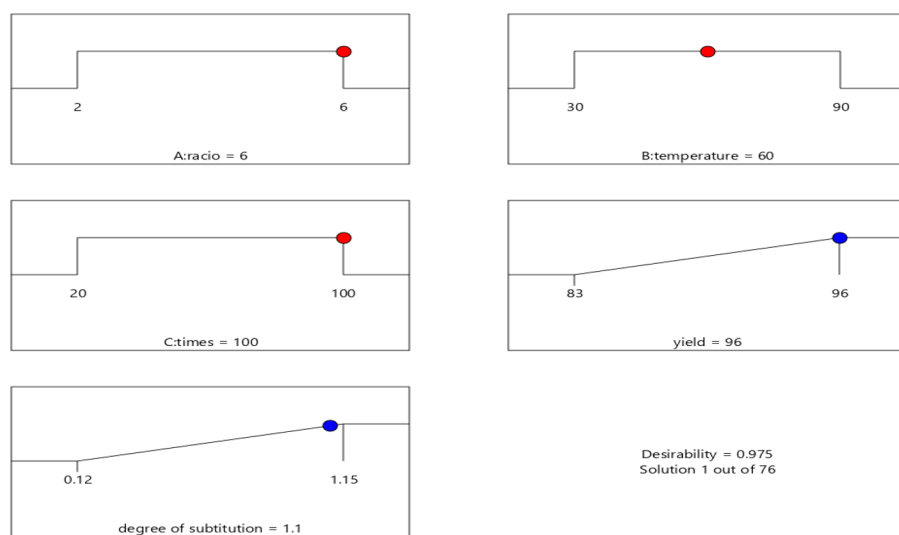
Fig. 3. 3D response surface and contour plots of the effect of process variables on the degree of substitution (DS) of cellulose acetate, (a) combination of acetate anhydride– cellulose ratio (A) and reaction time (C), (b) the combination of reaction time (B) and reaction temperature (C), (c) the combination of temperature (B) and reaction time (C)

Overall, the response surface and contour patterns for DS are consistent with the ANOVA results, confirming that the ratio of acetic anhydride to cellulose (A) and reaction time (B) are key variables governing the degree of substitution, with a clear AB interaction evident. Reaction temperature (C) contributes to DS development but plays a secondary role in the experimental domain studied. These results suggest that further increases in DS require expanding the temperature range or modifying reaction conditions, such as changing the catalyst or solvent system.

3.3 Optimization of the cellulose acetate process

The optimization graph in Response Surface Methodology (RSM) shows the best combination of variables that produces the maximum response value. The optimization results of acetate cellulose with the acetylation process are shown in Figure 4.

Based on the graph, the optimum conditions were achieved at an acetic anhydride to cellulose ratio of 6:1, a reaction time of 100 minutes, and a temperature of 60 °C, which resulted in a high yield of 96% and a DS of 1.1 with an excellence value of 0.975. These conditions indicate that a high anhydride ratio and long reaction time are the most influential factors in increasing DS and yield. According to Yang et al. (2020), excess acetic anhydride and reaction duration strengthen the degree of cellulose substitution. Overall, this optimization graph reinforces that the RSM model is capable of identifying effective reaction conditions.



4 Conclusion

The process of acetylation of cellulose from oil palm fruit waste (EFB) into cellulose acetate was successfully optimized using the Response Surface Methodology (RSM) with a quadratic model that proved feasible based on a high R^2 value for the yield of 0.9728 and a degree of substitution (DS) of 0.9793. The variables of acetate anhydride to

cellulose ratio and reaction time were significant factors affecting the increase in yield and degree of substitution, while the effect of temperature was relatively smaller in the analyzed range. Optimal conditions were obtained at an acetic anhydride to cellulose ratio of 6:1, a time of 100 minutes, and a temperature of 60°C, which resulted in a yield of 96% and a DS of 0.51 with a desirability value of 0.973. This shows that the combination of these factors is effective for producing good quality cellulose acetate from EFB.

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