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Research Article

Extraction and Characterization of Natural Coagulant Made from Banana Plant Stems (*Musa acuminate*) for the Removal of Turbidity from Wastewater

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Wastewater treatment with chemical coagulants has a variety of drawbacks, including sludge management, cost, concerns for human health, and environmental pollution. In light of this, a study was conducted to determine whether banana plant stem (*Musa acuminate*) made coagulant can effectively reduce turbidity (NTU) of wastewater. In this study, conventional extraction method was used to extract the coagulant from the banana plant stem by using NaCl (0.1, 0.5, 1 M) solvent. After extraction, the coagulation efficiency of each produced coagulant was computed in terms of their turbidity removal efficiency (%) from sampled wastewater. The sampled wastewater had an average turbidity value of 893 NTU. Response surface methodology (RSM) and central composite design (CCD) were used to study the effects of NaCl solvent concentration (M), extraction time (min), and particle size (mm) on the coagulation efficiency (%) of the extracted coagulant. In addition, the coagulant was characterized such as FTIR analysis, point of zero charge value determination, and inulin compound presence analysis. From all prepared coagulants, the maximum coagulation efficiency obtained was 86.3% at the optimum conditions, such as 0.55 M (NaCl) of solvent concentration, 1.25 mm particle size, and 20 min of extraction time. The characterized coagulant had 6.2 points of zero charge value and also had various types of functional groups. Based on the findings of this study, it can be said that the coagulant prepared from banana stems (*Musa acuminate*) was an efficient natural coagulant that could be applied to treat wastewater.

1. Introduction

The world is faced with problems related to the management of wastewater. Increased population density, widespread industry, and highly urbanized societies are to blame for this problem. The primary sources of natural water pollution are effluents produced by household and industrial activities [1].

To tackle this problem, synthetic coagulants are employed to treat water and wastewater. The most popular coagulants used in water treatment around the world are aluminum salts, ferric salts, and synthetic polymers. Many developing nations struggle to afford the expenses of imported chemicals for the treatment of water and wastewater since these coagulants are frequently very expensive. In addition, a lot of academics are worried about the health effects of Alzheimer's disease brought on by leftover aluminum ions in the treated waters. Furthermore, some synthetic organic polymers, like acrylamide, are thought to be neurotoxic and have a potent carcinogenic effect [2].

Seeds, leaves, roots, bark, fruit peels, vegetable peels, and peels from the plant have all been utilized for cleansing purposes of water since the dawn of time. However, because their exact composition and the method by which they work are unknown, these natural materials have not been acknowledged or properly supported. Natural coagulants have many benefits, including reducing sludge build-up,

low cost, control over pH variations, nontoxicity, and environmental friendliness. Okra, the nirmali plant, banana stem juice, tamarind powder, and other coagulants have been used in exploratory analyses on their effectiveness in water purification [3, 4].

Most published papers were mainly focused only on some common types of plants. However, banana which is densely available in the country has not been given much attention. In addition to that, most previously done studies focus mainly on the peel of the banana. On the other hand, the stem of the banana which has the potential for the treatment of wastewater is left untapped. The -OH, -CH,-NH -COC-, -CN, -COO-, and -COOH are the functional groups in the banana stem. The presence of this huge number of functional groups and crude protein in the banana stem was thought to be responsible for the considerable elimination of a variety of pollutants [5]. As previously discussed, crude protein, organic matter, polysaccharides, gelatin galactomannans, cellulose derivatives, chitosan, and alginate are the key agents in treating wastewater, and those molecules and compounds are mainly found in bananas [6, 7].

Various solvents have been used in the process of extraction of active components to enhance the coagulation, namely, distilled water, KCl, NaCl, KNO_3 and $NaNO_3$, HCl, $BaCl_2$, NaOH, and NH_4Cl [8]. Yet, several experts state that the coagulant's ability to work depends on the turbidity of the water when it is first introduced and the solution in which it is made. Saline/salt solution is recommended for use in the manufacture of coagulants due to its demonstrated ability to solubilize both protein and other soluble active components from plants [9–12]. Furthermore, most of the coagulant preparation-related studies utilize the powder form of coagulant to treat wastewater, which has less dissociation compared to its aqueous form [13–15].

The main goal of this study was to extract a natural coagulant from banana plant stems (*Musa acuminate*) and to remove of turbidity of sampled wastewater by employing coagulation-flocculation test (coagulation efficiency). Furthermore, the study is also aimed at characterizing sampled wastewater and produced coagulant by using appropriate standard methods and procedures.

2. Methodology

2.1. Collection and Preparation of Natural Coagulant

2.1.1. Collection of Banana Plant Stem. In this study, purposive, subjective, or judgmental sampling techniques (nonrandom) were used to collect banana plant stems. In this technique of sampling, a desired number of sample units is selected deliberately or knowingly depending upon the object of the examination so that only the important items representing the true characteristics of the population are included in the sample. Based on the selected sampling technique, matured or ripped banana plant stems were collected since they have the maximum fructooligosaccharides, inulin concentrations, and crude protein [6, 16]. Therefore, ripped banana stems were collected in the nearby market of Kombolcha city, South Wollo, Amhara region, Ethiopia.

2.1.2. Preparation of Coagulant. The coagulant preparation method was done by following the procedure described by Kakoi et al. [5]. Matured banana plant stems (*Musa acuminate*) were collected in Kombolcha city, South Wollo, Ethiopia. The thorns were removed, and the stems were then separated from the foliage. The stem was thoroughly washed with pure water, and then it was cut and fried for 6 hours in an oven at 60°C. Again, according to Al-Jadabi et al. [17], dried pieces were ground into a powder, and the size passing through 2 mm, 1.25 mm, and 0.5 mm sieve was used for the experiment.

Furthermore, 100 mg/l fine powder coagulant was added to different concentrations of NaCl (0.1, 0.55, and 1 M) solution. According to the study of Cao et al. [18] and Orellana-Palacios et al. [19], the temperature of the solution was set at 41.5°C to extract coagulant from the raw material. The suspension was stirred using a magnetic stirrer for selected minutes (10, 20, and 30 min) to extract the active component. The suspension was stirred with a constant mixing speed of 70 rpm [20]. After 30 min of settling, the supernatant was filtered through a rugged filter paper (0.45 microns) to obtain filtrate extract of an active coagulating agent. Coagulation-flocculation test or jar test experiment had taken place to evaluate the coagulation efficiency [21–23]. The main steps in the preparation procedure of coagulants from banana plant stems are shown in Figure 1.

2.2. Determining the Coagulation Efficiency (%) of Produced Coagulants. Using six-paddle rotor jar test equipment (Velp Scientifica), jar floc tests were carried out to identify the most powerful coagulant. According to the previous study of Alwi et al. [16], during the experiment, 500 mL of wastewater was filled into six beakers and get mixed. While extracting the active coagulant, a required dose (100 mg/l) of it was added to determine coagulation efficiency in terms of percentage removal of turbidity (%).

The jar test was conducted at a constant room temperature of 24°C. In this experiment, the pH, dose of coagulant (mg/l), and extraction time (min) were held constant at the selected optimal value. The constant values of pH, dose (mg/l), and extraction time (min) were taken from previous studies of optimal values. Therefore, according to Owoicho et al. [24] and Bari et al. [21], study pH of 7, extraction time of 50 min, and a dose of 100 mg/l were selected. 100 mg/l of banana stem coagulant was applied, and the solution underwent 3 min of quick mixing at 180 rpm, 20 min of extraction time at 10 rpm, and 30 min of settling, according to Kakoi et al. [5] and according to Kebede et al. [3]; in each jar test experiment, one of the six jars received no treatment, serving as a control for the comparison of coagulation efficiency for all other jars. The following equation was then used to determine coagulation activity:

$$\text{Coagulation}(\%) = \frac{\text{Tur(FTU)}_i - \text{Tur(FTU)}_f}{\text{Tur(FTU)}_i} \times 100, \quad (1)$$

where Tur(FTU)_i is the turbidity of wastewater and Tur(FTU)_f is the turbidity of the treated wastewater.

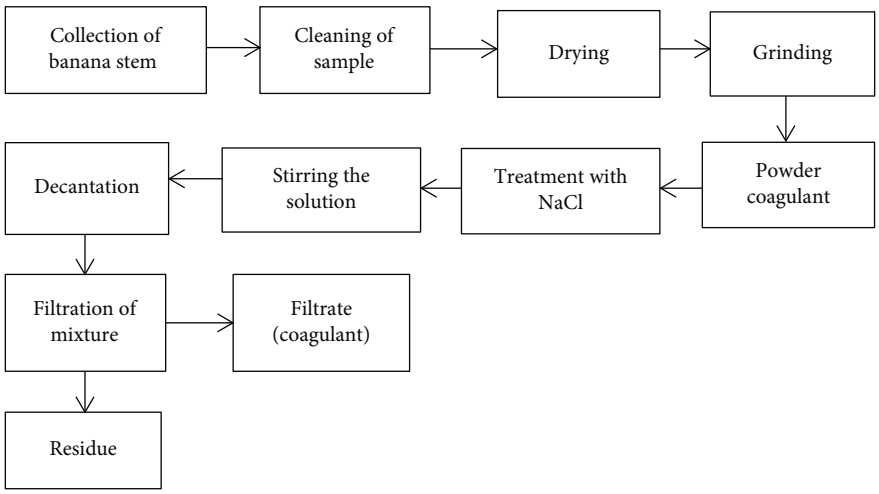

Figure 1: Preparation procedure of coagulants from banana plant stem.

2.3. Characterization of Produced Coagulant. The banana stem coagulant was characterized to identify the presence of various functional groups (FTIR analysis), to determine its point of zero charge (PZC), and finally to check the extent of the inulin compound presence by employing different standard techniques.

2.3.1. Fourier Transform Infrared Spectroscopy (FTIR) Analysis of Coagulant. The functional group of the banana plant stem was determined by employing an FTIR analyzer. According to Kathiresan et al. [25], the ground banana pith was mixed with potassium bromide (KBr). Compressors were used to grind and compress the mixture to create a thin slate for analysis. The material's functional groups were examined using the JASCOFT-IR model 8400.

2.3.2. Determination of Point of Zero Charge Value. While particle technologists intuitively understand particle size and its measurement, the idea of a point of zero charge (pzc) is less frequently recognized and implemented. The point of zero charge value (pzc) is related to the charge on the surface of the particle and strongly depends on the pH of the material; so, it influences a wide range of properties of colloidal materials, such as their stability, interaction with electrolytes, and ion exchange capacity. The pH levels at which the surface charge elements are equal to zero with specific parameters of temperature, applied pressure, and content of the aqueous solution are known as the point of zero charge (pzc) [26].

According to Bakatula et al. [27], the point of zero charge (pzc) of the banana stem was determined by solid/salt addition or pH drift method. The pH of the 0.01 M NaCl was adjusted to a value between 4 and 9 using 0.5 M HCl or 0.5 M NaOH. After a salt solution with the given range, a sample of 0.5 g was added to 20 ml of water by using a 100 mL flask, and then the pH-adjusted solution was in a capped vial and was shaken using a shaker for 24 h. The final pH was measured and compared against the initial pH. The pzc was determined to be the pH at which the initial and final pH is identical.

2.3.3. Determination of Inulin Compound Presence. Identification of inulin presence was performed according to the procedure of Nadezhda and Panteley [28] and Redondo-Cuenca et al. [29]. Briefly, the FTIR spectra of dried and ground inulin extracts were recorded using JASCOFT-IR model 8400. FTIR spectroscopy successfully applies in the identification of inulin and free oligosaccharides without the destruction of the sample.

2.4. Design of Experiment. The goal of this study was to determine how certain independent variables affected the process of extracting an active coagulant agent from the stem of a banana plant to achieve the highest possible coagulation efficiency (%). The preparation of a natural coagulant and wastewater treatment experiment was accomplished using a central composite experimental design (CCD) based on the response surface methodology (RSM). For the preparation of an efficient coagulant, three levels of solvent concentration (M), extraction time (min), and particle size (mm) were used. To investigate the impact of these variables on the coagulation efficiency (%) (in terms of percentage removal of turbidity) of wastewater, 20 experimental runs were conducted.

The factors for coagulant preparation had three levels as follows: low level (−1), center level (0), and high level (+1). The actual values of the coded levels for these factors were selected based on previous research. Therefore, the low and high coded levels for solvent concentration (M) and extraction time (min) were taken from the previous studies of Grasiele et al. [10] and Mechmeche et al. [30]. According to their studies, 0.1 M and 1 M for solvent concentration and 10 min and 30 min for extraction time were selected. Moreover, the value for particle size (mm) was selected from the previous study of Lee (2017) and Rodríguez-Miranda et al. [31]. According to their study, the high and low levels were 0.5 mm, and 2 mm mesh sizes were selected for the test, as shown in Table 1.

2.5. Statistical Analysis of Experimental Results. Results were examined using Design-Expert software version 13.00, Origin-2022, and Microsoft Excel software. The individual

Table 1: Coded independent variables for coagulant preparation.

Factor	Name	Units	Minimum	Maximum	Mean
A	Particle size	mm	0.5000	2.00	1.25
B	Extraction time	min	10.00	30.00	20.00
C	Solvent concentration	M	0.1000	1.0000	0.5500

effects of process parameters on the preparation of efficient coagulant (efficiency in terms of turbidity removal) were analyzed both numerically and graphically by using the above software. The statistical significance of each factor in the regression models for each response was evaluated with analysis of variance (ANOVA) using F value and p value < 0.05. The values of predicted and adjusted R-squared (R^2) were also generated and analyzed.

3. Results and Discussions

3.1. Coagulation Efficiency of Produced Coagulants. The coagulation efficiency of every produced coagulant was computed in terms of their ability to remove turbidity (NTU) of sampled wastewater. To compute the coagulation efficiency, equation (1) was used, and the values are listed in (Table 2). Maximum coagulation efficiency (86.3%) was obtained with experimental conditions of 20 min extraction time, 1.25 mm particle size, and 0.55 M NaCl solvent concentration. This value is greater than the value reported by Rizwan et al. [32] who reported a maximum coagulation efficiency of 78%. According to the study of Ana et al. [6] and Gautam and Saini [7], the maximum coagulation efficiency of the banana stem-made coagulant is due to its content of inulin, crude protein, crude fat, soluble polysaccharides, and oligosaccharides.

Another study done by Aho et al. [33] also reported a maximum coagulation efficiency of 88.54%, which is higher than the maximum value obtained in this study. This difference might be due to reasons for using different extraction procedures followed and equipment used in the extraction process, as well as a difference in the factors and levels taken. On the other hand, the minimum value (77.9%) was recorded at 0.5 M solvent concentration (NaCl), 10 min extraction time, and 1 mm particle size.

Furthermore, comparing the coagulation efficiency of the banana stem-made coagulant with inorganic salt coagulants gives encouraging results. According to the studies of Sahu and Chaudhari [34], inorganic ferric and alum salt coagulants have 70% coagulation efficiency to remove turbidity from wastewater.

3.2. Characterization of Coagulant. The banana stem-made coagulant, which had maximum coagulation efficiency, was characterized to identify the presence of various functional groups (FTIR analysis), to determine its point of zero charge (PZC), and finally to check the extent of the inulin compound presence by employing different standard techniques.

3.2.1. Point of Zero Charge Value (PZC) of Coagulant. The extracted coagulant had a 6.2-point of zero charge value. Because acidic solutions contribute to H^+, the pzc (point of zero charge) suggests that charge balance is possible under acidic conditions. To settle out of wastewater, this positively charged coagulant must first attract and bind with anions. The low point of zero charge (pzc) values, according to Pena et al. [35], indicate that positively charged surface groups prevail in the solution with pH above PZC (6.2) value.

Table 2: Coagulation efficiency of produced coagulants (%).

Run	Factor 1 A: P. size (mm)	Factor 2 B: E. time (min)	Factor 3 C: Solv. Conc (M)	Response Coagulation efficiency (%)
1	1.25	20	0.55	85.9
2	0.5	10	0.1	78.4
3	1.25	30	0.55	85.2
4	1.25	20	0.55	85.8
5	1.25	20	0.55	86.2
6	1.25	20	0.55	86
7	2	10	1	79.4
8	2	30	0.1	79.5
9	1.25	20	1	81.5
10	0.5	30	0.1	80.3
11	0.5	10	1	77.9
12	1.25	20	0.1	81.9
13	2	30	1	79.2
14	2	20	0.55	85.7
15	2	10	0.1	81.7
16	0.5	20	0.55	84.8
17	0.5	30	1	80
18	1.25	20	0.55	86.3
19	1.25	20	0.55	85.6
20	1.25	10	0.55	84

3.2.2. FTIR Analysis Result of Banana Stem Coagulant. In Figure 2, the peak between 1000 and 1300 cm^{-1} was assigned to –C=O-, and according to the study of Santhi and Sengottuvel [36], this is due to the existence of stretching vibrations in the amines, alcohols, and ester groups. Again, another strong peak was observed in the range of wavelength from 1600 to 1750 cm^{-1}, and this indicates the presence of -COOH- and -COO-.

Moreover, there is a medium-strong broader peak around a wavelength of 3600 cm^{-1} due to the presence of -OH hydrogen bond stretching vibration. According to the study of Miriam et al. [37], this broadband is due to the presence of –OH in cellulose. Finally, the presence of a peak at 3745 cm^{-1} and 3845 cm^{-1} can be assigned to -N-H stretching. According to the study of [8, 36], the presence of this band

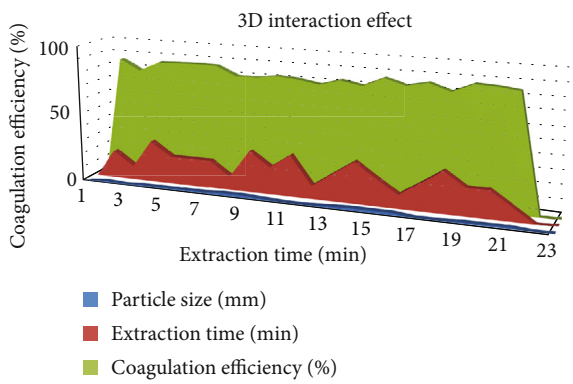

Figure 2: Interaction effect of extraction time (min) and particle size (mm) on removal efficiency of turbidity of wastewater (%).

Table 3: ANOVA for coagulation efficiency of coagulant (%).

Source	Sum of squares	*Df*	Mean square	*F* value	*p* value	
Model	175.58	9	19.51	180.43	<0.0001	Significant
A-particle size (mm)	1.68	1	1.68	15.55	0.0028	
B-extraction time (min)	0.7840	1	0.7840	7.25	0.0226	
C-solvent concentration (M)	1.44	1	1.44	13.35	0.0044	
AB	5.12	1	5.12	47.35	<0.0001	
AC	0.4050	1	0.4050	3.75	0.0817	
BC	0.6050	1	0.6050	5.60	0.0396	
A^2	1.51	1	1.51	13.96	0.0039	
B^2	5.32	1	5.32	49.20	<0.0001	
C^2	50.63	1	50.63	468.27	<0.0001	
Residual	1.08	10	0.1081			
Lack of fit	0.7479	5	0.1496	2.24	0.1979	Not significant
Pure error	0.3333	5	0.0667			
Cor total	176.67	19				

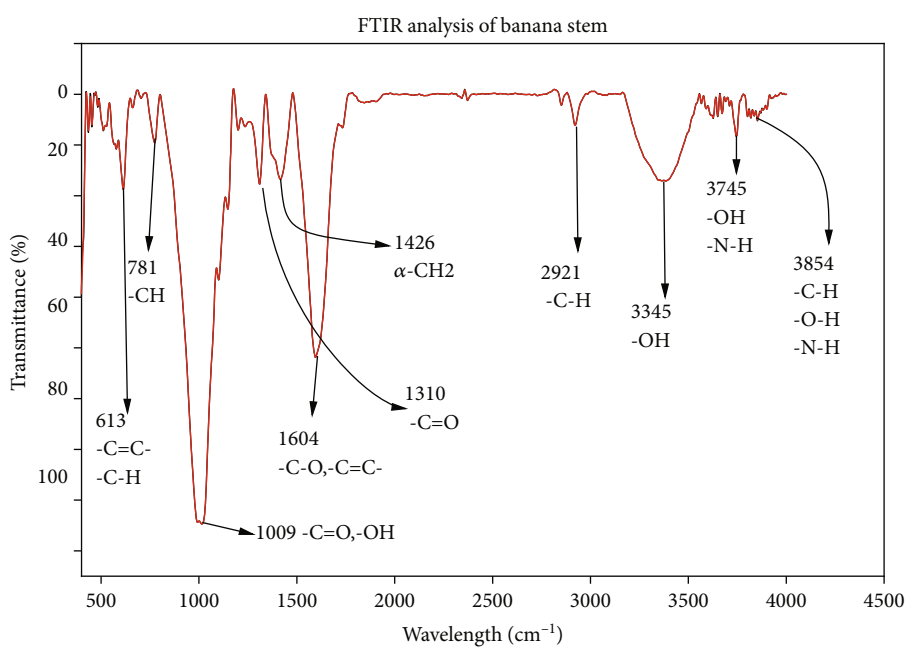

Figure 3: FTIR spectrums of banana plant stem coagulant.

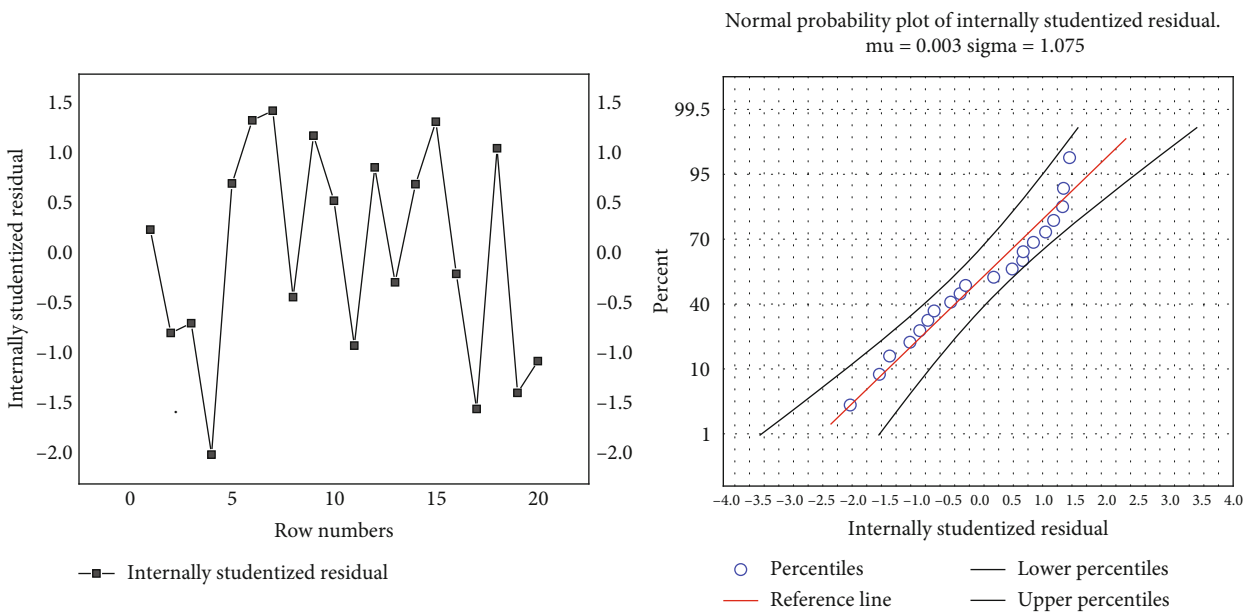

Figure 4: Residual versus predicted and normal probability plot for coagulation efficiency (%).

confirms the presence of amines, amides, and alcohols which again implies the presence of crude protein structure in the banana stem. Finally, there is also a peak from 600 to 750 cm^{-1}; this is due to the existence of cis-disubstituted alkene. Therefore, depending on the above FTIR result and analysis, it can be concluded that banana pith coagulant can be utilized to remove pollutants from wastewater.

3.2.3. Identification of Inulin Presence. As shown in Figure 2, the bands indicative of the inulin structure were found in the FTIR spectra recorded in KBr pellets. According to the study of Nadezhda and Panteley [28], strong broadband from 1010 to 1020 cm^{-1} was seen in the spectra of FTIR, and this strong broadband indicates the presence of inulin.

The peak between 1000 and 1300 cm^{-1} was attributed to -CO-, stretching vibrations due to the presence of lactones, ketones, aldehydes, or carboxyl groups. Another peak was seen in the wavelength region between 1600 and 1750 cm^{-1}, which confirms the existence of -COOH and –COO-. According to the study of Redondo-Cuenca et al. [29], all these data in FTIR spectra suggest the presence of an inulin compound.

3.3. Statistical Analysis for Coagulation Efficiency of Coagulant. The dependent variable of this study was the ability of the produced coagulant to coagulate and remove turbidity of wastewater which was measured by the percentage removal of turbidity (%). A quadratic model with a p value of less than 0.0001 is shown in the fit summary, indicating that the model is significant because it falls within the permitted p value. Additionally, the model is significantly based on the F value of 180.43. The lack of fit F value shows that the lack of fit is not significant in contrast to the pure error. The Adeq precision which measures the signal-to-noise ratio is very high. A ratio greater than 4 is desirable, which is 35.88 indicating an adequate signal of the study. Again, from the model adequacy test, it can be seen that the "predicted R^2" of 0.9289 and the "adjusted R^2" of 0.9884 are in reasonable accordance, having a difference of less than 0.2 between them.

3.4. Regression Model Equation for Coagulation Efficiency of Coagulant. According to the ANOVA analysis in Table 3, the lack of fit of the model is not significant, but the models with all components are significant except the AC term. Model terms that have probability values or "Prob > F" values lower than 0.05 are considered significant. Significant model terms for this model included are A (particle size), C (solvent concentration), B (extraction time), AB (particle size and extraction time), BC (extraction time and particle size), B^2 (extraction time), A^2 (particle size), and C^2 (solvent concentration). The fact that AC (particle size and solvent concentration) have a p value greater than 0.05 means it is not significant. Consequently, the following equation was produced after regression (with the lowest p values) to represent the suggested quadratic model:

$$\begin{aligned}\text{Coagulation efficiency (\%)} = {} & 85.98 + 0.41 * A + 0.28 * B \\ & - 0.38 * C - 0.8 * A * B \\ & + 0.275 * B * C - 0.74 * A^2 \\ & - 1.39 * B^2 - 4.29 * C^2.\end{aligned} \tag{2}$$

3.5. Diagnostic Test for Coagulation Efficiency of Coagulant. Furthermore, the adequacy of the model was checked by constructing different diagnostic plots for efficient coagulant preparation shown in Figures 3 and 4. The normal probability plots of residuals for the response were normally distributed, as they lie reasonably close to the straight line and show no deviation of the variance. Again, residuals versus predicted plots were constructed to facilitate the satisfactory

fit of the developed model, and the plots show that all the data points lie within the limits (±3). Furthermore, the graph of residual versus predicted shows that the residuals' plot against the increasing values of the predicted response shows no clear pattern or distinctive structure, indicating that no adjustment is necessary to lower personal error.

3.6. Effects of Independent Variables on Coagulation Efficiency of Coagulant. The effects of particle size (mm), solvent concentration (M), and extraction time (min) were examined on the coagulation efficiency of the produced coagulant.

3.6.1. Effect of Solvent Concentration (M) on Coagulation Efficiency. According to Figure 5, as the concentration of NaCl increased from 0.1 M to 0.55 M, coagulation efficiency increased from 81.9% to 86.2%. However, it starts dropping to 81.5% as the concentration increased over 0.55 M. The study done in [8] supports this finding because 0.5 M was the most effective one, producing the highest removal of turbidity compared to other concentrations. This improvement in this coagulation activity is due to the salting-in effect (increasing solvating power). The solvent will dissolve more active components and will increase coagulation efficiency. On the other hand, increasing salt concentration beyond 0.55 M leads to the sequestration of water molecules and will result in a decrease in protein solvation due to the salting-out effect.

3.6.2. Effect of Extraction Time (Min) on Coagulation Efficiency of Coagulant. As Figure 6 implies, increasing the extraction time (min) affected the coagulation potential of the produced coagulant both positively and negatively. The greatest reduction in turbidity (86.2%) was observed at 20 min. However, increasing extraction time (min) beyond 20 min will start to affect coagulation efficiency negatively. This mixed effect of extraction time is also confirmed by the study of Megersa et al. [38], and according to his study, increasing extraction time excessively will decrease the extraction of an active component of a coagulant. This reduction of active coagulant extraction may be due to the extraction of other organic matter, which may hinder the coagulation process.

3.6.3. Effect of Particle Size (mm) on Coagulation Efficiency of Coagulant. As presented in Figure 7, the coagulation efficiency significantly increased as particle size (mm) increased until 1.25 mm (maximum coagulation efficiency of 86.3%), and then it decreased. In other words, the plot shows that the coagulation efficiency was directly proportional to the particle size (mm) of the coagulant until it reaches 1.25 mm. According to the study of Idiok and Nwaiwu [39], the increment of coagulation efficiency when particle size increased up to 1.25 mm is due to smaller particle sizes reducing the obstacles to the diffusion of the solvent into the particles and that of solute and solvent out of the particle pores. Therefore, when active component extraction increased, coagulation efficiency will also increase.

3.7. Interaction Effects of Independent Variables on the Removal Efficiency of Turbidity. The possible interactions between independent experimental variables on the removal efficiency of turbidity were demonstrated by employing design expert software. A different shape of the 3D surface plot indicates interactions between the variables. These plots illustrate the relative effect of any two variables by maintaining the third variable constant.

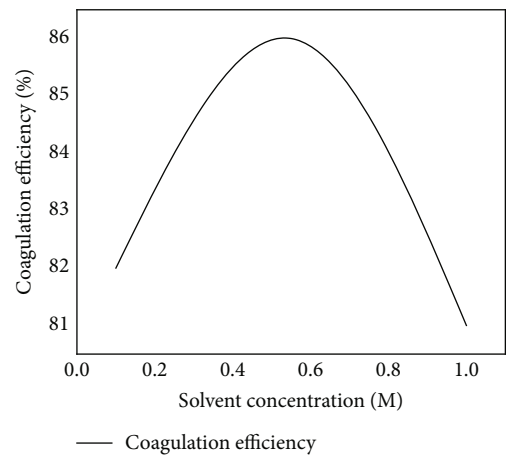

Figure 5: Effect of solvent concentration (M) on coagulation efficiency (%).

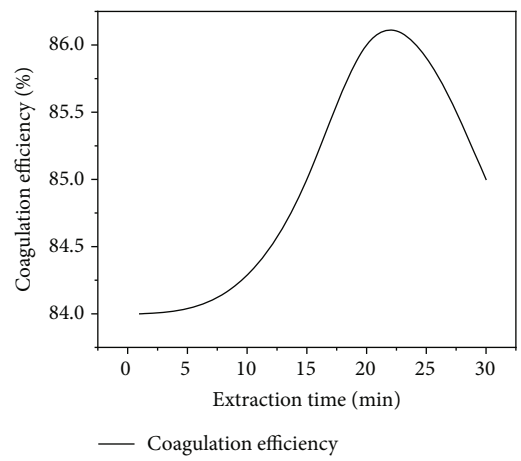

Figure 6: Effect of extraction time (min) on coagulation efficiency (%).

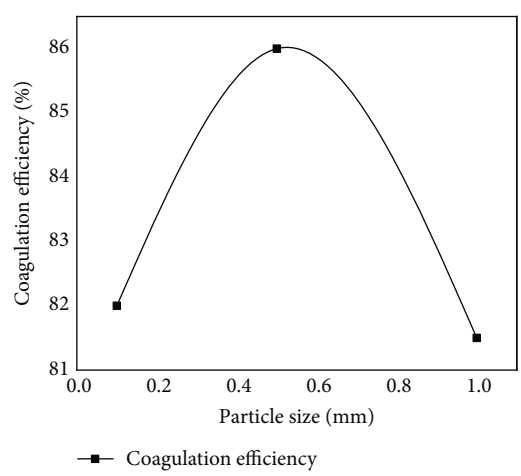

Figure 7: Effect of particle size (mm) on coagulation efficiency.

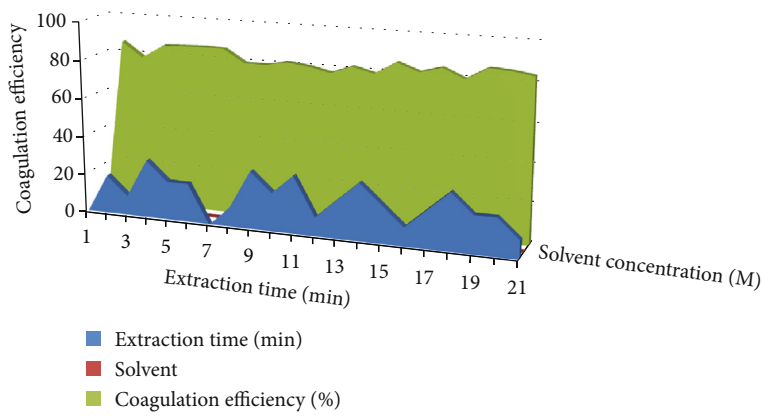

Figure 8: Interaction effect of solvent concentration (M) and extraction time (min) on removal efficiency of turbidity (%).

3.7.1. Interaction Effect of Extraction Time (Min) and Particle Size (mm). In Table 3, ANOVA analysis and AB (extraction time (min) and particle size (mm)) interactions affect the removal efficiency of turbidity significantly. To examine the interaction effect of AB (extraction time (min) and particle size (mm)) of the experiment, solvent concentration (M) was kept constant. In Figure 2, it is observed that the removal efficiency of turbidity (NTU) increased as the extraction time (min) gets longer and when particle size (mm) was reduced. When the extraction time increased up to 30 min, the turbidity removal efficiency increased. Again, the removal efficiency of turbidity also gets increased as the particle size increased up to 1.6 mm. However, increasing both particle size (mm) and extraction time (min) after mentioned values, the removal efficiency starts to decrease.

3.7.2. Interaction Effect of Solvent Concentration (M) and Extraction Time (Min). The removal efficiency of turbidity (%) is only moderately impacted by the BC (extraction time (min) and solvent concentration (M)) interaction, according to Table 3's ANOVA analysis. Particle size (mm) was held constant to assess BC's interaction effects. Figure 8 shows that the effectiveness of removing turbidity (%) from wastewater increased as extraction time (min) was increased (up to 20 min) and when the solvent concentration was increased (up to 0.55 M). However, after passing those mentioned values (20 min, and 0.55 M), turbidity removal efficiency of the coagulant starts dropping.

4. Conclusions

The conventional extraction technique was used to prepare coagulant from the banana plant stem. Response surface methodology (RSM) and central composite design (CCD) were used to determine how particle size (mm), mixing time (min), and solvent concentration (M) affected the coagulation efficiency or removal efficiency of turbidity of wastewater. Furthermore, the coagulant which had maximum coagulation efficiency was characterized to check for inulin presence, to know its point of zero charge value, and to determine the presence of different functional groups. As the FTIR analysis implies, the characterized coagulant was rich in inulin compound and had different functional groups. Again, a point of zero charge of the coagulant was 6.2, which indicates the presence of both cations and anion compounds in the coagulant. A good degree of turbidity removal efficiency (86.3%) was discovered. As the concentration of NaCl increased from 0.1 M to 0.55 M, coagulation efficiency increased from 81.9% to 86.2%. However, it starts dropping to 81.5% as the concentration increased over 0.55 M. Increasing the extraction time (min) affected the coagulation potential of the produced coagulant both positively and negatively. The greatest reduction in turbidity (86.2%) was observed at 20 min. However, increasing extraction time (min) beyond 20 min will start to affect coagulation efficiency negatively. The coagulation efficiency significantly increased as particle size (mm) increased until 1.25 mm (maximum coagulation efficiency of 86.3%), and then it decreased. Based on the findings of this study, it can be said that the coagulant prepared from banana stems (*Musa acuminate*) was an efficient natural coagulant that could be applied to treat wastewater.

Data Availability

The data used to support the findings of this study are included in the article.

Disclosure

The funders had no role in the study design, data collection and analysis, publication decision, or manuscript preparation.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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