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Research article

Determination of Significant Factors and Optimum Condition for Pineapple Leaf Fiber Extraction as Potential Dielectric Material

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Abstract

The aim in this study was to evaluate the most significant factor affecting the extraction of pineapple leaf fibers and to optimize the extraction conditions. The selected four factors of pineapple leaf powder mass, pineapple leaves to distilled water ratio, pulping time, and heating option were analyzed through two-level factorial analysis via Design-Expert software. The optimum conditions were determined using central composite design (CCD) of response surface methodology (RSM). The extracted fibers were analyzed through the Kurschner-Hanack method for cellulose content and were used to produce dielectric materials. The permittivity value of the developed dielectric material was measured through an Agilent vector network analyzer (VNA). The best condition was obtained with a heated sample at 3 g pineapple leaf powder mass, 1:10 PL: DW, and 49.24 min pulping time, which produced 59.25% cellulose content and 2.89 permittivity value. The optimum condition was achieved at 50 min of pulping time and 1000 mL water with 46.84% cellulose content and 2.97 permittivity value. Therefore, based the obtained permittivity value, pineapple leaves could be further explored as potential dielectric materials.

Keywords: pineapple leaf fiber; cellulose content; permittivity value; dielectric materials

1. Introduction

Pineapple, *Ananas comosus*, is an edible fruit and is favored not only by humans but by animals as well. The global consumption of pineapple as fresh fruit or as a can product has led to the abundant production of pineapple waste since the other parts of pineapple plants are thrown away without further exploitation. Pineapple waste, including leaves, stems, pulps, and peels, is commonly accumulated from the pineapple processing industry by-products. Dumping these wastes in landfills or burning could lead to severe environmental impact (Koul et al., 2022). Therefore, valorizing pineapple waste as a valuable by-product can be an innovation to handle the massive waste generated by the canning and

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pharmaceutical industries (Ketnawa et al., 2012). One of the possible ways to overcome massive waste generation is by converting the waste into a valuable material. Utilizing agricultural waste for material production has a strong contribution to the environment. Rather than being disposed of in landfills, which could consequently trigger environmental pollution, valorizing these wastes into valuable products could reduce the burden on landfills and the environment. Exploiting agricultural waste into material development could also reduce the dependency on other valuable natural resources. Less reliance on natural resources, such as petroleum-based material, could reduce environmental impact associated particularly with the extraction of those materials and hence could aid in overall natural resource conservation (Satrovic et al., 2024). Being biodegradable is the utmost benefit of exploring agricultural wastes since this material can be disposed of easily at the end of its lifecycle, further reducing the environmental impact.

Although pineapple waste has long been used as feedstock in energy production (Rabiu et al., 2018), the large amount of waste is still unmanageable. Previous studies reported the use of pineapple leaf as a potent material for polymer matrix-reinforced composite (Jayamani et al., 2017). Recent advancements in material engineering industries, as well as increasing demand for materials, have drawn attention to the exploitation of natural fibers as raw materials. Incorporating pineapple leaves into the production of dielectric materials, for instance, demonstrates a shift towards a circular economic model, where waste materials are viewed as valuable resources that can be reused or recycled in various applications. This is because dielectric materials are commonly developed from alumina, plastics, mica, teflon, glass, ceramics, and silica, which are non-biodegradable, and subsequently urging the need to switch to environmentally-friendly materials (Mishra et al., 2004). A dielectric material is a poor electrical conductor and can basically be classified as an insulator, which is most frequently utilized as energy storage in capacitors. Several authors have long recognized pineapple leaves as a potent dielectric material (Mishra et al., 2004; Baharudin et al., 2014; Jayamani et al., 2017; Karim et al., 2023).

Pineapple leaves contain fine-quality fiber with well-separated filaments (Karimah et al., 2021). The arrangement of filaments and fibrils in the leaf cell wall contributes to a high dielectric constant, which is a desirable property for dielectric materials and represents the ability of a material to store electrical energy when subjected to an electric field (Dagade & Shaikh, 2015). The 3D cell wall network reacts as a compressible material that elastically collapses upon pressing with the existence of specific surface structures that can sensitively respond to the pressure applied (Shin et al., 2018). Also, the complex 3D structure provides a larger surface area, allowing for greater interaction with electromagnetic fields, hence improving the dielectric properties of the fiber. Pineapple fibers are multicellular and rich in cellulose, and demonstrate high specific stiffness and strength (Girijappa et al., 2019). The robust structure helps ensure that the produced dielectrics can maintain their integrity when exposed to various weather conditions, making them a suitable replacement in electronic devices for long-term usage.

Several processing factors must be considered when evaluating the factors affecting the preparation of the dielectric materials from the pineapple leaves. Different factors with varied ranges can affect the possible amount of cellulose being extracted, hence affecting the permittivity value of the developed material. For example, higher temperature selection could trigger the solubilization and degradation of cellulose content (Ameen et al., 2021; Erdal & Hakkarainen, 2022). Also, longer pulping time can cause the breakdown of the cellulose chains (Jiménez et al., 2005), hence reducing the amount of extracted cellulose. However, reducing pulping time did not necessarily increase the amount of cellulose when the temperature setting and soda concentration used for pulping were low (Jiménez et al., 2005). Furthermore, the permittivity value is said to be associated with the amount of cellulose present in the sample, in which a higher amount of cellulose contributed to a higher permittivity value (Elloumi et al., 2021). Therefore, considering the complex relationship between processing factors, a suitable mechanism to monitor all these factors is crucial. Factorial analysis is one of the promising approaches to determine the number of factors influencing a response and analyzing which factors are best suited to each other. Factorial analysis is a method of condensing multiple variables into fewer significant variables, avoiding undue emphasis on insignificant variables. Therefore, factorial analysis is useful in analyzing the influence of several factors contributing to dielectric material development by evaluating all factors involved. Two-level factorial analysis, for example, is a useful method that can be applied to evaluate the most significant factors contributing to one process and identifying the interaction factors simultaneously (Karim et al., 2023).

Several authors have discussed the effects of factors such as temperature, pulping time, and extraction methods. However, to the best of our knowledge, only a few studies focus on evaluating the factors using the design of experiments (DOE). The use of DOE in evaluating the factors could significantly benefit dielectric material development since the method can determine the most significant factor affecting the material development, which can be used to further optimize the preparation conditions. Therefore, this study was aimed at identifying the most influential factors in the extraction of pineapple leaf fibers and the optimization of the extraction conditions through the DOE.

2. Materials and Methods

2.1 Sample collection and preparation

The pineapple leaves used in the study were collected from a pineapple plantation at Pekan Pina, Pahang, Malaysia. The collected leaves were cleaned to remove impurities before being dried under the sun for 24 h. The dried leaves were cut into 5 cm long. The soda pulping method was used in this study for pineapple leaf fiber extraction. A fixed quantity of 45 g of sodium hydroxide (Rasid et al., 2023) was consistently employed throughout the study. The sodium hydroxide and distilled water mixture was placed in a beaker and stirred with a glass rod before being boiled at 100°C (Rasid et al., 2023). The pineapple leaves were placed in the mixture until submerged according to the pineapple leaves to distilled water ratio (Table 1). The cooked mixture was filtered with a sieve tray and squeezed to eliminate water, producing pulp. The obtained pulp was desiccated for 24 h in an oven at 105°C (Baharudin et al., 2014) before being heated at 150°C on a hot plate for 1 min. Heating the sample aided in the grounding process in order to produce micro-scale powder and to produce more carbon compounds in the sample. The heating of the pulp was performed based on the experimental setup tabulated in Table 1, to observe the effect of heating on cellulose content and permittivity value. The overall process flow for the extraction process is portrayed in Figure 1.

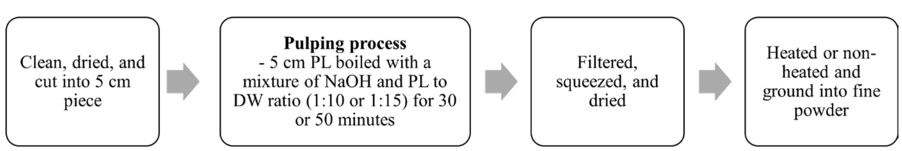

Figure 1. The overall process flow for the pulping process and production of pineapple leaf powder

2.2 Experimental setup for factorial analysis

The two-level factorial analysis (TLFA) was employed to identify the most influential factor affecting the permittivity value and cellulose content. Four factors were investigated: mass of pineapple leaf powder (3 and 5 g), pineapple leaf to distilled water ratio (PL: DW) (1:10 and 1:15), pulping times (30 and 50 min), and heating options (heated on the hot plate and not heated). Sixteen experimental runs were conducted according to Table 1, established through the Design-Expert software with completely randomized factors. The experimental outputs were analyzed through the analysis of variance (ANOVA) based on a p-value of 0.05. The experiments were performed according to the method mentioned in Section 2.1.

Table 1. Experimental design table for factorial analysis experiment

Std	Factors				Responses	
	Powder Mass (g)	PL: DW (g/ml)	Pulping Times (min)	Heating Option	Permittivity	Cellulose Content (%)
1	3.00	1:10	30	No	2.79	48.67
2	5.00	1:10	30	No	2.81	40.93
3	3.00	1:15	30	No	2.74	46.93
4	5.00	1:15	30	No	2.82	38.67
5	3.00	1:10	50	No	2.82	50.97
6	5.00	1:10	50	No	2.69	46.37
7	3.00	1:15	50	No	2.79	39.88
8	5.00	1:15	50	No	2.72	45.36
9	3.00	1:10	30	Yes	2.89	51.63
10	5.00	1:10	30	Yes	2.93	40.70
11	3.00	1:15	30	Yes	2.83	38.54
12	5.00	1:15	30	Yes	2.79	46.13
13	3.00	1:10	50	Yes	2.91	59.25
14	5.00	1:10	50	Yes	2.91	42.87
15	3.00	1:15	50	Yes	2.74	45.83
16	5.00	1:15	50	Yes	2.84	50.61

2.3 Experimental setup for optimization experiment

The setup for optimization was designed following the central composite design (CCD) to get the optimum extraction conditions using the response surface methodology (RSM) of the Design-Expert software. The factors involved in the optimization experiment included pulping times (40 to 60 min) and water volume (800 to 1200 mL). The experiments were performed in 13 runs, as presented in Table 2. The experimental outputs were analyzed through the ANOVA based on a 95% confidence level.

Table 2. Experimental design table for optimization experiment

Std	Factors		Cellulose Content (%)	Permittivity
	Pulping Times (min)	Water Volume (ml)		
1	45.00	900.00	2.75	45.12
2	55.00	900.00	2.89	44.04
3	45.00	1100.00	2.76	48.79
4	55.00	1100.00	2.92	45.55
5	40.00	1000.00	2.75	39.15
6	60.00	1000.00	2.81	40.83
7	50.00	800.00	2.61	39.60
8	50.00	1200.00	2.85	40.12
9	50.00	1000.00	2.95	46.89
10	50.00	1000.00	2.97	46.84
11	50.00	1000.00	2.95	46.89
12	50.00	1000.00	2.93	46.93
13	50.00	1000.00	2.95	46.89

2.4 Determination of cellulose content

The cellulose content was evaluated by the Kurschner-Hanack method (Moshi et al., 2019), in which the main principle of this technique is the insolubility of cellulose in water and exhibits resistance to both acids and bases. Concentrated nitric acid (1.5 mL) and acetic acid (15 mL) were poured into a tube comprising 1 g pineapple leaf powder. The mixture was cooked for 20 min before being filtered. The residues were then rinsed and dried at 105°C for 24 h in the oven (Kulic & Radojicic, 2011). The cellulose content was determined by recording the dry weight of the residue (Karim et al., 2022).

2.5 Determination of permittivity value

To produce dielectric material, the pineapple leaf powder (3 or 5 g) was mixed with 22.5 g resin and 7.5 g hardener (Zulkifli et al., 2017). The composite was heated on a hot plate to prevent air bubble formation. The heated sample was poured into a mold of 2.3 cm^3 volume before being left at ambient temperature for 24 h. The permittivity value of the developed composite was determined by a waveguide technique in the microwave region (Karim et al., 2014) within a G-band waveguide with a fixed height of TE10 mode at 5 GHz using an Agilent network analyzer (VNA) (Zazoum, 2019). The VNA was attached to the waveguide using G-band waveguide adapters and coaxial cable. Calibration of the VNA was initially conducted by a full two-port Short-Open-Load Thru (SOLT) calibration to reduce systematic errors. The composite was placed at the centre of the waveguide and served as the material under test (MUT). The transmission coefficient was measured across the waveguide, allowing for the determination of two unknowns: the real and imaginary parts of the complex permittivity. The permittivity was then calculated using an inverse method.

3. Results and Discussion

3.1 Experimental outputs for factorial analysis

Table 1 presents the cellulose content and permittivity values obtained at each experimental condition. The cellulose content ranged from 38.54 to 59.25%, and the permittivity values ranged from 2.69 to 2.93 F/m. The highest cellulose content value of 59.25% and permittivity value of 2.93 F/m were obtained under the experimental conditions of 5 g pineapple leaf powder, 1:15 PL: DW, 50 min pulping time for a heated sample.

The similarity of the data to the regression line was assessed using ANOVA R^2. A model with an R^2 value of more than 80% presents a well-fitting model (Karazhiyan et al., 2011). The cellulose content and permittivity values produced satisfactory R^2 coefficients of 0.9856 and 0.9412, respectively. The values imply that the model fits both experimental and predicted values. The relationship between dependent and independent variables is expressed in equations (1) and (2) in actual formatting, respectively, with Ce representing cellulose, Pe being the permittivity value, A being pineapple leaf powder mass, and C being pulping time.

$$Ce = 66.45 - 7.96177A + 0.14664C + 0.049029AC \quad (1)$$

$$Pe = 2.71646 + 0.052089A + 0.00395C - 0.001076AC \quad (2)$$

3.1.1 Cellulose content analysis

F-values were utilized to assess the significance of the regression equation statistically, and the significance of the coefficient was evaluated through the p-value. Table 3 demonstrates the ANOVA for the cellulose content value with a p-value of 0.0035 and an F-value of 24.94. From Table 3, it was seen that all main factors of A, B, C, and D, as well as AB interactions, were significant for the cellulose content, demonstrated by their p-values of less than 0.05.

Figure 2 presents the Pareto chart for the cellulose content. The t-value bar was computed by the square root of the F-value, in which the value was displayed by the t-value and Bonferroni limit line. All main factors (A, B, C, D) surpassed the t-value line and considerably affected the cellulose content value. The AB interaction surpassed both the t-value and Bonferroni limit line, indicating that the interacting factor is significant toward

Table 3. Analysis of variance for cellulose content

Source	Sum of Square	F-value	P-value
Model	465.00	24.94	0.0035
A: powder mass	56.48	33.32	0.0045
B: PL: DW	54.17	31.96	0.0048
C: pulping time	52.35	30.89	0.0051
D: heating option	19.76	11.66	0.0269
AB	151.54	89.41	0.0007
AC	4.64	2.74	0.1732
CD	12.57	7.42	0.0528

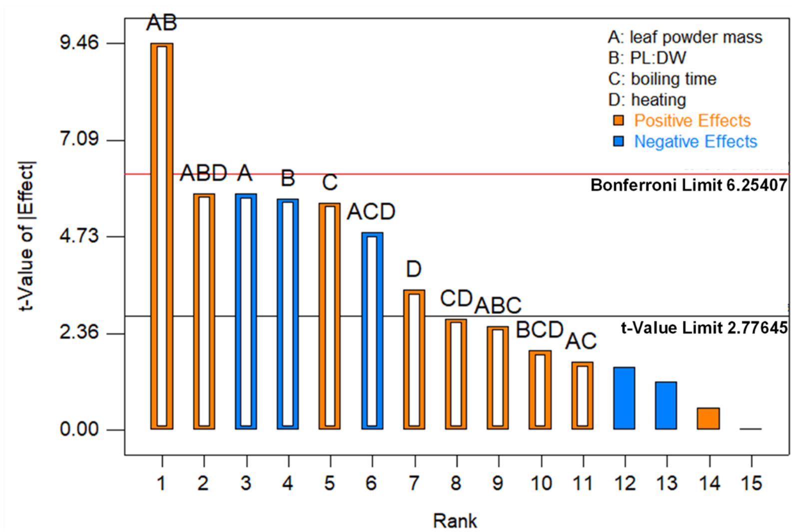

Figure 2. The Pareto chart showing the effects of factors on the cellulose content values

the cellulose content. Pulping time is significant on the cellulose content among the main factors, as the value increases with pulping time. Cheng et al. (2010) mentioned that a longer pulping time produced more cellulose, which was in agreement with the current study. A similar observation was reported by Lim et al. (2019), whereby the increase in time during the extraction of rice straw from 40 to 100 min significantly increased the cellulose content.

The effect of AB interaction is portrayed in Figure 3. From Figure 3, the maximum cellulose was obtained at 1:10 PL: DW and 3 g powder mass. The cellulose content was higher at a 1:15 ratio compared to that of 1:10 at 5 g leaf powder mass. As mentioned by Sridach (2010), pulp yield depends on the type of pulping process, temperature, and times. The cellulose content was the highest when the most concentrated sodium hydroxide solution (1:10) was used during the pulping process due to the concentration-dependent size of sodium hydroxide-water hydrates (Yamashiki et al., 1988). At lower sodium hydroxide concentrations, the hydrodynamic diameters of sodium hydroxide-water hydrates can become significant enough to penetrate the crystalline region of cellulose. The reason might also be due to the inadequate amount of sodium hydroxide to dissolve cellulose at a very low concentration (Zhang et al., 2010).

3.1.2 Permittivity value analysis

Table 4 presents the ANOVA summary for the permittivity analysis with a 10.67 F-value and p-value of 0.0047. A good model is characterized by a higher calculated F-value when compared to the reference value provided by the software (Hamzaoui et al., 2008). A lower p-value indicates the greater significance of a variable (Masoumi et al., 2011). The effects of B and D were statistically significant on the permittivity value, as proven by the p-value of less than 0.05. The BD interaction presents as a significant interaction with a p-value of 0.0116. The other main and interaction effects were insignificant with respect to permittivity value, exhibited by the p-value of more than 0.05.

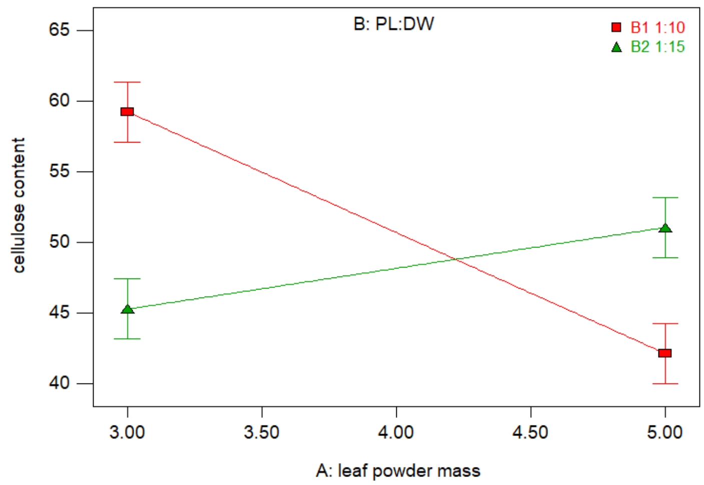

Figure 3. Interaction effect of leaf powder mass and PL: DW on cellulose content

Table 4. Analysis of variance for permittivity value

Source	Sum of Square	F-value	P-value
Model	0.073	10.67	0.0047
A: powder mass	0.00001147	0.015	0.9060
B: PL: DW	0.016	20.73	0.0039
C: pulping time	0.001768	2.34	0.1771
D: heating option	0.028	37.37	0.0009
AC	0.002499	3.31	0.1189
AD	0.002791	3.69	0.1031
BD	0.009719	12.86	0.0116

Figure 4 displays the Pareto chart for permittivity value. As shown on the Figure, factor D was the only main effect that significantly contributed to the permittivity value, surpassing the Bonferroni limit line. Factor B and BD interaction were likely to be significant as the bar was positioned between the Bonferroni and t-value limit line. The initial heat treatment of the leaf powder shows a remarkable effect on the permittivity value, which may be inferred from the more available carbon compounds in the heated sample. The increment of carbon compounds in a sample increased the permittivity value (Fendi, & Maddu,201 8). As investigated by Shah & Tahir (2011), the permittivity values of cottonseed and corn oil increases with temperature. This is due to the increasing dissolving capacity of substances with temperature increment (Song et al., 2016).

The interaction effects of BD on permittivity value are graphically explained in Figure 5. The permittivity value was the highest in the heated sample at a 1:10 PL: DW ratio. However, at 1:15 PL: DW ratio, the permittivity value was highest in the unheated sample. The reason might be due to the high cellulose amount in the 1:15 PL: DW ratio; thus, the heating effect might be negligible. The solid-to-liquid ratio (powder mass to distilled water) plays a substantial role in cellulose extraction (Song et al., 2016). Samples with the highest cellulose demonstrate a higher permittivity value than those with lower content (Elloumi et al., 2021).

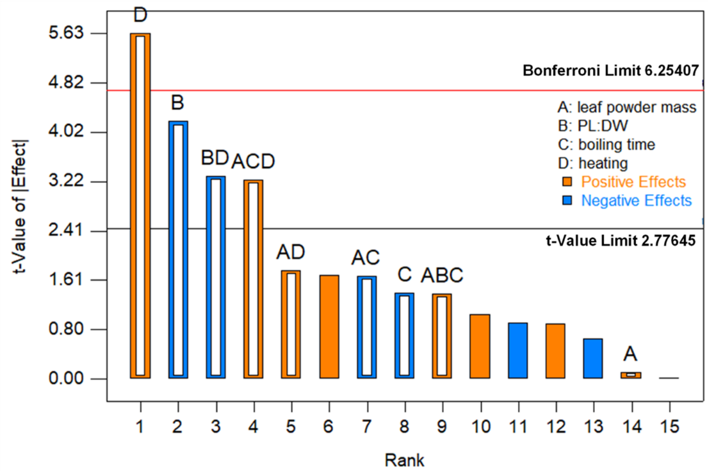

Figure 4. The Pareto chart demonstrating the effects of factors on permittivity analysis

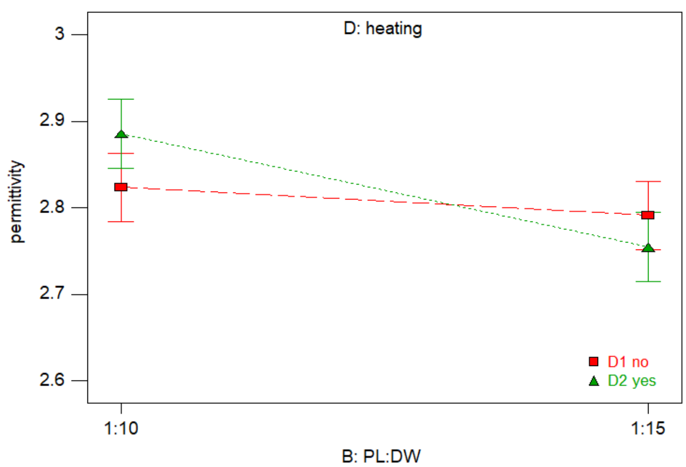

Figure 5. Interaction effect between factors B and D on permittivity value

3.2 Determination of the best experimental condition for dielectric material preparation

The best experimental condition for cellulose extraction was determined through the numerical optimization procedure from the Design-Expert software. To obtain the best experimental condition, all process factors were set to be in range to obtain maximum desirability; meanwhile, permittivity value and cellulose content were set up to maximum. The resulting solutions were portrayed in Figure 6. Six experimental conditions were recommended by the software to attain the goals mentioned above. The most desired process condition is the solution with the desirability value closest to 1. Therefore, solution 1 was chosen as the best extraction condition to obtain maximum permittivity value and cellulose yield. Under those conditions, 59.25% cellulose content and 2.89 permittivity value could be achieved.

Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:leaf powder	is in range	3	5	1	1	3
B:PL:DW	is in range	1:10	1:15	1	1	3
C:boiling time	is in range	30	50	1	1	3
D:heating	is in range	no	yes	1	1	3
permittivity	maximize	2.69381	2.93372	1	1	3
cellulose conte	maximize	38.54	59.25	1	1	3

Solutions for 4 combinations of categoric factor levels

Number	leaf powder mass	PL:DW	boiling time	heating	permittivity	cellulose content	Desirability	
1	3.00	1:10	49.24	yes	2.88558	59.25	0.894	Selected
2	3.03	1:10	49.90	yes	2.88525	59.2502	0.893	
3	5.00	1:15	50.00	yes	2.8243	51.3062	0.579	
4	3.00	1:10	50.00	no	2.82617	49.9063	0.550	
5	5.00	1:15	45.73	yes	2.81936	49.9736	0.538	
6	3.00	1:15	30.00	no	2.76048	46.2112	0.321	

Figure 6. The suggested solutions for maximum cellulose content and permittivity value

3.3 Experimental outputs for optimization

Table 2 displays the experimental outputs and responses for which among the center point of 50-min pulping time and 1000 mL water volume, run 9, 11, and 13 exhibited the highest cellulose content value of 46.89%. Meanwhile, run 10 showed the highest permittivity value of 2.97. It is interesting to note that each factor contributed to the responses differently. The highest cellulose content value was seen at 48.79% and 2.97 F/m for permittivity value. The fitting of the experimental data to the linear, two-factorial, quadratic, and cubic models, as well as the analysis of variance, indicated that permittivity and cellulose content were well described by a quadratic polynomial model. This was because the adjusted R^2 value of the quadratic model surpassed those of the linear, two factorial, and cubic models for cellulose content (0.8619) and permittivity (0.8025).

3.3.1 Cellulose content analysis

The summary of the ANOVA for cellulose content is tabulated in Table 5. The p-value of <0.05 implied that the model was significant. All main factors and their interaction (A, B, and AB) were insignificant, demonstrated by their p-values of higher than 0.05. The R^2 value of 0.8025 indicated that the experimental data adequately fitted the estimated model. Figure 7 illustrates the actual and predicted cellulose content, displaying a plot of their respective values. The linear distribution implied a well-fit model, with the predicted and observed values demonstrating close agreement.

Table 5. Analysis of variance summary for cellulose content

Source	Sum of Squares	df	Mean Square	F Value	P-value
Model	107.42	5	21.48	5.69	0.0207
A: Pulping time	0.077	1	0.077	0.020	0.8906
B: Water volume	3.22	1	3.22	0.85	0.3862
AB	1.17	1	1.17	0.31	0.5957
A^2	64.82	1	64.82	17.17	0.0043
B^2	67.35	1	67.35	17.84	0.0039
Residual	26.43	7	3.78		
Lack of Fit	26.43	3	8.81	8636.90	< 0.0001
Pure Error	4.08×10^{-3}	4	1.020×10^{-3}		
Cor Total	133.85	12			
R^2	0.8025				
Adjusted R^2	0.6615				

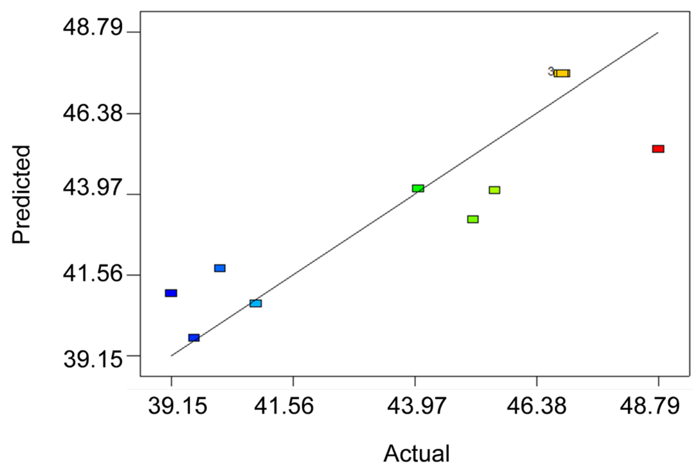

Figure 7. Correlation of actual and predicted values by the model for cellulose content

The effects of independent and interaction factors on cellulose content are displayed in Figure 8. From Figure 8, cellulose content increased with pulping time until it reached a maximum value and decreased afterwards. This might be due to the slight loss of carbohydrates that occurred with the longer heating process (Nie et al., 2013). A comparable pattern was also seen for water volume, as presented in Figure 8(b). The cellulose content increased with water volume, achieving its maximum value of 48.79%. The hydroxyl groups in cellulose make it highly reactive when exposed to water, as water molecules easily form hydrogen bonds with these groups. This interaction disrupts the hydrogen bonds between cellulose chains, allowing water to penetrate and interact with the polymer structure. The higher the concentration of water molecules, the more readily these reactions occur (Khazraji & Robert, 2013). The interaction effect between factors is illustrated in Figure 8(c-d) for the contour plot and 3D response, respectively. An elliptical contour plot depicts a significant interaction between the parameters. Notably, the optimum cellulose content was obtained at 45 min of pulping time and 900 mL of water volume.

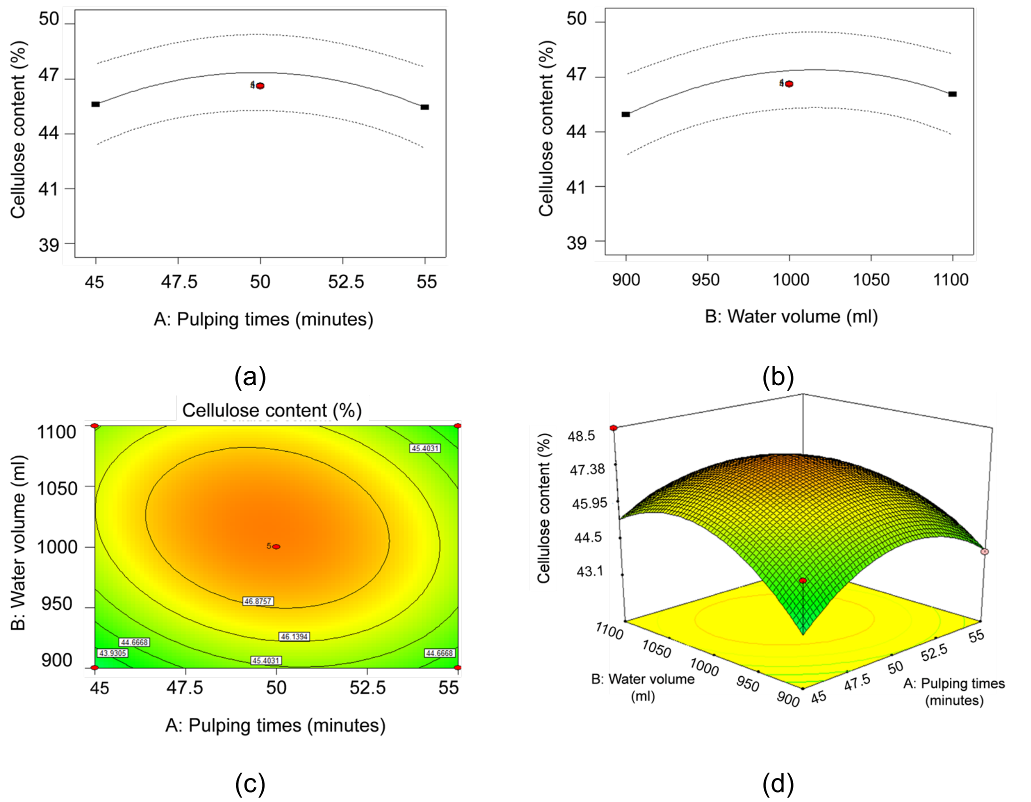

Figure 8. The effects of (a) pulping time and (b) water volume on cellulose content and the interaction effect in (c) contour plot and (d) 3D response plot on cellulose content

3.3.2 Permittivity value analysis

Table 6 presents an ANOVA summary for permittivity value. Pulping time and water volume presented a significant effect, with a p-value of less than 0.05. The AB interaction exhibited an insignificant value of 0.8319. The R^2 and adjusted R^2 of 0.8619 and 0.7633 showed that the experimental data adequately fitted the estimated model. Figure 9 shows a plot of the actual against the predicted values for permittivity. Linear distribution was seen in both responses, suggesting a good fit for the model. The normal probability plot indicates that the residuals, which are the differences between actual and predicted values, conform to a normal distribution, forming a nearly linear pattern.

Figure 10 presents the effect of two independent factors on permittivity value. An increase in permittivity value with pulping time was observed in Figure 10(a) at the center point, after which it decreased—the polarization of the molecules and ionic conductivity increased, affecting the dielectric properties. The dielectric properties will decrease after achieving the maximum point (Farea et al., 2008). A comparable pattern was also seen for water volume, as presented in Figure 10(b), in which the permittivity value increased with water volume and achieved its maximum value at the center point. This was because water possesses a greater dielectric permittivity than the relative permittivity of pineapple leaf fiber. An increase in pore water saturation led to a rise in the bulk dielectric permittivity of pineapple leaf fiber (Nizamuddin et al., 2016).

Table 6. Analysis of variance summary for permittivity value

Source	Sum of Squares	df	Mean Square	F Value	P-value
Model	0.13	5	0.025	8.74	0.0064
A: Pulping time	0.016	1	0.016	5.40	0.0530
B: Water volume	0.022	1	0.022	7.83	0.0266
AB	1.393E-004	1	1.393E-004	0.049	0.8319
A^2	0.042	1	0.042	14.68	0.0064
B^2	0.069	1	0.069	23.91	0.0018
Residual	0.020	7	2.870E-003		
Lack of Fit	0.019	3	6.334E-003	23.36	0.0054
Pure Error	1.085×10^{-3}	4	2.712E-004		
Cor Total	0.15	12			
R^2	0.8619				
Adjusted R^2	0.7633				

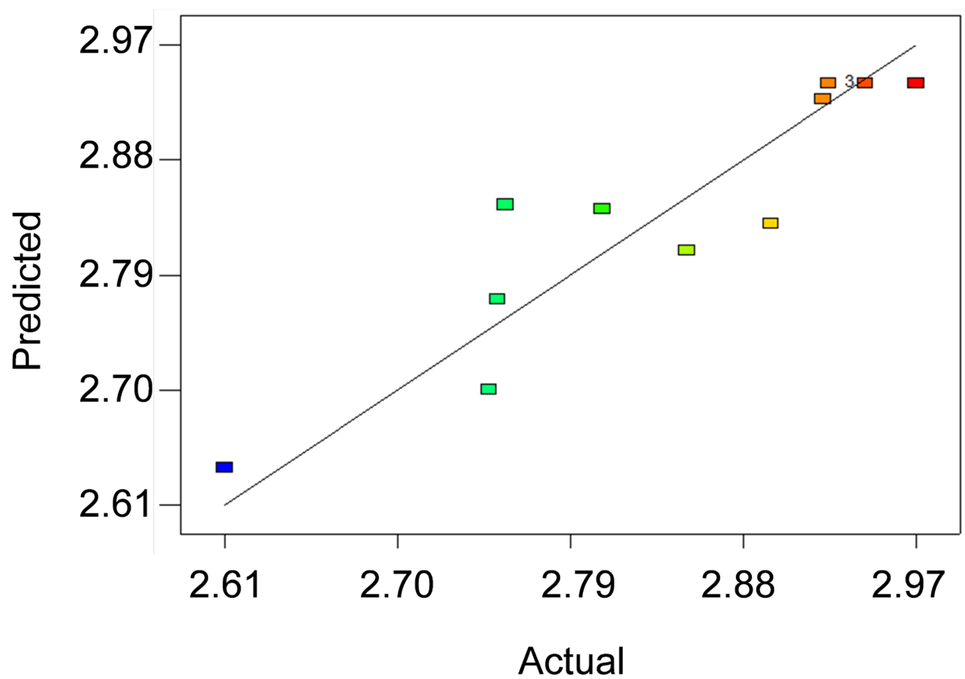

Figure 9. Correlation of actual and predicted values by the model for permittivity value

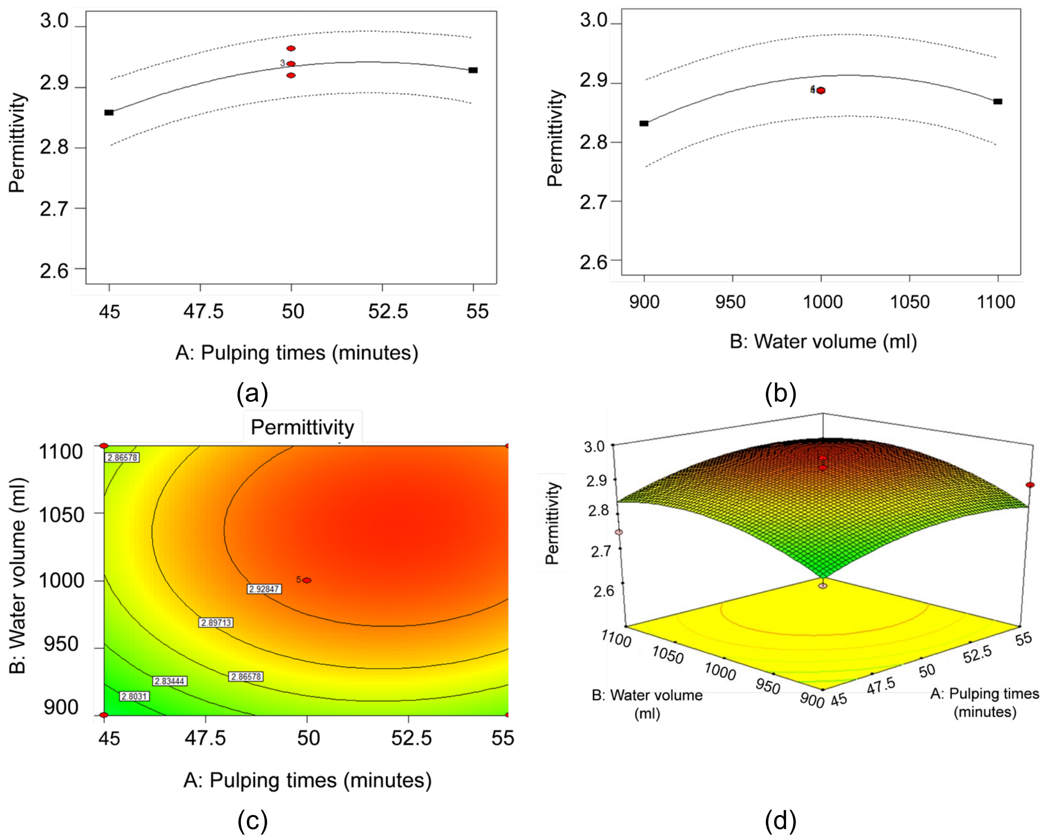

Figure 10. The effects of (a) pulping time and (b) water volume on permittivity value and the interaction effect in (c) contour plot and (d) 3D response plot on permittivity value

The effect of interaction between factors is illustrated in Figure 10(c-d) for the contour plot and 3D response, respectively. The curvatures on both figures imply that both factors had a quadratic effect on the permittivity value. Hence, the optimum condition can be determined from this design. It was notable from the figure that the optimum permittivity value was obtained at 50 min of pulping time and 1000 mL water volume.

3.4 Optimum process condition for maximum cellulose content and permittivity value

The numerical optimization method was employed to determine the optimum process conditions for maximum cellulose content and permittivity value. All process factors were set to be in range, and both responses were set to maximum to achieve maximum desirability. The optimum condition obtained from the analysis of RSM for maximum cellulose content and permittivity value was 50 min pulping time and 1000 mL water volume, giving rise to 46.84% cellulose content and 2.97 permittivity value. Nevertheless, the conditions were seen to vary among responses if the objective was to achieve maximum value for both responses.

Hu et al. (2017) obtained 14.2% cellulose extracted from Argan press cake through Kraft pulping. Argan press cake (powder form) contains only pure cellulose as compared to the cellulosic content of wood fiber. Kraft pulping requires a longer extraction time and also requires further purification; therefore, it can be considered less effective for cellulose extraction. Kulic & Radojicic (2011) applied the Kurschner-Hanack and Updegraff method for cellulose extraction from stalks and leaves of tobacco. Their result showed that tobacco leaves contained an average of 30.5 to 34.3% cellulose content. Das et al. (2016) obtained 56 to 68% of cellulose extracted from rice husks using Montmorillonite K-10/LiOH. The optimum condition was obtained at 6 h extraction time, 80°C temperature with 10% LiOH (in H_2O) and 20% maleic acid. This method required more time, was complicated, and involved more costly reagents that were not friendly to the environment. Lawal & Ugheoke (2010) studied the cellulose content of several agro-waste products, namely sorghum stalk, maize cub, and groundnut shell as alternatives for paper production. The results showed that groundnut shell contains the highest cellulose content with 65.2%, followed by maize cub and sorghum stalk with 62.3 and 47.4%, respectively. Based on the comparison between the current and the previous studies, the amount of cellulose obtained in this study can be considered high; therefore, the soda pulping method is proven to be a simple yet reliable extraction method. However, it is worth noting that different plant materials contain varying amounts of fiber, as well as lignin and hemicellulose composition; hence, the resulting cellulose content would vary.

Several studies were conducted by researchers on the permittivity values of plant materials for a specific application. The dielectric constant of pineapple leaf fiber (PALF) and pulverized oil-palm frond (OPF) obtained by Baharuddin et al. (2014) of 3.38 and 4.40, respectively, showed that both materials could be used as potential X-band absorbers. Sharma & Chand (2013) studied the dielectric properties of agro-waste rice husk/polypropylene composites with cenosphere. The results suggested that the dielectric constant value increased with rice husk content. The treated rice husk gave a lower dielectric constant value compared to the untreated due to the removal of impurities from the surface. Osman et al. (2017) examined the dielectric properties of ceramic materials obtained from rice husk for electronic applications. The rice husk sintered at 1100°C and 1200°C at 100 kHz had an ideal dielectric constant value for commercial insulating materials. It was found that the values of the dielectric constant for most commercial insulating materials varied from 2 to 10 (Inegbenebor & Adeniji, 2017). Therefore, based on previous studies on the permittivity of plant materials, the permittivity values obtained in this study fall within an acceptable range, which certifies their potential application as dielectric materials.

4. Conclusions

The study was focused on determining the most significant factors involved in the dielectric materials prepared from the pineapple leaves. The TLFA was applied to determine the most significant factors, while central composite design (CCD) was applied to discover the optimum conditions for maximum cellulose content and permittivity value. Response surface analysis was a proper method for reflecting the process parameter interaction. The results obtained in the factorial analysis could be used to tailor the processing factor to achieve the dielectric materials with the preferred permittivity value. The optimum conditions obtained in this study could be used to maximize the permittivity value and cellulose of the dielectric materials. The findings reveal the potential of pineapple waste as a base for dielectric materials. Further exploitation and manipulation of these wastes could remarkably reduce the amount of waste generated from the pineapple plantation, reducing environmental pollution.

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6. Conflicts of Interest

The authors declare that they have no conflicts of interest that could influence the work reported in this paper.

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