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Assessment and optimization of a natural coagulant (*Musa paradisiaca*) peels for domestic wastewater treatment

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Abstract

Sustainable wastewater treatment necessitates the application of natural and green material in the approach. Thus, selecting a natural coagulant in wastewater treatment is a crucial step to prevent secondary environmental pollution due to residual inorganic coagulant in treated effluent. Present study investigated the application of *Musa paradisiaca* (banana) peels in domestic wastewater treatment. From the experimental results, the banana peels were found to have a higher yield with lower moisture content compared to the other fruit wastes. The surface charge of the banana peels was +6.53 meq/g MLSS while the recorded protein composition was 0.248 mg/L. The scanning electron microscopy (SEM) showed that banana peels have rough and pore surfaces compared to the others fruit wastes. At optimum conditions of 50 mg/L dosages, pH 4, and 100 rpm of agitational speed, the maximum turbidity removal of up to 89.9% with initial turbidity of 76 NTU was obtained. The banana peel was also evidenced in efficiently removing COD and NH_4-N from domestic wastewater up to 80.0% and 62.5%, respectively. Overall, the findings suggested that *Musa paradisiaca* (banana) peels is efficient and suitable to be applied as the natural coagulant in treating domestic wastewater.

Keywords :
Natural coagulant, *Musa paradisiaca* (banana) peel, wastewater treatment, coagulation

1 Introduction

The discharge of non-properly treated effluent that contains various types of contaminants into the water bodies have received worldwide attention due to their effect on the environmental health (Vega Andrade et al., 2021). Numerous method such as ion exchange, electrolysis, membrane separation, flocculation and coagulation have been applied in the treatment of contamination and pollutions in the wastewater (Priyatharishini and Mokhtar, 2021). Among the technologies, the coagulation-flocculation process is seen as an alternative in the treatment of domestic wastewater due to its efficiency in removing suspended solids, colors, turbidity, and organic matter (Bahrodin et al., 2021). This process combines smaller particles into larger flocs or aggregates which will be removed in the solid or liquid separation process (Zaidi, 2019).

The mechanism of this physicochemical process involves the reduction in the repulsive potential present in the electrical double layer of colloids which enhance their potential in combining into larger aggregate (Priyatharishini and Mokhtar, 2021). According to Benalia et al. (2019) the effectiveness of the coagulation treatment process is largely dependent on various factors such as type of coagulant, coagulant dosage, nature of particles and pH of the water.

Currently, there are many types of coagulants available in the markets and the conventionally used are chemical-based coagulants such as aluminum sulfate (alum), polyaluminum chloride (PAC), ferric sulfate, or ferric chloride. However, these types of chemical coagulants possess various types of drawbacks in terms of health and environmental perspectives such as nervous system failure, Alzheimer's disease, and production of toxic sludge (Amran et al., 2021). Hence, the development of new potential natural coagulants becoming more concerned in the markets of wastewater treatment. To date, natural coagulants of plant and mineral resources were used in water and wastewater treatment. Natural coagulants are becoming the main interest of many researchers due to their cost effectiveness compare to chemical coagulants, easily accessible, abundant source, multiple functions and can be used for a wider range of effective dosage (Sanghi et al., 2006; Zhang et al., 2006). Some of the plant-based waste such as *Carica papaya*,

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orange peel, *Moringa oleifera* shows potential as a natural coagulant due to the ability to conduct coagulation mechanisms such as charge neutralizing and polymer bridging (Amran et al., 2018). However, the existing studies do not give comprehensive facts in terms of the complete physiochemical properties of these natural coagulants. Moreover, due to the various types and species of plant-based waste available worldwide, hence lead to the various profile of coagulant dosage, pH, and agitation speed. The optimization is crucial to investigate taking into consideration that the natural coagulant used in the study can be different than others.

Although, various types of natural coagulant have been utilized including banana peels, the existing studies do not give comprehensive facts in terms of complete physicochemical properties of these natural coagulants. Moreover, due to the various species of banana and source of wastewater available worldwide, the operating factors of coagulant dosage, pH, and agitation speed might differ for each study. Therefore, this study was conducted to investigate the removal performance of domestic wastewater using banana peels as a potential natural coagulant, to characterize banana peels as coagulant based on physical, chemical, and morphological properties and to investigate the effects of pH, dosage, and agitation speed on the removal performances of wastewater using banana peels as the natural coagulant.

2 Materials and methods

2.1 Raw wastewater

Raw wastewater was collected from the selected wastewater treatment plant (WWTP) located at Mutiara Mas, Johor Bahru. The collected raw wastewater samples were analyzed for water quality parameters including turbidity, COD, and NH_4-N.

2.2 Preparation and extraction of used coagulant (banana peels)

The banana peels were collected from the local markets and nearby restaurants at Taman Universiti, Skudai. This study focusses on application of agro-waste (banana peels) as natural coagulant. The collected peels were done at random thus, the collection of peels may be comprised of different banana species. Then, the collected peel was washed under tap water twice, followed by cleaning and drying for at least 24 hours at 105°C. After that, the dried banana peel was ground into powder using a common blender at medium speed. The ground banana peels were graded for 30 minutes. This is to allow the ground powdered banana peels to be sieved through 500 µm sieve using a motorized sieve shaker while the unused coagulant powder was kept in airtight plastic. Figure 1 below shows the flow of the preparation and extraction of banana peels natural coagulant powder.

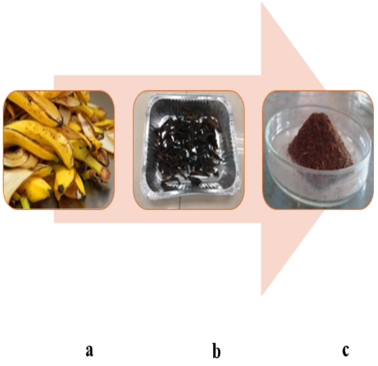

Figure 1 Preparation and extraction of banana peels natural coagulant powder: a) Raw banana peels; b) Dried banana peels; c) Ground banana peels as natural coagulant

2.3 Jar test assays

The jar test was used to carry out the coagulation and flocculation on the water samples. The water samples were added into 5 beakers with different conditions to determine the optimum dosage, pH condition, and agitation speed for the coagulation. Jar test was conducted based on One-Factor-At-A-Time (OFAT). The optimum coagulant dosage was determined at fixed pH and agitation speed of 6.68 and 100 rpm, respectively. This step is the continued for determination of optimum pH at fixed coagulant dosage and agitation speed of 50 mg/L and 100 rpm, respectively. Finally, from the optimum coagulant dosage and optimum pH, the optimum agitation speed was then determined.

1 mg of coagulant powder were diluted into 10 mg/L, 30 mg/L, 50 mg/L, 70 mg/L, and 90 mg/L in centrifugal tube, respectively. 5 beakers were filled with 200 mL of wastewater and each beaker was added with 5 mL of stock solution. All beakers were controlled at pH 7 and the sample was mixed at 200 rpm for the first two min, followed by 60 rpm until completed 30 min of reaction time. The same way was applied upon determining the optimum pH and agitation speed. For determination of pH, 200 mL of wastewater in each beaker were adjusted to pH 2, 5, 7.5, 10, and 12 respectively. Each beaker was added with 5 mL of stock solution with optimum dosage (50 mg/L) and the sample was mixed at 200 rpm for the first two min, followed by 60 rpm until completed 30 min of reaction time. Lastly, 200 mL of wastewater in each 5 beakers was prepared with optimum dosage (50 mg/L) and pH (pH 4) from previous experiment. The sample was mixed at 200 rpm for the first two min, followed by different agitation speed of 60 rpm, 80 rpm, 100 rpm, 120 rpm and 140 rpm, respectively, until completed 30 min of reaction time to determine the optimum condition for the agitation speed. The initial turbidity was measured every time the jar test was set at different conditions. Upon jar test process, the temperature for all beakers was set at room temperature of 27°C. After setting up the specified operating conditions, the jar test was allowed to run for 30 min followed by the settling process for 1 hour. After that, the final turbidity was recorded.

2.4 Characterization of banana peels natural coagulant

2.4.1 Yield and moisture content of banana peels

Identifying the moisture content of banana peels is crucial with the aim to evaluate the yield of coagulant that will be produced. The banana peel was cleaned with distilled water and then weighted (Mi). After that, the banana peel was put for air-dry for 24 hours, followed by oven-drying for another 24 hours. Then, the fully dried banana peel was put into an aluminum foil for weighting. The dry weight of banana peel was taken and recorded (Md). The dried banana peel was ground into powder by using a blender to obtain the yielding mass. The yield mass of banana peel was recorded (Mf). The yield mass was determined in triplicate and calculated based on Eq. (1) while the moisture content of banana peel was determined in triplicate and calculated based on Eq. (2).

$$\text{Yield}(\%) = \frac{M^f}{M_i} x100\% \tag{1}$$

$$\text{Moisture Content}\ (\%) = \frac{M_i - M_d}{M_i} x100\% \tag{2}$$

Where,
$M_i$is the initial mass of banana peel
M_f is the final mass of banana peel
M_d is the dry mass of the banana peels

2.4.2 Surface charge

The surface charge of the coagulant was carried out in triplicate using the colloidal titration method. Three solutions were prepared for surface charge testing. 0.25 g/L Polydiallyldimethyl Ammonium Chloride (PDAC) is used to show the presence of cationic polyelectrolyte. Then, 0.2027 g/L Polyvinyl Sulfate Potassium (PVSK) is used to show the presence of anion, and 0.05 g/L Toluidine Blue is used to observe the change of color from blue to colorless during the colloidal titration. Initially, 2.5 g of powder coagulant is mixed into 200 mL of distilled water for three minutes. The solution was then diluted to 12500 mg/L as a stock solution and poured into a conical flask. The stock solution was added with 8 mL of PDAC solution and mixed thoroughly. Then, toluidine blue solution was added. The solution was then titrated with PVSK solution until the color changed from blue to pink or purple. The blank sample with only distilled water was repeated to take as a control parameter. The surface charge can then be computed using Eq. (3).

$$\text{Surface Charge (meq/g MLSS)} = \frac{(A-B)xN(1000}{VxC} \tag{3}$$

Where,
A : Volume of PVSK titrated to sample (mL)
B : Volume of PVSK titrated to blank sample (mL)
N : Normality of PVSK (eq/L)
V : Coagulant stock solution volume (mL)
C : Coagulant stock solution concentration (mg/L)

2.4.3 Aluminum and iron content

The banana peels powders were chemically analyzed for their aluminum and iron content. The standard solution of 5 ppm, 25 ppm, 50 ppm, 75 ppm, and 100 ppm for aluminum content, while the standard solution of 0.5 ppm, 2 ppm, 4 ppm, 6 ppm, and 10 ppm for iron were prepared. All the samples were filtered to prevent the large particle from clogging the AAS equipment during the test. The standard solutions were then tested using the Atomic Absorption Spectrometer (AAS) to obtain a graph of at least 0.98 gradients. Then, the banana peel samples were inserted in the AAS.

2.4.4 Protein content

Protein analysis was carried out based on Lowry Method. There are three solutions as in Table 1 that have been prepared. Initially, 2.5 g of coagulant powder was mixed in 200 mL of distilled water with a blender for three minutes. Then, the diluted Bovine Serum Albumin (BSA) stock solution was prepared by dissolve 50 mg of BSA in 50 mL distilled water, and 1mL of this solution contain 1 mg of protein. Then, 0.9 mL of solution A was added to all test tubes. The sample was then incubated for 10 minutes at room temperature. 1 mL of solution B was added and left for 10 minutes. After 10 minutes, 3 mL of solution C was added and left in a dark place for 30 minutes. Finally, the absorbance was checked at 650 nm. From the result of absorbent, the best-fitted line was obtained. The equation from the best-fitted line was used to determine the absorbance of coagulant samples.

Table 1 Mixed solutions for protein analysis

Solution	Mix Solution
Solution A	2g /L potassium sodium tartrate + 100 g/L sodium carbonate in 0.5 M sodium hydroxide
Solution B	0.2 g/L potassium sodium tartrate + 0.1 g/L copper sulphate pentahydrate in 0.1M NaOH
Solution C	Folin reagent in distilled water with ratio (1:16)

2.4.5 Scanning electron microscopy

Scanning Electron Microscopy (Hitachi TM3000, Quorum Sputter Coater) was carried out to observe the morphological property of banana peels powder, especially in terms of dimension. The microstructure of banana peels was studied in detail. The small portion of the sample was placed in a metal stub using a two-sided adhesive tape and coated with a fine layer of gold using a sputter gold coater. Sample micrographs were observed with a variety of magnifications at an accelerating voltage of 15 kV under a scanning electron microscope.

2.5 Analytical methods

The removal of wastewater with regards of the used natural coagulant was determined for turbidity, COD, and NH_4-N. The turbidity of the wastewater was measured using the HACH 2100Q turbidity meter, COD and NH_4-N was conducted based on HACH 8000 and HACH 8038 method, respectively.

3 Results and discussion

3.1 Characteristics of banana peels as natural coagulant

3.1.1 Physical characteristics of banana peels

Table 2 shows the recorded yield and moisture contents of banana peels. Based on the table, the recorded yield of banana peel in this experiment was 41.8%. The result indicates that 41.8% of the whole prepared material is contributing to become accessible organic-based coagulant. The yield obtained in this study was considerably high as compared to the other fruit wastes such as orange peels with 21.7%, maize with 23.2%, and mango peels with 25.2% (Zaidi et al., 2019; Zaidi, 2019). The higher yield might be due to a considerable increase in yield during the pretreatment of certain fruit material by microwave heating (Kratchanova et al., 1996). Apparently in this study, microwave pretreatment of fresh banana peels led to destructive changes in the plant tissue. The changes in the plant tissue after microwave pretreatment attribute to the considerable increase in the yield of extractable pectin and the improvement of parameters such as molecular mass and gel strength (Zaidi, 2019). However, the expected yield obtained was not as high as in bagasse with 79.5% (Zaidi et al., 2019). In terms of performance-wise, yield did not give any effect. Nevertheless, high yield provides ease for accessibility, abundance, and reproduction, as well as a high opportunity for commercialization purposes in the future.

Table 2 Physical characteristics of banana peels

Parameters	Unit	Value
Yield	%	41.8
Moisture content	%	25.3

Besides that, the recorded moisture content of banana peels was 25.3%. The percentage of moisture content obtained in this study is considered moderate. Usually, a higher yield of coagulant material will be followed by lower moisture content. The moisture content of banana peels obtained in this study was way lower if compared to other studies by (Zaidi, 2019) that reported moisture content of 62.6%, 78.3%, and 74.8% for banana peels, orange peels, and mango peels, respectively. Among the three peels, orange peels were always reported of having higher moisture content compared to other peels. This is because the orange peels have a higher water holding capacity which allows their peels to retain water (Kammoun Bejar et al., 2011). In contrast, according to (Anhwange et al., 2009), the moisture content of banana peel was 6.7%, lower than the moisture content obtained in this current study. The relatively low value may be due to the time of harvest. This revealed that the moisture content of banana peels might depend on seasons and some other factors like the period of collection. In comparison to the well-known and established natural coagulants, *Moringa oleifera*, the moisture content that had been recorded was far lower with a percentage of 7.1% (Madukwe et al., 2013). Still, with that percentage of moisture content, *Moringa oleifera* was evidenced in resulting in fairly high turbidity removal. Hence, the observed moisture content of banana peels in this study is considered sufficient and may be able to contribute towards sufficient coagulant agents during the coagulation process.

3.1.2 Chemical characteristics of banana peels

Table 3 shows the recorded surface charge, protein content. iron and aluminum ion content of banana peels. Based on the studies, the surface charge of banana peels was +6.4 meq/g MLSS. This finding is close with the result reported by Pathak et al. (2017) which obtained a +6.53 meq/g MLSS surface charge of banana peels. Besides that, the surface charge of orange peels was +0.19 meq/g and citrus peels were +0.25 meq/g under acidic conditions. The acidic surface favors the attraction of anionic contaminants, whereas the basic surface favors the attraction of cationic contaminants (Calatayud et al., 2003). For this study, banana peel is considered highly cationic thus and is useful in treating anionic contaminants. Other than that, the protein content of banana peel obtained in this study was 0.248 mg/mL. According to Amran et al. (2021), the protein content of several developed natural coagulants such as deshelled *Carica papaya* seeds is 0.363 mg/mL, *Phaseolus vulgaris* is 0.081 mg/mL and *Moringa oleifera* is 0.371-0.739 mg/mL which is comparable to our studies. Usually, higher protein content in natural coagulants provides more active agents to trap the contaminants, which further facilitates the coagulation activity (Antov et al., 2010).

The mean concentration of Al^{3+} of the banana peels was recorded as 0.197 mg/L. According to (Liang et al., 2019), the Al^{3+} content in banana peel coagulant was considered low as compared to other fruit waste with an average Al^{3+} concentration of 1.3 mg/L. The aluminum in banana peel plays a role in the attraction of anions to remove suspended solids and reduce turbidity. High positively charge Al^{3+} aids the attraction of negatively charged molecules in the solution. Other than that, the mean concentration of Fe^{3+} was recorded as 0.061 mg/L, exactly similar to the value obtained by (Anhwange et al., 2009). Fe^{3+} content in banana peel coagulant recorded in this study was considered very low as compared to other fruit wastes such as orange peels with 0.8 mg/L, mango peels with 0.25 mg/L, and *Moringa oleifera* with 0.282 mg/L (Gopalakrishnan et al., 2016). Like aluminum content, iron also plays a role in aiding the attraction of anion contaminants. High positively charge Fe^{3+} helps attraction of negatively charged molecules in the solution. Since both aluminum and iron show very low concentration contents in banana peels, these ions do not tend to cause residual metal problems in drinking water. Moreover, these ions can be easily removed through further purification and clarification processes. With these advantages, the treated water can be consumed freely without taking into consideration the effects of invisible residual metals inside.

Table 3 Chemical characteristics of banana peels

Parameters	**Unit**	**Data**
Surface charge	meq/g	6.4
Protein content	mg/mL	0.248
Aluminium ion (Al^{3+}) content	mg/L	0.197
Iron ion (Fe^{3+}) content	mg/L	0.061

3.1.3 Morphological properties of banana peels

Figure 2 shows the Scanning Electron Microscope (SEM) images the morphological form of banana peels coagulant under (a) 1000x (b) 1800x (c) 60000x (d) 200000x and (e) 400000x of magnifications under microscope. The general views of SEM images display clearly on the particles' geometry and structural variations of the banana peels surface. Figure 2 (a) and 2 (b) shows that the surfaces of banana peels were uneven and rough. The images reveal the microstructure of starch, protein, and carbohydrates on the surface of the banana peels. The particles' shape and size are also different which vary in shape from spherical to long flakes. Meanwhile, Figure 2 (c) and 2 (d) shows some macropores and micropores observed on the surface. There are many pores with varied sizes and shapes on the surface which ensure sufficient active sites for the attachment of colloidal suspended solids on it (Amran et al., 2021). Moreover, fiber structures that can further catalyze the coagulation process are observed in Figure 2 (e).

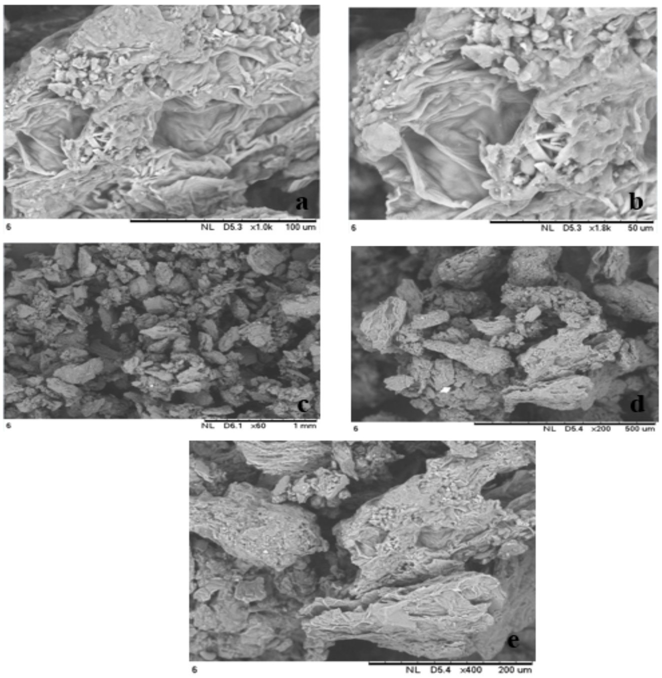

Figure 2 Scanning Electron Microscope (SEM) photographs: (a) 1000x (b) 1800x (c) 60000x (d) 200000x and (e) 400000x of magnifications under microscope

3.2 Effect of coagulant dosage on turbidity removal

Optimum dosage is significant as it will minimize the cost of materials and sludge formation as well as achieve optimum performance in the treatment process (Patel and Vashi, 2013). Figure 3 displays the trend of turbidity removal at a different dosage of the banana peel coagulant. Based on the figure, it was perceived that the banana peel extract efficiently worked at a dosage of 50 mg/L as the turbidity removal achieved was 71.12%. For dosage lower than 50 mg/L, the turbidity in wastewater remains high. This might be due to insufficient dosage which causes the low coagulation activity. Upon 50 mg/L, the wastewater appeared to be purer and more flocs were successfully formed. The effectiveness starts to decline gradually when the dosage was increased to 70 mg/L and above. This showed the dosage of coagulant above the optimum value might hinder the reaction between the coagulant and particles in the wastewater. This reduction can be inferred that overdosing contributes to the destabilization of colloidal particles and charge reversal. According to Zaidi (2019), the excess coagulants that simply get added upon the optimum dosage may cause turbidity in water. Besides that, hydrolyzation of coagulants in wastewater produces cationic species which can be absorbed by a particle with negative charges and neutralize their charge. Priyatharishini and Mokhtar (2021)stated that the coagulant overdosing may interfere with the mechanism of particles destabilization that promotes the flocculation process to take place.

3.3 Effect of pH on turbidity removal

The optimum value of pH depends essentially on the properties of wastewater, type of natural coagulant, and its dosage used (Lestari et al., 2010). Figure 3 shows the trend in removal performance of banana peel coagulant with different pH range. Based on Figure 4, pH 4 contributed to the highest turbidity removal for all the natural coagulants thus, this pH was taken as the optimum value of pH. The coagulation performance of banana peels in reducing turbidity favored the acidic condition. At that pH, the water appeared to be clearer, and more flocs were observed. This condition resulted in maximum turbidity removal efficiency, which was 88.86%. This could be because the turbidity substances in wastewater samples were mostly of negative charge or basic nature. Hence, the acidic solution may aggravate the coagulating agent comprised in the natural coagulant, thus resulting in greater coagulation activity and turbidity removal. As reported by Lestari et al. (2010), the acidic condition of wastewater promotes the attraction towards the positive charges on the amino acids in the molecules of protein. This might enhance and influence the performance of the molecules to perform efficiently as coagulant agents. The turbidity removal was then started to decline gradually after pH 4. It was observed that the water turns cloudier and fewer flocs were found after the settling process due to the incremental pH from pH 4 onwards. Besides that, the lowest turbidity reduction was found at pH 12 when the wastewater condition is most alkaline. The turbidity reduction was only 75.06%, which indicates the least effective pH for the banana peel to perform like the natural coagulant.

3.4 Effect of agitation speed on turbidity removal

Agitation speed is one of the important factors in achieving higher flocculation efficiency during the coagulation-flocculation process. High agitation speed during the coagulation process aimed to distribute the coagulant through the wastewater. Optimum mixing speed is important because it improves the formation of primary floc particles (Theodoro et al., 2013). Figure 5 shows the removal performance of banana peel coagulant with different agitation speeds. Throughout the study, it was observed that the banana peel extract works best at 100 rpm of agitation speed. Based on the figure, the highest turbidity reduction of 89.87% was obtained at this speed. Beyond the optimum speed of 100 rpm, there are obvious changes in flocculation performance as the wastewater was suddenly turned much clearer than before, and thus, more flocs were formed. At lower agitation speed like 60 rpm and 80 rpm, the removal efficiency was too low. This may be because the suspended solids are still separated, far away, and non-contacted with the surface of the natural coagulant. Hence, the flocs formed in coagulation-flocculation processes were easily broken. However, for a higher agitation speed like 140 rpm, the result indicated a substantial reduction in turbidity removal efficiency. This may be because the sudden movements can make the floc breakage and therefore caused loss of removal (Rosmawanie et al., 2017).

3.5 Optimization for banana peel coagulant

The impact of coagulant dosages, pH value, and agitation speed on the coagulation procedure was contemplated to streamline to the best removal of turbidity. The optimum dosage, coagulation pH as well as agitation speed will lead to the optimum conditions of the jar test (Kumar et al., 2017). Table 4 shows the summarization of optimum coagulant dosage, pH, and agitation speed based on the tested natural coagulants.

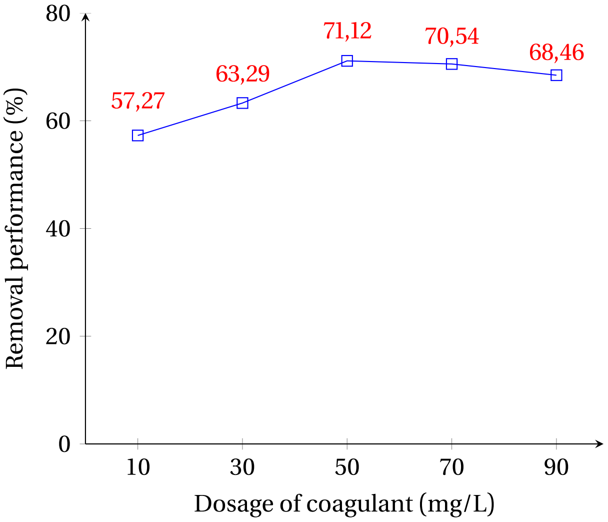

Figure 3 Performance of turbidity removal with different coagulant dosage (constant value: initial pH = 6.68; agitation speed = 100 rpm)

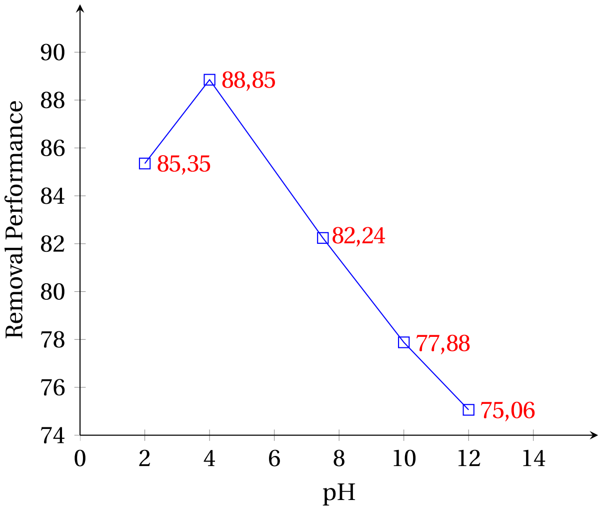

Figure 4 Performance of turbidity removal with different pH (constant value: dosage = 50 mg/L; agitation speed = 100 rpm)

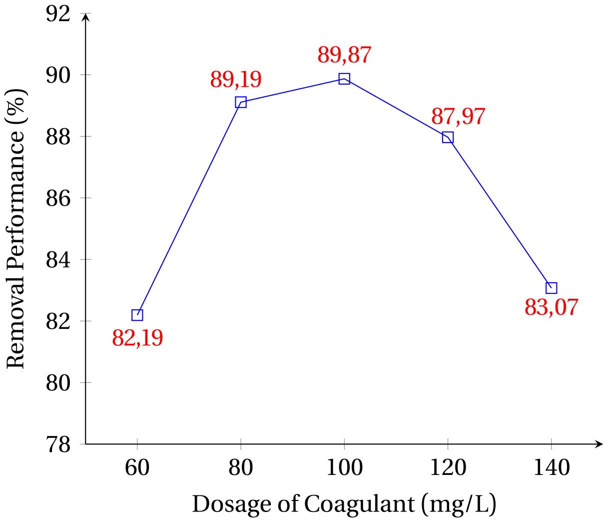

Figure 5 Performance of removal with different agitation speed (constant value: dosage = 50 mg/L; pH = 4)

The optimization had resulted in maximum turbidity removal of 89.87%. Based on the table, the optimum dosage obtained was 50 mg/L instead of higher dosage as higher coagulant dosage shows no significant increase in turbidity removal, but a slight decrease in efficiency with 2.66%. This is probably due to the dosage required might depend on the turbidity ranges of the wastewater. If the initial turbidity of the wastewater sample is higher, then a higher optimum dosage of coagulant might be required.

Table 4 Optimization of banana peel natural coagulants

Parameters	**Unit**	**Value**
Dosage	mg/L	50
pH	-	4
Agitation Speed	rpm	100

Next, pH 4 is identified as the most suitable pH condition for coagulation which facilitates the coagulation process between coagulant and colloidal suspended solids. This is probably because more amine groups of natural coagulants were produced at low pH to trap the suspended solids. This also indicates that coagulation in high acidity is more likely to catalyze the type of collected wastewater. While agitation speed of 100 rpm with 30 minutes of contact time is identified as the optimum speed for coagulation, which resulted in turbidity removal up to 89.87%. This is due to higher speed beyond optimum might cause flocs breakage, which resulted in poorer efficiency. The obtained result by banana peel was approximately similar and slightly higher than the result of similar material obtained by Mokhtar et al. (2019) that achieved maximum turbidity removal of 88% using banana peels. Furthermore, the performance of banana peel obtained in this study was higher compared to other natural coagulants such as tamarind seed powder with 78% and bagasse with 84% turbidity removal (Madhavi and Rajkumar, 2013; Thirugnanasambandham et al., 2016). Moreover, as compared to the well-established natural coagulant (Moringa oleifera), banana peel coagulants still have a higher chance to become potential natural coagulants as their turbidity removal is higher than 82.02% (Kumar et al., 2017).

3.6 Removal of COD and NH_4-N under optimum condition

Other than turbidity, the removal performance of other contaminants such as chemical oxygen demand (COD) and ammonia-nitrogen (NH_4-N) was also investigated. Table 5 summarizes the removal efficiency of banana peel coagulant for COD and NH_4-N removal. Based on Figure 6, the removal efficiency of COD under optimization conditions was 79.89%. The efficiency of COD removal of banana peel in this experiment was considered high as compared to maximum COD removal of bagasse at only 67% (Thirugnanasambandham et al., 2016). While as compared to established natural coagulants such as Moringa oleifera, the COD removal obtained in this present study is still higher than results conveyed by Bhuptawat et al. (2007) with 64% COD removal and Kumar et al. (2017) with 83.3% COD removal. Nevertheless, there are also studies reported on the use of other natural coagulants that resulted in higher COD removal. According to Ramavandi Farjadfard (2014), the synthesis of Plantago ovata using $FeCl_3^-$ induced crude extract (FCE) improved the removal of COD up to 89% with a very low dosage of 1.5 mg/L. Freitas et al. (2015) also reported that the COD removal in textile wastewater can achieve 85.69% with the addition of a small amount of okra mucilage.

Other than that, the efficiency of NH_4-N removal under the optimum condition of banana peel was 62.50%. The result in this experiment was higher as compared to the efficiency of NH_4-N removal in leachate with only 41.2% using lateritic soil coagulant (Syafalni et al., 2012). According to (Banch et al., 2019), tannin coagulant which is extracted by Black Acacia (Acacia mearnsii) and modified by ammonium shows good removal efficiency of ammoniacal nitrogen at 64% which is approximate to the result obtained from our study. Although some of the coagulants reported resulted in higher COD and NH_4-N removal compared to the present study, however, those coagulants were facilitated with various extraction and addition to meet with higher removal purposes. Unlike this study, the banana peels were prepared conventionally, and such removal was resulted in using solely banana peels as coagulants without any addition of other chemicals. Therefore, banana peels show great potential as an efficient natural coagulant in the removal of COD and NH_4-N in different types of water and wastewater.

Table 5 Removal efficiency of COD and NH_4-N by using banana peel as natural coagulant

Parameters	**Initial Concentration (mg/L)**	**Final Concentration (mg/L)**	**FRemoval Efficiency (%))**
COD	373	75	79.9
NH4-N	0.24	0.09	62.5

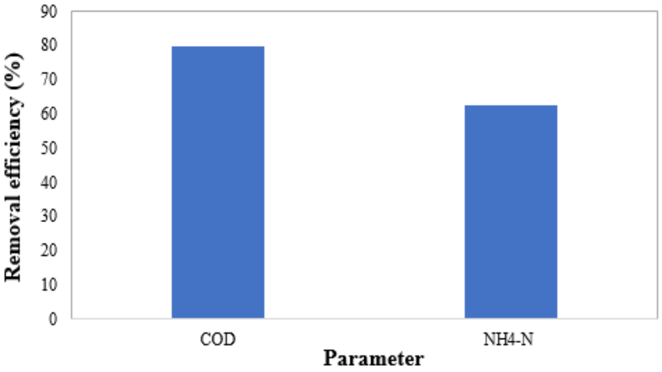

Figure 6 Removal efficiency of banana peel natural coagulants on other parameters using the optimum dosage of 50 mg/L, pH 4, and agitation speed of 100 rpm

4 Conclusions

Conclusively, the banana peels stand a great chance and promising potential as a natural coagulant in treating polluted water and wastewater. From the studies, banana peels have a relatively higher yield and lower moisture content as compared to the other fruit wastes. The recorded surface charge was 6.53 meq/g MLSS, suggesting that the banana peels coagulant is effective in treating alkaline-based wastewater as it has high surface charge of cation that could attract negatively charged contaminants. The recorded protein composition in banana peels was 0.248 mg/L, comparable with the other well-developed natural coagulants such as Moringa oleifera and Jatropha curcas. All these characteristics indicate the potential of banana peels to be developed as natural coagulants. From the jar test assay, the optimum coagulation of banana peel coagulant was at 50 mg/L of dosage, pH 4 with agitation speed of 100 rpm. Under these optimum conditions, it resulted in sufficiently high turbidity removal up to 90%, and efficiently removed COD and NH_4-N from sewage up to 80.0% and 62.5%, respectively.

Declaration of competing interest

The authors declare no known competing interests that could have influenced the work reported in this paper.

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